Robert Bradford Newman: Lectures in Architectural Acoustics

INTRODUCTION

Robert Bradford Newman was a founder of Bolt Beranek and Newman Inc. (BBN), where he was an acoustics consultant for over thirty-five years. He was a profoundly effective teacher in his field, and taught primarily at the Massachusetts Institute of Technology (M.I.T. where he was an Adjunct Professor of Architecture) and at the Graduate School of Design at Harvard University (where he was a Professor of Architectural Technology). He was a Fellow of the Acoustical Society of America, and consulted, lectured, and wrote widely on acoustics as an important aspect of the environment.

Bob Newman was born in China in 1917, received a B.A. and M.A. in Physics from the University of Texas in 1938-39, a M. Arch. from the Massachusetts Institute of Technology in 1949, and a Sc. D. (Honorary) from Lawrence College in 1963. He was also a member of Phi Beta Kappa and Tau Beta Pi, and an honorary member of the Instituto Brasileiro de Acustica (1958). He received, for BBN, the Brown Medal of the Franklin Institute in 1966 for contributions to the building industry in the field of acoustics. In 1977 he was awarded a Quarter Century Citation by the Building Research Advisory Board of the National Research Council for “significant and lasting contribution to building science and technology.” He was invited by the Chinese government in 1983 to give a four week series of lectures on acoustics in three universities. He passed away suddenly in October 1983.

The lectures presented herein were recorded during his course 4.41 at M.I.T. in the fall of 1970. But this is not a re-creation of that academic course: there are no visuals, no captures of what was written on the blackboard; no handouts, no quizzes; no field trips. Some lectures are missing or re-arranged incorrectly. But they do represent Bob Newman’s teaching style and engaging manner.

One part of this package is the audio files, recorded on a cassette tape recorder. The recorder was placed on a desk at the front of the room; the microphone picked up all the noise in the room (without a close mike for the speaker), and all the extraneous noise in the environment as well (aircraft flyovers, mechanical equipment, noise from the corridor, etc.). Questions from students are often unintelligible. The tapes are not of very high quality, and the cassettes were not very good fidelity, either.

The other part of this package is the edited transcripts of the audio files. The tapes were transcribed at the end of the lecture, but the transcriptions were not checked at the time of the recordings. The transcriptions were typed sheets, with incorrect words and interjections throughout. After about 30+ years, the sheets of onion-skin on which the lectures were typed were copied, then processed through an optical character reader, then turned into a Microsoft Word document, with many lines jumbled and lost. The lectures were then edited to be more readable as text, with editorial modifications of punctuation to make them more coherent as text.

Listen to the lectures, or read them, or both. The essence of the class engagement still resonates after these many years, and the reader/listener will be enlightened by Bob’s enthusiasm and knowledge of the topic.

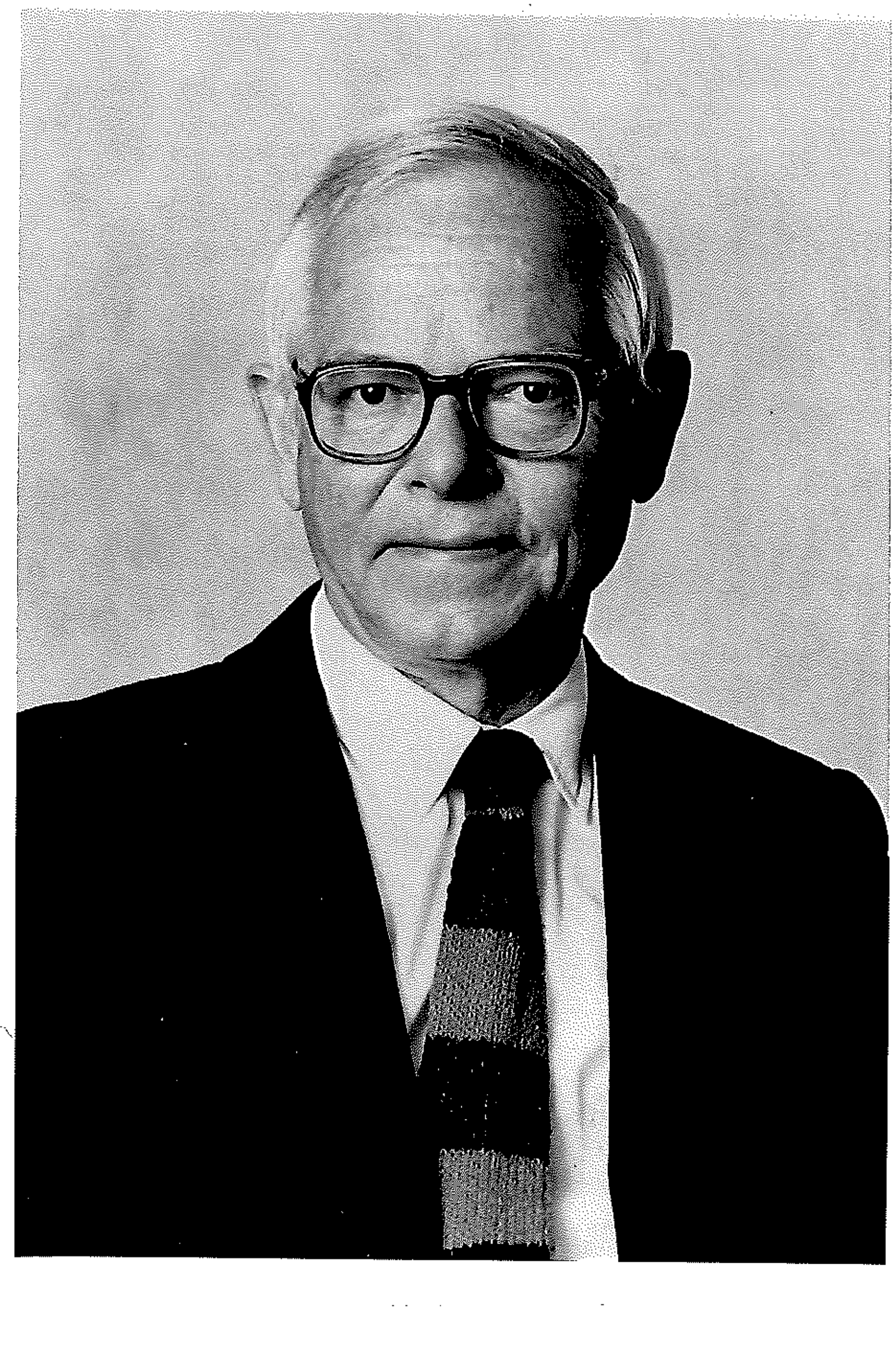
But the flavor comes through, and Bob Newman’s teaching legacy lives on.

ACKNOWLEDGEMENTS

Thanks to Lily Wang and her students at the University of Nebraska – Lincoln [Jared Paine, Jennifer Solheim, and Samuel Underwood] for their work on the transcripts. Appreciation to Jay Bliefnick for audio editing and organization. Credit to Eric Wood who had the foresight to save the cassettes from oblivion for 45 years. Thanks to the unknown person who made the original recordings.

Errors are mine. I did hear the same course lectures in the fall of 1966, 4 years before these recordings were made, and I worked at BBN with Bob Newman from 1970 until his demise in 1983. I then had the honor and challenge of teaching this course in the M.I.T. curriculum in Bob's footsteps. I always kept his voice in my mind as I edited the typed copies of the lectures.

- Carl J. Rosenberg (November 2019)



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Robert Bradford Newman Lectures

10 February 1971

LECTURE 1

Title: "Intensity and the Decibel"

Summary: In this lecture, Newman discusses the notion of sound intensity and introduces the decibel, a logarithmic unit used to describe the measurement of sound pressure. Newman also touches on how the measurement of the decibel relates to human hearing.

Part A: Beginning of Audio File 1A

….If you decide, for example, that you're going to use concrete as your building material, let's recognize the fact that concrete reflects sound. Concrete has an absorption coefficient of exactly 2%, and this is true in all parts of the world. If it has an absorption coefficient of 2% it reflects 98% of the sound. Some friends of mine and clients recently did a student union building for one of our large eastern universities. The student union building contained a swimming pool, an ice hockey rink for spectator performances as well as just ordinary hockey and skating, a number of dining halls, meeting rooms, etc.--things that naturally go into a student activities building.

I went to talk with them about the building because they asked me to come to their office and I went there and I said, what are you going to make the building of? Well, it's going to be concrete. And I said, yes, that's very up to date and fashionable; now what are we going to do about acoustics, for example, in the swimming pool? Well, it's all going to be concrete. I said, well, we've got to work out some kind of sound absorbing treatment in this or it's going to be a reverberation chamber. Oh no, no, it's going to be concrete. We can't cover the concrete, that's not honest. Oh, that word *honest*, how often that's invoked for almost any kind of whim the designer happens to have in mind.

So they went ahead and built an "honest" building, concrete, concrete, concrete, concrete, concrete everywhere, including the hockey rink, all concrete. Now the owner takes over this building, and he assumes that the architect, being all knowledgeable about all aspects of the environment, has done a careful studied and considered job of providing for the control of various environmental aspects, and he's shocked when he goes to the building and finds that it can't be used. He says it can't be used. An all-concrete student union building is one big fat reverberation chamber. They tried a sound system, they put in some kind of a squawk box system for announcing at the hockey events, and this just, you know, everything lasted forever. The swimming pool was total chaos for any kind of instruction, and unfortunately in the swimming pool, you have nude people, who are less absorptive than clothed people. Our skin is not nearly as absorptive as our fuzzy coverings that we all wear. And the whole thing was just very, very bad.

The dining rooms were impossibly noisy, and the owner called us and said, hey, you were the acoustics consultant, you know, what's the matter here? And we quickly dug out of our file the letter in which we said, you must do something about acoustics, you cannot expose concrete everywhere and expect it to be a satisfactory building. The architect hadn't shown this letter to the owner, the owner was not aware of this fact and was even more angry with the architect than he had been before when this was revealed. They've since corrected things by gluing in some not altogether attractive acoustics. This is a case where the glue-in job has to be done later, and the architect is not always happy about it.

This happened at MIT in the Compton Laboratory which Messrs. SOM [Skidmore, Owings & Merrill, Architects] did in 1956, and they said to me, I said, you're not going to put any acoustical treatment in this building? This is a physics building, classrooms, offices, research labs. We did design a lecture hall because lecture halls have acoustics, you know, but labs don't have acoustics and offices don't have acoustics. Well, their answer was, they don't have any acoustical treatment where they are now and they're not bitching. I said, mark my word, my friends, when they move to their new quarters without any acoustical treatment, and with no accumulated junk and dirt and cracks and crannies to soak up sound, they're going to be unhappy. They got in there and the very first week they got hold of Buildings and Grounds and asked to have acoustic treatment put up. Buildings and Grounds sent out, and got bids on acoustic tile, the cheapest guy got it, and they went in there with some pretty horrible looking acoustic tile. I can't remember exactly whether it had pink and blue dots in addition to random perforations, real ranch-house modern, you know, lumber yard do-it-yourself weekend supply kind of place--Grossman's would carry the kind of stuff that they bought. Fine for its application, but when Messrs. Skidmore Owings & Merrill came up from New York to view the building and to fetch guess who as restorer, you know that's the important part of any building. And they looked around and they saw all this dreadful (inaudible) and said, what's that? Ugh! And Fred Gan [architect with SOM?] said, Bunshaft [Gordon Bunshaft, architect with SOM] will just have a fit when he hears about that. And they said, let him, it's our building. Let him have a fit. You didn't put in the stuff, we will.

Now all I'm trying to say is, the sorts of things I want to talk about during this term are things that we as designers of buildings can do ahead of time, can do well, and can do in the idiom that we're working with. We can make them handsome and presentable, and if we don't, the owner will, because there are certain standards for human occupancy that we've simply got to recognize. And none of us can be so arrogant as to say, "my taste is the people's taste." Sure I'm a human being, you're all human beings and we all have certain ways of reacting to the environment, but we do know some things that the majority of people will like and will dislike, and these we have to come to grips with.

I want to make you reasonably ad-proof and mag-proof and newspaper-proof. There was an ad in the September Progressive Architecture from Mcgee's, the carpet manufacturer: "Mcgee's anti-noise carpets," and they had an airplane flying at you with a sun behind it, red and slightly jiggly, and below that anti-noise carpet, jiggle jiggle jiggle, anti-noise, and then below that traffic, cars, cars, cars in a telephoto lens collapsed picture, red and yellow, red traffic lights, and then down below this, a text. You're all psyched up now for noise. And then it says that Mcgee's anti-noise carpets will hush the scream of a jet, will silence the noise of traffic, will do all kinds of miracle things. Call your Mcgee's anti-noise carpet expert.

So I wrote them a letter and said, what the hell are you talking about? What's so good about your carpet that's different from anybody else's carpet, and cut out all the miracle stuff, was my conclusion, sincerely yours. And I got a letter back that, well, yes, nothing their carpet did was different from what any other carpet did, but they said just to tout carpet wouldn't promote Mcgee's very much, would it? And I have to agree, from an ad man's point of view, you're selling Mcgee's, you want to sell Mcgee's and not carpets in general. And then they said they got carried away a little bit, just a little. Well, I said they were trying to mislead the innocent architect, because most architects are terribly innocent and will believe anything that comes along in an ad, so long as it promises to get them out of trouble and they don't have to think about it anymore. Just put in carpet and that will solve all the noise problems. And they promised me that they will leave out the airplane and the miracle stuff in their next ad, and I'm waiting patiently to see the next Mcgee's ad.

You say, well, nobody would believe that kind of stuff. I know mature grown-up practicing money-earning architects who have specified acoustical paint in projects. Now acoustical paint is an absolute total fraud. I mean, carpet has some value, carpet absorbs a little sound. Acoustical paint is ordinary vinyl paint with ground-up walnut shells in it. It goes on, looks just like this ceiling, kind of a gritty paint. Now do any of you think that ceiling has any particular interest acoustically? Well, the notion is that acoustical paint is not a reflective paint but is an absorptive paint, because acoustical materials in the common parlance means things that absorb sound. And yet this material has been marketed and specified and used in projects, and then they say, why is it noisy in there, we used acoustical paint. My God, it's like taking anti-gravity pills and then going over and jumping out the window and wondering why you still go down. There are certain inevitabilities in this world, and there is a great deal of physical reality.

Now in a newspaper item that appeared back in April of last year on both UPI [United Press International] and AP [Associated Press] was a statement that research under the sponsorship of the Department of Agriculture, result of a three-year program, research done at the University of Nebraska has shown that a planting of trees will reduce the noise level from traffic by 50%. And if you add grass (I'm not sure where the grass is added; I think they smoked it, but I don't know how else you could use grass to get this result), you gain an additional 15% in noise level reduction. Noise level reduction, and they said that non-deciduous trees were better than deciduous trees, and taller plantings were better than shorter plantings. Now they're all worth exactly zero, so I'll have to agree with the thing, anything times zero is still zero, therefore taller times zero or thicker times zero is still zero.

This business of trees and noise is something that landscapers for years have been peddling. Just plant some trees and all the noise will stop. We're putting up a high-rise apartment building here, and here's a noisy throughway going right by, we'll plant a row of arborvitae down in front and that'll stop all the noise. Baloney, it won't do anything. And even if we had a hundred feet of woods it would do very little. I happen to live a mile away from Route 2, and I'm separated from it by thick heavy woods the whole distance, and in the summertime when we have our windows open at night we hear Route 2 as if it were in our bedroom. A mile away. Now if 70 feet of woods or 100 feet of woods as he described it in this newspaper article would cut the noise level in half, my God, we'd have inaudibility right away with a mile of woods.

Now what this man found was that there was a reduction over and above what you get with sheer distance away from the highway, because the farther away you get from the source of noise the less intensity it has. What he found was that the energy level is about half after you go through 100 feet of woods, half of what it would have been if the woods hadn't been there. But that's a reduction of only 3 dB, as we will learn, which is just very slight. Now when I say zero, I mean almost zero. I mean, trees are no cure for traffic noise. Right this moment the city of Baltimore is putting in a freeway through the city. SOM have been designing it. We've been working on the acoustics aspects of it. And about 10% of the cost of this highway is going into noise control. It's going into walls and earth berms and other things, but <u>solid</u> things to cut off and cast a decent shadow, and we're not spending one cent on planting. Now you say, this is a concrete man and doesn't give a damn about trees. I love trees, I love them, and I work with them all the time. Every weekend I'm out working on my trees because I love them so much, but I don't give them any credit for noise isolation. I mean, let's keep things in their proper perspective. If we've got a noise isolation problem to do, let's do it with concrete, with glass, with earthworks, with something that can stop the noise. Let's not diddle around with trees.

Now I'll tell you a quick tree story where it worked, and only one row. In Newtonville, the Boston Edison company has a power substation with two large transformers, and the setup was sort of like this. Here was the Boston and Albany tracks, which are now part of the Mass Pike, and here were the two transformers, and they had a fence all the way around, and these transformers just sat there all the time, "MMMMMMM," day and night. And here's Washington Street going by, the main heavy street, and here are a lot of houses here. Now there was a lady who lived upstairs in this house and she said to Boston Edison, those things keep me awake at night, they make too much noise, you got to do something about it, so Boston Edison hired us to go tell them what to do.

So we went and parked all night in the station wagon here in front of this place, and we took physical measurements, you know, if the doctor wants to find out what's wrong with you, you get an electrocardiogram and he does all kinds of tests. Well, you've got to get some facts on which to base a judgment. So we took some measurements and at about 3:00 in the morning we could detect these transformers above the ambient background of the city—just barely detectable at 3:00 in the morning. You hear "MMMMMM" and you can measure the "MMMMMM" sound of the transformers. So we said, well, if she's being bothered, and she probably could hear it if she opened the window and stuck her head out, but not in the house, but nevertheless….

Question: "She could possibly hear it louder in the house, couldn't she?"
No, unless she had some peculiar resonance of a room that happened right then, but in any case it was a very small amount of noise. But I'm going to just tell you the rest of the story. We said to Boston Edison, what you've got to do is build a brick building around this thing and put in forced ventilation that's got to be quiet itself and so on, and we ran up about $50,000 worth of construction just before we could bat our eyes. Boston Edison said NIX, and they said we're going to plant some trees. We said that won't do any good, and they said we're going to plant some trees anyhow, we'll just see. They planted one row of arborvitae, mature specimens, close together right around like this, you don't have to worry about the railroad because it isn't complaining, so they planted arborvitae on 3 sides, full height and dense, none of this waiting 10 years until it fills in a bit.

And the lady said: oh, I'm so grateful, that just solved it completely, I don't hear anything anymore, thank you Mr. Boston Edison, and they said to us, haha, so it did work, and we said, well, it didn't do anything, we bet. Well, they said, you go back and make some more measurements, so we did and we made measurements again and we found exactly the same numbers that we'd gotten before. But it worked and solved the problem for this lady, and many times we find the psychological aspects of sight and sound are not separated but are tied together, and if we plant some trees and cut off the line of sight of traffic or a transformer or an ugly old cyclone fence or something of the sort, we can often make people quite happy without doing anything to the thing that they originally said was bothering them, because none of us is immune from getting mixed up between visual and auditory input.

Well, this course is going to be sprinkled throughout with illustrative examples of this sort. Most of my students when I see them 20 years later tell me that all they remember about the course is the examples, but I'm astonished—I was giving a lecture the other day somewhere, Ball State, in early January, and one of the guys in the faculty there, we were having a discussion, and he said, aren't you going to tell them the one about so and so? I had completely forgotten it, I hadn't used it in 5 years, and he'd had the course about 10 years ago, and he remembered it, so I naturally had to tell it. Okay, I don't care how we do this, how silly some of these things may sound, how informal we may get in the conduct of this. I want to teach you something about sound in buildings and outside buildings, and that's what we're going to achieve here. Now, I don’t know, should we take a—do you want to take break in the middle of this hour, or do you want to go on through? I don't care. All right, why don’t we—let’s literally keep it down to 5 minutes because I want to have at least another 50 minutes.

(break)

I want to start now with a notion—a few notions, basic notions about sound, and let's set architecture aside and applications aside and learn a little bit of what sound is. First of all, sound is a physical wave in the air. I'm standing here talking to you, I am radiating a sound wave out of my mouth, this sound wave is going out into the room here and is moving your eardrums in and out. I personally am standing here and moving your eardrums whether you like the idea or not. If one of you speaks up or wiggles a chair or something, you wiggle all the rest of our eardrums.

This is a very important concept to get. You say, well, everybody knows that. Sound is a wave in the air. Sure. What does that mean? I’m a source of sound energy. I’m generating sound energy, a certain number of watts of sound energy, it is some work for me to talk. It’s some work for you to talk. What's the work involved? The work is expelling air through the vocal cords and forming the sounds of the mouth and radiating sound out of the front of the mouth. Now it’s not a lot of work, I’m not getting tired talking, I’d get tired if I had to yell, but that would be just (inaudible). I am transmitting power through the air, I'm transmitting watts through the air, physically through the air to your ears. I am compressing the molecules in the air that I have to expel from my lungs. I compress them and then I pull them apart. Compress them and pull them apart. Compression, rarefaction, compression, rarefaction.

This elastic wave that I sent out of my mouth in the air moves at 1120 feet per second, and it moves the molecules, the molecules, the molecules, like a bunch of dominoes hooked up with elastic bands. One molecule pushes on the next, pushes on the next, and pulls back and forth, and this molecular motion transmits the energy. A pressure wave that changes the pressure of the atmosphere is what I’m doing, and it goes out at 1120 feet per second in a spherical pattern around my head, and there's not a thing I can do about it. When you talk about an actor throwing his voice, he doesn’t throw his voice, he just makes a good loud sound to start with, and that is throwing your voice. It’s not throwing your voice.

I was recently, as I mentioned a while ago, at Ball State giving a lecture, and they have a perfectly horrible Quonset hut. They have two Quonset huts, they’re building a new building across the road, and their main lecture room is a great big Quonset hut with a ventilating system in it that sounds sort of like Niagara Falls nearby. And they also have an alleged sound system, which consists of some loudspeakers and a microphone. That doesn’t make a sound system, but it makes a simulation of it. And they had Soleri (visiting architect) there a month before, he was their last lecturer, and apparently even with the sound system and everything else, nobody could hear it because he doesn’t make any sound at all, and you can’t amplify no sound. I insisted on having the Niagara Falls turned off because we had all these warm bodies to keep us warm for a period of an hour, and discarding their sound system and just talking in a great big loud voice, and everybody could hear me with no difficulty at all. You generate enough watts and you will force the agitation of everybody’s ears. It's very simple, you just make a big loud sound and it will carry out. It's a power proposition, it’s energy, it’s watts.

Now every single situation that we're going to talk about in acoustics is going to involve 3 things. It will involve a source of sound, and a path by which the sound goes, and a receiver. The receiver, 99 times out of 100, will be a human being with two ears. The source is often a human being. The path is often simply free air. The path may involve some barriers; it may involve partitions; it may involve open windows; all sorts of things that could be in the path. But every acoustics situation we're going to think about involves the transmission of sound energy from some kind of source through some kind of path to some kind of receiver. Even the low rumble that we can hear occasionally with a jet airplane flying over is another source-path-receiver problem. The airplane may be quite high. We're separated from the airplane not only by a great distance but by windows, closed windows, glass and brick, and the whole business of the absorption of sound that you all present by your fuzzy beings here reduces even further the amount of energy that is transmitted to it. But we've got to be able to analyze all of these aspects of every single problem.

Basically then, sound is power. It's energy flow. The molecules themselves in the air do not move from me to you, it's merely one set of molecules pushing on the next, creating an elastic pressure wave in the air that causes you to hear. When your eardrums move in and out (and mine move in and out the same way), there's a whole series of things that happens. There's the outer eardrum, the tympanum, and then there's a series of three little bones which act as a mechanical amplifier. And these little bones are hooked together; they're very, very tiny, and they're hinged together with little hinges, I can't even remember the names of them, one's the stirrup, the anvil, and something else. But in any case, they then are attached to another diaphragm, which is smaller than the tympanum in the ear, and which receives the sound from the air, and this is a fluid-driving diaphragm, and that's on one end of what's called the cochlea, and the cochlea is simply like a snail shell, a curled up thing in here with a little diaphragm on the end, and these little bones push and pull on that, and the fluid in here is compressed and rarefied just exactly as the sound which strikes the tympanum is. And then there are a whole batch of little hair cells and nerve endings in there to send a signal to the brain and we translate that into sound.

It's a complex mechanism, and it's pretty well understood now. There are some very fine illustrations of it in a Time-Life Science Series book on sound and hearing. Very good illustrations of the hearing mechanism and how it works. That isn't a big concern to us as designers of environments, but we must keep in mind always this notion that energy is involved, sound power. It isn't electricity, it isn't light, it's simple physical waves in the air, and the power is being transmitted always at the same speed through the air in all parts of the world from the source to the receiver.

Now let's get down to a very basic concept which we must have in thinking about sound in free field. Let's take some kind of a source of sound, let's say it's a tennis ball, if we like, that is pulsating in and out. We somehow make the tennis ball pulsate, and I want to start with an omnidirectional source of sound because I, a human being, you, all human beings, are one-sided. I haven't yet seen anybody with a mouth that went all the way around. This would be a magnificent kind of acting development for theater-in-the-round; that would be marvelous to have. Maybe we could breed up such a cast with an annular mouth all the way around, and then they could specialize in theater-in-the-round performances. The problem with us human beings, the way we're made, is that we are one-sided, and while we radiate a spherical wave, it's really only hemispherical because out of the back side of my head is not coming any sound.

Let me just illustrate. I'll hold my jacket up here, and we'll use this as a sound absorbing material. This is fuzzy and porous and absorbs sound. Now I'm talking directly to you and I'm radiating this sound out of the front of my face, and you all hear me, and when I turn around to the blackboard and talk, you'll continue to hear me not because sound is coming out of the back of my head but because sound is being reflected from the blackboard. And whenever anybody says to you, this lecture room is okay when the lecturer faces the students, but when he turns to the blackboard we can't hear him, it means he's miming at the blackboard, he's not talking at it, because the blackboard is a perfect sound reflector unless it's black velvet.

Now I'm going to substitute this coat for the black velvet and I want you to listen to the difference in the sound of my voice as I stand and talk to the blackboard here and then drag this absorption up in front of my face and prevent the blackboard from receiving very much and from reflecting it. Can you hear the change in the quality of sound as I put this absorber up in front of it? It isn't "*BLAH BLAH BLAH*" that you don't hear anymore, it's "*PSSS PSSS PSSS PSSS PSSS*," "*HA HA HA HA HA HA*." A little change in the "*HA HA HA*" part which is 100 cycles per second and a lot of change in the "*PSSS PSSS PSSS*" part which is out around 10,000 cycles per second. Very high frequencies, very short wavelengths are cut off by my head, which is 6" or so across, whereas a 10' wavelength, it's nothing at all. So when I say I radiate only in the front hemisphere, I have to say at what frequency because "*HA HA HA*" down at 100 cycles per second I'm absolutely omnidirectional, I'm just like this tennis ball that's going to be pulsating here uniformly, whereas at "*PSSS PSSS PSSS*" I'm very much unidirectional. The intelligibility, as we will learn, of speech comes largely from the "*PSSS PSSS PSSS*" part and not from the "*HA HA HA*" part. And so that's why when you have theater-in-the-round or you have someone who wanders into a curtain, you can't hear very well.

Well, back to physical reality. Let's take this pulsating tennis ball and put it out in free space. Just miles and miles from anything, free space. Or we could go over onto Vassar Street and go into the anechoic chamber, which is again free space—total absorption of everything, nothing comes back. Let us let this tennis ball or this spherical source of sound radiate a power of P watts. Now we're going to have a few little formulas here, but they're very simple. P = power of source in watts. Now these are sound watts, not electric watts, but they're watt watts. They will heat something up. If 80,000 people shout at the top of their lungs for one hour, "*AAAAAH*" for an hour, 80,000 of them….

End of Part A: Audio File 1A
Beginning of Part B: Audio File 1B

Here's the kind of sounds that we hear. Okay, so the things that go "*WEEEEE*" or "*OOOOH*" or anything else that we'd like it to do. And it radiates sound outward uniformly in all directions because we're in free space. So let's draw some spheres around these things, and if we had a bigger blackboard we could go on out to infinity. Now this energy that's flowing out of this thing, these compressions and rarefactions are zapping out of here at 1120 feet per second, this wave, if it's just going "*BEEP*," this goes "*BEEP*" right back, 1120 feet per second, just one little "*BEEP*" in the air and that's all that we have. So we have a velocity here, we call it C, C = velocity of sound—we use C because I want to use V for something else—of sound in air = 1120 feet per second or 340 meters per second. So, 1120 feet per second. Now suppose I stand out here at some distance away from the source of the sound, D. I stand at D distance away. We would use D in centimeters at the moment, and we can change it to D feet. And here's my ear. Okay, there we are.

Now where cometh the energy from to stimulate my ear? It cometh from the source of sound with power P watts. How much energy is there at this distance away? Well, the energy that started out at this little point source has now spread itself out over that whole sphere and there's been none added to it. We have no amplification going on. There's no way to feed additional energy in. All of the energy that we find at this distance over this sphere is the same power P watts that started out at the source. Is that an okay argument? It's just flowing out. Energy flows, it flows in a wave. We change the pressure of the atmosphere a little bit, and it takes energy to do that. But the energy is spread out over this whole sphere. If this P is in watts, I could calculate how many square centimeters I have at a distance D, over which P watts are spread. The area of the sphere will be $4\pi D^2$. D is not the diameter but is the radius, but I use D for distance, so it's $4\pi D^2$.

If I divide the power in watts by the area over which that power is spread, I can get the number of watts for each square centimeter over the surface of the sphere. Is that reasonable? And I'll call that the Intensity, I. Intensity I will be equal to P watts divided by $4\pi D^2$ where D is distance in centimeters. And this intensity now will be in watts per square centimeter. Watts per square centimeter. We will use the metric units in talking about intensity and talking about power and other things simply because everybody in the world has agreed we will all do that, and this doesn't complicate our lives if we use the English system because we can make suitable transformations. But the intensity of sound at any distance D from a source of sound in free space will be given by $I = P/4\pi D^2$. It simply says we take the power and we spread it over the whole sphere of radius D.

Now that's all very well and good, what really is interesting to us is what happens if we go twice as far away. Suppose we're already here, and I wonder, now suppose I went to 2D, what would I find for intensity? Well that's very easy to do. Knowing that $I = P/4\pi D^2$ I can say let's call this D_2 and let's call this D_1. And here I have what I call I_2 and here I have what I call I_1. The intensity at a distance D_1 as compared to the intensity at a distance D_2. Now obviously the intensity is going to be greater here because the power has spread over a smaller sphere. This is exactly like blowing up a balloon, you know, the rubber has to get thinner and thinner and thinner as you spread the rubber out over a greater and greater spherical area. And I'll simply just write it down here, $I_1 = P/4\pi D_1^2$, $I_2 = P/4\pi D_2^2$, and if I'd like to know what is the ratio of I_1 to I_2, I can simply divide these expressions one by the other, and so I use algebraic manipulating, the P's go out, the 4π's go out, and I have I_1 is to I_2 as D_2^2 is to D_1^2. And of course you recognize this immediately as the Inverse Square Law, which says that the intensity of sound is inversely proportional to the square of the distance. The same thing holds for heat, for light, for radio waves, for any kind of spherical radiation. It must—the intensity must decrease with the square of the distance. So if I go twice as far away, I'll have a quarter of the intensity. I go twice as far away again, I'll have a quarter of that again.

Student: "This is assuming an omnidirectional source?"
Absolutely, idealized case. It happens (inaudible), they have some directional characteristics, but in the simplest sense, this is the case. And let me just throw in a comment at this point because the question is very well taken. All the things we're going to talk about this term and the things on which we'll try to do calculations are based on simplified assumptions, because lengthy, accurate, rigorous assumptions get so complicated we learn nothing. And in actual practice we use simplified terms because it isn't all that important to get much more precise than that. When we use the Inverse Square Law on over-fly aircraft even though we know that they're not truly spherical radiuses, but for all practical purposes what we're interested in is what happens if he goes over at 3000 feet instead of 1500 feet, then it's true that for whatever directional characteristics it has. The energy distribution will be the inverse square law. And if I ask the question: what if I put a highway twice as far away, what will happen? You know, the highway is going to be 100 feet away from the building, we're going to move it to 200 feet. Well, we're not solving any

kind of highway noise problems by doing that, we'll find if we do the calculation, especially when we catch on to what it means to reduce the intensity to a quarter of what it was before. We have affected very little to the actual perceived level. It's a terribly slow process because our ears hear the logarithmic progression rather than linear. This we'll come to in a few minutes. Is this—this is probably something that you all had in first year physics, but you may have forgotten. But it's a very important, very simple concept that we use all the time in studying the behavior of sound outside of ordinary exposures.

Now when we come inside, we have an entirely different set of things happen. You all realize, of course, that sitting here in this room, you at the back of the room are hearing me much better than if we were out here in the quadrangle. Let's presume that we could get rid of all the traffic noise and aircraft noise and wind noise. Still, outdoors you cannot hear as well—in fact, at the very greatest distance from me here you would have some trouble hearing me outdoors. And I'd really have to talk very loudly to be heard. I hope you experience this so you can believe what I said. The reason for that is that inside, the room is reinforcing my voice by many, many reflections, and you're getting a buildup of sound energy due to these many reflections, and it fact, farther than about 4 feet away from me, here in this room, you're all getting about the same level of sound, you in the back and you in the front. An inverse square or free field behavior of the sound only happens very close to the source in a room like this because of the many reflections and buildup of sound energy that we have in the room. We look at that as a separate proposition. At the moment, we're talking the idealized behavior of sound outdoors. Now are there any questions about this at all before we go on?

Okay. Our first problem set, which I'll give you next time, will have a few exercises in comparing things at different distances and in trying to come to grips with this a little bit better. Now before we go any farther, I want to talk just a little bit about this business of Intensity and how we hear Intensity, and let's get the decibel out on the table because it's one of our very useful tools. But whenever I see the word decibel used in the newspaper or in popular press, it's misused just atrociously. The decibel count is high today, it's some kind of Geiger counter counting the little decibels zinging by, you know, they build up a high count. But the decibel concept is really not very complicated, and after we do our demonstration of procedure in a couple of weeks you'll have an even better notion of what the decibel is all about.

Back in the last century more than 100 years ago, there were a couple of German psychologists, physiologists-cum-psychologists, by the name of Weber and Fechner. Any of you who have had an elementary course in psychology have been exposed to Weber and Fechner. These two clowns cooked up a—it's very fashionable in psychological circles to argue whether Weber and Fechner, you know, really are precisely accurate or not, and probably not, but they certainly were in the right direction. What they found out was this, and they just put down what we all know. I take a sharp needle and I jab you, and it hurts, and then I take two sharp needles of equal size and I jab you with equal force, it does not hurt twice as much. Or a hot end of a match. Or suppose you stick out your tongue and I put on a grain of salt, swallow that, and now we put on two grains of salt. That's not twice as salty as the first one.

And if I ask one of you to get up here in front of me and perform, and we rehearse "da da da da da," and then we both do it together, "da da da da da," same power, same output, same kind of voice, it's not twice as loud. No, it's not nearly “twice as loud” as one person doing it. Also, if I light a candle in a room and I put in two candles, it's not twice as bright. It's twice as much light energy, but you don't perceive it as twice as much. But what these guys found out was something that they wrote down on paper, namely that the sensation, any sensation that you get in your perceptual mechanism, the sensation is proportional to the logarithm of the stimulus. You say, what does that mean? Well, it means it's not proportional to the stimulus. If I have a stimulus of 2 as compared to a stimulus of 1, the sensation that I get is not proportional to 2 to 1, but the logarithm of 2 to 1, which is quite a different number from 2 to 1.

Well, quantitatively what we have decided to do in the field of acoustics—and this has been carried over into a number of other fields now—is to take the Weber-Fechner Law, which says that sensation is proportional to the logarithm of the stimulus, and write it down in a simple formula, and we developed the term that we call the decibel. I've already said that the Intensity of sound is given in watts per square centimeter. The Intensity Level (IL) of sound we will give in decibels: Intensity Level in decibels. Now I'm going to give the abbreviation dB for decibel. Actually the "bel" part was named after Alexander Graham Bell and is spelled properly "decibel." And there is a school of thought today, some of the people who sit around with nothing better to do than think up standards, that whenever you name a unit after a person, you should capitalize the unit, and therefore we should capitalize volts and watts and amperes and everything else, and so they insist that this is decibel, d capital B. I refuse to be shoved around like that, and I use 'db,' which has been good enough for many generations, and you may do as you please. But if you see little d capital B, that's a conformist wearing the latest in uniform of the decibel school.

Okay, intensity level in decibels is given by 10 times the logarithm in base 10 (and I won't repeat that again), of the intensity of the sound in question compared to the intensity of the minimum audible sound, I/I_0. Now don't faint away at the sight of that because I'm going to make this crystal clear (inaudible). Our ears, all human beings, and in fact all animals and all insects, all living creatures on the earth who hear, have a threshold of hearing very similar to that of human beings. You say, oh, I thought dogs were more sensitive. No, they're not. They're sensitive in a different range of frequency. But as far as intensity is concerned, all hearing devices on earth have the same threshold of hearing. The threshold of hearing which all of us have, in the average, and at middle frequencies (and a lot of other ifs and ands and buts), but about most people generally have approximately the same threshold, the threshold, which we'll call I_0, is equal to 10^{-16} watts per square centimeter. 10^{-16} watt per square centimeter is a 10,000th of a millionth of a millionth of a watt per square centimeter, and that tiny, tiny, tiny bit of energy is just enough to begin to stimulate you to hear something.

Now in order to get that, I'd have to put you into a silent room, close several sets of doors, isolate you totally from everything, put headphones on, because the trouble is you gurgle around inside and make a certain amount of noise, and if you get into one of these silent environments, you hear all your digestive processes going on. It's most unpleasant, because while we all know it happens all the time, we generally don't hear it because we have some amount of noise around us. So I put you in this room and then I go "*BEEP, BEEP, BEEP,"* and every time you hear "*BEEP"* you push the red light, and after about a week of practice you get where you can hear a very tiny beep with only that much power. It's not something that you ordinarily encounter. Below that, you would hear static. If you had sensitivity greater than that, you would hear static, which is the Brownian movements of molecules in the air, the random thermal motion that goes on all the time, remember that in physics. The Brownian movement all the time all around us is going on, and this would cause static and we would not be able to hear anything but noise. So the floor is set by the static level through the evolutionary process that we would have and would not permit us to hear usefully. Now this is the number that I'm talking about here: I_0, the threshold of hearing.

At the other end of the scale, at the point at which you would begin to hurt, if I should get right up next to your ear and scream (and I won't do this because you all (inaudible)), it hurts, it's painful. You can cause pain for another other person by yelling in his ear. That level, or that intensity, is the order of magnitude—the pain threshold is approximately 10^{-3} watts per square centimeter. That's a thousandth of a watt, that's beginning to be understandable. I've got no perception of what 10^{-16} watts is—it is beyond my power of comprehension. A thousandth of a watt I can begin to sort of have some sense about, because I understand what a watt is, and 100 watts I can understand very well, but a thousandth is okay. We have there a range over which a human being can hear from 10^{-16} watts per square centimeter up to 10^{-3} watts per square centimeter, or a range of 10^{13}, isn't it? That's 10 million million-fold.

The sound that just causes pain or discomfort is 10 million, million times as intense as the sound that you can barely hear. Now what this means is that we have an enormous range to think about, don't we, between just being able to hear and really hurting, of 10 million million-fold, and it's just too much for us ordinary human beings to carry around and work with and think about. And so to save ourselves a lot of trouble we've gone over to the decibel notation. The intensity at which I'm talking to you here in this room is approximately 10^{-9} watts per square centimeter, or that's a thousandth of a millionth of a watt per square centimeter I'm putting out at your eardrums. Let's see, my speech in this room is approximately 10^{-9} watts per square centimeter.

Now let's see how this relates to this decibel business. What is the level, the intensity level in decibels, of the sound that you're receiving in this room? I will merely stick the numbers into the formula, turn the crank, and out will come the answer, and I love formulas that all you have to do, you don't even have to think, just stick them in and crank it out. And we do not have a computer program to do this because you can do it with your slide rule. Nobody's wasting computers on that.

All right, in this room, speech—and we'll put that "approximately" just because everything's kind of approximate--is 10 times the logarithm of the intensity of the sound in question. The intensity level will be for this intensity. The intensity level of speech in this room will be for the intensity of speech in this room, and we will define a level for that intensity. You can see how this goes in just a second. 10 log 10^{-9} watt per square centimeter <u>divided</u> by the intensity of the minimum audible sound, 10^{-16}, and that will give us 10 times the logarithm of 10^7. And does anybody remember what the logarithm of 10^7 is? Somebody must remember. Don't be bashful. And so this is equal to 10 x 7 = 70 decibels. Isn't that easy? Now what I've said is that as I'm talking to you here in this room, I've decided I'm going to set up an arbitrary definition, I'm going to compare the intensity of the sound that you're hearing to the intensity of the minimum audible sound. I'm going to make the comparison between those two things. And I'm saying that on the basis of that arbitrary decision of comparing 10^{-9} watt per square centimeter to 10^{-16} watt per square centimeter, I'm 10^7 times as intense as the minimum audible sound. Is that all right? I'm 10 million times as intense as the minimum audible sound, and I'm going to assign arbitrarily a level number to that, which I'm going to call 70 decibels. Each time I say the level of sound, i.e., the noise level or the Intensity Level (IL) or any other kind of level, is so many <u>decibels</u>, I automatically mean by that compared to the minimum audible sound. I don't say it each time, but it's part of the shorthand that we use. The level of sound in decibels is always related back to the minimum audible sound as a base. What is the intensity level of the minimum audible sound? What would you think it might be?

Student: *"1 decibel?"*

Well, it's 0 decibels. It's 0. Why is it 0? Well, it's just calculated IL_{min} is equal to 10 log 10^{-16} over 10^{-16}, which is 10 log 1, and the logarithm of 1 is 0, so it's 10 x 0 = 0 decibels. Well, that makes sense, doesn't it? It's a scale that starts at 0 someplace below which you can't hear, it's the least you can hear, therefore we call it

0 decibels arbitrarily. Then we go up the line in steps, and every time we increase the intensity by 10-fold we'll increase the Intensity Level (IL) by 10 decibels. 10 to 1, 10 times the logarithm of 10 is 10 times 1 or 10 decibels. And when we get up here to 10^{-9}, we'll find that we have a 70 decibel intensity level. Is that even beginning to be clear? What is the intensity level of feeling, the threshold of feeling?

Student: *"10^{3}?"*
10^{3}, correct. It becomes very simple after a while to take this number away from 16 and you've got it times 10. I mean, it's a cinch. It's all up there on the paper. So if we had 10^{-3} here, obviously this would be 10^{13}, and this is 10 x 13 or 130 decibels. Please don't get troubled with my blackboard technique, it's not very good (inaudible) anywhere on there. They have a book that tells you how to teach, which I went and looked at and discarded and decided I knew better. But one of the things is blackboard technique, you're supposed to begin at the left hand side of the board and work in a neat and orderly fashion down in panels across the room, and everything is nice, but I somehow can't do it, so just follow me around and if you want to take it down, do so, or not. And I also like to economize by just erasing.

We have the range then corresponding to these numbers—this is in dB, and 0, we have 70, we have 130, and obviously the whole set of numbers in between and their fractions. But somehow or other, for most of us, the business of coping with numbers going from 0 to 130 is just an awful lot easier and easier to grab hold of than going from 10^{-16} to 10^{-3}. It's just a different kind of animal. And in reality we hear much more like 0 to 130 than we do like 10^{-16} to 10^{-3}. The decibel scale is not, however, a completely true representation of the loudness that we perceive. It's a lot closer to it than the intensity numbers, it's much easier to cope with and to handle, but in making calculations it is not precise. Because I want to come back to that again a little later, how do we actually perceive the loudness of things, and this will become clear when we do our demonstration.

Any comments or questions on this? Please don't hesitate, my purpose is not to impress you or leave you behind, I want you to stay with me on this. If it isn't just real clear, say so. I don't want to bore you to death. What about numbers that are in between these numbers, these nice whole numbers? Suppose we have something like 3 x 10^{-9} watts per square centimeters, or even more simply, 2 x 10^{-9} watts per square centimeter. If I say I'm creating an intensity in your ears of 10^{-9} watts per square centimeter, and I have one of you come up here and join me and we talk together, we're going to generate twice as much power, there's no question about that. Each of us puts out so many watts, 2 people put out twice as many watts as one person does. So the intensity of sound in the room would now be 2 x 10^{-9} watts per square centimeter. What would be the intensity level of that?

Student: *"Log 2?"*
Yes, which is? Do you remember? Well, let's just do that. The logarithm of 2 is .3. Let's just—I really don't want to spend a lot of time on logs but I think we should just take a quickie look at it. You remember, and I don't even have my slide rule here today; a slide rule is plenty good for any kind of calculations in this course, it could be for looking up logarithms. If you want to use the log table to 50 places of accuracy, go ahead.

End of Part B: Audio File 1B

THE END

Robert Bradford Newman Lectures

14 September 1970

LECTURE 1

Title: "Intensity and the Decibel"

Summary: In this lecture, Newman discusses the notion of sound intensity and introduces the decibel, a logarithmic unit used to describe the measurement of sound pressure. Newman also touches on how the measurement of the decibel relates to human hearing.

No Audio File

You will find that from time to time in the term I will ask you if I have said something before. This is simply because of my imperfect memory and the fact that I am speaking in a lot of places at the same time. For example, right at this moment I am speaking at Penn [University of Pennsylvania] as well as here—and I said that before. In any case, I taught all of the first half of the course last Tuesday, and then I am teaching all of the second half of the course tomorrow in four hours. Some things I tell you that I think I have already told you, and I haven't or vice versa. So just pick me up if I am making a fool of myself; I would much rather be told than make myself a fool.

Last time we had developed the notion of Intensity. The Intensity of sound, I, is given in watts per square centimeter, and we had looked at the source of power, P, in watts, into free space. And given the continuing spherical diffusion of the energy, this energy that had moved out in speed at 1120 feet per seconds, and at some distance, D, we found the intensity of sound to be given by $P/4\pi D^2$, $4\pi D^2$ being the area of the sphere over which the energy from the source power, P, was being spread uniformly (assuming, of course, free field radiation into the free space). And we had also noted that the intensity or the distribution of power per unit area falls off inversely as the square of the distance. We had also written down the relationship: I_1 is to I_2 as D_2^2 is to D_1^2.

Note in the case of doubling the distance, we would reduce the intensity four-fold. Or, if we go ten times the distance, the intensity would be down one-hundred fold. It would be inversely related to the square of the distance, and the fact is that this is a useful description for many real-life situations, such as traffic, or generator sounds in the countryside, or aircraft flying over, and so on—whenever we actually use this approach to the analysis of the problem.

Before we go further, and I have already hinted at the fact that in a room such as this, we hear considerably more than this formula would suggest; that is, that the Intensity is indeed higher because of reflections from the walls of the room. So, before we go on to that, I want to introduce the notion of the *decibel*, which is an extremely useful notion for us to have in this field and in other fields having to do with sensory perceptions. And I hope in the course of today to make some sense out of it. We see all sorts of silly uses of the word *decibel* in the popular press. We hear decibels used to refer to frequency, as in: "this sound has a very high decibel count" as if it were some kind of a Geiger counter. Or: "it's real loud and high pitched" meaning perhaps high pitched sound or something else.

Let's get the words right and use them properly and it will be very, very easy for us. The intensity of sound to which we are sensitive suggests some answers on questions of sound. The range of intensity over which you and I as human beings are sensitive is perfectly enormous. The very least amount of sound that you can hear—the minimum audible sound—(and to hear the minimum audible sound we would have to put you in an isolation chamber free of any kind of disturbance, and let you sit there for awhile and let your ears adjust and you would hear that MMMM sound that goes on in my head (and I would assume in yours). And you would hear yourself settling around inside while the digestive process is going on, and your heart beat and blood circulation in your head and great many unpleasant things that are happening all the time which we are spared from hearing most of the time by the presence of life in general).

So this minimum audible sound which you hear is 10^{-16} watts per square centimeter approximately. A very, very tiny amount of energy; in fact, it is ten-thousandth of a millionth of a millionth of a watt. I have no comprehension of what that means, nor do you. You can write it down and we know that it is an exceedingly small amount of energy.

Now why aren't you sensitive to lower intensity levels? The reason is that if you were sensitive to any lower intensities, all you would hear would be static. The movement of molecules in the air—the agitation of molecules are always kicking each other around [Brownian movement]—if there is any temperature present, it would jostle your ears and give you static at the most sensitive part of your hearing spectrum, (which is that of a jet going over somewhere up in there, sound at 1,000 or 2,000 cycles per second). At very low frequency, your ears are much less sensitive than this.

Almost everything I say here, by way of generality you can always put your hand up and say: "Isn't that a function of frequency?" And I would say, yes, it is. Almost anything we are going to talk about is a function of frequency, and we'll get to that as we go along. But at this point, as a very general concept, if you were able to hear any less intense sound that that, it would be static that you would hear.

Now this applies to all animals and insects. We have some funny ideas that dogs are more sensitive than humans in their hearing. Certainly, animals seem to be much more sensitive than we are. But actually, they are not more sensitive. Rather, they have a different range over which they can hear. Dogs can hear higher pitches than we human beings can. Our upper limit of audibility—and I'll try to illustrate that to you when we do our demonstrations—is around 20,000 cycles per second; that's the upper limit at which we can hear everything. We hear between 20 cps to 20,000 cps. That's when you are about 20 to 21 years old. Now I'm way down on the downhill slope. I remember when I was about 21, already interested in acoustics, and I accepted that my upper limit of audibility that I could hear was 20,000 to 21,000 cycles per second. Now today, I can hear about 15,000 cycles and in another few years, it will be down to 12,000.

Did I mention the new convention of cycles per second? I will stick to the old cycles.

Now I just mentioned that it really begins to hurt when you get in the order of 10^{-3} watts per square centimeter. This would be a level that I could produce (and I won't do it to any of you right now), but you might try and yell in your neighbor's ear, scream as loud as you can; that's about that level. Now it hurts, it is really is painful. But a more pertinent question is: is any such painful experience detriment to your eardrum? Now if I come up and scream in your ear; you can't sue me for permanent hearing loss because you will recover. But if you had that level in your ear all day, eight hours a day for about a year, say, every day you come in here and I scream in your ear, you would go nuts and so would I, but you then have a permanent hearing loss.

If you get very much louder that, even a lesser exposure can damage your hearing, but even at that level, you will experience permanent hearing damage based only on continues exposure, like a jack hammer or any kind of a noisy operation that goes on. I have a son who plays the electric guitar. I told him one day: you're ruining your hearing. And so that at the end of the summer (he hadn't been playing his guitar all summer, he was a lifeguard at a swimming pool up in Maine), and he has come home just before he went back to school, and I said to him: we are going down to the office and I'm going to do an audiogram on you and see whether or not you have lost any of your hearing.

Now he came out with above normal hearing over most of the range, so he said: you see, pop, there's nothing to it. Well, he'd been recuperating all summer, he has young ears, and he recuperates more easily than if he were older. And I'm sure that because he tells me his ears ring all night after one of these big bashes, that he's getting temporary hearing loss.

The same thing happens to us when we get riding around in a noisy airplane, small airplane, or even a DC-3. I always get out of a DC-3 after riding around a couple of hours, and somebody is there to meet you, and you say "how do you do" and you can't hear them because you are temporarily deaf. But in a half an hour, or an hour, you recover. And we can recover from many of these dramatic experiences. But after a while it begins to take its toll. Well, we did get off the subject but that's perfectly all right; that's the way this course is going to run.

We have this straight range from I_{min} to I_{max}, of the order of 10 million, zillion of watts of difference between the intensity that just begins to produce the sensation of hearing, to the intensity that begins to hurt at that level; and I'm using sound in this room where for reference we are getting somewhere in the order of 10^{-9} watts per square centimetre. Now don't hold me to the tenth, it might be more or less, but that's that order of magnitude of 10^{-9} watts per square centimetre which I hear.

Now in the last century, about a little more than 100 years ago, a couple of Germans working in physiology made an interesting discover that forms the basis for our decibel notation of today. There chaps were named Weber and Fechner. If you've ever had a course in psychology, and which I presume you have had, you've heard about Weber and Fechner; and they were the first to discover that when I prick you with a pin, it hurts, and if I then jab you with two pins, it doesn't hurt twice as much. Does everyone agree to that? Or if I stick you with a hot match, and then I take two hot match heads, that does not hurt twice as much. If I say stick out our tongue and I put a grain of salt on the end of your tongue, then that tastes salty. Now then, we try it again with two grains of salt the same size; it's not quite twice as salty.

If I have one of you come up here and stand with me and we say "*BABABAB*" and then we did it together, and we say "*BABABAB*" the same way, it isn't twice as loud. We are not going to get any traumas from two people performing instead of one. Weber and Fechner found that <u>all</u> of our sensory perception, whether it be touch, taste, seeing (one candle, two candles; one light, two lights)...all of these things and our hearing as well,,,, that the sensation that we get is in proportion to the ratio of the stimulus, and is not in proportion to the stimulus itself. Now you say, what is the ratio of two pins? Well, it's difficult, but in any case, it's not to the ratio by which the two pins relate to the sensation to one pin, but rather the logarithm of two, and we'll see in a minute how that works, don't worry about it.

Now in acoustics entirely for convenience related to the work of Weber and Fechner, we have decided to use the following formula and the following definition to which we all agree. And we don't have to explain it to each other every time we talk about. It's like telling Joke #16, and if you are in on it, you'll remember what Joke #16 is, and you laugh and laugh and remember all the innuendos of Joke #16 and how bad it is.

I measured the intensity level of Mass Avenue traffic. (This by the way, beats aircraft flyover, which are half as loud or perhaps less than what it would be at the new Columbia Point site where the University of Massachusetts Boston campus will be, which is the reason all the buildings are going to be air-conditioned and have double block thick and concrete walls and everything else, because you cannot teach classes if you have very much more interference than this.)

We are considerably farther away from the airport. Intensity levels here are ten times lower, and I will not repeat "base 10" because you know that is what the intensity of sound in question is, as compared to the intensity of the minimum of the sound. Let's see what this means. It should be quite clear as we go along: I_o, it seems safe to say can be the minimum audible sound: $I_0 = 10^{-16}$ watts per square centimeter.

What I want to do is following Weber and Fechner, and recognizing the logarithmic relationship of the sensation that we feel to the stimulus, we're going to test the ratio between the intensity of the sound that we are actually hearing to the minimum audible sound, and then we are going to take the logarithm of that ratio and multiply it by 10, and this is all purely arbitrary, by definition. And this will come out in decibels.

Now *decibels* is named after Alexander Graham Bell, and this is 1/10th of an Alexander Graham Bell. There is a school of thought amongst these idiots who have nothing better to do but to sit around and standardize our modes of behavior, which says that if this is named after Alexander Graham Bell, it should be capitalized at the B point, so the abbreviation for this is: "little 'd', little 'b'" and sometime used as "little 'd', capital 'B'." You'll see it this way in current writings; and all the mags that are proper will insist on your conformance to this even though you write it properly yourself. Just as one time I wrote an article in which I said something should not only look good, it should sound good; and the Editor changed it to "look well and sound well." The dope.

Weill, I would use "little d, little b" here in this course. When we capitalize Volts, Amperes, and Ohms and all the other units that we use that are named after people in common usage, I would then be prepared to capitalize the B. Meantime, we'll stick to this.

What do you suppose is the Intensity Level of the minimum audible sound? What is the Intensity Level? We're going to write down here the decibels in current form with the "little 'b'". Well, let's try that one first. The intensity level of the minimum audible sound is equal to 10 times the logarithm of the intensity of the minimum audible sound (which is 10^{-16}) divided by the intensity of the minimum audible sound (which we know is 10^{-16}), and this is 10 times the logarithm of one. Does anybody remember what the logarithm of 1 is? Zero; correct.

So at the point of starting, we have zero. And that's a nice convenient place to start. Well, there's no use in talking about anything less than that because nobody can hear it and nobody is sensitive to it. And so, for practical purposes, we'll say let the minimum audible sound has an Intensity Level of 0 (zero) decibels. Arbitrarily, we'll place that [at one end of the spectrum], and that's the way our definition has been made to work.

Now, how about the intensity level of the sound in this room due to the sound of my voice? Let's calculate that. All you've got to do is jot the numbers in and we'll get some answers. The intensify level of my voice in this room, I'd say, is about the order of magnitude of 10^{-9} watts per square centimetre. 10^{-9} divided by 10^{-16} will give us 10^{+7}. What is the logarithm of 10^{+7}? 10 times 7 = 70 decibels.

What is the Intensity Level of the I_{max}, 10^{-3} watts per square centimetre? You'll excuse my economy of writing, but I realize that you can't do it quite so readily: $10^{-3}/10^{-16}$: that will give us 10^{+13}. It will be 10 times 13, which is 130 decibels, so this will correspond to 130 decibels. Now there are some others in between; we'll examine them in a minute. Let's take the very simple stuff first.

I'm going to talk about logarithms in just a minute, and how I handled it. The logarithm, you'll remember, is the power to which 10 must be raised to give the number in question. The logarithm of 100 is 2; the logarithm of 1,000 is 3; the logarithm of 10^7 is 7; etc. It's the power to which 10 is raised to give us the number in question.

Here we have a very tractable set of numbers, a set which most of us can think about: 0 to 130, rather than 10^{-16} to 10^{-3}, which is 120 million billion fold in intensity, with variation. Here we have seven numbers from 0 to 130, which we can sort of begin to think about a little bit. This is the range over which we hear. Every sound that one hears can be assigned an Intensity Level arbitrarily figured out on the bases of its intensity and what is the ratio between that intensity and the minimum audible sound as a reference level. For example, wherever I say the Intensity Level of sound is 69.3 decibels, I mean automatically with reference to the minimum audible sound.

I don't repeat that whole business each time, but by definition, if I say the Intensity Level is so much, that's what I mean. Now the Intensity Level is numerically almost exactly equal to the sound pressure level, which is more often used in making actual measurements. So that for all practical purposes, the Intensity level equals Sound Pressure Level, and which you will see—it's what you read on the meter and it's what actually moves your eardrum in and out. The pressure variation (we talked about this the other day) is what makes your eardrum move, so that the presence of the energy there causes retrovariation, and, of course, it's the basis of hearing.

The question is: why is "10" here? It just makes a better set of numbers: rather than 0 to 13, we go from 0 to 130. We do need the first decimal place to describe the ratio, and if we didn't have the 10 in there, then we would have two decimal places, and it would begin to look more precise than it really is. In fact, some years ago we arbitrarily changed the reference level for sound pressure because it came out that 1 dyne/square centimetre gave us 73.8 decibels, and this looked as if we were dealing in greater precision, when in truth we weren't. We changed it so that the reference level would give us 74 decibels for 1 dyne/square centimeter, and 74 is a much rounder number than 73.8. We do not create precision by arithmetic manipulation by division or multiplication, and we could calculate things out to several decimal places, but this doesn't mean that it is morally accurate. We have to be very careful about that.

And in this business of acoustics, for God's sake don't go getting precise on us. Things are all an order of magnitude. We've been through the ropes on the magnitude; we're still a very loose, very sloppy field, as you can see.

If amplitude (which is what we hear) is directly proportional to intensity (it is), then it's the same. How do you measure intensity? I can see how you can measure amplitude. Intensity is calculated from the pressure. How can I measure the intensity? You measure the pressure, the sound pressure level. You'll see, I'm going to bring in here a sound level meter and we'll have a demonstration, and you can watch the needle whip back and forth as I talk, talk, talk, talk, talk....

This range from 0 to 130 is a first approximation for getting around to the way that we hear the intensity of sound, but it is not precisely accurate. When I change from 70 dB to 80 dB, the loudness that you perceive goes 2:1 higher, rather than merely 7 to 8; so this scale is a little bit compressed; it's overdone. This scale is wild, 10 million million. Now we go down to 1 to 130 and that is a little bit too compressed, and we'll come back to the reality of the perceived loudness that we get with a straight response kind of measure.

But for the moment, I want to deal just with the physical definition. This definition is arbitrary, and it is based on the basis of which all our physical measurements are made. Now there is no coming into this room and saying "gee whiz, this is fairly quiet" or "fairly noisy" or something. Until I know exactly how many decibels the level of sound is in this room, I cannot give an accurate description. And just giving the number of decibels is no good at all until I analyze it in a whole frequency spectrum. I've got to see how much "*WHOOOOSE*", how much "*BOOM BOOM BOOM,*"and when an airplane goes over, I'll have a completely different picture of the intensity level of sound in the room. It's the physically measurable thing, and when we say that the level at 1,000 cycles per second was 72 dB, everywhere in the world you know exactly how much sound there was, if the measurements were made by a careful observer. It's very important that we have these arbitrary methods of measurement.

Question: *(inaudible)*

No, it doesn't mean either of those things because your ears don't know about logarithms. Your ears merely tell you how loud it is, and what we find is that for every tenfold increase in power or in intensity, we get a 10 decibel increase in level, and we get a 2:1 change in perceived loudness.

Let's look at a little bit more of this. There are three or four ideas that I have to get across; we need to develop all of them and then I think it will come out crystal clear. Is this okay so far? Everybody happy about this? Anyone unhappy or curious about any aspects of what I've written up here so far?

In between 10^{-16} and 10^{-3} is a whole series of numbers from 0 to 130 with as many decimal places as we like to develop. I'd like to look at a couple of very simple relationships of decibels. For example, what about adding decibels? Suppose I tell you that the level of sound from my voice in this room is 70 decibels, and then I have one of you come up here and join in with me.

70 decibels plus 70 decibels, what do you suppose that equals? Is it going to equal 140 decibels? 140 decibels—which is above the threshold of pain, and in fact can do permanent damage to your ears; you will probably throw up and begin bleeding—that isn't going to happen. What is 70 plus 70? Well, we have a very interesting kind off arithmetic: it is 73. How did we get that? Well, what we have to do now is go back to the basic intensity of the sound involved.

We can think between 1 and 10, and between 1 and 100, but out of that scale I can't do it; if we stay down between 1 and 10 with our whole numbers here, we can think them out, handle them. And then, all we've got to do is the bookkeeping of adding exponents. Well, that has nothing to do with this; we certainly are jumping around here.

The point is that the logarithm of 2374, for example, can be very quickly obtained if I just put this into base 10 format because right away I've written down the decade, haven't I. And that logarithm will be: log of 2.347×10^3 , and will be equal to .3 something. And all I've got to do is look up the logarithm of the number 2.347 (and I don't get very precise here: 2.3 and can't get it any closer here than 2.35, maybe I could a little bit), and that comes out to be .37. All I've got to do is look up and write things down and keep very simple books, and we just stay out of an awful lot of trouble if we don't count zeros, count commas, and all the other jazz that you may have learned at some time or other. Reduce everything to this form and you will just be very much out of trouble.

For our problem over here, we go back and we see that we have 10 x 7, and the logarithm of 2 is .3; 7.3. You see how I got that: the logarithm of 2 gives us the .3, and the 10^7 gives us the 7, the decade of the logarithmic number; and that will be 73 decibels.

Now I have a different way I'd like to approach it. Suppose I say that the level is now 71.7 decibels, and someone joins me and we perform together with another 71.7 decibels; how much will that give? Well, I can tell you right off the bat that that will give you 74.7 decibels because I just add 3 decibels every time I double the top value.

Let's see what that means. Suppose instead of saying the Intensity Level is such and such, I say: what's the *difference* of the intensity levels between two numbers (e.g., an un-muffled internal combustion engine). You all know the notation: big W for difference between things; and the difference between IL_1 and IL_2 is the change in Intensity Levels.

The difference between two numbers can be written as 10 x log of I_1 compared to I_2. I can take any reference level I like. You asked me a minute ago if I ever take the reference level as the ambient, and I say: no never, never, never. Now, we'll turn right around and say: yes, yes, yes. Lots of times we change the reference levels if we are in touch with ourselves and know what we're doing. If I have I_1 is equal to x; I'd refer I_2 over I_1 in this example, and it will be IL_2 - IL_1...(it won't matter, always stay away from negative logarithms because they're just troublesome to deal with).

(I will go back and mention them in a minute, but if you find yourself running into a negative logarithm that is a logarithm of a number less than 1, why just turn the thing over and change the rule a little bit. You can do that, it's pretty legal.)

$I_1 = 10^{-9}$ watts per square centimetre, $I_2 = 2 \times 10^{-9}$ watts per square centimetre; so I have the relative level between these two is 10 x (log of $2 \times 10^{-9)} / 10^{-9}$), the 10^{-9}'s cancel out and we have 10 x log 2, and logarithm of 2 is 0.3, so that's t 10 x .3 = 3 decibels.

Now this number "3 decibels" is not the intensity level. I didn't say with reference to the minimum audible sound; I said with reference to some other sounds that I had before. This is one of the very simple ratios, 2:1, that is very useful to keep in mind. You can do a great deal with a simple ratio, like 2:1, if you're thinking about the change in Intensity Level. This is how much difference the Intensity Level of two sound is when their ratio of power or intensity is 2:1: 3 decibels.

Now I'm going to illustrate to you a decibel change when we do our demonstration, but I can tell you that it's <u>almost imperceptible</u>. A 3 decibel change, a change of two-fold in intensity level, is almost imperceptible. If you say to your roommate: "turn that God damn radio down, please," and he has a calibrated volume control in decibels, and he turns it down 3 decibels, he will not have done what you asked him to do as far as what you hear is concerned. It just won't make that much difference. Three decibels is barely noticeable. A human being <u>can</u> detect changes of the order of 1 decibel, but you have to be sitting in a lab all psyched up with headphones on and nothing you can see. You keep telling whether they're equal or a little louder, or a little softer, and after about a week of this kind of thing, you can begin to detect decibel change. That's one reason why we don't get very precise about fractions of decibels.

There's another ratio that we ought to look at, and that's 10:1. If you want I_1 is 10^{-9} and I_2 is 10^{-8}, ten times 10^{-9} equals 2×10^{-8}. So we have a 10 fold ratio, and this will be logarithm of 2 times 10, won't it? If I can stick to my rules and don't write is as 20 but write it 2 times 10, I'm going to stay out of trouble because this is 10^1….

Question: *inaudible*

This is...this is wrong; that is that better, thank you.

This is what I get for trying to be economical on the blackboard writing. MIT has a marvellous book that they put out on how to teach, and amongst the things in the book are how to use the blackboard. You always begin in the upper left-hand corner in the beginning of the hour, and work in an orderly fashion down each panel and you arrive at the other blackboard at the end of the hour with everything on display. I can't do it.

I was beginning to wonder what I was going to do with that 3 that I was going to get at the "2 time" there. Okay; 10 x log 10—this is much simpler—is equal to 10 times 1, which is 10 decibels.

Now 10 decibels is a change that we produce when we go ten-fold in power. For example, I have one power generator, I put in ten new generators in this power plant and the noise will be 10 decibels louder, and as I said a minute ago, you will hear the noise as about 2 times as loud.

And you can judge two times as loud. Again if I put you in this room and you close your eyes and I begin to go "*WHOOOOOO*" and then I go *"whooooo,"* you way say: oh, that person was twice as loud as the other one. More or less, this is the sort of thing you do. And one of you can make this judgment of 2:1 louder. The nice thing is that no matter where I am on the decibel at that moment, I'll say I got the level of the sound here, due to the operation of single machine that is 52 decibels. Suppose we're going to put in now 9 more machines so that we have 10 times as much energy, what will the new level be? Right away, all I have to do is add 10 decibels to this and I'll come up with 62 decibels added on; so in this case 52 + 10 = 62, where 70 + 70 = 73. Now in one case I'm adding Intensity Levels and in the other case I'm adding a change in Intensity Level to an Intensity Level.

Now we're also going to use decibels when we talk about the change in Intensity Level going from room to room. I'm going to say that wall is a "40 decibel wall;" that doesn't mean the wall sits there throughout its entire existence and goes "*WHOOOO*." Not at all. It means that the wall reduces by 40 dB the sound from one room as it arrives at the next room. It's down 40 dB so we can add and subtract these numbers; we can use them in the most wonderful way merely using arithmetic addition rather than having to go through multiplication and division. The logarithm has a real advantage in this particular kind of manipulation. Is this clear?

I'm going to hand out—and I'd like to do so right now—a set of problems that I'm going to ask you to try to get done by Friday, and it'll take you about 20 minutes to do them, or may be half-an-hour. So see if you can't find some time between now and then to do them. Again, as I said, it's not just to keep you busy but to force you to come to grips with this. There is no form that we have that is required for turning in problems. Generally a piece of white paper will do, 8-1/2 x 11 or any other size that you find convenient. Let's use something softer than a 6H pencil. It's very hard and Terry will thank you if you write in ink or big black pencil. You can turn in several sheets of paper.

The first [problem] is just to work out a number of these Intensity Levels. The second is: given the Intensity Level and go back to the intensity. We haven't done that yet, but I will do that first thing on Wednesday, and then a couple of problems that begin to show how we would apply these relationships in actual cases. I will give you the material to do Problem #2 on Wednesday, so don't sweat about it.

THE END

Robert Bradford Newman Lectures

17 February 1971

LECTURE 2

Title: "Decibels and Absorption"

Summary: In this lecture, Newman continues his discussion of decibels and explains how to calculate the change in intensity level. He also talks about the effectiveness of various sound-absorbing materials and the effect of absorption on reverberation time.

Part A: Beginning of Audio File 2A

I would like to change the locus of our meeting from here to another part of Cambridge where I want to give you some demonstrations, and the only reason for suggesting that you meet elsewhere is that I just can't haul all the equipment here to do the demonstrations. And I'd like to have you meet with me at my office. Let's see, this is Wednesday 24 February. Meet at Bolt, Beranek and Newman office, which is at number 50 Moulton Street in Cambridge. Now let me tell you where that is; it's relatively easy to find. Is it possible, by the way, for everyone to arrive fairly promptly at 11, or do you have other classes before it? Okay. Well then, get there as soon as you can. The trouble is the room where I want to do this is available only until about 12:15, and then we can go out and do some other things in the laboratory. With this many people, let's see, how many of you are there? (Counts) About 35. Well, we'll just do the best we can. We can always just run over and make the other people wait. That's one technique, it's not very popular. But I've reserved the room, I've already moved them off from 12 to 12:15 by persuasion and pressure, but get there as quickly as you can. If you can come by car, it's about a 5 minute trip. By bus, it depends entirely on how long between buses. It's maybe 10 minutes by bus.

Now our office, let's see, how can I best describe it. Here's Concord Avenue going out towards Belmont, here's Superior Laundry, and here's the lovely Pancake House, some of you know that. And here's where Joyce Chen's used to be and is now the Osaka restaurant, and then here's Fawcett Street and here is the Fantasia restaurant, and here is Howard Johnson's on the corner down here, and this is Route 2, and here's Zayre's [now defunct discount store] and all that trash over here and are you sort of with me now? And Fresh Pond is right in here, and the old folks' home is right there, and then this is Fresh Pond Parkway going back up towards Brattle Street and so on, here's another circle, and, well, something like that. It's a lot of (inaudible) that jump, jump, jump. Real jumpy area. This is Concord Avenue towards Belmont, Belmont is out that way, and this is Moulton Street here, and we're at number 50 here. Now if you come by car, it's very easy, you pull in on Fawcett Street, which is right beside the Fantasia restaurant. Pull in there and go back here behind these buildings, and you'll see a large parking lot in here, which is our parking lot, and you're welcome to park there. If you can't find anything in our lot, park in Fantasia's lot, because they won't know whether you're customers or not. We have reciprocal arrangements with them anyhow so that use our lot at night. If you take the bus from the Square [Harvard Square], Belmont bus or the Arlington, what's it called, Park Circle bus, either one of those goes right out here and you can get off right at the corner here. Be sure you take one that is marked "Concord Avenue", not "Spy Pond," because this Spy Pond bus goes out this way and the Concord Avenue buses go this way. So this is Concord Avenue going towards Belmont. Is that clear?

I'm sorry I asked you to do this, but it just is an awful lot of junk, loudspeakers and amplifiers and other stuff that I just can't haul here to too easily. So you'll meet there Wednesday 11 am sharp, let's say, and we'll try to get started just as quickly as we can so we can have a full hour for demonstrations. It's very important, I think, when we're talking about acoustics, to hear some of these things, other than my imitations, which aren't always accurate, and I'm not well-calibrated in decibels, and I want you to hear some decibels and some changes in levels and some pitches, the effects of noise on masking of speech, and the fact that noise has pitch characteristics. You'll hear noise filtered in various frequency bands and you'll hear distinctive pitch characteristics to the noise as it steps up from one range to the next. So if that's okay, we'll meet out there, and we'll certainly be finished in plenty of time for anyone who has to get back here for something at 1:00 pm. Just make it as quickly as you can. I will try to get rid of the dishwashing here.

I also have the first of four sets of problems I'm going to ask you to do, and as I told you last time, I'm not giving you these because I have any notion that you haven't anything else to do, simply that only by doing some problems, going through some of these exercises, will you get some facility with the manipulations that we're talking about. There's no particular requirements for form of submitting problems, just turn them in so I can read them. I've got to read them, and I would appreciate it if you use something softer than a 4H pencil that the answers that you get are clearly in evidence, that major research isn't needed to find them, because if any of you have ever marked papers you know that at the end of about 30, when you're groping around wondering what the hell he did, you get sort of tired. I'm marking them for your benefit, so please make it easy for me to do. I'll just hand these out right now. Don't start to do them now. Again, I hope there are enough.

There have been two moves made here by members of the class in the last few minutes which illustrate a very important point about acoustics, namely getting rid of noise by closing doors and windows. This is an automatic reaction by sensible people who have ears. You may not realize sometimes how deleterious the effects of noise can be, but noise is definitely something that we don't want when we want to have good hearing conditions, and this is one of the reasons why in this class we treat noise control before we treat room acoustics, because without noise control there's no use talking about room acoustics, or worrying about reverberation time or any of the other aspects that we will cover in the second half of the term. I'm going this afternoon to, rather, to look tomorrow at a very interesting noise control problem related to hearing conditions. This is in Dallas where there is a large auditorium that exists in Fair Park, Dallas.

This auditorium was built about 45 years ago and was built with the cheesiest imaginable construction. It's got a very Spanish-type front, you know, the Texas Spanish style. It's sort of like economy-Georgian in this part of the country, Howard Johnson Georgian is another version of this particular style. This is Texas Spanish, but behind the very elegant towers in front is an incredibly pasted together bunch of junk. Now the citizens of Dallas have just voted a bond issue of several millions of dollars, partly because I told them it would work, to remodel this auditorium into a new facility, more than a paint job, a total remodeling. And one very important aspect, and the aspect that we have to solve tomorrow before we can do anything else, is to fix it so that the noise of aircraft flying overhead will be totally inaudible inside this rickety building. The roof trusses exist, there's no question of putting on a new roof, the roof is spanned with 3" or 4" timber decking (I'm not sure of the exact thickness), but it's heavy decking spanning over these great big steel trusses, 10 feet deep.

And the question will be to work out what is the most economical possible way to add weight to this system to exclude noise. Would it be better, for example, to pour 3" of concrete on top of the wood deck? You say, well, maybe the wood deck would collapse, well maybe it would, and that may well be one of the reasons we don't do that. Or, how can we add layers of heavy plaster and other things down at intermediate levels in this truss system in order to achieve the sound isolation we've simply got to have before we even begin to talk about how to shape the auditorium or anything else? I'm not even worried about that until I get the problem of excluding aircraft noise solved, because last year when I was down on the first visit to the sick patient, we found while sitting and standing around in the empty auditorium we constantly had to stop and wait while an airplane flew overhead, and this was not speaking from the stage but four or five people standing in a tight little group trying to talk to each other at 5 or 6 feet, and even then aircraft flyovers were disastrous for our conversation, so you know what it does to performances. They're using the hall, and you say, well, how can they possibly use it? Well, they just wait. That's all right if you have to, but if you're doing something new and you're going to spend a lot of money, then we do have to worry very, very much about this business of noise exclusion. Well, as I told you at the outset, this course is not a well-ordered one. I'm likely to talk about anything that happens to come to my mind that involves acoustics. I try to stay out of politics. But these things are all important and they do relate to what we're talking about, and I think the more you can see that what we're talking about here relates to real life and real problems, the more it's going to stick and the more you're going to believe me. I'll give you a report next week on what I find tomorrow in Dallas.

I'd like to go back to the stuff that we were talking about last time and which we rather hurried through a bit at the end, and just do a little bit more dishwashing work on decibels. Speaking of dishwashers, I just saw an article this morning that appeared on Sunday. Did any of you by any chance see the [Boston] Record American? I never see anything. It's one of the Boston tabloid papers. What a discriminating crowd. Only the New York Times, I'm sure. Well, that's good. (Laughter) In any case, in the Record American last Sunday in their supplement was a two page spread on Newman's house with as few photographs as I could persuade them to put in, and one particular photograph shows our dishwasher mounted in a proper way to reduce noise. Another photograph shows one of the bathroom exhaust fans with its spring balance and so on. It's really quite a nice coverage. And this all has to do with noise control and with the things that we're talking about here, and there was a little attempt in there to get across the notion of what decibels are. But this lady reporter who came to interview me kept wanting to know, first of all, did the application of acoustics principles in the design of our new house improve in any way the relations between me and my wife, and I said not that I could tell. Well, how may percentage points were things better now than before? They always want some numbers, and then she wanted to know how many decibels better was it. I said I can't tell you, my dear woman, you don't even know what a decibel is, I said. And what good is it going to do me to tell you something to tell your readers about decibels?

Decibels are very useful. Those of us in the trade use them. If we really understand what we're talking about, it's a very useful thing to describe exactly how many decibels louder something is than something else. If I want to tell you or write to you or have my Australian clients write to me and say we have measured the sound levels at the corners and we find that the decibel levels are the following and they give me the numbers, and that's like telling joke #13: we all remember it as being very, very funny and we all laugh when joke #13 is mentioned, we don't have to go through the whole business. The same with this decibel notation, it's an internationally accepted method of specifying the physical characteristics of the sound. How many decibels is it? What's its level? And how many decibels louder is this than that and by how many decibels do we have to reduce the noise, this to get that. For example, in Dallas the flyover of the aircraft. We know that aircraft fly over at 3000 feet, we know by many, many measurements exactly what kind of sound levels we're going to get through the roof of the building from a fully loaded 4-engine jet aircraft taking off and flying by this time at 3000 feet. We know the levels. We know how many decibels it is. We know how many decibels of loss we can get through the roof structure and we know what our criterion for design is in the hearing space: 20 decibels or so, that's all we want inside, and if we have 100 outside we've got to reduce it by 80.

Well, this is all very useful as an engineering tool, but when you get into the popular press, when you get to talking with your clients about the advantages of doing acoustical work on a building, it's sometimes going to be very difficult to tell them just how many decibels is this better than that, or how many decibels is it, as this lady reporter asked me. I said I just can't tell you, it's better, it takes the jangle off your nerves, and she said, how much? And I said, I can't tell you, it's just better. Well, is it worth the money? I said, anything that improves the quality of my life is worth the money. I happen to be a car nut and I happen to be a number of other kinds of nuts, and I spend a lot of money on some of these things just because I like these sorts of things, and you can't decide—tell me that a Rolls Royce isn't worth it. It's a very expensive toy, but it's just lovely. And so it goes with this general philosophy.

Well, back to decibels and what we were talking about the other day. I want to put them in proper perspective and have you develop a suitable amount of—not disrespect, but understanding of when and when not to use the term. We did put down the very simple relationship, and I'll just repeat it one more time, that the intensity level (IL) of a sound is 10 times the logarithm base 10 of I_x, the intensity of the sound in question, divided by I_0, where $I_0 = 10^{-16}$ watts per square centimeter. Now any of you who were not here last time, I suggest you get some notes from somebody because I don't want to go over all of this again, but the point is that the decibel, the intensity level in decibels, is defined as the logarithm of the ratio of the intensity of a given sound to that of the minimum audible sound. The minimum audible sound then becomes our floor, our reference point, and in fact has an intensity level of 0 decibels, because if I say what is the intensity level of the minimum audible sound, I will say the intensity level of I_0, which is the minimum audible sound, is 10 times the logarithm of I_0 over I_0, which is 10 times the logarithm of 1, which is 10 x 0, which is 0 decibels. Therefore, this corresponds to an IL_0 = 0 decibels.

And I also told you that in this room, as I'm talking to you, you're getting an intensity of sound of 10^{-9} watts per square centimeter. Now don't somebody ask me, is it 2 x 10^{-9} or is it 9/10 x 10^{-9}? I don't know, it varies all over the place. In my voice, in your voice, there is range of 1000 to 1 in intensity between the "*ssss*" and the "*ah*." These have very different amounts of sound energy. You can't say one is more important than the other in producing intelligibility, but the "ah" part of the level, the vowel sounds that I'm making, are producing an intensity of the order of 10^{-9} watts per square centimeter in this room. And as we'll see, as we develop these notions, and we may get to this today, the level that you're getting at your ears in this room is higher than it would be outdoors simply because the room is building up the level by many, many reflections, and thus we certainly know that outdoors you would get much less intensity at the back of the room than you're getting here now by these multiple reflections and buildup, 10^{-9} watts per square centimeter.

And we looked at that number and we found that the intensity level (IL) was equal to 10 times the log of 10^{-9} over 10^{-16}, which is 10 times the log of 10^{7}, which is 10 x 7, which is 70 decibels, and I pointed out that 70 decibels is the intensity level of the sound of my voice in this room with relation to the minimum audible sound. That latter little canticle I shan't say each time, with relation to the minimum audible sound. That is assumed in the basic definition of intensity level, the level of the intensity in the room. And we also pointed out that this scale going from 0 decibels to 130 decibels, which was the pain level, with 70 here somewhere, that these levels are a much more understandable, practical scale of numbers than the full range of intensities that we have from 10^{-16} watts per square centimeter to 10^{-3} watts per square centimeter, which was a range of 10 million, let's see, 10^{13}, which is 10 million million-fold in intensity ratio.

In other words, your ears are sensitive over that range from the very least thing you can hear to the very greatest thing you can hear.

Now, any questions about this? I don't want to labor this at all further. Any of you who weren't here last time and who haven't got it clearly in mind, if you do have some questions at the end of the hour, please speak up and ask me about it. Now, I wanted to go just a little farther with the notion of the addition of sound intensities, and in fact next week when we do our demonstration I'm going to show you some of these things by making changes of 2 to 1 in the power of the sound, 10 to 1 in the power of the sound, and get some notion for what this does to the change in level. Let's just very quickly look at this business of—I said last week that we looked at business of 70 decibels plus 70 decibels, drawing the analog of 2 people performing here in unison as compared with one person performing by himself, and you know perfectly well that the resulting level is not going to be 140 decibels, which is 10 decibels above the threshold of pain. I could produce that if I got right up next to your ear and screamed in your ear. That could produce the order of 130 decibels. If you want to try it on somebody, go ahead and try it, or have him try it on you, if you want to feel what it's like to be hurt a little bit, and you will have temporary deafness. It won't last, but it will be a little bit deaf for just a little while. 70 decibels plus 70 decibels is just a little louder than 70 decibels.

We went through this last time, and I showed you that the—this is 10^{-9} watts per square centimeter, and this is 10^{-9} watts per square centimeter. It's just as if I have one 30 watt lightbulb burning in the room and I now put on a second 30 watt lightbulb next to it. I'm now burning 60 watts, I have twice as much power, I do not have twice as much perceived brightness, nor do I have twice as much perceived loudness. And we said what we have to do is add these two together and we get 2×10^{-9} watts per square centimeter, and now we can find the intensity level of that and compare it with the original 70 decibels, which we'll do very quickly. IL = 10 times the logarithm of 2×10^{-9} divided by 10^{-16}, and that's 10 times the logarithm of 2×10^{7}, which is 10 x 7.3. The logarithm of the number 2 is .3. The characteristic is always given us right away by this exponent, therefore this is 7.3, the logarithm of 2×10^{7}, and that of course will give us 73 decibels.

Suppose I have 10 of us performing instead of 1, suppose I get 9 of the rest of you and we have a little rehearsal, and we go "*DA DA DA DA DA*," and then we all go "*DA DA DA DA DA*" together, exactly in the same fashion. What's that going to do to the intensity level? Well, let's just take 10×10^{-9}. What is 10×10^{-9}? That's 10^{-8}. So what is the intensity level IL of 10 70 decibels? 10 x 70 decibels equals what? It's going to be equal to 80, we'll discover. IL is equal to 10 times the logarithm, and I said we have 10 times the power of 10^{-9} watts per square centimeter, therefore 10×10^{-9} or 10^{-8} watts per square centimeter. Can you see how easy it is? This is 10 log 10^{8}, which is 10 x 8, which is 80 decibels.

Now these two ratios, 2 to 1 and 10 to 1, are the two that I carry around in my mind, because if I want to think about some situation, like I'm going to double the distance from the source of sound to the receiver, and we looked last time what happens to the intensity when we do that. We double the distance, this cuts the energy to 1/4 of it because it goes inversely as the square of the distance. If I reduce the intensity by 1/4, what have I done to the intensity level at that point? Well, I cut it in half and half. If I cut it in half, I reduce the level by 3 decibels. Whenever I change by 2 to 1, I make a 3 decibel change either up or down. If I reduce the level to half, I go down 3 decibels. If I reduce it in half again, I go down another 3, or 3 and 3 is 6 decibels. And I can analyze almost any problem with a simple 2 to 1 half, half, half, or 10 to 1 change knowing that each 2 to 1 change in intensity or power will represent a 3 decibel change in the sound level that I get, either up or down.

And in fact I can write down a very simple relation here, delta Δ IL, using the mathematical notation delta meaning change, change in intensity level from one number to another will be given by 10 log I_1/I_2 to compare the difference in intensity level between intensity #1 and intensity #2. Intensity #1 may be 2 x 10^{-11} and intensity #2 may be 10^{-11}. The ratio is 2. The difference in intensity level will be 3 decibels. 10 times the logarithm of 2 will be 10 x .3, which will be 3 decibels.

Now that is not an intensity level of 3 decibels. That's a difference in intensity level of 3 decibels. If I say that wall over there has a transmission loss of 50 decibels, what does that mean? That means that if on one side of that wall, out in the corridor, assuming the doors aren't there, we have a 90 decibel intensity level, that the wall will reduce it by 50 decibels, giving us 40 decibels on this side. And I can add and subtract like that if I say this is a change in intensity level of 3 decibels or 40 decibels or any other number of decibels, but I cannot simply add together a bunch of intensities and say 70 + 70 = 140 because no, that's a false number.

Now several years ago, I was called by the plant engineer at Raytheon at their new office building out in Lexington at the corner of Route 2 and 128. The guy says, we've been had! And I said, oh? By whom? And he said, by the partition manufacturer. We bought these 'g-d' Hauserman [manufacturer of office furniture] partitions and we paid a lot of money for them, they're metal partitions and you people recommended them. And he says that the sound level in the offices, and I said, yeah, uh huh, and he says they are rated at 42 decibels. I borrowed a sound level meter and I went into the office and I measured 65 decibels. Therefore, we have been had. Now this is in logic what is called *non sequitur*. The two numbers have nothing whatever to do with each other. 65 decibels that he measured with a sound level meter was the ambient intensity level of sound in that office made by God knows what—an aircraft flyover, mechanical equipment, somebody running down the hall, somebody talking in the room, or whatnot, we don't know. It has nothing at all to do with that partition.

The partition is sitting there passively waiting for somebody to try to move it back and forth and to send a little bit through on the other side. The partition is capable of reducing by 42 decibels the sounds that are made on one side going through to the other side. That's a delta Δ IL, that's a change in intensity level that the partition is capable of doing. You'll find all sorts of ratings and things, and we'll talk a lot more about this and it will become crystal clear to you. But you'll find that partitions are always rated in decibels, not intensity levels, but it is the decibels' capability for reducing intensity levels. You have to be—the term is the same unit all the time, it's always 10 times the logarithm of a ratio, but you've got to be sure what you're taking a ratio of before you can (inaudible) add or subtract it. But if I say that one sound is 6 decibels higher in intensity level than another, then I mean that. I mean that if one sound is 70, the other is 76, and I add the 6 onto the 70.

End of Part A: Audio File 2A
Beginning of Part B: Audio File 2B

You can't do that. But if you just think about this a little, you'll realize that this is the way it is in real life. The wall behavior, just as its mass is constant, its color is something—I mean, this wall appears generally whitish, but if we had nothing but very red light in this room it would appear reddish, simply because that's all we have to reflect. So we just keep in mind that this is a physical characteristic of the partition, this notion of transmission loss or decibel reduction. We will come back to treat this in much greater detail in a couple of weeks, but I wanted to get the idea across at this point.

Any other question or comment? Well, the problems that I've asked you to work out for next time, and please try to find a half an hour, that's all it will take you to do them, between now and next time and get them done on time so that you can keep up with what we're doing. The first two are simply exercises in calculating intensity level from a bunch of intensities and then doing the reverse process.

Now just one word about the reverse process. If given 73 decibels, and I keep working with 3 because I happen to know the logarithm back and forth. If you prefer 74.6, we could do that, but I've got '3' up here. 73 decibels equals 10 times the logarithm of I over 10^{-16}. And I want to know what is I? What is the intensity? Because there are times when we've got to convert a bunch of contributors to the sound field back to the initial energy levels in order to add up the energies or powers involved in order to give us the total intensity that we've got. $73 = 10 \log I/10^{-16}$. Now don't get hung up on words, just say this thing in English. 7.3 is the logarithm of I over 10^{-16}. Is that all right? If 73 is 10 times the logarithm, then 7.3 is the logarithm of I over 10^{-16}. Now don't get clever at this point, or you can get clever if you wish, but you'll just get in trouble, and say oh, I know something, I know log of $1/10^{-16}$ is the log of 10^{16}, and that's 16. Yeah, and what are you going to do with the 16? Write it down somewhere on a piece of scrap paper and throw it away. And then come back and do this properly. Keep this as a unit, as a thingy in parentheses, don't fiddle with it right now. 7.3 is the log of some number. What is the number? What is the number whose logarithm is 7.3? Well, right away, I over 10^{-16} is equal to something times 10^7, isn't it, because I know that the number whose logarithm is 7.3 is something times 10^7. I know that because of the way that the logarithm scale is set up.

So this is times 10^7. What is the number whose logarithm is .3? Well, if I didn't have to know, I'd pick up my slide rule and I'd look on the log scale marked L and I'd set it at 3, which is .3, and I would then go to the D scale or the C scale, whichever is handy, and I would look at the number whose logarithm is .3, and that says 2 again, which is a big surprise to all of us. So that's 2×10^7. Now that's all of it. 2×10^7 is the number whose logarithm is 7.3. Therefore the intensity in question is $2 \times 10^7 \times 10^{-16}$, and we merely add these exponents together, and that gives us 2×10^{-9} watts per square centimeter, which is a familiar number we've seen before. Now if you just do these calculations in the simplest possible way, the most straightforward way, and say the words in English, the number whose logarithm is 7.3 is what? We don't fuss around with anti-logs and all these fancy words and worry about the characteristic and the mantissa and everything you think you're know. Just talk it out in English, and it's really easy. So those examples you'll do in that simple fashion.

The other two examples, 3 and 4, are merely working with inverse square law and again a little bit of application of the decibel notation to that business. I think in one case I've asked you to calculate the power of a source, working backwards, knowing the intensity level, calculate the intensity, then go back and compute the power from $I = P/4\pi D^2$. Now by the way, last time, we wrote down this relation, $I = P/4\pi D^2$, and I gave you D in centimeters, and I don't remember whether I gave you the conversion to feet. You should be able to make it, since 2.54 centimeter = 1 inch and 12 inches = 1 foot, so on and so on, but this is D in centimeters, and if D is in feet we have $I = P/(930 \times 4\pi D^2)$ for D in feet, since there are 930 centimeters squared per foot squared. And I personally prefer to keep it in this explicit form rather than figuring out what's $930 \times 4\pi$. You can figure it out if you like, but I like to see $4\pi D^2$, then I know I've got my inverse square law, and 930 is just something that use to I convert centimeters to feet. So D here will be 100 feet or 150 feet or something, and I'll still get I in watts per square centimeter, which I must have as my final unit. So don't forget the 930 if you're doing a calculation in feet. And for Christ's sake, don't put in here

70 decibels equals the power over this. You'll get megawatts of power, which don't exist. This is not decibels, this is watts per square centimeter.

And be very careful what you're using. If you're talking about the power itself, you talk about watts. If you're talking about the level of the power, the level of the intensity, you talk about decibels. And I think—do this very seriously, work them through, because you'll find that you'll learn quite a little bit about these manipulations. And you may think I'll never use this in my architectural practice, you may not, but at least you ought to know what it's about so you can talk in a sensible fashion with other people. And most of all, so you can counteract salesmen. They're the great evil influence in the architect's life, and they're constantly around trying to seduce you with all manner of garbage and high-flown technical language, and almost any student who's had this course can compete with any salesman and then some, and get him off of this decibel foolishness. Okay, so we've looked at sound outdoors. I want to go to the sound indoors, because this is the other aspect that we want to—Why don't we take a break now before I start this and reassemble at 11 or at 12, which will be in about 8 minutes. Let's try to start at 12 promptly.

Did anyone not get one of the problem sheets that I handed out? I think only one—if you didn't, please get a copy from somebody else. Sorry I (inaudible) last time, and I thought I was being way overabundant in my supplies. Apparently I accumulated a few more adherents. I'd like to talk for our second hour about sound indoors. We won't begin to exhaust the subject because I have a number of side issues I want to bring in, and as with the notion of intensity of sound outdoors, some of this may be familiar to you already from earlier studies in physics or classes in acoustics, but let's go through it anyhow (inaudible) everybody and kind of congeal this into one way of thinking.

When we come inside, as I said before, the intensity of sound, especially heard by those of you in the back of the room, will be considerably higher than it would be if we were outdoors. Why? Would it be any different in this room, let's ask ourselves, if this room were covered with carpet on the floor, with acoustic tile on the ceiling and draperies on the wall? Would it sound any different from what it does now in its relatively hard sound reflecting state? What is your intuitive reaction? That it would or wouldn't be any different? It would be. Now do you think at the back of the room you would have as much intensity or less intensity or more intensity in the padded cell as compared to the concrete box? Less. I think less would match the experience of most of us. And we can calculate how much less. We can figure out how many decibels less if we like. And this is the subject of this discussion. You say, well, hell, then it's obvious that if we put in more "fuzz" we'll get less sound, and why don't we just let it go at that. Well, I think we need to be a little bit more precise. I will use the word "fuzz" in this class for sound-absorbing material, and we'll talk a little bit about it today, and in fact I've gotten so identified with the word "fuzz" that recently in an issue of the *Diapason*, the national organists' magazine, reprinted a talk that I gave out in Chicago about a year ago, and the talk is entitled "What About All That Fuzz?" This is in a very serious journal of the American Institute of Organists, and my most irreverent little paper I think has tickled some fancies. It's sort of like the funny papers, you know, about that level of coverage. "What about all the fuzz?" Well, when we add fuzz to a room, sound-absorbing material, we do indeed change the level of energy, and we can calculate what that change would be, and it's very, very important that we understand this mechanism that we have for sound.

Before we even develop that notion, I'd like to talk a little bit about absorption, what absorption does for us besides affecting the quantity of sound in the room, and how we got started in this field anyhow, and I want to give a little historical recitation on the history of the work in the Fogg Art Museum, now Hunt A, by that eminent professor of physics at Harvard, Wallace Clement Sabine, to whose collected papers I referred you last week and I will refer you again, "The Collected Papers of Sabine" will make some very interesting reading for all of you. Now Sabine was faced with a problem here in Hunt A, and as you all know, this has not been solved, though it was solved better a few years ago than it is now when they put all the Homasote [Homasote if a board of compressed cardboard, most often used as a tackboard surface] over the fuzz. Homasote isn't fuzz, by the way. Sabine decided that there was something about that room that he didn't understand, there were some things that could be changed in that room that he didn't understand, and yet he felt there must be some way to come to grips with this and to write some formulas that would help him predict the characteristics that he heard. Sabine went into Hunt A with some organ pipes, he didn't have electronic instrumentation in 1900 when these experiments were done, President—I believe it was Lowell, or was it Elliot at that time? In any case, one of those good reliable names suggested that this lecture hall needed fixing up, and we have this young professor in physics, and why don't we assign him the job of fixing the acoustics over there: physics is something to do with acoustics, or acoustics and physics, and he ought to be able to fix it. Any Harvard professor can fix anything, so off he went. And he went over there to the lecture hall and he blew some organ pipe, "*WHOOOO*," and he stopped his stopwatch and he timed it.

And I think I told you my great pleasure the other day in Melbourne going into a hall that we'd just done in which the seats hadn't been put in yet, the floor is entirely concrete, the walls are brick, the ceiling is concrete, and I went "*WHOOOO"* like that and timed it for 12 seconds while the sound "*EEEE*," just magnificent noise, great thrill to do that. And of course Sabine went into this room over here, he probably did some hollering first because this happens to be something that we carry around with us all the time, a hollering device, and I have transparent facing that I can easily put up in front of my mouth to demonstrate that, and several other things that I carry all the time. He had a chronometer, which is a more elegant form of stopwatch, larger scale and so on, in which he could read the persistence time in the auditorium after the source of sound had been stopped. Go "WHOOOO" and stop, and then how long does it last after that, and this "how long does it last" question tells us how reverberant the space is.

We say that a space is very reverberant when it's very live and when the sounds last a long time. The space upstairs here, the great space, I think that's what it's called, at the time of Dean (inaudible)'s retirement, they had a very lovely party up there for him, they had beautiful potted peonies arranged up on the gallery, huge collections of gorgeous peonies, I guess they were cut, and champagne with strawberries being passed around, very posh sort of party, obviously a lot of money had gone into it, and then they had the most incredible non-communication system for the speeches. They had loudspeakers mounted up on sort of elaborate music stands, collapsible kind of things, they were quite high, they were battleship grade announce loudspeakers, bullet-proof, rain-proof, explosion-proof, and everything, but quality—"*WRUH WRUH WRUH*" quality battleship speakers, and they were played in this space. Now the space has a very long reverberation time. Why does it have a very long reverberation time? It has a very long reverberation time because it doesn't have any fuzz in it. It had people in it, but the result was total non-communication. The system went "*WUHHHHH WUHHHHH*," and then (inaudible) Jackson got up and talked, and Mr. Pusey came over and talked, and everybody talked, and all the people stood around drinking champagne and talked to each other. Total non-communication! Incredible performance in the School of Design at Harvard University saying farewell to its dean. Needless to say, the acoustics section wasn't asked about this ahead of time or I think we might have done better.

Well, this reverberation business, the persistence of sound after the source is stopped, was the subject of Sabine's work. He got a bunch of eager students and did some experiments by night. Why by night? Well, partially because by night it was quiet and students were available, and the cushions from the Sanders Theater across the street in the back of Memorial Hall were available for transporting across the street to do some tests. Now I may have mentioned this to you the other day; if I didn't I'll mention it again. When you come out to my office next week, we have under glass in our lobby one Sanders Theater seat cushion, the original Sanders Theater seat cushion, which is an absolutely holy piece of goods for the acoustician to have. We only have one. It's the only one remaining, so it's preserved under glass. The covering looks like an old red damask curtain, not the brown plastic we have today. This was fortunately before plastic had come into common use for upholstering and dampening people's rear ends and sitting on it. But this was nice cloth on horse hair. Now, he had some Sanders Theater seat cushions hauled over to Hunt A and discovered that things got better the more Sanders Theater seat cushions they dragged in. And before long, they were able to write down a formula which said that the reverberation time T in seconds (and we'll define this in a minute) in Hunt A was equal to a constant times the volume in cubic feet divided by the number of Sanders Theater seat cushions.

That's a real red-hot formula now. Everybody's got some handy dandy Sanders Theater seat cushions sitting around and they can drag them in. Actually, I believe his second formulation is in meters of Sanders Theater seat cushions, so you didn't have the number because they varied in length, so you had to measure how many meters you had. This is very scientific, so we work in meters, meters of Sanders Theater seat cushions. But in any case, it was in terms of those cushions.

But the important thing was that he found out that the reverberation time or the persistence of sound after the source had stopped was a function of the volume of the space and inversely proportional to the amount of absorbing material, linearly. If he had twice as many Sanders Theater seat cushions, he'd get half the reverberation time, assuming them to contribute all of the absorption in the room. Now this was a very important discovery, and in fact today, in 1971, we have not improved upon this. Sabine very quickly changed the formulation to read T, the reverberation time, .05 times the volume divided by A, where A = total absorption. And you say, what in the hell does that mean? And we'll see now, won't we, what that does mean. A is the total absorption. Sabine was quick to point out that the Sanders Theater seat cushion, while an interesting mechanism for making the initial discovery, was something that could be brought in and out in specific units, so many meters, 10 meters in, 20 meters in, 30 meters, 100 meters, 1000 meters, and so on, that you could very quickly arrive at this linear relationship, observe it by going "*WHOOOO*" and stopping and seeing how quickly the sound dies away. It dies away more rapidly as we have more Sanders Theater seat cushions, and it dies away linearly with the quantity of absorption in the space.

He quickly pointed out that an obviously more universally, obviously a more universally available standard unit would be the square foot of open window. Everybody's got open windows all through the world. When you open up a window, we presume it not to be in a brick area such as this but outdoors. You open a square foot window and the sound that strikes that window is completely absorbed because it goes out and cometh not back, and therefore a square foot of open window is considered to be one unit or one Sabin of absorption. This, by the way, is in English units. V is the volume in cubic feet, A is the total absorption in square feet units, and T will be in seconds, and T is arbitrarily defined as the time required for the sound to decay to one millionth of its original intensity or to be reduced in intensity level by 60 decibels. 60 decibels corresponds to 1 million, which is 10^6, and therefore if you start out with 90 decibels in the room, it must drop to 30, and the time it gets to 30, we say that's it—that's the reverberation time of the room. It's not just what you hear when you're in the room and go "*WHOOOO*" like that; whatever you time on your stopwatch may or may not be the reverberation time depending upon whether you can hear a full 60 decibels of decay from the time the sound stops until it reaches the ambient background level. More on this anon.

For the moment, this is the reverberation time in seconds as a function of the volume of the room and the total absorption. Now what is A? A is the summation of all the things in the room that absorb sound. It's a little bit like doing a grocery list. A = ΣSα. My God, the guy's going Greek on us. We had delta already, we've got alpha, we're going to have a couple more before we're finished, and none of them is very scary. ΣSα. ΣSα means add up all the things in the room that absorb sound. S is the area of each of these units and alpha is its absorption coefficient. Alpha (α) = absorption coefficient, or the fraction of incident energy absorbed. What's the absorption coefficient of an open window? It's 1. What's the absorption coefficient of the brickwork, painted brickwork? Well, it's about .02. It's very little. What's the absorption coefficient of most of us clothed in sweaters or woolen jackets or something of the sort? Well, our absorption coefficient on the surface here will be something like .5. About half the energy that strikes us is absorbed and other half is reflected. A regular acoustic tile ceiling will have an absorption coefficient of α = .7 or .8, maybe. There is a variety of absorption coefficients, and these are given in this Time Saver Standard reprint that I gave you for a number of common materials as a function of frequency. Now ΣSα is exactly like going to the grocery store and buying 1 or 2 dozen oranges, 2 dozen oranges at 25 cents a dozen or whatever they cost, and that would give us 50 cents, and then we buy a pound of hamburger for a dollar and we put that down and we buy some grapes and we buy some milk and so on, and we add them all up and we get a total price. That's sigma (Σ) price of groceries. It's as simple as that.

Let's do a simple example here. I won't take this room to start with because it's a little bit complex, but let's just imagine a very simple situation. Suppose I have a room that's 10 feet cubed, and I always use 10 foot cubed because it's so easy to calculate. I don't know how my perspective drawing is this morning. Let's not worry about it. Suppose I have a 10' x 10' concrete room, and I have on the floor a rug that measures—let's make it 8 x 8 for fun, and oh, we'll put a tapestry on the wall back here on one side that's 3' x 9'. I don't know why the hell I'd do that, but let's presume that I've done that. And that's enough, I guess. Terrible perspective, I'm sorry. Alpha (α) concrete is .02, alpha rug, and we can make up any kind of notation we want just so you can keep track of it, but alpha—everybody uses alpha for absorption coefficient so I figured we might as well go along. Alpha (α) rug is .6, and alpha tapestry, alpha tap, is, let's say .3. Okay? What is the reverberation time of said room? 10' cubed with a rug on the floor, tapestry on the wall and nobody there? Nobody in there at all. Don't argue that there isn't any sound in the room because there's nobody there. Physically there is, and we're talking about physics right now.

Okay. First of all, we've got to find A in order to calculate the reverberation time, because the reverberation time T = .05V/A. By the way, in some texts, and in some more exact works on acoustics, you will find the number T = .049V/A and it's true that .049 is a little more precise than .05, but it gives a false sense of precision because we don't know any of the other numbers that closely, so why fiddle around with a lot of Mickey Mouse about .049 when .05 is almost exactly the same thing. So this is the non-Mickey Mouse number. That's about as rough as we can get. A = ΣSα. Let's add them up, A for this room. Okay. So first we'll take the rug. We'll do the easy ones. Rug is 64 square feet, that's S, times alpha, which is .6. Now we'll just indulge in a little bit of slide rule accuracy here. I'll say that's about 36, but let's just see what it is. 6 x 64 is, oh, 38. This is equal to 38 sound-absorbing units due to the carpet. Now how about the tapestry? That's 27 square feet times .3. That will give us 8 units, won't it? 8.1, I think, 3 x 7 is 21 (inaudible), that's right, 8, and I'm not going to put out beyond the point because I don't know it that well. Now how about the rest of the room is concrete. How much concrete is there? Well, there's 600 square feet of concrete altogether, minus 27 and 64, so we've got 600 - (64 + 27 is 91)...We're really straining a gnat's eyelash here; say 509 square feet. So concrete is 509 square feet, or might as well be accurate as long as we can, times .02, and that'll be approximately 10 units, won't it? That's why I'm not getting too excited about having strained a little bit at the 09 here. That really doesn't count very much. So .02 x 500, that's $5 \times 10^{2} \times 2 \times 10^{-2}$ is about 10 units. The rug, which is 64 square feet, has contributed some 4 times as much absorption as the rest of the room put together, and you know that to be a fact, because something like a rug or a drapery makes a tremendous difference in the character of a basically hard and reverberant space. ΣSα is the addition by arithmetic processes of these three numbers. 38 + 8 = 46, +10 is 56. ΣSα is 56 units. Is that clear to everybody? Just take each element in the room that contributes to absorption, its area times its absorption coefficient, put it down in a list and add up the list, and there you have ΣSα, the total absorption in the room.

End of Part B: Audio File 2B
Beginning of Part C: Audio File 2C

This is a very good question and a perfectly sensible one to ask. Any question is sensible as far as I'm concerned in this class. RT is equal to .05 (or let's write it down as 5×10^{-2}). The volume of this room is 1000 cubic feet, isn't it? $5 \times 10^{-2} \times 10^{3}$ divided by (5.6 x 10). And RT is equal to this, so this is 5×10^{1} or 50 divided by 56, and 50/56 is .9 seconds. Okay? I think you'll find that arithmetic to be credible.

Student: *"I have another question. Isn't the absorptive coefficient a factor of the frequency?"*
Yes, of course it is. And at this point I'm painting everything gray, I'm saying let's assume at some frequency that this is the case, this will be the Reverberation Time at that frequency. Absorption, like transmission loss, like everything else in acoustics, is a strong function of frequency, and we must deal with this as we go along here. But for the moment, I'm just developing the simple notion that this is an absorption coefficient at some frequency, and I should have said at 500 cycles per second. When I don't say that, assume that I'm making some generalized assumption of that sort. Now the question up front here was, does it make any difference where this stuff is, will you always get 9/10 of a second no matter which way you face or what? First of all, realize that the sound in a 10 by 10 room is going to make a hundred traverses of that room in the first second because it's going at 1120 feet per second. The sound is almost infinitely everywhere in the room. No matter which way you face, no matter what you do in the room, the sound in a 10 by 10 by 10 room is going to make at least 100 trips around in the first second. Now in that course of time, the sound will have encountered this wall, this wall, this wall, this wall, this wall…. many, many times, won't it, up and down.

Student: *"From your example last week, if you talked directly into this little tapestry on the wall, you would lose a certain frequency right away, right?"*
Yes, and suppose I got over here in this corner and I acted as the source and went "*WHEEEE*" like that, and then you say, well, you're going to get less sound in here than if you did it at the concrete. However, once I stop, then I begin to time the reverberation time. And I'll establish some average level out here in the middle of the room where I'm going to make my observation, and while that level may be lower because I was squeaking into the tapestry rather than if I was squeaking into the wall, it starts at a lower point and we've got to go down farther in order to get our 60 decibels of decay which is the reverberation time. It's the definition of the rate of decay rather than the total thing.

Now let me just be clear. Sabine's Formula, which we use today, and which is the one we're going to use whenever we calculate reverberation time, we use it in practice, and there's no need to get any more complicated than this because it just doesn't matter anywhere unless we do a lot of work. This formula does assume that you have uniform distribution of the absorbing treatment over all the surfaces in the room, and this is not true in my example, and it's never true in real life. This formula assumes a uniform rate of decay, $1/e^{-xt}$, one of those formulas, where you have a logarithmic rate of decay. But the fact is that in most real-life situations, in this room, for example, where we are now, this room has junk in it galore. We've got pipes, we've got recesses, we've got people, all of you, different shapes and sizes, different activities, we've got stools, chairs, the blackboard, and the room is filled with things, all of which contribute to the random scattering of sound throughout the space, and a very good approximation is reached to the assumption of uniform distribution.

Now a notable kind of exception is this. I'm sure that you've all, or I hope you've all had the experience sometime in your life, of in the springtime getting down into an empty swimming pool to clean it up after the winter, to repaint or to fix the plumbing or whatever has to be done, or to be down in an open cistern outdoors or some kind of a hard wall space that's open to the sky. Do you know what I'm talking about? Have most of you had that kind of experience? If you haven't, you should go try it somewhere. Now a very interesting experiment can be done in this. I once built a garage at our old place in Lexington, and this garage had a concrete floor, it had concrete block wall on three sides, and the fourth side was open to the air. This space, if you calculated its reverberation time, should be very non-reverberant because the top was open to the sky, the front was open to the sky, and only the ends and the back and the floor were concrete.

This was during construction, mind you. I did put on a roof after a while, that's sort of what a garage is about. But during construction, I had a bunch of people come out from the office because we suddenly had a very interesting phenomenon that at that time was called the new garage effect. Because when you stand in this garage, and I get the contractor to get all this junk out of the way, and the floor has just been poured, and everything looks nice, you can stand there and go "*BEEEEP*," and that's more than half a second or so. You calculate the space, 8' high, 22' deep by 30' long. We come up with .4 seconds because the ceiling of the room and one wall of the room are 100% absorptive. You add up $\Sigma S\alpha$, you add up the concrete, then you add 100% absorption for the roof, 100% absorption for the wall, and you get $T = .05V/A$, you get .3 seconds, but it doesn't sound that way at all. It sounds more like 2 seconds. And you get down in an empty swimming pool with 4 hard walls and a hard floor and a totally absorptive ceiling, and you say something, "*OOOOOH*," and it sounds much longer than you would calculate.

Now this is simply because the sound is not being permitted to behave in a free fashion as it is in this room with all these irregular surfaces, but it's going back and forth between these parallel planes. In the case of my garage there's only 2 of them, 2 end walls, in the case of the swimming pool there are 4 walls and the floor, and all the corners are hard, and you get a false sense of reverberant quality. You can change the reverberation time in the space very simply not by adding any fuzz, but by adding something that will enable the sound to escape. Just throw in a piece of plywood into the swimming pool down there where you are and you'll be amazed at how it changes the reverberant quality of the space. And the same thing happened in this garage. We simply brought in some boxes, simulating desks or furniture, and a piece of plywood standing against the end wall, a little bit of ordinary kind of furnishing, and the thing reduced itself immediately to exactly what you would calculate the reverberation time to be.

Student: “The formula doesn't work for that kind of space?”
We had the reverberation. It isn't a clean kind of reverberation as we get in a random room situation, but it was perceived persistence of the sound. And the formula does not work in those cases. We have to be very careful about this. And when I say that the formula works only for uniform distribution of fuzz throughout the space, I mean for some reasonable approximation of that, and the fact is that in most normal rooms we do have a reasonable approximation of that. Now if we get into the kind of situations that I've been in a few times, for example, dealing with Meese's office [Harry Weese Associates, Architects, Chicago] in the design of some courtrooms. The walls were to be smooth and white and parallel. The floor could have carpet, the ceiling could have fuzz, but not the walls. Okay, you get in a room like that, that that has very accurately parallel walls, and maybe all the treatment on the floor in the form of carpet and very sparse furnishings, you'll find yourself with some very funny sorts of sounds. Now there are other things than simple reverberant quality that we get in this case. This is leaping way ahead into the second half of the term when we're going to talk about room acoustics, but when we have accurately parallel surfaces, we get what we call *flutter* between the surfaces, and flutter echo is a reflection of sound back and forth, back and forth, back and forth. You've sat, I'm sure, in a barber shop with a mirror in front of you and a mirror behind you and seen yourself going on off to infinity. It's that kind of reflection, back and forth, back and forth, that we can get in rooms with accurately parallel surfaces. But this is a different problem from reverberation.

Student: "Is this what happens over at the Hunt Hall?"
The phenomenon in Hunt Hall, the whispering phenomenon that you get there, is called “creep,” believe it or not. Creep of sound occurs along a curved surface like a wave guide at very high frequencies. The sound simply clings to the surface and goes right around. St. Paul's in London has one of the best whispering galleries up in the dome, and one of the reasons it's so good is that the wall is slightly conical, and this conserves all the energy and you get a magnificent whispering effect from the whispering wall around here. That's simple conservation of energy. That's one of many kinds of freakish observations that we can get. Now the whispering gallery in Washington that Sabine described in his book was the coffered ceiling, which originally was done in painted wood, paper on wood with painted coffers. It was quite a good whispering gallery by focusing of sound from one place to another with this mirror effect. It was burned out, rebuilt in plaster, with real plaster coffering. It didn't work so well anymore, so all the critics said, ‘haha! Acoustics is just a big guessing game, they duplicated it exactly the way it was, and it didn't come out the same.’ Well, they didn't duplicate it exactly as it was, and the acoustical analysis could have predicted exactly what happened because they roughened the surface up, adding the diffusion. All of these things relate to what we're talking about, so I'm getting awfully far into room acoustics, it's just the noise aspect of this, but it's very important to develop the notion that the character of the space, its reverberance, its liveness, is determined both by how big it is and by the amount of absorption that it has in it. These two factors are things that we can control, and we can control not only the reverberation time, but the level of the sound in the space, the loudness of the sound from a given source. Is this notion clear or not? I'm sure most of you have had this before in elementary physics and had to calculate a room, and this is usually what in most acoustics courses is first drawn on a blackboard because this is the one thing you can calculate.

Okay, so Sabine did this work, gave us this formula, developed the notion of absorption of materials, that the materials all have certain kinds of absorption characteristics that are a function of certain physical characteristics of the material, and like walls for transmission, which we talked about a while ago, a material has a given absorption coefficient no matter how loud the sound is that comes to it. Now this is within limits of ordinary levels of sound. If a material absorbs 50% of the sound energy that strikes it, it absorbs 50% of

"*AAAAH*" (loud) and 50% of "aaaah" (quieter) and 50% of "ah" (very quiet). 50%. Whatever you give it, 50% it keeps and 50% it reflects off, or 30% or 70% or whatever its coefficient may be. How does it keep it? What happens to the energy? What's happening to you with your sweaters and jackets and clothing and hair? You're getting heated up. You're getting heated up. I mentioned this the other day, but I'll just repeat it. Sound is absorbed in a sound-absorbing material by reducing the sound energy to heat. How can this happen? A sound-absorbing material that is useful is always one that is made of a matrix of fibers, of things with interconnecting air cells, very tightly packed close together, into which the molecules in the air that are carrying the sound energy penetrate, and their wiggling back and forth scrapes on the walls, on the fibers of the sound absorbing materials, and generates friction, which is heat. And the sound energy is simply producing heat by frictional drag on the molecules that are sound, the sound wave moving back and forth into this matrix of fibers and scraping on the walls.

Now right away we have a feel that there must be something about the sound-absorbing material that can be optimized. In other words, if I have a material that is a very densely packed bunch of fibers that's very dense and heavy and solid, Tectum, for example, if I have that kind of a material, the sound wave, which is due to the molecular motion, isn't going to be able to get in very well or to scrape on the fibers very efficiently. On the other hand, if I had something, you know, the fiberglass stuff that's used sometimes for reinforcing plastic, and it's also used at Christmas time sometimes for decoration on Christmas trees, very gossamer white stuff, very open. This stuff isn't a very good sound absorber either because it's much too thin. There are not nearly enough fibers on which to drag. The optimum porosity or fibrousness, “fuzziness” if you'd like, comes in materials like carpeting, heavy drapery, sweaters, jackets, woven woolen fabrics, fiberglass, hair felt that's used under carpet, a whole raft of things of that sort are very good sound absorbers.

Now what about cork? Cork isn't a sound absorber. How many times do I see an architect putting cork tack board down, thin cork, and saying that's the sound absorber? Baloney! Cork doesn't absorb sound because it doesn't have open pores. It doesn't have interconnecting air cells of the right size to dissipate the energy of the sound that is scraping on the fibers. It doesn't have the right kind of porosity. And it's got to be of some finite thickness. Generally for useful sound absorption you'll find that when materials are applied to a surface by being tacked up on the wall, they've got to be at least ½” thick if they're going to do any good at all to absorb sound, and this relates to your question of frequency range, over a reasonably broad span of frequencies. Materials have been developed from time to time and sold as remarkable sound-absorbing materials which are very thin. For example, there was a felt, 1/16” felt, called (inaudible), just give it a fancy name and advertise it in the New York Times Sunday mag and you're in business, as long as the public doesn't find out about your fraud. It was a totally fraudulent product. They advertised it would absorb sound in a manner never before possible, and it was available in 16 pastel shades ranging from pale pink to pale blue, all icky colors. A 1/16” of felt is an excellent sound absorber above 10,000 cycles per second, way up there. And if I had 1/16" felt on this wall and I went “squeak” at the wall, you wouldn't hear it because it would be absorbed, but if you went "*BLAH BLAH BLAH*," it would come back "*BLAH BLAH BLAH*," come right back because it doesn't have any absorption due to its very small thickness. There's another material called (inaudible), ¼” thick urethane foam. Urethane foam is an excellent sound absorber. It's a very expensive one. Interconnecting cell urethane foam, not closed cell urethane foam. Closed cell urethane foam, closed cell Styrofoam, closed cell anything doesn't absorb sound because the molecules can't get in there and scrape around. So Styrofoam has no benefit at all from an acoustic point of view. It's not heavy, it's not resilient, it's not porous, it's nothing. But it's a useful material for certain kinds of things. I'm not knocking Styrofoam. Just don't count on it as a sound-absorbing material. It's got to be porous and fuzzy.

Now immediately we begin to see why acoustical plaster is a totally illegitimate bastard material, never to be used under any circumstances for any purpose whatever. Acoustical plaster is a plaster that's put up in a room and it is so constituted with a lot of additives such as asbestos, mineral wool, and foaming agent that it will come off a bit porous when it sets, and you'll get about a 50% absorption coefficient. Now then, being porous, having a porous face, it is exceedingly attractive to dirt, and in the course of 5 or 10 years' time, it becomes dirty. Then the owner says, my ceiling is dirty, what do I do? And you say, the architect says, paint it. So he paints it, and then big surprise, he suddenly has a reverberation cancer. He goes, you ruined my acoustical plaster with paint, and all you can say is, tough luck, buddy, I knew it was going to be a 5 year treatment anyhow when I put it in. I think it's downright immoral, immoral and stupid to put materials in a building of sort like plaster and so on that won't last more than 5 or 10 years, and I must say I would encourage you never to give in to the use of any material that's called acoustical plaster or the like.

Student: "It's going to get dirty, so how do you go about cleaning it?"
Well, this is something that I'm going to talk about quite a lot here, how to be cleaned and washed and painted, and this is not solved easily. The essential element of a sound-absorbing treatment is porous, fuzzy, attractive to dirt, and will get dirty. It's usually soft, can be damaged, can be taken off with a hand cloth. It's not a fit material for exposure to the public and we try to find ways of covering it up and hiding it behind things that will let the sound go through into the fuzzy part and there get absorbed.

Student: (inaudible)
No, the dirt itself tends to be porous and fuzzy, and I've never yet seen a sound-absorbing material hurt by dirt. There was an amusing situation over here in Boston, I can't remember the name of it, it was a big Catholic church where they broadcast a lot of sermons. In any case, a few years ago, they cleaned it after some 40 or 50 years, and there was all kinds of dirt settled on all the little thingies sticking out from the wall and lots of cracks in the plaster and everything was quite dirty, and they cleaned it out and painted it and suddenly the reverberation time went up quite considerably, and they complained about a problem broadcasting the sermon. So junk and accumulation of dirt and grime is to be recommended if that's the way you want to solve your acoustics problems. You can also do it with clean fuzz if you prefer.

There are lots of ways that we can go about covering these materials, and maybe we should talk about that before we talk about the effects they have on rooms. Essentially what we've got to do is understand what it is that makes a surface transparent to sound, what it is that makes it possible for sound to go through. Now I have demonstrated here a few minutes ago that my hand is relatively sound transparent. If I should put a grille in front of a sound-absorbing blanket that's about like my hand, a series of wood sticks spaced perhaps—these are 5/8" sticks spaced 1/2" apart or so, you would not lose very much of the transmission of sound from my voice. Does everybody agree that it doesn't make very much difference—some difference, yes, particularly at the high frequencies. I can tell it makes a difference to you because I can hear it coming back to me, and if it's coming back to me, it does not go out to you. Now if I put my hand, however, in front of my face, this is a different proposition. This is not such a hot job of transmitting sound, and if I had something the size of my hand in front of the sound-absorbing blanket, I'd venture I would change its characteristics quite measurably.

Now this, in turn, comes back to another matter, and I wish I could give you the acoustic skill at the beginning of the term, so you'd know all these little facts and then we could just talk about all (inaudible). Sound in the air, (inaudible) about frequency, at different frequencies has different wavelengths, and this you will see next week when we do our demonstrations, and I'm going to let you listen to some wavelengths by wiggling your head back and forth, and you will begin to get a sense of the size of sound. The fundamental frequency of my voice, "*HAHAHA*" down at the bottom there, is of the order of 100 cycles per second. This has a wavelength of about 10 feet. 10 feet between successive points of the same phase in the wave, the compressions and rarefactions in the same phase would be about 10 feet apart in the wave "*HAHAHA,*" whereas at "*PSSS PSSS PSSS*" the wavelengths will be of the order of a half an inch between successive points of the same phase in the wave. So "*HAHAHA*" low frequencies are big sound, have big wavelengths, and "*PSSS PSSS PSSS*" high frequencies have very short wavelengths.

Now if you think about a wave in water, think about a pole standing in water, a pole or pile, single pole of some sort. If you've ever watched it when a water wave is coming up to this, you will see that what happens is that the wave goes right around, it goes right around the piling, and if you look very carefully on the surface of the water, you will see coming off this pole or pile a new wave of the same wavelength as this wave that went by, but a much lower amplitude, and you will see this new wave moving out on top of the other wave, the main wave goes right on through, and the new wave is established coming out from the piling. Essentially what's happening is that the sound or the water wave is going right by the piling without any loss of energy to speak of, and a very small amount is being re-radiated from the surface itself. The same thing happens to sound. When I find or when you find a column between me and you, you don't suddenly lose my voice. The sight of me will disappear because the wavelengths of light in this room are exceedingly small, as they are in all parts of the earth, microns rather than inches and feet. This is a perfect optical barrier when it's between us. It's no acoustical barrier at all hardly, especially in the room here where the sound is being reflected all over the place, because it isn't big enough to constitute a sound barrier. Outdoors it will begin to cut off the "*PSSS PSSS*" sounds in speech, where this becomes large compared with the 1" or 1/2" wavelength.

Now the point of this long harangue, and again I'm going to develop this much more when we begin to talk about reflective surfaces in our course, the purpose of this is to say that what we want is a facing, something to cover the fuzz, something that will give us the minimum of reflectivity, because what we want is absorptivity. Therefore we want the elements that make up the facing to be as small as possible, and the reality of life, small as possible usually means the order of a half an inch, or perhaps a quarter of an inch, but not much smaller than that, because we're talking about real materials like metal and wood and so on, and we simply can't deal with much smaller sizes. Now take a perforated metal, for example. You've all seen perforated metal acoustic ceilings. They're made with metal sheets, aluminum, steel, --generally painted on the surface, and filled with tiny holes. These tiny holes may open up only 10% of the surface area, yet because of the small space between them, that perforated metal can be just as transparent to sound as my hand here. My hand is about 50% open, 50% closed, more or less, with 1/2" spacing between the elements, and this is almost entirely transparent to sound. What we're asking is that whatever we put in front of the fuzz has no reflective characteristics, but rather be openly transparent and let the sound get in. Now what we put in front of the fuzz is something that we can wash or paint or hit or bump against and not damage the fuzz, not scrape it off.

Let me just give you one little example and then we'll wind up today. Later in the term, as soon as the snow is over and warmer weather is here, I'm going to invite you all out on a Sunday afternoon for some sherry and some acoustics observations. We won't have any lecture, I promise, just drinking and sociability, but I want you to see a few things that we have done for acoustics in my house. In my entrance hall and in my dining room, both of which have stone floors, glass and plaster walls, no carpet, I wanted non-reverberant conditions. At a dinner party, I don't like a dinner party for a dozen people to turn into a big yelling match. I hate yelling at a cocktail party or a dinner party, and we won't have any noise buildup, not when I know what to do about it. I don't want people to be quiet, I want them to have a good time and talk, and I'm just as loud as anybody, I can assure you. But there's no need for the room acoustics to reinforce that.

End of Part C: Audio File 2C

THE END

Robert Bradford Newman Lectures

23 September 1970

LECTURE 3

Title: “Calculating Reverberation for a Space”

Summary: In this lecture, Newman uses the notion of sound intensity to motivate the calculation the reverberation for a given space. He then expounds upon some reasonable manipulations of the equation and how they can be used to help analyze a space.

Beginning of Audio File 3

…to the definition of the reverberation time. T is the time required for the sound to die away by 60 decibels from its original value. This is for 60 dB. That would be one millionth of its original intensity. In other words, if I go “*WHEEK*” and stop, the level of sound I was generating there was in the order of 80 dB, and the level of sound from outside in that frequency is probably at least 40 dB in this room, and at most you are going to hear 40 decibels of decay because the background level of sound from outside will mask it and therefore you will not hear it. You will only hear 40 decibels with the decay for the arbitrarily defined reverberation time of this room is for a full 60 decibels of decay, then what I have to do then is to extrapolate another 20 dB or another third of the time, and add that on to what I actually observe. In other words, if I have a sound going here “*WHEEK*” and I cut it off and it drops down like that and it hits the hash here at 40 decibels down. This is time increasing in this direction.

The time I measure here is the Time 1 (T_1) –that is not the reverberation time—I’ve got to extrapolate this down to a full 60 decibels of decay, so it is different from here -- it is 60 decibels and then I call this total time the reverberation time as arbitrarily defined here.

Student: "Does it decay linearly?"

Logarithmically. This is all a logarithmic proposition. It's an ‘e’ to the minus something or other function. It's a logarithmic decay. You plotted it out in linear units, you've got a curve like that instead of a....Decibels, it straightens itself out.

This is another lovely thing about using logarithmic units. It seems to relate rather well to a lot of things that really happen. So this is in decibels here, and the ordinate is time.

That is the way a trace will come out when you run it through a high speed level recorder. It will actually trace that as the sound dies away. Paper moves by at great speed and it scratches on the wax. This, by the way, is all discussed at some length in this reprint so I will not spend a lot of time on it right here at this point, and we are going to come back to talk about reverberation time later when we begin to talk about room acoustics, but for the purposes of this argument I'd like at least to describe the calculation.

Now, the total absorption in the room is a summation of all the elements in the room that contribute to absorption. That is all it is and we can write down a very simple mathematical notation:

$$\sum S\alpha = A$$

Sigma in mathematical terms merely means “add them up.” When you go to the grocery store and you buy so much for 69¢ and so much for 59¢ and so on, what the clerk at the checkout counter does is compute sigma c (sigma 'cost'), and you get a total -- just a summation, it's adding up the grocery list or adding up anything else.

Let us now make a grocery list of what is in this room. First of all, we have the ceiling, and that is 100 square feet with α [alpha] = .70 and that gives us 70 sound absorbing units, square feet of open window equivalence. In other words, if this ceiling is 70% absorptive, it is only 70% as good as so much open window would be—if we have 100 square feet of open window, we have 100 units of absorption, and we have only 70% efficiency so we only have 70 units of absorption from this stuff that is on the ceiling. It isn't as good as an open window. It gives us 70 units.

These are sometimes called Sabins after Wallace Clement Sabine – his name is spelled "Sabine" and the unit is spelled "Sabin." I will generally talk about units and when I say units I mean sound absorbing units. Actually, the units of 'S alpha' are square feet, aren't they, because alpha is an absorption coefficient that has no units and S times alpha will still have the units of square feet. S would be the area of the sound absorbing material and this is its coefficient of absorption.

The word coefficient — I think I mentioned to you, maybe I didn't, the first day—about acoustic paint in which the ad says acoustic paint (which is a fraudulent product – I didn't say that) is more coefficient than regular acoustic tile -- you can't be more coefficient —you can be more efficient, but not more coefficient. A higher coefficient but not more coefficient. So you know the guy doesn't know what he is talking about to write an ad like that—it must be a fake.

Now, let us take the rug. The rug is 64 square feet and I say it has an absorption coefficient of .60. And what does that give? Let's be precise – once in a while, it doesn't hurt: 64 x .60 = 38, or something like that. Let's just say 38 units. The precision with which I know .60 if I have any sense at all I'll say that is 40. Put a little approximate sign over the top. It's about 40 units. It isn't going to matter very much in the long run. Now, then, you say that is all there is in the room. Oh no it isn't – there is a lot of concrete. I thought you said concrete doesn't absorb any sound. Oh, it does a little bit. Now, take this brick pier here or concrete pier that has plaster on it. This is very hard – when I talk to the surface, my voice goes over here and the sound wave wiggles back and forth, encounters the surface and bounces off. This is sort of a toll for turning the sound around. The molecular disturbance that goes on right at the surface takes out 2% of the energy just in turning it around and sending it back. There is nothing that is perfectly reflective, even the hardest, most impervious surfaces have an absorption coefficient of at least .02. So let's assign .02 to the rest of the room. How much concrete is there? Well, there is 100 square feet. on each of the four walls – that is 400 square feet – and then we've got 36 square feet left on the floor, so that is 430 square feet or 440 square feet – I don't care – times .02, and that will give us about 8 units.

Not very much, but if we are going to do this job with any kind of accuracy, we have to account for 8 units. Now we add them up. We perform $\sum S\alpha = A$ = 118. Is that right? Yes, 118 units. What will be the reverberation time of this space? The reverberation time of this space will be T = .05 x V / A. T is equal to .05 times the volume, which is 1000 cubic feet, 10^3, divided by A, which is 118. Now let me do what I say one should do and reduce this to numbers that I can comprehend because .05 x 10^3 doesn't mean anything to me. T = 5 x 10^{-2} x 10^3 / 1.18 x 10^2. Now I can do something. 5 divided by 1.18 is to the order of 4, I think it's about 4.2 times what? 10^{-2} x 10^3 is 10^1, 10^1 / 10^2 = 10^{-1}. 4.2 x 10^{-1} or .42 seconds.

Now, this says then that if we have this room with the acoustic tile ceiling, the rug on the floor, the concrete walls, if we go in here and sound the standard source, and shut it off and make a recording of the reverberation time in this room, we should read .42 seconds.

This is quite true. If that room were just like that, it would probably sound as if it had a reverberation time of more like .6 seconds. Sabine's formula, .05V/A, assumes that the sound-absorbing treatment is uniformly distributed throughout the space, and not concentrated on one surface or another. The only way this room could obey Mr. Sabine's formula would be if we had some gross irregularities in it, some bumps and wiggles, or laid in some pieces of plywood or something at various angles so that the sound can find its way very quickly into the fuzz and be absorbed in a proper and uniform fashion.

If any of you have ever had the experience of painting or cleaning out a swimming pool in the spring, you know this effect. If you drain the water out after the winter, or perhaps it has been out, and you've got to get down in there and scrub it and clean it and paint it and muck around with the drains and the plumbing and so on, and you are down 9 feet in a pool—you are outdoors, you have a ceiling that is 100% absorptive, isn't it—it must be, it is open-air. So whatever the area is, you multiply it by 1 and you get the total number of absorbing units in the space and you say we will neglect the concrete, because it won't contribute more than 8 or 9 units, and then you go in there and you go "*POOOH*" and it sounds like "*POOOOOHHHHHH*" - it doesn't sound like P!, which it should, because the sound can't get out quickly enough, it doesn't get out as quickly as it should.

Now if you take a piece of plywood, and I've done this experiment, take a piece of 4 foot by 8 foot plywood, and stand it up against one side, just at an angle, maybe two pieces four feet apart – stand them up against the side of the pool – here's the top and you're down in here standing the pieces up about 4 feet apart, 4 foot, 4 foot, 4 foot, and you do the experiment again, and suddenly the space is very dead. You've added no absorption at all, you've merely forced the energy to get the hell out, and get up into this absorption and be absorbed in accordance with St. Sabine, rather than just staying down there and whacking back and forth.

Now this happens lots of times in rooms. We have these very weird sorts of effects that are due to non-uniform distribution of absorbing material and the lack of opportunity on the part of the absorbing material to find its way into the fuzzy stuff that is provided.

Now, if we said here we are interested in investigating what would be the average level of sound in this room, due to a source of a given power in watts. This number A that we computed – A – where was it here – A here, is the number that we would use in calculating the average level of this room, and if we carpet the entire floor instead of just a 64 foot square rug and we had 100 square feet of carpet, A [total absorption] would increase and the average level of sound in the room would decrease. The reverberation time would decrease, and we would have some predictable changes. The point is this is something that can be calculated and can be predicted in advance.

Now you may think this is a little bit abstract, possibly a little removed from the reality of ordinary buildings, but it's an extremely important concept that we get, because it's very, very relevant in the matter of sound transmission between rooms. It's not quite as important as what the partition is made out of, but we'll see that it's a very important factor how much absorption is there in the sending room and in the receiving room, because it will determine the average level of sound in the space, just as surely as the transmission loss of the partition will determine.

As the room gets deader we get more and more reduction in actual level. Now let me just do two little manipulations, and I think we have time for it and then I will say something more about it next time.

If I write down I = P/A, obviously I've got to put A in square centimeters if I'm going to have this come out right, so usually we have 930 in the denominator if A is in square feet, then I = P/930 x A.

Suppose I have this room completely bare to start with, bare concrete, and then I cover all the surfaces in the room with fuzz, let's leave the floor alone, we cover all the walls and the ceiling with 3" thick fiberglass batts. Oh boy! And you just know what that would sound like, don't you? You've been in an insulated attic where it is just absolutely incredibly dead and you can hardly holler from one end to the other. If I_1 is the condition given by absorptive sound of power P $930A_1$, if that's the concrete room, and A_2 will be the condition for the completely fuzzed room, I_2 will be $P/930A_2$. I can very quickly calculate what the reduction in intensity will be due to the addition of this fuzz, can't I?

If I divide I_1 by I_2, divide these two formulas, I come out with another inverse relationship which says that I_1 is to I_2 as A_2 is to A_1. So the intensity in the room to start with will be to the intensity in the room when you finish as the inverse ratio of the absorption in the room will be.

How much reduction is that in decibels? Well, if I want to compute the number of decibel reduction, what do I do? I'm interested in delta IL, or the relation between two intensities, delta IL, the change in intensity level would be given by ten times the logarithm of I_1/I_2, which is equal to ten times the logarithm of A_2/A_1. Isn't it?

Is that all right? I think these are all perfectly legitimate algebraic manipulations. The change in intensity level in the room will be ten times the logarithm of the ratio of the absorption in the room before and after. And let's just see what that might be for our example of a 10 x 10 x 10 room, all concrete, Sα will be – or Σ (sigma) x S x α (alpha) -- will be 600 square feet x .02, the absorption coefficient of concrete, which will give us 30 units. I didn't follow through all my rules here, but I sort of know some things, and if I already know, then there's no sense in writing down anything else – it's a useless operation. Now if I cover 500 square feet of the room, the ceiling, the walls, if 500 square feet of Alpha α= .80 fuzz added, I'll now have 500 x .8 = 400 units plus the floor which will be 100 x .02, which is two units, so we have 402 units here, which says that isn't right, is it? Well, why didn't somebody holler? Please don't be afraid to make me look stupid—it's not very hard! 12 units, and so we now have 402 units in the room. How much reduction does that represent on a decibel scale?

Student: *"Why is 12 +400 = 402?"*
It isn't. I had 12 units because I had 600 square feet of the room all concrete. That's .02 x 600. Now I've covered 500 of it with fuzz, put fuzzy stuff all over the ceiling and walls, and I've still got the floor left, it's 100 square feet x .02, so I have 400 from the fuzz, plus 2 from 100 square feet of wall, excuse me, I didn't write it down, and that gives us 402 units.

Well, very quickly, the ratio here Delta IL in this room - if I have some source of power in the room going "*OOOOOO*" and it just ·keeps going "*OOOOOO*" all the time, and I add the fuzz, what happens to the level of sound in the room? How does the average level drop? Delta IL will be ten times the log of (402 divided by 12). And 402 divided by 12 will be 33.5, is it 33 or 3? 33, then log of 33.5 or ten log of 3.35×10^1 -- right? And the logarithm of 3.35 is .53, so the answer will be 10 x 1.53, .53 belongs to 3.35, 1 belongs to the 10; that's 15 decibels. Now I know that's the right answer.

That's more or less right. About the most reduction you'll get in a room due to the addition of a fuzzy lining really going whole hog, from very, very live to very, very dead will be about 15 decibels. In other words, if I have some very severe noise problem to solve in this room—for example, suppose you were working in this room, and the Walsh-Healey Act says that you shall not have at your ears more than 90 decibels for eight hours a day, and the level in here is 120 decibels, now any fuzz isn't going to solve the problem, and we damn well better know that before we start adding the fuzz on the surfaces. The maximum reduction that we get is 15, and practically – because we never start out with a completely bare room, we never go whole hog the other way – practically we get 3 or 4 decibels reduction.

Student: "Will you get into solving that problem if you get the noise sources, something like a vacuum pump, which obviously has to have access to the outside?"
Yes, we're going to talk a lot about quieting machinery and so on, but if I don't deal specifically with something you want to talk about, raise the question again, please. I am going to fetch in my black box here in a few days, and show that to you, and that'll explain a lot of things.

Well, I will take up at this point on Friday but I just wanted to carry it that far. Anyone else need a reprint or a problem set?

End of Audio File 3

THE END

Robert Bradford Newman Lectures

25 September 1970
LECTURE 4

Title: "Sound Absorption Treatment"

Summary: In this lecture, Newman expands upon the topic of sound intensity in a room and relates it to the effectiveness of sound absorption treatment methods being used in the field.

Part A: Beginning of Audio File 4A

[Note: Audio track for this lecture includes comments on recording technique and procedures, and comments on visit to Newman house for a class gathering, for about 1:35 min.]

We begin with interfering noise, noise pollution we're faced with, and some chance of getting rid of it. Last time at the end of the hour, I very quickly, and I apologize for jamming it in that way, jammed in an example of the amount of noise reduction in a space that can be achieved by the addition of sound-absorbing treatment, and I pointed out that this was sort of an extreme amount of reduction that we could get. I want to talk about that example a little bit more this morning and then go on and talk about what effects sound-absorbing treatment really does have; what good is it; how do we use it in noise control; what are sound-absorbing treatments anyhow; what do they look like; how do we handle them architecturally; and so on.

Last time, we looked at this situation, and I'll just recap very briefly: the intensity of sound in a room will fall off inversely as the square of the distance and then level off to some value determined by the amount of absorption in the room, A. And in this section we have $I = P/4\pi V^2$. Sound falls off inversely as the square of the distance for a certain way out and then after 3 or 4 ft. in ordinary rooms—for this distance it is the order of 3 to 5 ft. for most ordinary situations—we level off to a more or less constant value of sound throughout the space, and the level at which this happens will be determined by the amount of absorption in the space. And intuitively you would agree with me that the deader the space becomes, the more nearly it becomes like free field throughout the space, and the lower becomes this level and the farther out we obey inverse square law behavior.

We have at our office a room that we call an anechoic room; it is a room that is completely treated on all its surfaces, floor, ceiling and walls, with very deep fuzz, sort of 2 feet thick fuzz. Some anechoic rooms (anechoic means it doesn't have any echoes in it) . . . An anechoic room is one that is treated with extremely deep treatment and has a very, very large amount of *A,* and in such a room you will find that the inverse square law holds out to within a couple of feet of the walls. This may be 5 ft.; it may be 10 ft.; it may be 20 ft., depending on how big this room is. Fuzz like this all over all the walls; then there is a stainless steel trampoline net with a 1" square grid stretched across here and you can come into the room and walk along on this grid and you are completely surrounded with fuzz and it's an exceedingly disagreeable room in which to be, uncomfortable as the very devil. And if any of you want to come out sometime, I'll be glad to take you in and give you a brief treatment. You feel as if the atmospheric pressure has increased. You are totally deprived in such a space of any reflections from anything to which we are normally accustomed. The room is very quiet to boot, and you just get an extremely oppressed feeling and if I were to go into this room with you and stand here and talk in this direction and then turn around and face in the other direction, you would miss almost everything I say; you would have almost no comprehension of what I'm saying when I turn around.

Student: *"Would almost the same thing happen if you were out in the woods?"*

It can, though with the woods, if you were in an evergreen forest where you have pine needles and everything down to all around you and pine needles on the ground, yes. If you are in big woods with big trunks then you get a lot of reflection from those back…. the crickets, the birds, the wind in the leaves and everything. I have been in woods at times, and these were very rare situations where I have experienced, as you describe it, an almost anechoic chamber effect when for some reason or other there wasn't any breeze. and all the crickets shut up and it was midday and there were no birds and it was just extremely quiet, But the thing, as you point out, the thing that makes this different from any natural situation is the total lack of anything; it's a real nothing environment. It is sort of like, it's analogous to these experiments where people have been immersed in a swimming pool with body temperature water, and no movement of water, and you just kind of sit there and it's just dreadful after a while. You need something to jab you once in a while and stimulate you.

Well, this is the ultimate, absolute ultimate, in sound-absorbing treatment. We would never resort to this as a solution to a noise control problem in real life. It's much too expensive and there are much better ways of getting reduction of intensity level than just by soaking it up at the boundaries, and I merely cite this as the ultimate case. We build these rooms, not to make people uncomfortable, but to use them for testing purposes when we are going to take a microphone, which we want to calibrate and know exactly when this microphone puts out so many volts, exactly how much sound pressure was there on the microphone to start with, then we have to do this calibration in a very accurate way in a free field situation approximating outdoors. If we go outdoors, we would have all the troubles that you have already suggested—of noise and wind and everything, so we go inside and make like it's outdoors. It's free field. It's exactly analogous to the light testing which goes on in a completely black interior space, a totally black room, so this is black acoustically.

Now, back to this argument here . . . I pointed out and developed very quickly the notion that if $I = P/A$, if we have two conditions of A, A_1 and A_2, we can compare the intensities of the result, I_1 is to I_2 as A_2 is to A_1. They are in an inverse proportion and this we saw by writing down: $I_1 = P/A_1$, $I_2 = P/A_2$ assuming the same power of the source, then we get this inverse relationship, and then I said, let us compute the change in <u>intensity level</u> in the room, not the <u>intensity</u>. These are in watts per cm^2 but the change in intensity level due to added treatment, and by treatment I always mean sound-absorbing treatment. When we add sound-absorbing treatment to the room, what is the change in intensity level?

I said, "Now let us compare these two numbers; and, as in computing any change in intensity level, we merely take the ratio of the two numbers and multiply by 10 times the logarithm of the two numbers and we get a number of decibels so that the change in intensity level or delta, Δ IL is equal to 10 times the logarithm of A_2 over A_1. This is the relationship we wrote down towards the end of the hour last time and on the basis of which we computed that we would get the order of 15 decibels of reduction at most in a ridiculous case of going from total concrete to total fuzz, average reduction or reduction in the average levels. Now it's very important to think about this curve when we think about this, the distance increasing down here and to realize that this reduction in average level does <u>absolutely nothing</u> to the reduction of free field level or to the free field level. And that as long as you are in what we call the near field of the source, that is where inverse square holds, it doesn't matter what we do to the periphery of the room, we are going to have no effect at all on the near field levels.

This is very important when thinking about factory quieting. If I am operating some kind of a noisy grinder or a punch press or a weaving loom or something of the sort, I am the operator, I'm standing right here with the gadget, I could put all the fuzz in the world around the room and it won't have one speck of effect on what I get at my ears as a result of this noisy operation. Now, there have been thousands of dollars wasted, millions, maybe—I don't know—in applying sound-absorbing treatments to rooms in the hope of solving near-field noise problems and the effect is only when we get away from the point where inverse square holds where we are beginning to get build-up in the room by multiple reflections from the room, thus increasing the levels at a distance and we can decrease that build-up by making the room more absorptive and by preventing the reflections, by preventing them from happening.

Student: *“This near field is a varying, varying…”*
It varies as a function of how dead the space is. Now, I've said in this room which is not a terribly dead room, because we have lots of reflecting surfaces, that the near field ends at somewhere around 4 feet. Now, if I go into a much larger space with a quite a lot of treatment around it, it may go as far as 10 feet or even 20 feet. In a very small room, it might only be a foot.

Student; *”Can we treat a room in such a way that the intensity of the sound is increased?”*
No. We can't manufacture energy except by using electronic amplification.

Student: *”What if you have a room with a parabolic ceiling and at one point, wouldn’t it increase?”*
Yes, OK. One can focus energy just as you can take the energy from the sun and focus it on a piece of paper with a lens and burn the paper. Yes, you can increase the local intensity. Now what you're going to do, though, is to take the energy, if you take a lens, for example, and take the sun's light and focus it on a little piece of paper, you take the total energy that comes through that lens and merely concentrate it. You haven't really increased anything but you have increased the intensity. For all practical purposes, yes, it is louder. And, of course, this is the horrible thing about any form of concave geometry for rooms, one of the many reasons why we never, never, never dream of having a barrel vault for a ceiling of a room, or a dome or have a smooth curved plane, handsome though it may be, beautifully though it may photograph, it's a dreadful, dreadful shape.

Student: *”Do you consider a geodesic dome the same thing as a spherical dome?”*
Answer.Yes. There was a marvelous geodesic dome, there are many of them, but there was one, I believe it is still standing, out in Acton that the Bemis Company used to store lumber in. I don't know whether that's still there or not. It was plastic, a rigid plastic geodesic dome and it was good for storing lumber in, but that's about all. I mean, if you went in there and tried to communicate, you would experience all the horrors of curved geometry. We'll come back and talk about this in much greater detail in the second half of the course when we're talking about room acoustics. It is a little bit off our present subject, but I'm always glad to get off the track a little bit.

This business, though, of understanding the effect of sound-absorbing material, what does it do, when does it help, when doesn't it help, is very, very important. And it really is usually—the effect of sound-absorbing treatment is usually—much more important than just how much does it reduce the average level of sound. There are many psychological factors that I want to talk about.

Now, for God's sake, don't ever get yourself in the trap of making “before” and “after” measurements in a situation like an office. I’ve seen this happen—someone says so the acoustic tile salesman comes in and says, "Hey, Mr. Manager, this office is full of girls typing on their typewriters or running business machines or whatnot, would be much quieter if you put in my brand of fuzz, and for $20,000 we would put in an acoustic ceiling and it will reduce the levels. So they make a measurement before they put in the ceiling, and they have all the girls type, and then they put in the acoustic ceiling.

Now, in an ordinary room such as an office with this shape and we have a whole bunch of people in here all ready with typewriters, and they are all fuzzy and there may be carpet on the floor or there may not, but there will be filing cases, and there will be paper and there will be junk. Junk is a tremendous sound absorber, dust, dirt, filth—all these are great sound absorbers (if that's what you want, but there are other ways of getting it besides dirt.) Nevertheless, a room full of people is not a concrete room and then you say, well, were going to treat the ceiling with fuzz and put on a fuzzy ceiling here.

You'll find if you make some very careful measurements or even some computations, that probably what you'll have is a change from I_1 to I_2 that will give us a change of $2A_1$ to A_1. In other words, we might double the amount of absorption in a room by adding a totally absorptive ceiling. How much change does that make in the intensity level? 3 decibels, which is not a very noticeable and certainly not accurately measurable when you are using as a source of sound people typewriting or some other variable sort of source. What you may find is that you measure more noise after the treatment than before, which doesn't prove anything, doesn't say the treatment isn't effective. It just shows that measurements are very difficult to make. If any of you decide in the second term to go on into the Special Problems in Acoustics course that we offer, you will find how very difficult it is to make meaningful acoustical measurements. They are very, very tricky to do because our sources are so variable and the things just move around.

Now, I'd like to talk to you in just a little detail about one particular case that I happened to have experience with a few years ago. This is an industrial situation in which the question was asked, "Should we or should we not put in a sound-absorbing ceiling to solve the problem?" Let me describe it to you and I'll tell you what we did. This was out at the General Motors Technical Center in Detroit, and this has been probably 20 years ago, I don't know, that order of magnitude. This was the building, the complex that Eero Saarinen did. There was a big shop in this complex that had been treated with nothing. It had a concrete floor, it had concrete walls up to this height, it had glass walls up to there and a steel deck roof. The roof was the order of 20 feet high and so the space was in the order of 100 square feet. This room was occupied by a bunch of men hammering on metal, riveting metal, sawing metal, grinding metal and doing all sorts of things that are noisy. This was a Wood and Metal shop. They were shaping wood. Remember, this was in the high era of tail fins, and they were all making new kinds of more horrible and more pointed tail fins and such. So here were these tables and here these guys are in here banging away on metal and grinding and sawing, and so on.

Now, why was I called in to look at this shop? Well, I happened to be there anyhow on some other acoustical problems, but the thing was they were having trouble. Almost every case history I will tell you about here will be one where there was some difficulty, because you don't call in consultants and pay them to come from Boston and pay their per diem, and so on, unless you’ve got trouble. If you're feeling fine, why ask him to come in? There's no sense in my coming into this room and making a lot of observations about the acoustics. It's OK, let's leave it alone. We might be interested in knowing what it is but let's not pay anybody for it.

The foreman in the shop said, "When I go out to this man's table"—and the tables were about the size of this lecture desk here—"when I go out here, we're going to spread out some drawings, and the man is going to be over there and I'm going to be over here and I want to talk about what we're going to do, I want this changed this way, and I want this more pointed and get it sharper at the top, and so on." At present, he says, "what I have to do is get right up to this guy's ear and holler in his ear."

Now, he stops banging, doesn't he, the guy right here (if he doesn't, then you whack him one—"Shut up, fool, I want to talk to you") so he stops banging, so in the near-field, we stop. The guys over there in the next place continue to bang because they are not concerned with it. We've got a near field situation in which we have some control. The local source will stop. He says "I would like to be able to speak to this man at a more comfortable social distance," which we generally regard as about 3 feet (Anything less than 3 feet begins to border on intimacy, and there's no occasion for that here in this shop situation.) Anyhow, let's get back to this shop. He said, "I would like to converse or to be able talk to these men," and I'll describe it in my terms, in raised voice at 3 feet.'

Now, raised voice is the level at which I'm talking to you here. You say, well how do you know that's raised voice. Well, I know it Is raised voice. I'm not shouting, I'm not straining, and yet I would not use this level of voice in ordinary conversation. You'd think I was a nut or deaf or something if I talked to you at this level at 3 feet. Now, you in the front row are getting more sound from me than you would get if I were just talking to you because I wouldn't talk this loudly. OK, he wants to talk at that level, not shout, not spit in the guy's ear, and be at 3 feet. Would acoustic treatment on the ceiling do this job? That's the question. It's going to cost—it's 10,000 square feet and it's going to cost $25,000 to put up this ceiling. Now Mr. Consultant, will you please tell us whether or not we should spend $25,000, and if we spend $25,000, whether we are going to get our money's worth. Is it going to work? Well, we've got to do a little bit more than just say, "Oh, it probably will work"—that's not what I'm being paid for. I've got to make some scientific evidence.

Now, we may come down to something as simple as "I think it will work because I know it worked over in Mrs. Jones' factory and it'll probably work here, too." I made measurements here, and at one of these desks the sound level meter, which I'm going to show you when we have our demonstration, a gadget that measures how much sound there is there, like a light meter only this sound level meter tells us not only how much sound there is, but what is the color of the sound—how much of it is "*WUP, WUP*," how much is 'beep, beep,' and so on up the line. We break it down into a spectrum, a function of frequency: 10,000 cycles per second out here, very high frequencies and 100 cycles down here and 1000 in here, and so on. These are intensity levels, and so I made a measurement of the average level of sound in this space. Due to everybody else hammering, but the guy at my bench stops because I want to duplicate the condition we are going to have when the foreman comes and talks to the guy. Now then, from here on out it's calculation and estimation and using your brains. I used this very formula, a very useful formula, and I computed what would be A_2 after I have added a sound-absorbing ceiling and compared it to A_1 which I had in the room to start with. Both of these things I have to figure out.

Now, if I really want to do this carefully and if I had gone out prepared for this job, I would have made a reverberation measurement in this space to start with as is, and from the reverberation time and the volume of the space, I would have been able to compute A_1 quite accurately, wouldn't I, because RT = .05V/A. RT I could measure. I could go in there with a balloon. That's what we use, nice big red balloon, and then break it like that, and I could record that decay on a high quality tape recorder. Then, I take it back to the lab and we would reduce the data, and we could see what the reverberation time quite accurately is in seconds, and from that we could then compute A_1.

I didn't do that because I wasn't prepared for the job in that they threw it at me after I got there, so I merely looked around and said, "Well, you know, concrete is .02 and steel is .02 and concrete is .02 and glass is .02 and there are 30 guys in there and each of them is worth about 5 units and miscellaneous, 100 and you know, you just throw some stuff together and it really doesn't matter very much to be too precise, because when we cover the ceiling with fuzz, we're going to have orders of magnitude of greater absorption in the place later than we have now, and to be terribly precise about what it is now isn't awfully interesting, (it means a few tenths of a decibel). So on the basis of calculation with putting perforated metal and some fuzz up there, we calculated that the new sound level would be something like this in the space with a reduction out here in the higher frequencies of the order of 10 decibels, almost no reduction at the "*WUMP WUMP WUMP"* end of things.

Why? Because the sound-absorbing treatment is not efficient at the very low frequencies. A thin sound-absorbing treatment such as we were going to put in, an inch thick of stuff, isn't going to absorb any energy down at the bottom of the spectrum and so we have almost no reduction at the bottom, and an increase in its effectiveness as we got higher and higher frequencies. Now, on the basis of this new predicted spectrum and on knowledge of how speech sounds are, how loud they are and what's their frequency range and what's the necessary range for speech intelligibility, which also we are going to talk about in more detail, if I draw here an area (and this is going to be very hard for you to understand in any detail without a lot more explanation), but this hatched area is the range of frequency and levels that raised voice speech at 3 feet will have.

If that range of frequency and level is covered up by the noise, you will not hear. If it is not covered up by the noise, you will hear, not masked, just as these damned airplanes go by and mask my speech. And a while ago, one of you was asking me a question and an airplane was going by and I could barely hear because the noise was coming off and covering the speech sounds. So let's say this was the speech and it was quite heavily covered by the first noise and only about half covered by the second noise. Now, with a little knowledge of how we hear, we learn pretty quickly that if we uncover about half of this dynamic range, you get really quite good sentence articulation. You may not understand whether it's a 'B' or 'D', but you know whether it's 'bad' or 'dog,' which is the reason for using words for letters sometimes just so we can improve articulation in difficult communication situations.

Well, the answer here was very simply "yes," put in the treatment. It will work. It will make it possible for this man to use ordinary raised voice at 3 feet and be able to communicate. At present, in the hard finish shop he was communicating by doing what? By getting closer—which increases the level. If we reduce the distance, we increase the level—so he was going up with the level and he was shouting so he was raising this thing both by shouting and by getting closer and at present he was communicating by getting his speech levels way up here. Now this means reduced effort and the ability to hear.

Now, if the levels had been reducible by this treatment only down to this level, suppose it had been much higher to start with, then I would have to say that treatment will not do the job you're asking it to do. Now, what it would have done if that other had been the case would have been to make communication possible at all, because it probably would have been impossible to communicate even by shouting. Well, this is just one example of how one goes about analyzing a problem and answering the question: “What can I do, what should I do, and what effect will it have on the noise in the situation?"

Student: *“What about the reflectance of the concrete?”*
Answer. Well, the reflectance of the concrete, this wall over here, for example, and the floor, will have very little primary effect because, first of all, the walls are far away, and secondly, we are not engaging really the whole space in our speech sound, what we're doing here is engaging the whole space in the banging sound and we're reducing that.

Student: *“Hasn’t it reduced the reverberation time?”*
Not much, a little yes, but the point is that this is fairly well distributed reverberant energy and it really isn't (I mentioned the other day the empty swimming pool effect where this is that sort of thing). But we really have so many things in the room that are scattering sound around, it isn’t a pure simple empty space. The minute we get a lot of junk in a space, we get a great deal of scattering and we almost satisfy Mr. Sabine's formula without any difficulty.

Student: *“Is it best to treat the ceiling?”*
Yes, the ceiling is almost always the most effective place to put treatment and, in fact, if we had only put treatment on the walls, it would have had very little effect on the total noise because the ceiling is the free surface, the surface that matters.

End of Part A: Audio File 4A
The First 12:03 Minutes of Part B: Audio File 4B

THE END

Robert Bradford Newman Lectures

28 September 1970

LECTURE 5

Title: "Sound Absorption Treatment (continued)"

Summary: In this lecture, Newman continues his discussion of sound absorption treatment methods being used in the field while also citing more of his personal experiences with the matter.

Beginning of Audio File 05

Last Friday we talked about the treatment of a big shop and you may wonder why I spent so much time talking about it. I will not discuss every example in such detail, but I thought it was a very good example of what can and what can't be done with sound-absorbing treatment. I also discovered at the end of the hour that I perhaps had left a false impression with you. I mentioned the fact that when you have an office in which you have a lot of people working, typing, drafting, or whatever they may be doing, operating machines, that the addition of a sound-absorbing ceiling in such a space might reduce the level of sound by only 2 or 3 decibels, and I have been talking about 2 or 3 decibels as not a very important change. The implication may have come through that I would not recommend such a treatment in an office.

Quite the contrary! It is very, very important to have sound-absorbing treatment in such a space to keep sounds where they belong and do all the localization kinds of things that we talked about, to improve the feel of the space, and it certainly does help at some distance away from a given source to have had the ceiling not reflecting.

Sound-absorbing treatments in such places should always be recommended; in fact, I want to talk this morning considerably more about the open plan, and how this can be made to work and be useful for people. About the only time I would <u>not</u> recommend a sound-absorbing ceiling in the space where noise control is the objective would be if it were a very high bay factory in which you have a whole lot of very noisy operations going on. For example, there is a big screw machine plant down in Norwalk, Conn., and we got in a great hassle with Owens-Corning Fiberglass because we told them it didn't make any difference whether they used a fiberglass deck or a gypsum deck – didn't make a bit of difference – and they called up and said "What are you guys doing not recommending fuzz?" and we had to point out that it didn't make any difference in this case whether they had a fuzzy ceiling or not because you had a whole lot of noisy operations very close together and everybody was so immersed in his own noise field that the addition from other machines around didn't amount to a hill of beans. There are times like that when it doesn't make any sense. Also, as I mentioned before, in textile mills quite often we find that the addition of a sound-absorbing ceiling would do very little because we are dealing with a sound absorbing material in the manufacturing process.

A_1—you remember that the change in intensity level, delta IL, was given by 10 log A_2/A_1 where A_2 is presumably greater—but A_1, if you have a lot of cloth and yarn in the space, might already be quite large, and the addition of a little bit more on the ceiling just isn't going to make A_2 very much bigger than A_1, and the resultant reduction is going to be very, very small. Open-plan offices, open-plan schools, open-plan houses, restaurants, and all the rest are very much with us today. We have heard a great deal of talk in recent years, the last three or four years, about the office landscape. This test came from the other side of the Atlantic and a bunch of Germans by the name of *the Quickborner Team*. Quickborn is a suburb of

Hamburg, and they invented what is translated as office landscape. Their notion is that you shouldn't have partitions to separate people, that the flow of information and contact in a business can be improved by having everybody sitting out in the open and be free to circulate everywhere. They use a lot of fancy cybernetics terminology, which I don't quite understand but apparently this is just great, and they put a lot of rubber plants around in amongst the people. They also use screens to separate people for visual privacy and for some acoustical advantage, and they use great quantities of sound-absorbing material. Their approach is perfectly good, and many of their offices do, indeed, work very well. But there are some startling examples of total failure of such things to work because certain things aren’t quite right, and we want to talk about those today.

What is it that makes an open-plan office work or what is it that makes an open-plan school work, or an open-plan house? For several years, about 20 to be exact, we lived in an open-plan house in Lexington --- it was an early TAC house [The Architects’ Collaborative, Architects, founded with Walter Gropius], circa 1947. It was glass and stone and cinder block painted. That was an OK material in 1947; all the OK architects including TAC were using cinder block. A ghastly material to put anywhere near people. Just a horrible material. One of the requirements my wife had when we built a new house was absolutely nowhere did she want to see any cinder block—and that was followed very carefully. This was a very interesting acoustical experience to me. I had, prior to this time, lived in a variety of apartments and houses as I grew up and as I was married and had kids, and somehow or other the places we lived in always had doors and had small rooms and was kind of chopped up, and we never seemed to experience any tremendous difficulty with being able to live in the space.

We moved to this new—or it was about two-year-old house—in Lexington with a stone floor, and the glass walls, and the hard ceilings, and we had an open-plan living room, with a study, dining room, kitchen, and laundry in one space. This is open-plan. Why not? It was 54 feet long, 16 feet wide, and 8 feet high, all on a very careful 4 x 8 grid system with mill construction and 4 x 4 posts, 4 foot on centers, 1 foot ridge plate glass infill, or door infill and all extremely intellectual, and very, very pure architecturally. Now I, at that time, had three very young children, all of whom made noise. Even acoustician's children make noise, just like other children, and they fight, they argue, they beat each other up. This usually takes place in the middle of the kitchen, and wife is beating up things with pots and pans, and perhaps father is in the living room listening to some string quartets or something, and trying to read the New York Times on Sunday. All this chaos going on in this one space. Oh, the washing machine and the drier will be running. But all of this noise fills the entire space with I [Intensity] average given by P over A for each of the things, and A is very, very small, in a space with a stone floor, glass walls and a hard ceiling. It is very, very small this A [absorption].

Of course, at that time, all of us who were just through architecture school were in the leather Hardoy chair phase. [The Hardoy chair or “butterfly chair’ is a style of chair featuring a tubular frame and a large sling hung from the frame’s highest points, creating a suspended seat.] We had a leather Hardoy chair, we had several wood Eames chairs, and one very small Chinese rug, and just everything very simple and woody and none of this fat, luxurious down-filled stuff that we go in for today, and certainly no extensive area of carpeting. Well, this place was absolutely impossible to live in unless we drew all the draperies. Now the glass was completely covered with drapery, fairly heavy stuff which could be drawn if you wanted to. But then you say, what the hell is the sense of living out here in Lexington, out in the country with all this glass if we draw the draperies across it all day in order to add A into the space, to reduce average I [Intensity], because the sources of power P watts were always there, and they were not about to shut up and behave and be quiet. I immediately set to work after a very few months of living in this house to put in some sound-absorbing treatment. It had to be done architecturally because it would be too bad to just glue up this sort of stuff, and besides the detailing was such that everything came out exactly flush and you couldn't drop anything below it. So I removed a great deal of the existing ceiling which was 4 foot x 8 foot sheets of Homasote [compressed wood fiber, best used a tack board] with no attempt to cover the joints or to spackle them or anything. It was all very modular so it really looked quite decent, and I found some 4 foot square sheets of perforated transite of a very rare supply of some remaining here in Boston from some war-time production. I don't know what it was made for—but they were great big 4 foot square sheets of perforated transite, which I then was able to mount over some fiberglass and paint out white and flush with the existing ceiling where I didn't take it out. I took out about half the area and put in sound-absorbing panels. A very fussy, very tricky thing to do. By the way, the first thing I tried as a facing was 4 foot x 8 foot sheets of perforated Masonite. I put this up on a Saturday, and Sunday morning turned out to be a hot, humid day. And this stuff had gone up dead flat and yet by the middle of Sunday morning it sort of looked like this. Masonite is an abominable material. If you restrain it in any way at its edges, it will come and go with humidity something awful. It just looks absolutely awful—I mean, the ceiling is like droopy wallpaper. So I took that right down and returned the other sheets of material I had bought and got the transite, which is dimensionally stable. The result in the house was absolutely fantastic in terms of livability because, while the A was increased we got some delta IL due to having A_2 much larger than A_1. The effect of having the noisy sounds in the kitchen stay in the kitchen and not surround it was just absolutely tremendous and the house became a very livable space.

However, when we decided to build a new house, we decided to have separate rooms again – very old-fashioned – and have a separate dining room with doors, and a kitchen with doors, and a study with doors, and a sewing room way off yonder, and so on, so we don't have to put up with the inconveniences of open planning. I think it has some very good features and it has some disadvantages. I have talked with a great many people who have open-plan houses, some of them new and some old, and in almost every case you will have complaints about acoustics if something isn't done about sound-absorbing treatments. It cannot be just carpet on the floor. Carpet on the floor is good, carpet is good sound absorption, but the ceiling is the surface that is doing the spreading, and I feel very strongly about this that at least for most people, and I consider myself fairly normal, you will find a great deal better acceptance of an open-plan scheme and a great deal more livability in it if some kind of sound-absorbing treatment can be incorporated into the ceiling structure. If you are an architect who must have smooth white plaster or must have exposed concrete, then this is very difficult because it cannot be smooth white plaster and cannot be exposed concrete if it is going to absorb sound. Those two materials do not absorb sound because they are not porous and they are not fuzzy, and you have got to have something that is reasonably soft. The perforated kinds of treatments that I mentioned – the big sheets of transite are good – as is the use of wood stripping, to cover the sound absorption.

Student: *"What is transite?"*
Oh, I'm sorry; transite is asbestos cement board, it's grey in its natural state, it has a sort of grey cement color. Transite is the name of Johns Manville's product—it is like calling a refrigerator a Frigidaire, I shouldn't do it—but it is available in, I think, the largest sheets today are 2' x 4'.

Student: *"Perforated transite probably has considerably less than 1/3 of the surface…"*

That's correct, and let me just say something about that. You had another?

Student: "What does it look like?"
No, it looks just like this stuff, except in bigger sheets. The holes are the same size as this, and these are on ½ inch centers. Now the question is, there isn't very much of that surface area that is open, is there? You say less than a third, it's actually less than a tenth. Now how does it work? It works exactly the way my fingers work when I demonstrate to you that if I put my fingers up here in front of my face, and I've got roughly 25% open there probably, I can't tell exactly, but you're still able to hear even the higher frequency sounds, "*SWISH SWISH SWISH*." Now there's a little bit of degradation. Can you hear some cut-off of that? I can hear some reflected back to me, but here is a case of a facing, this is a perforated facing, we don't care whether it's slotted or holes or what, with elements of the order of 1/2", my fingers are somewhere about 1/2," 3/8," I mean 3/4" or something of the sort. At wavelengths longer than 3/4", and this means frequencies as high as 5,000 or 6,000 cycles per second, the sound simply goes right around these things, and never experiences them at all as a barrier.

On the other hand, something the size of my hand which is 4" across or so, will give quite a cut-off of the speech "*SWISH SWISH*" sounds. Yes?

Student: "It's not actually the type of material, it's the way the sound…it's the holes that do it. In other words, if there was an acoustic ceiling made of metal with perforated holes, it does the same job."
That's right, exactly the same job.

"So it doesn't matter whether it's this material or whether it's metal?"
Absolutely not, in fact, the advantage of a perforated facing, and remember I'm talking about a lot of materials, I'm not trying to sell perforated facings, but one advantage of this is that it can be painted, and buildings somehow after ten years do get dirty, and if you care at all about the finish and the looks of it, it has to be either washable or paintable. And usually paintable is a hell of a lot more satisfactory than washable.

Now the essential thing about any sound absorbing treatment is that, first, the surfaces have fuzz inside, and second, that you put something in front of it that's going to be serviceable, because the fuzz isn't serviceable; it's soft, it is very attractive to dirt, and, of course, this is another trouble with acoustical plaster. If it is porous and does work, which is very unusual, then it's very attractive to dirt because it has a wholly porous face – and dirt comes to it, and it gets just filthy, especially if you have any kind of a situation with a diffuser in the ceiling or air blowing against the ceiling regularly, even diffusers which send air down like this re-entrain room air, and you find a dark circle on the ceiling around the diffuser, that is caused not by air in the system but by the air in the room being re-circulated like this and being deposited. So, you need something that's hard and has a space in between the holes – sort of a 1/2" max – and that opens up circa l0% to 20% of the surface area.

Student "What about the blocks that have all sorts of different sized holes? Is there any advantage to that?"
No, that's entirely visual.

There is a problem with perforated facing like this and even with wood strips sometimes—we'll talk about wood strips in a minute. If you have this on a wall in front of you and it is painted white as this ceiling is, it will drive you absolutely nuts in short order if you have to look at it because what happens is that the contrast between those little holes and the white—the holes are black and the rest of the surface is white, and the thing will start coming at you and going away from you. I found while I was painting this ceiling in my other house which had exactly this pattern only in big 4' square sheets—I'd get up there with a roller on top of the stepladder and be painting away, and all of a sudden this ceiling would start coming at me. The only way I could make it stop was to reach out and hold it. I could see my hand and I know where it is and it stops moving.

This is a visual thing and not acoustical at all. But once in a while we use this sort of stuff on walls in rooms—in teaching studios in a music school, we might decide to use something like this on a wall. Not only does it have about the same size as the notes in the music but it absolutely comes right at you and goes back and forth. The only cure for it is to paint it a dark color. We have a seminar room at our office where we put some of this stuff on some wall panels, and it was painted white. People sitting near it were almost sick; we had to paint it dark grey just to reduce the visual contrast. I have also seen wooden strips used – wood slats something like this – where the background is very dark and this is finished very light. Again we get this strong dazzle, this visual conflict and it is quite a vibrating sort of thing. This is the sort of thing Kepes [George Kepes, artist on MIT Architecture School faculty] used to like to do his exercises in.

Student *"Can you have holes in the tiles and there's a light source above the tiles which filters down through them, so you don't need lights and the whole thing sort of diffuses light?"*
I don't know how efficient you could have a lighting system—well, there is a system, we invented it and have a patent on it, as a matter of fact—I'd almost forgotten about it—in which we have a sheet of plastic, vinyl, and the vinyl is perforated, but laminated to both sides of that is an acrylic paper, like tea bag paper only made with an acrylic plastic—a very thin tea bag paper on both sides of this—so that in big scale here's a hole in the plastic—this is very thin, of course, and here's this tea bag paper on both sides—and then you have your lighting system, whatever it may be, up here above this, and about a foot of space in there, and then this does serve as a very good sound absorber that has just the right kind of flow resistance to do the job. But other than that, if you just use ordinary fiberglass or something, it's going to be so opaque, by the time you get enough of it to do any good as a sound absorber it wouldn't work out. But if you want a continuous luminous ceiling, then one approach is to use something like this. The only reason you need your transite up against the fuzz is to hold it in place. And to be paintable.

Student: *"But I mean, the fuzz could be… (inaudible)"*
Yes, that's all right. In other words, here's the fuzzy stuff and if you had a hung ceiling and you wanted to have your hung ceiling down here, that's all right.

…"And then put your lights in between?"
Yes, you could. But 10% transmission of this thing would be pretty poor efficiency.

…"You would assume that it would be a transparent or translucent material."
OK, yes, you could do that.

Student: *"How do you change the tea bag paper?"*

You don't. It can only be washed. It gets kind of brown pretty soon because all the fumes go back and forth through there and it's just a big filter. It gets pretty raunchy looking fairly soon.

Student: "How does wood—does that have any [acoustic] value whatsoever?"
Not at all. Wood is good and sound is round. I'll say that little ditty several times. There's a lot of mystique about wood and I'll get back to this later on, but I think about Jones Hall in Houston. One time I went to talk with him about an auditorium we were doing at Connecticut General. He said he wanted it to be all wood inside, just like a Stradivarius, he said. And I've heard this: "just like a Stradivarius", so many times. There's just no connection between a Stradivarius and the interior of an auditorium. They're two totally different things. It's like a Mercedes-Benz or something. So what? Wood is a sound-reflecting material but if wood is very, very thin, it also acts as a diaphragm and you get some absorption just by flexing the wood. If you put up a piece of 1/4" plywood with occasional bracing members and randomize them, not have them all exactly the same space so that you get panels of different sizes. So if you thump it, it doesn't all go "*BUM BUM BUM BUM*," it goes "*BEEP BEEP bum bum bum bum BEEP BEEP*" and so on up and down the line.

By the way, if you ever lay anything out and say to the carpenter, "Do it at random," you have to tell him that this is 6-1/4" here, and this is 8-3/4", and this is 16-1/2" or whatever it is, because if you don't they will come out on 16" centers precisely. There is no way to lay out studs except 16" on center. There isn't any other way except to do a very precise drawing. I discovered this one time. I had random spaced studs. That just isn't what happened. If I do this with 1/4" plywood I will find that I have an absorption coefficient as a function of frequency that looks sort of like this. This at very low frequencies may be as much as $\alpha = .25$ at 100 cps, and drops down to $\alpha =$ about .1 out here at the higher frequencies. Maybe .06. So yes, it has a little bit of absorption; it is more absorptive than this concrete surface here.

Student: "When you say absorbing, do you mean that the level of sound in the room on that side will be less because it is transmitted through?"
No. Of course, if it were freestanding, there would be some transmission through. As far as the room is concerned anything that leaves the room is absorbed; we don't really care whether it goes into heat or goes into warming up the air for the people in the next room, but the kind of absorption I am talking about here is more the simple flexing of the panel. Because the molecules in the air are pushing back and forth, the mechanism of transmission is moving the wall and getting through it. The wall is moved and, in being moved, it must take energy from somewhere to be moved and that energy comes from the sound that is not reflected back. It is a flexural loss as opposed to the fuzzy kind of loss where there is actual penetration. There is no molecular penetration when it merely moves it.

Student: "There's the question then of transmission…"
That's an entirely different animal. We're going to get to that very shortly.

Student: "What is the point in an auditorium then—to absorb the sound or reflect the sound?"
Reflect the sound. That's right. In fact, if we did a room all in 1/4" plywood, it tends to absorb too much of the low frequency sound and has no guts left to the music. It's very clear and sharp. In Jones Hall—I just finished that story, I get started in so many different directions and I forget where I am—they wanted to do it in wood. This is a 3000-seat auditorium in Houston, Texas, and even in Houston, Texas with oil millionaires pouring in with the bucks, they couldn't afford to do this 3000-seat hall in 1" deep plank, which is what we wanted. We said, if you're going to use wood, you have to use very heavy, very solid wood – none of this

thin plywood bit. What we did was instead to do a total fake – I'll just call it what it is, it's a fake – we put up concrete block and plaster, then we put on wood wallpaper. Now, the wood wallpaper is flex wood – it is real wood – it is veneer. It is extremely thin slices of wood, mounted on cloth, and then glued to the plaster. It is a beautiful job. The pieces of veneer are great wide sections, 30' long planks, this wide, slice that and slice that and slice that, and you can get a lot of pieces out of a single board, and it covered the entire interior of the space, and the orchestra shell—which, again, we're going to talk about later—is lined with this stuff and it is glued to steel, on the backside of which is a material called Aquaplas which is a damping material, and you thump on that shell and it sounds just about like this wood desk. All the musicians come in and say "Ah, wood. It must be good." It would be just as good in concrete and steel as in that wood, but it does look very nice, and everybody is happy about it, so it's a good thing.

Student: *(inaudible)*
Well, this can be done in a very limited way. The problem is that all of the phenomena of sound are extremely random. The distribution of sound in this room is different for each of you, and different as I move around. These differences are not major and they don't bother you particularly, and all of you hear more or less the same sound but not precisely the same. If I were to construct some kind of a cancellation device, it couldn't possibly work in here. It could work if you were running a noisy grinding machine of some sort, and you put some loudspeakers right beside your ears, and you hold your head right there and you're doing just one thing here, and there is a very definite source of sound. We can take a microphone and run it through a phase-shifting system and get the signals out of the loudspeakers here, just out of phase with the sound that gets here, and we can get about a l0 decibel reduction that way. But the minute you move or do anything, then all of that's wrong. So it's a very tricky, very specialized kind of thing.

Student: *"As you move around, your phase shifts. Also, due to reflection, there's a phase shift across frequency bands, which would make it almost impossible for that to work…" (inaudible)*
You're absolutely right. These questions come up every year. I'm delighted that you're thinking, and thinking of possibilities. Also, when we get to talking about sound transmission, the question will come up, "What about a vacuum in the wall, wouldn't that work?" There are some practical problems of 15 pounds per square inch that has to be supported by this wall, and the minute we put in the supports that make it work, then the whole thing acts as a single unit anyhow. Well, we're getting a little ahead. I want to finish talking about absorption before we talk about transmission, because absorption comes first and then transmission, but you're right, it's an entirely different kind of mechanism.

I was talking about sound-absorbing materials and the kinds of things we can do with them and make them look acceptable and be durable and long lasting. There are many commercially made acoustic materials as you know. Most of the products that are marketed as "acoustic materials," prefabricated types at least like tiles and boards and the like—have almost identical characteristics across the board of all manufacturers. The fuzziness of the filling material, whatever it's made of, has been optimized so that it is neither too dense nor too light; it lets the sound in in an optimum sort of way and we lose energy—they have absorption coefficients of 0.85 and so on in the middle frequencies. They really are quite a good sort of standardized line of materials and you buy them according to price and appearance. Many of them are not refinish-able, and I think that of all the materials we use in buildings today, probably the crummiest and the lousiest are the acoustical materials—the sound-absorbing materials. They don't last well, they beat up easily, they can't be repainted, they breathe, the whole essence of sound absorption is breathing in and out. When you get a lot of people smoking in a room, and with the general dirt of civilization and so on, and this stuff breathes back and forth, these materials get dark and dirty and ugly and have to be taken down or, if they are not perforated facings, they really cannot be repainted. You try to vacuum clean them and you try this and that and you can sort of clean them up but never really satisfactorily. I chose in my new place instead of going the perforated transite route, to use the wooden strip treatment and I put behind the wood strips some fiberglass—here is the plaster—there is about 3/4" of fiberglass, and I used a board that is commercially available that has a painted face. Now this painted face is a very “holey” paint, and full of little pin perforations so that the sound goes right through the paint. This is fine. It is done at the factory with a special non-bridging paint, but you can't paint it later. It is quite unpaintable because the minute you put ordinary paint on it, the holes fill up and you are sunk!

I decided that I would use it in a white finish and there are cross strapping members here and there going the other way, and covered it with 1 x 2's, which come out to be ¾” x 1-1/2” finished dimensions, with approximately 5/8” airspace in between these things, and then you have 1-1/2" of wood and so on. I had these all painted white to start with, the ceiling above is white to minimize the visual dazzle in contrast. In time, this is going to get dirty, I know it will, and I will be faced with refinishing it. What I am going to do is merely refinish the face and let the sides get darker if they will. That is going to be tricky to paint the faces without getting any gloops up on the sides. I can see myself with a 2” brush going down strip after strip, being very careful not to get up in there, but it’s just one of these things that we have to face. It’ll have to be redone.

Student: *“You said that there was a fiberglass…”*
Fiberglass board up in here. That was just put up and sort of temporarily secured between the strapping members, which were all painted white, and then the strips were nailed on underneath that.

Student *“Where is the special paint used?”*
The paint is on the face of the fiberglass board. The board is all painted. It’s made for a lay-in ceiling unit in 2’ x 4’ units.

Student: *“What would be the difference in sound absorption be if you didn’t have those wood strips at all?”*
The sound absorption would be better without the wood strips. Anything you do in the way of facing is a degradation in the performance of the materials. I plot here α as a function of frequency, and this might get up to .8 or something like that at 500 cycles per second, and might be as low as .3 down here at 200 or so, I don’t know, but that order of magnitude. And then at 4000 cycles per second it might have dropped down to .7. If I put the wood strips in front of it, which have the characteristics of two fingers—can you hear that cut off? It cuts off the high frequencies. It reflects them back because the high frequencies, the wavelengths are getting to be comparable in size, so what I get was degradation in the performance that looks like that. That is, we drop down to probably not more than α = .4 at 4000 cycles per second with the faced fiberglass.

One thing I will say about this treatment is that it is expensive. The fiberglass material—the guts of it, the stuff that does the absorbing—is worth 13¢ per square foot. The wood strips added in front of it, finished and put in place, all done right there on the job by fairly good carpenters, cost me very nearly $2.50 per square foot, an order of magnitude different. The architecture, the degradation, the stuff that makes it look good and perform a little less well than it would have in the first place is worth sort of twenty times what the basic material is worth. I think it is very good once in a while for all of us to prescribe some of our standard prescriptions for ourselves; then fill the prescription and discover whether it works and whether you like it or not, and most of all, how expensive it is likely to be.

Student *(inaudible)*
The materials aren't worth very much. Well, in our dining room we wanted 22' long strips without any joints. I had to do a little shopping around to find long enough ones. Actually, we had to use redwood. This is just what I had to pay a contractor. It isn't expensive. Also, I could not possibly have done the job that this skilled craftsman did because he did an absolutely magnificent job and every stick is exactly as far away from every other stick. He laid it all out on every one of these sleepers or furring strips, laid it all out from front to back and made it come out exactly right in the room and, well it's just a beautiful job, but these things do get very expensive when you start fussing around with putting up one thing after another.

Student: *"Would regular Homasote have worked?"*
No, regular Homasote is much too dense. It's not nearly porous enough; in fact, any fiberboard, Homasote, Celotex, any of these things, is much too dense. Now, materials like Tectum and Forex, these materials made with excelsior bonded together with Portland cement or Magnasite—I'm sure you have seen them—are very good sound absorbers and are really quite rugged and rigid enough to take the gaff of people. There is a very poor installation of Tectum in the Carpenter Center at Harvard in the lecture room. Any of you who know that room will remember that along the right-hand side as you face the front of the room is an 8' or 10' high panel of Tectum, and it has been painted a brilliant crimson. And the problem is that it is just a veneer of paint and this material will chip and when you chip it off, you see the white inside. Just leave it natural or leave it white. It looks pretty good and you can beat it up pretty badly, but if you try to paint it with something bright, then it doesn't stand up so well. It is so open, though, and so porous, that it's almost impossible to fill it with paint so it is a paintable kind of treatment. The criterion is "Does the paint seal the surface?" If the paint seals the surface, then the material is not going to work. It's as simple as that.

Student: *"You can use dye colors, can't you, that are absorbed into the material?"*
That's right. That doesn't hurt a bit. The rear wall in Kresge Auditorium has some wood strips 6" on centers. We wanted very little of this cut off. In fact, we wanted none, so the wood strips on Kresge rear wall, we have 6" of fuzz, then we have some metal grille cloth and then we have these little pointed wood strips 6" on center. That's the gesture toward wood. Now, Mr. Saarinen wanted to take the same pattern as we have on the side walls of the hall (which is oak flooring with an extra rabbet run-out here) and just leave out this cut through here and have this with a facing across the rear wall. That would have been very nice. It would have looked exactly the same all the way around. The only trouble is if you go make noise, everything would come back with that sort of sound—long delayed and much reflected from this wood. Instead, we went with 6" on center wood strips that are very skinny. And then we started putting it up, and this is one of the things you'll discover, you'll have horizontal framing members, and then you'll have some fuzz in between, and then you'll put on your cloth over this, and then you'll put on your wood strips like this across the framing members.

Well, even with that grille cloth up there, you could see every detail of what went on behind. You could see all these wood strips; you could see the fiberglass and the fiberglass was not the same color as the wood strips and there were little holes, and so on, and you could see every bit of it reading right through this cloth and it just looked like hell, so we took it down, we had only gotten about 10' of it up, and spray-painted the whole business black—the furring, the fiberglass, everything with a black stain paint and it didn't hurt the fiberglass a speck and then put the cloth on and it all reads perfectly uniform color. These are all things that you might as well learn from some of us who have had the opportunity to make some mistakes and not repeat it. If you are going to put any kind of a fabric in front of almost anything, you have to get rid of the background first because it will read right through if you are not careful.

Student: “Are you happy with it?”
I will talk at great length about Kresge. I would say that it is as good as could be expected under a dome. How's that. It isn't the greatest auditorium on earth. We’re going to make a field trip over there in the course of our work this term and I'll show you some of the interesting things about it. We may even by then have the new electronic reverberation going. We’re adding reverb to Kresge.

Student: “Is it, because of the fact that it is dome-shaped, that we can pretty well whisper anywhere within the hall and someone else can hear you?”
No. It isn’t because of the dome. I don't want to put you off, but if I start talking about room acoustics, we'll never get onto this dirty work of noise control. This is why I do this first in the term because it is the dirty part of the course, and probably the most important thing we can do in room acoustics is to have good noise control and keep noise out. Otherwise, all the rest of it is of no value.

Open plan schools work, and certainly maybe some of you even have been to school in them, have taught in them, or certainly have had a chance to observe them. Open plan schools will work if everything is very, very dead. You carpet the floor and you put fuzz on the ceiling and you have adequate screens and so on in between groups of people and never, never, never attempt to teach in this fashion. This kind of teaching—lecture teaching, at the college level or the higher grades in high school—simply won't work in an open plan if you have more than one of these going on unless you have 300 or 400 feet separating you. If you can afford that kind of space, go ahead and do it, but for small group teaching, for teaching the team-teaching approach where you work with smaller groups, certainly an open plan can be very, very satisfactory. We went out last year to visit a school in Concord, the Lowell School I believe, where the kids—it was Friday afternoon and they were all getting kind of psyched up for the weekend—and I have never seen a noisier or perhaps happier place in my life. All these little kids were running around like mad and teachers were talking at this level (raised voice) and everybody was going to town. It sounded like a very noisy restaurant, and they were all just soaking up knowledge like mad as far as I could tell. It seemed to be great fun. I would have hated to have to teach there, but I talked to some of the teachers and they said it was great, they didn't get tired at all and they liked it. Fine—I’m not going to argue with them. It probably is great. It worked because it was all dead and as much like outdoors as possible.

I have seen, and I recently was called to go to look at a case of an open plan office out at the Cummins Engine Company in Columbus, Indiana and this particular building had been designed by Harry Weese, and one of Harry’s things for this building was a coffered ceiling and the coffered ceiling was a 6’ square coffer, and these things were 6’ on center, and then he got a lighting unit up here, one of Bill Lam's units, and this was all lighted and gives the light for the office on these 6’ square coffers. Now, the floor is down here.

This point is 9' above the floor and the floor is carpeted throughout, and then there are partial height partitions, and they have used Herman Miller's new office landscape furniture—everybody is calling it office landscape furniture—just furniture, what the hell. And as is usually the case, I was not invited to go to

Columbus, Indiana at the expense of the Cummins Engine Company because they had an office that worked perfectly well and they just wanted to show it to me. Not at all. It didn't work, and that's why I was out there, and one of the principal reasons it didn’t work is the ceiling is concrete, and unfortunately to change it at this point from concrete to sound-absorbing treatment is not easy. I'll discuss this at greater length on Wednesday.

End of Audio File 05

THE END

Robert Bradford Newman Lectures

30 September 1970
LECTURE 6

Title: "Sound Absorbing Treatments"

Summary: In this lecture, Newman shows various sound absorbing materials to the class and discusses some of his experiences with designing sound absorbing treatments.

Beginning of Audio File 06

Let's move ahead, shall we? On Friday of this week I'm going to do the demonstration that I've been promising you, and we'll drag a lot of equipment down here to make some loud and non-loud noises and show you what a change of 1 decibel sounds like, and 3 decibels, and 10 decibels and so on. So be prepared for some ear-shattering experiences. I'll try to be gentle.

I thought today we would kind of wind up our discussion of sound absorbing treatments, and in doing this I felt that I really ought to bring in a couple of these things to show you. Now this piece of stuff here, this flexible blanket, is very typical of glass fiber sound absorbing material. This happens to be about an inch thick, and I discovered on opening up the box that it's an Italian product. One of the problems that we often have in thinking about these materials all over the world is that they're both heat insulating and sound absorbing, but not sound isolating. This is absolutely, as you will see, transparent to sound, and I can talk to you right through it without very much loss at all. I can talk right through this. Now if I put my hand on it (inaudible).

Now here is a piece of metal, this is called "Duratone." This material has holes that are, I would say, they're not quite ⅛", what's the next size down? 3/32". They are larger than 1/16". They're on approximately 5/16" centers and open up, I would guess looking at that, about 20% of the surface area, maybe a little bit more. Now one of the things of course that we do when we open up surface area in a painted metal of this sort is to reduce the light reflectivity, and this is very important sometimes in considering a ceiling, we want it very reflective to light, and as we punch out holes we reduce the area that is available for light reflection. Now this material is absolutely transparent and you just certainly cannot tell any difference at all in the sound of my voice whether this is in front of my face or not. I can even see you through it. This is almost exactly like--well, the holes are a little smaller in regular movie screens, because the loudspeakers in a cinema are placed behind the screen and speak through it through holes. If you stand behind the movie screen you can look out and see the audience, it's actually transparent with these little holes. There's no effect at all there. If you had a situation in which you wanted either to have a loudspeaker speaking through a ceiling treatment or speaking through a grille, this is something for a transparent installation or transparency of sound, then this kind of a thing is what you would have to select.

Here is a piece of plastic and you can't see this as well, I'll pass these around so you can look at them. This piece of plastic is perforated with much smaller holes. These are smaller than 1/16" and are on about quarter inch centers, and this too is absolutely transparent to sound. There just isn't any effect, at least I don't think there is. I can hear none coming back to me, and I assume that if I don't hear anything coming back to me it must be going out to you. This is the stuff that absorbs the sound. This is the stuff that we put in front of it to make it durable or to make it more handsome or whatever we may want. We put this in front of it and then we're okay. Now you asked the other day, could we put it up some distance away? The answer is yes, you could. This could be a translucent material with holes in it or something. But somehow the air has got to be able to get through into the material and this is only something that's paintable, washable, hard, kickable, and so on.

In Caracas, in Venezuela, we did a rear wall in a big hall there at the university. It was a rear wall that was in contact with people, there was a cross aisle along it. I wanted something very transparent because the rear wall was curved in plan. and as you will see later on, an echo coming off a curved rear wall is much more serious than an echo coming off a flat rear wall. But it was already curved in plan before I got to the scene and so we used 16 gauge steel. 16 gauge steel is 1/16 of an inch thick, it's rugged as hell. We had a perforated pattern about like this and you literally couldn't kick it in. This is very important. I've seen aluminum, corrugated aluminum, ribbed aluminum, flat aluminum sheet with this kind of perforation pattern, and this may well be aluminum here, used where people can touch it or get in contact with it, and immediately it looks like hell because it gets dented, gets kicked and pushed against, furniture gets jammed into it. Remember when you're selecting these materials, they've got to be just as rugged as any other, particularly wall materials, that you want to select.

Now here is a perforated aluminum pan. This happens to be shiny. You'd seldom use it this way, you'd probably use it painted or matte finished or anodized or something, and you'd never use it in as small width as this, this is just a sample. But now this has holes on ½" centers, and these holes are the order of 3/16", ½" on centers, and you will begin to detect some deterioration in the quality of my voice as I put this up in front of my face. You should hear some cutoff of the "*PSSSSS*," as contrasted with "*PSSSSS*." I can hear it coming back to me at least. Do you hear that difference? Now that's simply because at these very high frequencies, way out as you will hear on Friday, circa 10,000 cycles per second or so, at those very high frequencies, the wavelengths are very short, the sound has a very small size and is reflected back from these areas between the perforations. Now if this were a rear wall of an auditorium designed to catch echoes or to absorb sound so that the sound doesn't go back as an echo to the front of the room, this would be an unsuitable material because it would reflect the "*PSSST*" part of the spectrum, where this would be quite suitable because it doesn't.

It's just a matter of the size of the sound and the wavelengths that are involved whether we get this cutoff or not. Now in many situations this is a perfectly adequate treatment because we don't care whether it absorbs 10,000 cycles per second or not. In this room, for example, the treatment on the ceiling has exactly this sort of characteristic, it doesn't absorb the very high frequencies, but we don't care because we have all this fuzzy material in here that does absorb high frequencies, our clothing and so on is very absorptive at high frequencies, so we just really don't care that this is the property. So many times this is quite an appropriate thing, other times it wouldn't work at all.

Now one other thing I brought in, pass these around, we've been talking about wood slats and this is a slightly different sort of thing, this is a prefab wood slat material that comes in very large sheets. It's used for screens, for light screens and space divider screens and so on, and it has these dowels in it to form the spacing. Wood slats can be used this way, though generally we say that the depth of the slot through which the sound goes should not be any greater than the spacing between them, because this will begin to have some low-frequency implications. But this is really quite transparent and you can probably hear some difference as I talk through this. It sounds a little different from when I'm just talking naturally, I can't tell from here just exactly what's happening except that I'm getting some high frequencies back and a little bit of other stuff as well, for this is beginning to resist the transmission. That's really quite a transparent material though, and in many situations would be quite acceptable.

Now there is a problem with using a wood slat treatment, especially in an auditorium, and we're inevitably getting back to room acoustics. I don't know whether any of you have ever listened to it, but you should sometime, to what we call the picket fence effect. If you go, you know what a picket fence is, a wooden fence with slats, generally not turned this way but turned flat. The type of thing that's used sometimes for snow fencing in the winter, just the old fashioned picket fence or any kind of a fence with regularly spaced boards with spaces in between. If you go along such a fence and make any kind of a noise you like, clap your hands, drive by in a car, throw a rock on the road, or shout, or go PSSSHT or anything else, and if you have someone else down the line where he can receive this sound, for example if here's our fence, you're here and you have somebody else here listening, this is in plan, the sound will go over here to the fence and some of it will be reflected off back to this person. Now what happens is that a little bit of energy is reflected off each one of these things, and you've got a "*PING PING PING*" sound on top of any other sound that you make, and the "ping" pitch is determined by the spacing of these things. It's merely the presentation of a whole batch of little bundles of energy off each one of these things, each one presents another one to this ear, and he gets a series of things coming off that go "*PING PING PING*."

That's the worst thing in the world that you could put in an auditorium, so that everything that was said on stage or played on stage would have a little extra "*PING PING PING*" on it. It would be really quite dreadful. So when we're using this sort of treatment, wood slats or something of the sort, particularly on side walls in auditoria, we space them at random. We don't have them exactly an inch apart or at 1¼ inches on centers, but we have some closer together and some farther apart. And you'll see this sometimes in auditoria where wood slatted treatments are used, the very random spacing of these things. I think the first time we ever did it was in the United Nations General Assembly, where in the large council chamber there is a wood screen that surrounds the room on a portion of a cone facing the spaces between the translators' booths, and these are wood slats of very elegant design, they're very fancy shapes sort of like a number 7 with a little bit of an extra thing on it here, and they're quite big wood strips but if you look at photographs or look at the building itself you'll see that they're not regularly spaced, they're spaced at random. Some of them are 3 inches apart, some are 5 inches apart, some are 7 inches apart. This was all dimensioned ahead of time very carefully, 3, 5, 7, 3, 7, 5 and in a regular system of random alteration--it wasn't random, it was regular, but regularly random. Again because if we had said to the people putting them up, "Just put them up any way you like," they'd put them on 6 inch centers. It's just a lot easier to get them straight if we don't have to remember what the hell we've got for the last one. So there is that little caution in placing these sound absorbing materials.

Student: "I don't understand exactly what mechanism you're dealing with when you.[talk about regular reflections.]..I understand that you want to put things randomly, but I don't understand exactly why."
Okay, if I have the series--let's say I have a ribbed facing. If you come out to my office sometime I'll show you the most magnificent example of this--our building is clad with Reynolds aluminum siding that's ribbed

like this, and then we have another building, and this is the building with the aluminum siding, then this other building down here, and if you stand here somewhere and clap your hands, you get the sound that goes down here to this building and comes back to you in the most magnificent "boing boing boing," just exactly what it sounds like. Now the thing is that the sound is being reflected from each of these little ribs and each of these arrives a little bit later at this wall and then comes back again as a whole series of little specks of reflection, discrete bundles of energy.

Student *"Does it have anything to do with certain frequencies?"*
No, the frequency is determined by the spacing. What you hear is a repetition, it isn't a smooth sine wave of frequency. This "*BEEP*" is not a smooth tone, it's not a pure tone, it's merely a repetition of whatever you do. If I do this, I get something, if I go "*BA"* I get "boing "*BA*" with an extra reflection.

Student: *"Now what happens when it's irregular?"*
When it's irregular, it will come back but without any pitch, and you won't detect it as a "ping" because it'll be spread out all over the place. There's no regularity about it. It's the regularity that gives you pitch. There's another thing that we're going to talk about later on which sounds very much the same, which is flutter echo. Flutter echo you hear between two parallel surfaces and whatever you do there you hear this "*BOINK BOINK BOINK*" and that's again a repetition of whatever the sound is at a regular rate as the sound goes whizzing back and forth between the two surfaces.

Student: *"So the idea is to get it messed up enough so that you don't hear regular reflections?"*
Exactly. If you just remember to mess things up, that's the greatest thing to do for acoustics in rooms is to have them messed up. This has nothing whatever again to do with what we're talking about right now, but Paul Rudolph once asked me to look at a living room that he was doing in a very elegant house near Baltimore, and the people apparently liked to have concerts in their living room and they had two concert grand pianos, you know, facing each other for duo piano works and other kinds of chamber music, and it was a room I would judge the size of this classroom more or less, a little narrower perhaps and a little longer but quite high, and it was done in pure white plaster on both sides, pure white plaster. At the ends, there was a very fancy jutting out ledge for a window and some things happening, excrescences, you could choose to call them.

And at the other end, there was a door and so on. Now these two side walls were perfectly parallel, and I said, well, it won't work. I said, don't these people have any works of art, sculpture, so on that they'd like to put in this room? Well, he was afraid they did, but he was hoping they could be dissuaded from displaying any of their junk, and I said, all I can tell you is that until they get their junk in there they're going to hate the room, and the more junk they get in there, the more oil paintings hanging at angles and big pieces of sculpture and maybe a Calder mobile or two with lots of big things on it, until they get all that junk in there, the room is just going to be a horror chamber because the absolute regularity will just cause the sound to have this singing tone on it that will drive you up a wall. Well, that's getting into room acoustics and it isn't dealing with our subject at the moment, how do we use fuzz for noise control.

Student: *(inaudible)*

All right, when I say this was transparent I mean almost transparent. This however, even in being almost transparent, isn't quite because you can hear some loss when I put this in front of my face, and that loss is the order of 80% in the middle frequencies, it's being absorbed in heat in this thing. That's the thing, 80% isn't very much, you know, that's a little over 3 decibels. As you'll see in our demonstration on Friday--this is why I want to do it right away--3 decibels or even 10 decibels isn't very much, and 10 decibels would be 90% loss in here, and even if this were 90% we'd drop it only 10 decibels which is just half as loud as before.

Student: *(inaudible)*
No, if I put this up here on the wall, okay, and I were able to measure the effect of this in the room here by making a reverberation measurement before I put it up and after I put it up, all I'd say is that 80% of the energy in middle frequencies will not come back. 20% will be reflected. Now that reflection presumably takes place by going to the wall and coming back again. Now if on the other hand I have it out here in free space, then I'd say it's going to absorb that much and the other 20% may come back, it may go through, I really don't care, I'm not interested. It is an energy dissipator though, and it is capable of using up 80% of the energy that strikes it in mid-frequencies in developing heat.

Now the point is (as we'll see very shortly—we're coming right away to this business of transmission through the next room--), this is worthless as a partition, almost worthless, and you know, I'm sure you've had the experience of being in a room that has been subdivided with curtains at some time in your life, surely you've been exposed to that in Sunday school or someplace where they draw some curtains across the room and it's just as if nothing were there. There's absolutely nothing but keeping the paper airplanes from sailing back and forth and people from making faces at each other, and that sort of stuff. You can't do that, but you can hear everything right through the cloth. I'll have another demonstration on that very shortly with my black box in which I'll persuade you that this is true, that sound absorbing material is not a sound isolator, but it is quite transmissive.

Now you're absolutely right in calling me on when I say <u>this</u> is absolutely transparent and <u>that</u> is absolutely transparent, and you say what's the difference? That is so transparent it can't do anything to dissipate energy; and this has got enough fuzz and stuff in it so that it does use up 80%. The point is that for non-transparency, as far as room-to-room transmission is concerned, we're going to talk totally different orders of magnitude. We're going to talk a transmission coefficient of 1/10,000 to be just barely adequate as an isolator, where this has a transmission coefficient of ⅕. It's just the wrong order of magnitude.

Student *"Will a 3 decibel reduction really be that much?"*
I'll let you hear it on Friday. I'd rather do that then--I can't imitate it, but it's very little. In fact, [a change of] one decibel you can't hear.

Student: *"How much of a reduction does this room give off with these? It's a lot more, isn't it?"*
Well, you see, it depends on what we're talking about. These decibel reductions, you have to be careful. The presence of that material on that ceiling has absolutely nothing to do with how much goes through that slab to the space above, nor how much comes through the other way. It does affect the level of sound in this room. If we had that stuff not there and then we put it up and we had something making a constant

level of sound in the room we would find that the level of sound would drop and it would probably drop with a full room here the order of 3 or 4 decibels. That's the average level of sound in this room. Now that's not available anymore to go up through.

Student: (inaudible)
But what I'm getting at is--now maybe it's because it would be reflected, I mean, if 3 or 4 decibels is so negligible, does it really make that much difference that it's there?

Now the point that I want to make, and I've tried to make, let me see if I can make it again so that it's clear. Let's be sure we understand this before we leave it. I said the other day, and one of you came and asked me after class, what did you mean by that, that in an office--and in fact one of the problems that I'm going to ask you to do here involves this question in a secretarial office--if we put acoustic material on the ceiling, remember I said we would probably not measure more than 2 or 3 decibels of actual reduction in noise, but that's not the important thing. It's the change in the quality of the space that matters. It's this non-reverberant quality, the localization towards particular sources that begins to pay off. And 9 times out of 10 we don't use sound absorbing materials for noise reduction but for spatial quality, for making surfaces non-reflective.

Student: "What do you use for inter-room noise?"
Up to 2 feet of concrete. We're going to come to that very shortly. I'm going to spend quite a lot of time talking about this because this is terribly important in buildings to understand.

At the moment though, sound absorbing treatment is something that affects the sound within a room. It affects the quality, it affects the magnitude to some extent. Now I have sound absorbing treatment in my dining room simply because the room has stone floor and glass and plaster walls, and if I didn't have a sound absorbing ceiling, if I get 20 people in there at a dinner party all gassed up with cocktails and yakking and laughing and talking and so on, it could be an absolute horror chamber in terms of everyone having to scream, and even dropping the background, the average level in the room, by 4 or 5 decibels as I do, I make quite a difference in the level of screaming.

The MIT Faculty Club was first finished off up there on the top of the Sloan building back about 1950, I guess thereabouts, and the sound absorbing material that was put into the ceiling in the main dining room, which is about 10 feet high, was a fissured mineral tile that looks sort of like travertine. Now this material, it turned out, was a particularly poor batch, and instead of having an absorption coefficient at mid-frequencies of .80 as it was advertised, it was only about .65. You say, well that isn't very much difference, is it, 15 points, what the hell? From the time that club opened until we finally took that ceiling out and put in a perforated metal ceiling with fiberglass behind it—which had an absorption coefficient α of .85—until that happened some 15 years later there was constant complaint about the place being noisy. Now people don't just go over there and start bitching because they don't like the food or something and start complaining about how it is noisy. There must be something to it if year after year after year, everybody bitches about the noise. Now who bitched about the noise?

Well we found out it was not the people seated like this at a table for two, it was the people at the big round tables where there are 12 people or so around, all the way around, and they said it's too noisy, we can't talk across the table. Of course you couldn't talk across the table with all the noise that was in there because this ceiling here overhead was scattering noise from everybody to everybody and making a rather high noise level. Now by just improving the efficiency by about 20%, we cut down particularly the noise from down at this end of the room even more effectively, and we dropped even the local noise, and it's now possible to talk across one of these tables. It's just a little bit of a difference there.

Now at certain points, and we'll talk more about this later on in the term, when it comes to speech intelligibility, you'll find that there are some breaking points and some very sharp knees where articulation goes all hot, when we begin to lose just a little bit more in level or have a little bit higher interference with it, so at some points 3 dB is worth a hell of a lot, so don't get me wrong and quote me that I said 3 dB isn't anything at all. If I'm listening to some kind of a noise and I want it reduced, 3 decibels isn't a reduction. And yet at times, in this kind of a situation, it can make a huge difference.

I got called down to look at a Red Coach Grill down in Braintree, a perfectly horrible place, but as a professional I'm just a regular whore, I'll do anything. *(Laughter)* So I went and they had this fissured mineral tile again, same stuff we had in the faculty club, only this was presumably a good batch, but they managed to louse it up. It's very easy to louse these things up. They had taken paint, and paint is an excellent "louser-upper." This material had a face with little fissures up into it like this. It looked like travertine again, all these little fissures. And it's painted at the factory, it's white, it's always sold white because the innards are white, it's asbestos and mineral wool and gypsum plaster, which is white, so they paint the face white, but the paint only gets on the face, it doesn't get down into the fissures. Now you decide it ought to be maroon as Red Coach Grill wanted, and so you get the painters in there and they really squish it in and the stuff is just like a sponge and swallows up the paint and seals the surface.

Now again, I wasn't called down there to look at the lovely restaurant, or to have a free lunch with them, or to get paid a good sum of money to go, but because their customers were complaining that it's too noisy here. And you must recognize that when customers complain and stop coming to a place, there's something wrong, I mean it isn't just imagination. And the only answer was to take that damn stuff down and put up something with a perforated facing like this that you can paint red or pink or blue or any damn color you please and it will absorb the sound. This business of treatment in restaurants is very, very tricky.

I went down to the Princeton Faculty Club last year. Warren Platner and Mr. Belluschi [Pietro Belluschi, Architect] had done a treatment in the faculty club in 2 new dining rooms. It was the old president's house there at Princeton, and they made it into a faculty club and added 2 dining rooms at the back and they've been published in the mags and so on. And it was a coffered ceiling. I'm going to come back, by the way, to Brother Weese's [Harry Weese, Architect] coffered ceiling before we finish today. These are supposed to be the same kind of coffers, sorry. It's a different scale. Now this room had a slate floor and big heavy tables, it's called a "Ratskeller," and there's a bar over here at this end and all the drinking members of the faculty go down there at noon and get soused up and sit around here and have sandwiches and talk loudly and bang beer mugs on the table and they complain that it's noisy. Upstairs there's a more refined dining room with a lower density population, nicer furniture, a higher ceiling, and glass walls all the way around.

This place just has a glass wall at the end, and both have exactly the same acoustic treatment: a little acoustic tile, sort of a 2' square plunked up in the top of each of these coffers.

Now in many cases this is a perfectly good gesture towards acoustics and really all you need. We have done, and I like the detail very much, a coffer like this in which we cast in place a block of *Tectum* or *Insulrock* or one of those wood wool materials 2" thick and secured with some little metal ears, and here's the concrete (of course, we have to pour the concrete a little thicker here to get the dimension that we need for structure), but this appears as an integral part of this concrete shape, and especially when it's painted out it merely represents a slight change in texture here rather than a glued-in piece of material. But my friend Platner [Warren Platner, Architect] had decided to glue up these things here in the ceiling. Now this dining room [upstairs] was satisfactory, this one [downstairs] was unsatisfactory. And again, this was not a matter of rumor, this is a matter of common agreement. People complained all the time that the ratskeller is noisy, and that the dining room upstairs is great. Now what's the difference? There's carpet on the floor up here, that helps a little bit, that's more A (absorption) in the room, isn't it? It's a little bit better. The ceiling is higher, the volume is greater, and the density of people is smaller. The source power level P, I = P/A, P is smaller because there are fewer of them. Down here they're packed in tighter, the ceiling is lower, the floor is hard, the tables are hard, everything is low A except for this little business up here.

Now I made some measurements there, and we have some data on a lot of restaurants, and we know exactly what kind of levels we're going to get in a given situation and what kind of levels are going to cause people to complain and what kind of levels people are going to be happy with. This is something that is just as precise as a description of the color of a light or anything else. We have so many case histories that we have built up a good backlog of information. I took data here and here and it was just as predictable as it could be. Now here we needed to drop the level by about 3 dB in middle frequencies to make these people say this is not any more noisy, because in a restaurant you don't want it to be dead quiet, otherwise you hear everything that's being said. You'd like to be able to talk about that idiot so-and-so right here when he's sitting right here, and have it heard at this table but not over here. Most of us would appreciate that kind of privacy, and we all are given to talking about people. And so here we want communication but privacy with lots of masking level, but they had too much masking level down here, so they had to shout at each other in order to be heard, and this gets tiresome after a while when you're eating.

The recommendation was very simple: you must cover these coffers completely with fuzz. Now this was found aesthetically unsatisfactory and nothing has been done, and it will probably not be done. It will continue to be a noisy ratskeller, and maybe the Princeton faculty will learn to live with it, and their architect will be pleased with his aesthetics. He isn't there, but he will be pleased up in Connecticut where he is. It's quite wonderful the way these things can be dismissed. But he tried and they didn't like the way it looked. And I must admit I didn't think it was a very red-hot solution either, but one way to do it.

The Harry Weese office that I described where they had an open plan with coffers, concrete coffers, they are experimenting with a number of treatments, one of which is to apply thick carpet to the interior of these coffers, white carpet, the color of the paint on the concrete now. This will do the job. There are other solutions with perforated metal, but somehow the concrete has got to be covered up. It cannot be exposed, that's all I'm saying, it's got to be fuzzy. Victor (inaudible) down in New Canaan, Connecticut 20 years ago did a supermarket with a series of cast-on-the-site square dome segments, 18' square, and these were carried on columns 18' on centers, elevated in place and plunked there upon the roof of the supermarket, you can visualize it. And each of these square domical segments was cast right there on the site on a form, and on the form he laid one foot squares of *Insulrock*, I think it was, one of these *Porex* or one of these Excelsior materials bonded together with Portland cement, like *Tectum* and all the rest, wood wool slabs, 2" thick. He put them around in annular rings, here's the square dome thing, now we're going to have rings come out and eventually reach the edge, and along these rings he laid in these blocks of material sort of like that, and then the next row, there would be another row of these things, and they didn't quite touch, and they formed – they were thicker than that, they were sort of 2" apart, and that would be a trapezoidal joint because we're radiating around the circle.

And he covered the whole thing on the form, here's the form, and he put these things on here and I presume nailed them down or I don't know just how he attached them, and then he poured the concrete dome and the concrete came down in between sort of like this approach here, and when he finished he stripped or lifted the thing off the form and there was all this wonderful mosaic of sound absorbing material in a concrete matrix, which was the actual dome itself. And he had a quiet supermarket, but he knew perfectly well that if he did these concrete little domes with their focusing effect, he would outdo Philip Johnson's horror at Dumbarton Oaks, it'd be even worse than that, and that's pretty hard to think about when the concrete surface in the supermarket, all reverberant, and then focusing as well, it would be a total disaster. It would be an experience, and it might give the housewives such a charge they'd love to go there, I don't know, but I think it would wear thin after a while. He simply recognized the problem and solved it with a very elegant solution, I think, in the nature of this kind of material. We don't have to hang in a supermarket ceiling every time we want fuzz. There are oodles of ways of solving the problem, but it's got to be solved.

Let me say just a word about another problem where fuzz can't solve it, and this will lead us eventually into our discussion of the transmission of sound between spaces. At the Connecticut General Insurance Company down in Hartford, we were the acoustics consultants – oh by the way, this is very funny, a guy from Herman Miller called me yesterday out at their research labs, and they're concerned because it's their furniture which is getting blamed for the lousy acoustics, and it's nothing to do with the furniture at all, furniture is furniture is furniture, it's metal, and it's a perfectly nice system.

One of the things the people there at Cummins were doing in order to improve acoustics was to take some metal cabinets that have doors that are about a foot high, this is the section through a metal cabinet door, it swings out like this, hinged at the top, and they had stretched fabric over this metal, very handsome fabrics, bright orange and red polka dots and all kinds of marvelous fabrics stretched over the metal in the interest of acoustics. Now what would you suppose this does? Zero. It's too thin. It isn't doing anything. Even if it were thick it wouldn't do the job because this is not where the problem is. The problem is up here on the ceiling where the sound is getting spread around by the concrete. But I was amused and he was amused to see this application of cloth to these metal doors in the interest of acoustics. The other thing – yes?

Student: *(inaudible)*

Oh yes. Yes sir. That's right. All of the acoustical materials now are rated for their fire retarding properties, and many times one must conform, and I think this carpet that's going to be used on the ceiling has to be fireproof carpet, you can't put ordinary carpet up there. This fellow from Herman Miller and I were sort of laughing because I think about the same thing in Connecticut General about this office setup, because these doors cover little cabinets here, and when you're not actively using some file or some book or some piece of paper or something on your desk, you're supposed to put it in the cabinet. And I've never seen such an unoccupied looking office space in my life. Everything is just absolutely immaculate, there's nothing on the desks, there's nothing on the tables, everything is inside cabinets and all picked up and you're allowed one family photograph on your desk. And he and I were sort of chortling about this regimentation and thank God we don't work there, we'd never make it. Connecticut General had the same kind of problem, all the executives had one family photograph on the back of the table and then an ashtray and just the right number of iron chairs and everything else, no individuality allowed at all.

Student: *"Is there any such thing as a way to make a roadway somewhat absorbing of noise?"*
No, there isn't, and we shall talk about roadway noise. The only thing you could do would be to install really sound absorbing panels alongside the road, and this involves using fiberglass or material like this, but it really isn't suitable at all for that sort of application.

Student; *"Have you been on (inaudible)?"*
No, I haven't.

Student: *"They set up plywood panels along one side of it, and I don't understand why."*
It might be to reduce the noise that's transmitted downwards towards the nearby residents. Any kind of a wall like that outdoors will do things if you cut off line-of-sight.

Student: *"They're not connected to each other, they're about 2 feet apart."*
Oh, well then they won't do anything.

Student: *"They just – I mean, when you drive by, you hear 'vroom, vroom, vroom.'"*
Yeah, OK, and then in between the sound will go right through. You're absolutely right. And again we'll see as we begin to talk about sound transmission how extremely important airtightness is and "non-gappiness" in the construction.

Student: *"Is there anything to do with tires?"*
Yes, yes. That's the way to attack it. Every noise problem has a source and a path and a receiver, and you always start with the <u>source</u>, particularly truck tire noise. Truck tires – and I don't know in detail exactly what its tread design and material is—it is said, and I won't vouch for the truth of it—that the quiet truck tires (at least, the ones that have been developed to this point and have been used) last only half as long as the noisy ones, and this, of course, is an economic factor. And of course, this all goes along with muffling of trucks and everything else that really could be done.

I wanted to talk about this other situation in Connecticut General, however, where the fuzz situation is <u>not</u> the problem. Here is a great floor of this space with baffles of sound absorbing material, and often sound absorbing material is not placed on the ultimate surface but is hung into the space as a sound absorbing baffle. These baffles were made of perforated metal, they were 2 feet deep and ran the entire length of the building; they had fuzz inside. They had fluorescent tubes here and then another baffle, and they were 2' on centers. So there was lots of fuzz in the space. The ultimate ceiling structure was not fuzzy, and there were ducts and pipes and so on running around up here, but this layer of fuzz here acted exactly as any other similar amount of sound absorbing material in the space would have. Many of these areas were carpeted as well.

Now in one particular case, this didn't work at all satisfactorily for noise control. In the big general offices, it was just fine as long as everybody was just typing or doing some kind of routine clerical operation. In one particular case, though, they had a 7' high partition surrounding an area where people were running punch card machines, these very noisy punch card machines that radiate a hell of a lot of noise out into the space. Now this is Department A and this is Department B, and the punch cards belong to Department A. The people in Department A said the noise is fine, and the people in B said it's intolerable. And you make a measurement here and you make a measurement here and you get exactly the same answer. These people say, oh that's just fine, and these people say those bastards over there are making too much noise and we've got to stop it. Okay, now what can we do?

The first thing we can say is: how much noise is "too much noise" in there, so we make a measurement and we see how much this noise rises above the ordinary ambient due to everybody else's noise at a desk somewhere in the place, and we were there to do this job so we could have them start and stop and do as we like. And we found an excess of perhaps 10 decibels above the ordinary office ambient from these – these are noisy brutes.

Now the question is, could we put fuzz around inside this here and contain enough of that noise to reduce it that much? Well, a very simple and quick calculation shows us the answer is NO because the direct sound is still going to come out over the top. Some of it will get up through here and be reflected. This is not a perfectly absorbing ceiling, it isn't outdoors, and even outdoors we get some simple diffraction over the top of this wall at the lower frequencies where the longer wavelengths get to be the size of the wall.

So the answer was very simple. We put in plate glass above here. Let it remain visually transparent, and this glass then terminates at one of these things, and we then blanked off the space above so that we have a blanked off continuum. We put a wall around the room, and a piece of plate glass will drop the level by 30 decibels. Plate glass is more than we needed, and yet visually we wanted it to be very clear. Now the architects, Messrs. Skidmore, Owings & Merrill, in person Mr. Gordon Bunshaft chap [principal designer at SOM], said: "We can't have that glass, it's so important to this space that we have visual openness, it's one great space." And Connecticut General said "thank you very much for your opinion, Mr. Architect," and then had the glass put up, because I had assured him that's the only way to solve the problem. We could have put a ceiling on this room, of course, and kept it visually open, but a 7' ceiling would be rather oppressive, and then a worse problem is getting air to these souls that work in here and a few other things like that, so that was vetoed, and up went the glass and I think everyone's been happy ever since. Question?

Student: *"Maybe lower baffles or something like that?"*

No, the problem is, if we're talking about a 10 decibel reduction, we're just in a different order of magnitude and we can't win with any more fuzz. We could have come down with lower baffles, but we'd still get [transmission to the neighbors.]

End of Audio File 06

THE END

Robert Bradford Newman Lectures

5 October 1970

LECTURE 7

Title: "Transmission Between Rooms

Summary: In this lecture, Newman explains the fundamentals of how sound transmits through a partition between two rooms. He also describes how a unique acoustical solution netted him the nickname "The Sandman" in the town of McAllen, Texas.

Beginning of Audio File 07

I won't blast you with any sounds today. We had that last time. I hope you found that demonstration useful in getting some sort of a notion of what we are talking about when we talk about high frequencies and low frequencies and when we talk about these changes in levels of so many decibels up or down. We are going to lead in this morning into a discussion of transmission between rooms and the notion of change of level is an extremely important one in this concept.

I have one scheduled announcement to make and that is on Friday, the 16th of October, which is Friday of next week, not this week, we will have our first quiz. I don't particularly think that you need to have a quiz necessarily; on the other hand, it is a very good way for me to find out whether what I have been pouring into you has sunk in and if it hasn't, then I'll do something about more sinking. So Friday, the 16th of October, we will have our first .quiz. I'm not sure if we are going to have two or three during the term. It just depends. This is a new shortened term and I don't want to waste time giving quizzes if we can get by with two, we'll do that. And then the other thing if we follow that with the dessert on Sunday the 18th and I'll give you some maps and so on. We'll be out at our house. I'll hand out maps next week so you won't lose them in the meantime.

I want to say just one or two words more about the use of sound absorbing material. You think we're going to never get through with this fuzz part in the course but we really will, but sound absorbing treatments are terribly useful, a terribly important part of the vocabulary of the architect who is going to control the acoustics environment. Often we use sound absorbing materials not in great continuous areas as on this ceiling, but in smaller areas in strips or in patches and so on, and it is often good to know what are the rules about using less than full coverage in materials.

Let me start with an illustration. Suppose I have an area like this with 10' X 10' made up of acoustic tile, one foot square acoustic tiles. These are laid out on the floor in the laboratory. We have a big reverberation space, a 10' cube, and we cover the entire floor of this ten foot cube of concrete with acoustic tile, just like these up here on the ceiling. And we go into the room and go "*BOOOOOOOP*" or "*PHSHSHSSSH*" or something else, and we make the measurements and we get a picture of the reverberation time "*OOOOOOOOOP*" sound like this, and then we measure this time for a 60 dB decay, and we find it's around two seconds, that's a nice number to use, 2-seconds. And then we say, well let's see now, the walls of this room have an absorption coefficient output even .02, and then we get some number with the formula "T = .05V/A," and you can figure out what the total A is because we know V, and we have measured T and that remaining absorption must be due to the acoustic tile that we have got on the floor.

We've got 10 ft. walls and our 10 ft. cube, and we've got the floor all covered with acoustic tile. We put it on the floor because gravity can hold it there; it's a lot easier than putting it on the ceiling. And we then compute the alpha α for the acoustic tile is equal to let's say .75 at some particular frequency. Is that clear to all of you how we would go about doing this? We calculate the total absorption in the room having measured the reverberation time and we should call it, in T-seconds, knowing the volume of the room to be a thousand cubic feet with calculated total absorption, we can attribute five hundred square feet at .02 to the five enclosing surfaces and that gives us a number which is ten, and the remaining must be due to the acoustic tile and then we calculate how much we had from the acoustic tile, let's see that's .75 X 100 equals 75 units so our total must have been 85 what .we got here and then we can figure out what the reverberation time is if we wanted to go through the arithmetic—1,000 square feet here and the reverberation time would be just a little over a second.

All right, I'll take this α =.75. Now what I want to do is to lift out alternate rows of this material, lift them out of the room, so that I end up with strips. I leave them in place, I don't move them. I just take out alternate ones, leaving strips of one foot acoustic tiles separated by one foot of concrete. Now, what am I going to measure in terms of total absorption? The first thing I have is alpha α = .75, therefore, 100 sq. ft~ X .75 = 75 units or Sabins of absorption. Now taking up an alternate row and I am going to find that I have about 60 units of absorption in the room if I redo my reverberation measurements. You say, well, how can that be? I would have 50 sq. ft. now. I have taken out half of them. 50 sq. ft. X what gives *601* Let's have 1.2~ I've done nothing to the acoustic tile; it's exactly the same material that gave me .75 a while ago, but I've arranged it in a fashion so that it can work much more efficiently than it did before for the same material.

I have what is called <u>diffraction</u>. If you remember whenever we have slots, little pin holes, in things we get light diffraction through these and the around them, and exactly the same way where wave lengths are large compared with the size of these materials, we get <u>diffraction</u>; we get a sort of tributary area, an attraction of the sound into this material greater than its actual proposed area would predict. Now while I get greater efficiency out of the material, the total number of units is still less than I would have had had I covered the whole area. The point is not by increasing the efficiency per unit that you necessarily are going to have a greater total effect. We cannot get a greater total effect than that of covering the entire surface and making it entirely absorptive.

On the other hand, there are many times when it isn't convenient to cover the whole surface. For example, the question comes, if I'm going to get maximum treatment into this room, must I cover the beams? Now most of us would be pretty horrified as architects to wrapping acoustic tile around a beam. It doesn't bother us to do it on absorptive slab, but somehow the beam ought to be expressed, and they've just got to have bare beams like that, and then it doesn't make any difference because at the edge of that material there is a kind of a tributary area that says the beam is hardly there as far as the total absorption given by this ceiling. And if I were calculating the "area" of this ceiling, I would just calculate the total dimension of the room and forget about the beams because they just won't count. They won't show at all and the tributary effect, the edge effect, the bending effect of sound into this material will make it behave just as if the whole ceiling were covered.

Now, lots of times we want to do something. I described to you the other day the supermarket ceiling that Chris Janner did down in New Canaan, Connecticut where he put in blocks, one foot squares of Tectum, on top of the form and then poured the concrete over it and he ended up with a mosaic of a sound absorbing material in the concrete with the concrete showing in-between. And he probably covered half the ceiling surface with this mosaic or sound absorbing material. And that's almost as good as covering the whole surface, not quite, but much, much better than just covering half of it as you would predict.

I told you the other day about hanging up the sound absorbing units out in the dome here at 77 Mass. Avenue [main entrance to M.I.T.],about 20 years ago, 21 years ago, I guess. Time goes by. And these sound absorbing units separated one from another, behaved in a much more efficient fashion than just a solid field of material will do. Sound absorbing baffles or Owens-Corning Fiberglass, a number of other manufacturers make 2' X 4' sound absorbing baffles, which are covered with plastic material to make them impervious to dirt.

Just a word on covering things with plastic materials or if we have a sound absorbing blanket or board and you know that the most important thing about such a board or such a material is the air can get into it. What if we cover it with a thin sheet of plastic? [There is one more chair up here in the front corner if you don't mind roosting.] What happens when we cover a sound absorbing board with a thin sheet of plastic that keeps out dirt and so on? Well, if it's very, very thin, extremely thin, and doesn't come rigidly in contact with the board and doesn't adhere to it with glue, then the plastic has got to move back and forth under the agitation of the sound wave and transfer energy into the fuzz (and we will lose [some of] it here very shortly when we begin to talk about transmission loss).

I was out at Ohio State about 15 years ago giving some lectures, and one of the professors said “would you come with me” and we went to look at treatment that we are trying in one of the drafting rooms. The drafting rooms were hideously reverberant and they wanted to do something about it. Now this drafting room—listen to this, this is a grown-up intelligent professor of architecture, therefore, presumably intelligent person. This room is about 75' long and 30' wide and is very reverberant. Now they had got from Owing-Corning some of these sound absorbing baffles at 4' wide, 2' high and 2" thick wrapped with Saran or Mylar, I don't remember which. And they had hung up about here about three of these wretched baffles in two rows.

This is the total amount of stuff that they had put into this room and he said “it doesn't seem to work.” It doesn't seem to work. Now this is like trying out a swimming pool, dumping in a glass of water and then you dive in and then you crack your stupid skull open. Sure it's not going to work. You think it should do. Well, they are supposed to be absorbing, aren't they? You know, I guess there's no pumping them. All they do is sit there innocently and not reflect, you know, and this is absurd. And they were about to decide that these things were no good and this Owens-Corning was a bunch of crap. They took to make a perfectly good product and just use it properly. In any kind of sound absorbing treatment the total effect is going to be determined by how much area of fuzzy stuff you have. You can use it more or less efficiently sometimes by having using in strips like this or in the three units.

There is one line in particular propaganda to which you will be subjected from time to time of Pittsburg Glass; they make a unit they call *Geoacoustic* Unit. They all got the damnest names—*Geoacoustics Unit*. And it is made of foamed glass and it is very thick. Oh, it's 1-1/2” thick and units are just off size about 13” or 14” inches square instead of 12” and that's all right; there is nothing magic about 12” x 12”. And you are supposed to make patterns of them and set them on the wall in various and sundry fashion and you can just do anything you like with them and the ad would have you believe that these are just going to solve almost any kind of acoustic problem as if by magic and they've got some super absorbing property...They do not have any super absorbing property; they are just like any other acoustic material, and if you use them scattered around in the pattern like this, each unit will give you more for your money than if the unit was in a solid piece. Separation makes the unit behave more efficiently. On the other hand, if I have a rear wall in the hall and I've got a terrible echo coming from it, the best thing I could do is plaster it over the whole business just to get better efficiency out of it. Are there any questions about this? Have any of you been exposed to any of these materials or seen the ad?

This course is, as I told you at the onset, designed to make you resistant to this company's marvelous propaganda. In particular [for example], about the transmission loss of wall, 42.3 dB wall vs. the 42.4 dB wall. I even demonstrated to you the other day changes of a tenth of a decibel because you certainly couldn't have heard it, and you were very able to hear one decibel change, and 3 dB changes (as you remember, a 2:1 change in power just gave change us a nice perceptible change). And it took a 10 dB change to really to begin to whack in to the loudness of the sound. So don't get carried away with these little numbers, these little diddly things and from something that has the name *Casco Sound Shield 85* or *Geoacoustical Plunkus, Plunkus 97*.

They give big fat numbers to their designation. It helps to sell the product but all these things are nothing more than fuzz. Remember that, they are all fuzz. They have fuzzy insides or porous insides, and at best they are going to be about 75 or 80 percent efficient, and how you use them then will determine what kind of results you get. What you put over them and what you face them with and so forth.

Now, having talked a lot about sound absorbing materials and their usefulness, I want to go to the matter of the transmission of sound between them. Because this is the other mechanism for the control of sound. I mentioned to you the other day the case down at Connecticut General where we had a large office area with some very noisy business machines out in the middle of it and the only solution was to put up some walls. We couldn't do it any more with sound absorbing treatment, and we illustrated that about a fifteen decibel reduction due to sound absorption is about all you can get in a room going from the extreme of all concrete to the extreme of all fuzzy lining. If we need to have greater reduction than this, we are going to have to go to partitions. What does a partition do? How does it behave? And can you predict in advance what's going to happen between two rooms?

Let's just examine this case very simply. It's a very straight forward argument. Let me draw two rooms here. Room #1 and Room #2. Let's just be arbitrary about our designation. And you say this is section or plan, I don't care, say it the way you like. I say it's the section if you like the plan. In room #1 we are going to make some noise, any kind of noise you'd like, we can have our demonstration gadget we had in here the other day or we can use any kind of source of noise, people talking, radio playing, machines running, anything you want. Run radiation noise in here. Now suppose I have a source of sound in this room with the power of P_1. How can I predict what the average intensity is going to be in this room? What have I got to know? I've got to know A, the amount of absorption in this room. But in Room #1 I have A_1 and I have P_1, I_1 in room #1. The intensity of sound added to this Room #2 will be given by the Power in room #1 divided by the Absorption in room #1. And, of course, if I'm dealing in English units; I could put it in 930. But let's not worry about this dimension. I ~ P. This is true inside any space.

All right. Now, this is something, “*BLUUUBLUUUBLUUUP*” or “*BUBUBUBUBUB*.” I am putting out just so many watts and establishing I_1. Just keep doing it. “*BLUBLUBLUBLUBLUB*” and we are going to go into the next Room #2, and we are going to hear something over here. What is I_2? Well, what's been determined? Obviously, one determinant is what is I_1? You know perfectly well if the person in the next room is talking too loudly or playing his radio too loudly and you go beat on the wall, he'll turn it down or stop talking so loudly to accommodate you or do something to ameliorate you. He doesn't want a big fight and he is reducing I_1, and, therefore, I_2 goes right down with him. (cough, excuse me}. It will be determined partly by how big this wall is.

Let's say this wall has an area S. S = area wall. It will be determined by the transmission coefficient of the wall. How much sound energy goes through the wall? And we are going to follow the transmission reduction in this wall, how? It's a fraction. (You remember absorption coefficient, with alpha α, the fraction energy absorbed. Well, the fraction of incident energy transmission is also a fraction, a coefficient.) In other words, all I'm saying is that when the sound wave which is in this room establishing an average I_1 throughout the space, when that sound wave which is a to-and-fro motion of the molecule encounters the partition, let's say this piece of paper is the partition of area S. These molecules pushing back and forth in the air carrying energy from the source to the room and to the wall are going to move the wall back and forth a little bit. That motion of the wall gives rise to a new sound wave on the other side which is the transmitted energy and the traction of the incident energy that goes through by moving the wall back and forth is what we call transmission coefficient, tau, or τ.

How much energy is transmitted through the wall? Now I'm going to make the assumption that the wall is airtight. It isn't full of little leaks and holes and cracks, and the whole wall being air tight, it reacts as a mass, reacts with resistance to the motion of these molecules or the forces of the molecules pushing on the wall and thus it will move not very much as it gets heavier and heavier. Now, I think it is perfectly obvious to all of us that a heavy wall is a much better sound isolator than a lightweight wall. Eight inches of brick makes a pretty good wall between two apartments, whereas a quarter inch plywood on two by four studs makes a lousy wall between apartments. Why? Because 1/4" plywood isn’t very heavy! It moved easily under the impact of the molecules back and forth, and the brick wall just sits there and says, “0h, I know all about Isaac Newton and I'm not going to move because I know I don't have to, I have lots of mass.” So it doesn't. It stands there; very heavy. In the Time Saver Standard reprint that I gave you (and probably you don't have it today) on page 69 is a graph showing what we call the Theoretical Mass Law for estimating transmission loss through a single panel based on the basis of its surface weight alone. We can predict to some extent the behavior of a given substance, a given wall material, on the basis of this weight. As the weight increases, the transmission loss or the transmission coefficient will decrease. The material becomes more efficient, transmitting less and less, and this is a predictable factor. It's a function of wave spaces and homogeneous walls.

Now, I'm not talking about double skins or anything tricky; I'm just talking about a solid chunk of stuff. The heavier it is, the better it's going to be as a sound isolator. If you have to choose in the building between lightweight concrete block or dense concrete block, choose the dense if sound transmission is your problem. This is for a homogeneous partition separating two spaces. Now this is not a wall outdoors to shield from traffic noise, this is not a partial height partition in an open plan office or an open plan school; this is a complete partition that really forms the boundary between these two rooms. The heavier it is, the better it’s going to be.

At the moment in this analysis we are only going to say that this has a transmission coefficient of tau, τ. I think it's rather important to get a notion of the order of magnitude for useful partitions. What is it? Now we've been talking about absorption coefficients of α= .75, or α= .8 and I've been telling you that's pretty good. That's about as good as we are going to get. There is no such thing as a 100% absorbing material except an open window, which the sound goes through and doesn't come back. Now, what about partitions? You listened the other day, didn't you? We had that very loud noise and I turned it down 10 dB, 20 dB, 30 dB, 40 dB, and by the time I got it down to 40 dB it was getting down to a fairly decent level. A 40 dB transmission loss or 40 dB reduction represents what in reduction energy? It's 10^4 isn't it? If I go down 10 dB I've gone l/10; if I go down 20 I've gone down 1/100; 30, 1/1000, 40, 1/10,000.

The point is that a forty decibel partition, which is just barely beginning to be good enough to use to separate two occupied spaces, transmits only one ten thousandths part of the energy, that is, incident energy going through to the other side. The order of magnitude of the transmission is much, much less than that of absorption. We're lucky if we can absorb 80% of the energy. On the other hand, when we were talking about isolating two spaces, we don't want to transmit even as much as a ten thousandth's part to the next space, and a ten-thousandth represents a hundredth of one per cent. So it would be blocking 99.99 per cent of the energy from going through, and we let .01% go through. And it is just a totally different over magnitude.

This will become clearer as we work with it here. Don't worry about it at the moment. Now, let's go back and examine just the conceptual "How much power in watts (and remember this is energy, "watts") am I moving to your ear drum?" Pertinently, I am moving your ear drums. I am generating sound power in this room and it's flowing out and it's wiggling all your ear drums and you hear me. This thing is sending out power, it's flowing out, it's establishing a certain intensity and some of this power will be incident on this wall. What is the incident power on the wall? Thus, the intensity is what we must multiply in order to get watts. Therefore, the incident energy or power (and I'm not trying to distinguish here between energy and power it's all the same thing; it's watts) is equal to I x S. It is equal to the intensity of the sound (i.e., how many watts per square centimeter are there on that wall times the number of square centimeters). That's their argument. If this some number of watts here all of those watts will not find their way to this wall because some of them are going to be taking their time pushing on this wall and this wall and this wall and this one and that one and only 1/5 of the energy will get onto this wall. But we can't calculate it quite that way. We have to take into account the fact that some of the energy is being dissipated in this room by the absorption A_1. Now let's forget about Power. I_1 exists in this room and a certain part of that is pushing on this wall, and the part that is pushing on this wall—that amount of total energy—is I_1 S.

Now I've said in my definition a certain fraction of that will be transmitted to the other rooms based on how heavy the wall is. So what will be transmitted? The transmitted power will be I_1 S. This is the amount of incident energy; that's my definition. This is the fraction that's transmitted. It may 10^{-4}, 10^{-2}, it might be a ½, or it might be a millionth—I don't care; it's less than one. It's a fraction. The transmitted power will be I_1 S times tau, τ.

Now that equals P_2 doesn't it? This is a new source of power, really as far as the guy in here with his ears listening is concerned; he doesn't care where that came from, whether it came through the wall or whether it is generated by a loud speaker in the room or how it's generated. It's now the source of power in the receiving room. Yes, it's higher if we change, say, if we had a carpet in here and that thing up here running (boom, boom, boom) and we take the carpet out, I_1 goes up. Therefore, if I_1 goes up the amount of energy incident on the surface goes up, the amount of transmission goes up, and I_2 will go up. There's a great lot of blanket hanging down in the interest of improving privacy between rooms under various situations and it doesn't do anything. It may give you a sense of improvement but unfortunately, it's the short end of illusion.

Now the intensity in I_2 will be its Power over A_2 isn't it. All right again, the average intensity in a room is a power of sound energy, P, flowing into the room from any source, whether it be through the wall or from something in the room pulsating or whatever, divided by the absorption, A, in the room. The total effect (and I hope this has gotten through to you and especially if you worked on the problem set I asked you to do), you will have had to deal with the idea of the average intensity being determined by Power and the Absorption in the room. Now if I_2 is P_2 over A_2 then it's quite obvious that I_2 is equal to I_1 x S over A_2. And there you have the relationship that holds for all situations of sound transmission between rooms. Note, that the units are now equal and correct and we don't have to throw in any 930 because we have S here in square feet or square centimeters, A it can be square feet or square centimeters, and a transmission coefficient does not have any units, they are fractions. I_1, and I_2 are both watts per square centimeter, therefore, this S and A should be in the same units.

Notice now what determines how much sound goes through: The intensity of sound in the sending room, in Room #1, the transmission coefficient of the wall, the area S of the wall; and the amount of absorption in the receiving room. Now you say what happens if I hang a blanket or a rug on the wall? Nothing happens to the wall because the transmission of the wall is determined by mass, and unless you have a lead rug that you hang up has a lot of mass, nothing is going to happen. Theoretically it doesn't make a bit of difference whether I put that rug here on the dividing wall or over here or over there. Usually, it's on the floor because again gravity is holding it there, that's an easy place to put rugs. And today, that is the area of the wall; now just let me show you, I'm not even going to show you numbers or anything but let's just think about it. Suppose I had two rooms, a pair of rooms like this, or I have the same pair of rooms end to end. I_1 in this is Room #1, and this is Room #2.

And suppose this area this is this and we call it 3S just for the moment. Say this wall has three times the area of this wall and they are the same material in all cases. The rooms are exactly the same; we'll just switch them around. I_1 will be the same in both cases. I'm just making all these assumptions. And it has exactly the same amount of absorption in the sending room (Room #1) and in the receiving room (Room #2), exactly the same kind of wall between, but in one case we expose three times the area of wall and in the other case we have a little itty-bitty end wall. There will be less sound transmission in this case then there is in this case, because three times as much energy flows through the three-times area wall. Three times as much energy, and S goes up here by three fold. Well, you can say a three-fold change in energy isn't very much. We listen to two-fold change the other day and that didn't amount to much, and three-fold isn't going to make too much difference. No, but pretty soon up here we will stack a few things that will begin to make a difference.

The point is that you cannot safely say that because I have a 4" brick wall here, in-both cases, I could predict how much sound is going to be in the adjoining room knowing only that it is 4" brick. I have got to know how <u>much</u> of it is there, how big it is? If it's twice as big, then twice as much energy will flow through it because all the energy is pushing on the whole surface of the wall. Now this little calculation here is probably one of the most useful formulas that we'll have in this course, next to the reverberation formula, one of those useful formulas where you keep in mind when designing partitions to separate spaces. We must consider how much there is and what is the absorptive finish on both sides. Now are there any questions at this point that need clarification?

Perhaps you might anticipate some points that I'm going to make. Are you satisfied about your carpet on the wall? You're not. You don't believe it? Now you tell me physically, how could this carpet do anything?

Student: (inaudible)
All right. And I'll have to admit that you're right. Now let me back off a little bit. The point is this, if you are hearing through the walls, too much sound, or your neighbor talks too loudly. Like Harvard, for example, in the Graduate Center Dormitories that-were built about 20 years ago. They put in a very poor partition. The partition was so poor that all of the students complained all of the time about the sound transmission between rooms. Now, all of the students aren't going to complain all of the time unless there is something wrong. I mean, you've just got to admit there must be something to it. Because these guys aren't all that sensitive and fussy; 15% of the population when it comes to worrying about anything like noise or light or things. Literally, there are just some people that are insensitive.

At Harvard the question came "What shall we do to the partitions?" Now the point is they were so deficient that the additional absorption by hanging a carpet just on the wall helped with of a couple of decibels or maybe a decibel, but it was nothing like the right order of magnitude. The problem is that if it's impossibly bad, it needs a lot more than you can get by the addition of absorption, I will admit, however, and I will agree with you; and the perspective to remember is that putting the fuzz on this wall is a little bit more effective than putting it on this wall because it indeed reduces a little bit of the amount of energy that gets to the wall and gets transmitted through. But at Harvard what we had to do (and I will describe this in greater detail very shortly) is we had to add a whole outer layer of plaster on resilient clips. On one side of each of these walls. It took a massive addition of separate structure.

Student: (inaudible)
Well, now I want to talk about that. I'll answer your question; however, if you have a stud wall, an ordinary stud wall, with plaster on both sides, putting a blanket in here does almost nothing. Because the energy transmission is going through the studs on 16" centers. They are always on 16" centers universally. Now, if you really want to improve that wall, what you want to do is pour in some sand. I had this experience one time, and let me caution you about pouring in sand in the wall. I had a friend in college, a classmate who built an office building in McAllen, Texas. McAllen. Texas is near Brownsville and it's right on the border of the Rio Grande River. And he had wood studs and not even plaster on them. He had ¼" plywood. Oh, this is elegant. And this was a one story office building, these were all walnut veneer and his own office was furnished with the latest in Knoll furniture and he had one rubber plant and everything was set exactly right. It was right out of an advertisement. His brother was in the next office and his brother listened to various stock market returns. They were investors, these guys, and he got fed up with the way his radio was so loud all the time and he could hear it through here. The rest of the people in the building were doctors and lawyers and oil prospectors. Now the oil prospectors are the guys that really have to have privacy. Now if you hear what's wrong with Mrs. Jones or something, that would just make good yack for the neighborhood. But if you hear where so and so is going to drill and then you rush out and drill ahead of him why that's real bad business.

So these guys were complaining and they said we are going to move out. The whole business. So he hollered and I went down to the [office building], and the basic problem was his partitions were no good. I said "You just got the building, and you really ought to start over again. You have people in here, you have carpets and you can't start bringing in people with plaster, wet plaster with carpets down and furniture and tenants paying money. It just doesn't work." So what to do? I said, well, there is only one answer that I can think of and there's lots of sand around here and I think what you ought to do is fill these partitions with sand.

Now, I said, for God's sake, though, secure the spaces before you do it. Plywood is attached to wood structure, you know, normally, with finishing nails that are counter-sunk, you can bash them in about 1/16" or 1/8" of an inch into your quarter inch plywood and then you put the filler on the outside and you've just got barely a little toe-hold of 1/8" of a finishing nail and doesn't have much of a head on it you know and that's all that's holding on this plywood.

Well, this fellow went away to Santa Fe for the summer because he couldn't stand it either. While he was gone he had his contractor and so on get with this filling of the wall. Now they hung ceilings and they had some kind of a high beam division above here and anyhow they could get up here and drill some holes in the high beams and go down through here and pour in the sand. Well, if the contractor had not been present at the conversation of about security for spaces, and needless to say they tried it in the owner's office first and they got it about this far and then one of these spaces went 'crunch' just like that. Sand, remember has hydrostatic forces just like any other gluey material, and the wall came off and then sand got out all over his carpet. He started banging his file case and everything and they finally got it all back together and put in straws and little plugs on the sand. And he wrote me after this and he said it's very successful. He said you are now known in McAllen as "the sandman." He said "Every time I open my file drawer, I think of you."

I'll never get over it; adding mass, I'm taking it from a very lightweight wall and making it into something very heavy.

Student: *"Could you blow in insulation?"*
Again I'm going to have to answer you as I did our friend about the carpet, it does make a little bit of difference, but if you've got a real problem, you will see that will be the first question. Could we blow in insulation? And the local Johns Manville guy had already suggested that. That would be a cinch. Blow in some insulation. The answer is NO; it would help a little bit but it wouldn't begin to solve the problem.

Student: *"Why not?"*
Well, also in the case of a lightweight skin like this, the skin moves and the air moves and then the other skin moves and then the studs move and the whole thing moves as a unit, a very lightweight unit, and then the spaces give a little bit of additional motion where they are not pressed together.

Student: *(inaudible)*
Well, if we didn't nail them, yes, but and again I have to say it would help a little bit and it would be a little better than rigid the contact. Just a second. For example, you know these steel studs that you use to make a plaster wall, the wire studs with a little can knuckle sticking out like this. You get a better behavior out of

this kind of wall with dry wall or rock glass and plaster where you kind of just hang it on there with some wires every so after. Then you can if you put on metal and some plaster and squeeze the plaster through the metal to get to the brown coat to hold.

You've got all this plaster in here really crunched up. And that's a poorer wall than one that sloppily put together with rock lath or dry wall just kind of slapped onto the surface and wired to it because it's a little bit looser. Now you say what if you wrap these things with fuzz. The realistic problem I see is that in order to get a true wall (and walls have to be pretty true), you'd have to nail it up very hard and it would be almost as rigid, maybe not quite. But that would be no solution to this problem where he's got much too weaknesses to start with.

Student: *"How about staggered studs?"*
We are all getting at questions I haven't even begun to talk about yet. That is what happens when we take a single homogeneous wall and divide it into two pieces? That's what you're doing, you are dividing it into two independently moving pieces. And that, of course, is a much more efficient way to build a wall than just beefing it up by pouring in sand or making it two feet of concrete instead of one foot of concrete. Either of which is much too heavy or too thin. We can't do that so we have other techniques. We will come back to that.

First, I want to get over the notion of just the basic idea of a very heavy construction that separates two spaces and move with it and add to the finish.

Student: *(inaudible)*
If they really move with the wall, yes they'll help. But I've never used heavy bolts to secure for a really bad situation. The problem is that the orders of magnitude that I keep coming back to. The only time I get called in to look at a situation is when it's really bad, it's not just barely a minor little headache that comes once in a while. This is a real migraine job that six aspirins won't cure and maybe morphine will help. The real sick, sick, sick, sick cases are the ones that I have to look at. And the fun is that a cure for one of these really sick cases is a massive thing. It's taking this 1/4" plywood and pouring 4 inches of sand in the middle and that changes the weight from 1/4" plywood (what weight is that? 1/2 lb. per square foot, let's say 5 lbs. per sq. ft.) and change it to the 4 inches of sand which will weigh 50 lbs. per square foot.

The order of magnitude we are doing 100 times as heavy as it was. Now this for what was called for you see. This wouldn't work in a multistory building; we might not be able to have all that weight and we'd have to do to something more sophisticated than that. But this is just the easiest way to do it without disturbing the structure, I believe, although I'm not absolutely sure, I know that he did some more partitions. I think he did the partitions between the two planning offices, but they did screw on the plywood facing and put a little wood on them rather than depending on the nail.

All of this argument to this point has assumed that the wall is homogeneous and is absolutely airtight—that there are no holes, leaks, or cracks through or around the wall, and this is an assumption that is not usually safe to make in a building. And we've got to come to grips with the reality of leaks and cracks and then what can we do to fix these things and how do we go about using materials in a much more sophisticated way in double construction.

This was all I wanted to introduce—this notion that is the fundamental basis to the business of transmission between spaces. Now it might be well to give a couple of other definitions before we start here. When I say a 40 dB, wall, remember I do not mean the wall that goes ‘*BOOOOOOOOOP*,’ but a wall that produces a transmission loss equal to 40 dB, I must say that the transmission loss is equal to 10 times the log of one over tau, τ; and if τ now equals $10^{-4,}$ then 10 x the log of one over 10^{-4} = 40 dB.

We'll begin there on Wednesday.

End of Audio File 07

THE END

Robert Bradford Newman Lectures

7 October 1970

LECTURE 8

Title: "Transmission between Rooms (continued)

Summary: In this lecture, Newman does some example transmission loss problems while also having a go at McGee's "anti-noise traffic carpeting."

Beginning of Audio File 08

You all heard that jet just go over. What do you suppose will be the difference in noise level in this room if the room were carpeted? Now let me read to you from the latest Progressive Architecture. Here is that jet going overhead, our anti-noise traffic ad says . . . that is a new one. McGee:. "They've heard the screams of a jet, the honking of a traffic jam, 105 piece orchestra playing, a room full of kids making a racket, or just a plain chatting session. If noise is your problem in an office building, school, hospital, hotel, motel church, concert hall, theatre or what have you, call or write a McGee anti-noise contract carpet experts. He'll bring you peace and quiet in any size." Baloney. Shear hogwash. Now Brunswick makes some acoustic wall covering that will do all the things, and there used to be this plastic material called *Cure-All,* this ¼" thick foam this would not only control sound in a manner never before possible but it would keep sound out as well if you put it on against the wall. It would insulate/sound transmission.

The carpet boys have been peddling their wares for some time as the absolute cure-all for all of the world's acoustics problems, and this has been perpetrated somewhat by the Educational Facilities Laboratories [EFL], a division of the Ford Foundation who sponsor a lot of work in school planning. And some of their publications would lead to believe that if you carpet a school, you don't have to worry about anything else. All the acoustical problems are solved, partitions aren't necessary; they don't have to go to the floor, you can just do anything, and everything will be great. Well, watch out for this sort of stuff, and for God's sake, don't get taken in by it. Carpet is a great material; it's a marvelous sound absorbing material and it does indeed add sound absorption to a room when it's added to the room. That's all it does. It may or it may not be the answer to problems and it certainly doesn't have any effect on whatever the noise from the jet airplane flying overhead . . . just as we heard now. Well, this is the latest Progressive Architecture with the gorgeous building down in New Haven on the front cover. That's the end of the funny pictures for today.

Terry [Terry is the Teaching Assistant for the class] is handing out to you three sheets of paper and one of you suggested at the last meeting that maybe I should hand out the later problems now. One is a regular problem set; this is No. 3. There will be only one more of these and then we won't have any more return, which I am asking you to turn by in next Monday. Oh yes, we do have classes Monday. I think that October the 12th is not a holiday. Well, then they've changed. It is. Well, then scratch 12 October and make it October 14. I don't care. I was going to come in here Monday and preach. I'm glad you told me. It is a holiday in my office but I thought we were not observing it this year because of the week off earlier…. I see… well, then that's my error. I followed an earlier calendar.

For the homework, you can sample hearing conditions, lecture rooms, a church, a theatre—in any kind of an auditorium (as there are lots of them around here), and I'd like to have you go and listen in this space at least a couple of times. It is very important while you are there listening that you move around. Now this isn't always possible and it may be that you can only attend one performance and that you can't move around. But it's amazing to discover, at the same performance, to move around and find how different hearing conditions are in different parts of a room. How often we make a judgment that the room has great acoustics on the basis of a certain seat and other people may be suffering with poor hearing conditions.

Symphony Hall in Boston is a perfect example. Here in Boston we all genuflect and cross ourselves at the mention of Symphony Hall. It's perfect, like Trinity Church and the Public Library. And there's nothing wrong with them and everything is straight. But in Symphony Hall there are a lot of lousy seats; perfectly dreadful seats, way back under the balcony, and at the sides of the room back under the balcony, [and in] the side balcony, which act as a kind of a wave guide and brings that side of the orchestra in about 5 dB louder than the rest of the orchestra and it's all off balance. And down in the front you can't see most the musicians and you get nothing very useful from the ceiling and you just have a great ‘woom woom woom’ sound. Now if you go to Symphony Hall it usually isn't possible to go skittering around particularly during the performance, and you may have to go back another time and find another seat.

Symphony Hall Boston it is very useful to move around if you can, at intermission, swap seats with someone. Something of the sort. If two of you want to do a project together, that's perfectly all right. Just both of you learn something. That's all I'm asking you to do. Just observe something and learn something from it. I'm not expecting to learn very much from the report but you can learn a great deal. This is what this course is all about, so that one will be due at the end of the term. You can turn them in anytime you want to, but I do have to have them by the end of the term and these are really two of the most important pieces of work. They are more important than quizzes or problems or anything else, because it really is something for you to do and to have fun at and learn something about it.

Now having disposed of McGee's carpet and our assignment, let's go on with our discussion of transmission of sound through walls and other kinds of barriers. Last time, you remember, oh yes, one point, Terry asked me to make sure he has corrected and returned the last problems we have here. A number of you went blindly in, used the formula I=P/A without questioning what kind of unit you had in the formula. Remember: I (intensity) is in watts per square centimeter and this P (power) is in watts, then A (absorption) must be in square centimeters if the units are going to come out right on both sides of the equation. So if you use English units, which we always do in this country, you have to have I = P/ 930 x A (in order to have 930 square centimeters per square foot), and A is in square in feet, and the square feet cancel and you end up with square centimeters. So don't forget the 930. It makes your answer off by about 30 dB if you don't use it.

Formulas are only sort of a way of telling you something, and you should look at them not as things in which you plug numbers and crank out answers automatically, but do a little thinking each time you use one and I don't image doing things very heavily with that, but it is a point. He [Terry] said that no one plugged in decibels here for I. Thank you; this is great. I'm so glad because usually somebody puts their 75 dB, you get 75 and you get megawatts for power! An incredible amount of power and energy flying around when you do that. This is something times N into minus something. Now in the formula that I put on the board concerning the transmission sound from one room to the other, $I_2 = I_1 \times S/A$, I said we do not need the 930. Why don't we need the 930? Because we have watts per square centimeter <u>equals</u> watts per square centimeter, which has no units. Square feet cancel and it’s all okay. Now this will work equally well if we use other units so it's a perfectly nice, straight-forward harmless formula.

I also put down on the board last time--just at the end of the hour—a definition of translation of this into what we call “transmission loss.” Transmission Loss equals 10 x the logarithm of 1/τ (tau). Now we make it

1/τ (one over tau) so that we don't end up with a negative logarithm because, you remember, this (τ) is the fraction of the energy that is transmitted and, therefore, it is a fraction and is less than 1. We want this to come out to be positive numbers.

Student: "What is "A?"
That's sabins. It's in square feet because you multiply area (S) times alpha (α), which is the unit for a coefficient), and $A = \Sigma S\alpha$. I sometimes just call them sound absorbing units. But you can call them anything you like to make of them. I don't really care just so long as you know what they are. Any other questions?

I'll work an example here in a minute, but I want to finish with the definition for the term "transmission loss" which is a property of the partition, not how it's used, not how much of it there is, but a property of the partition itself. Just as when I say concrete, just concrete, weighs 150 lbs. per cubic foot, we don't care whether it's in Africa or in Australia or the U.S.A. or wherever it is: it weighs 150 lbs. per cubic foot. And we can place it badly; we can place it well; we can do a lot of things but it always has that kind of physical property. The transmission loss (TL) of a partition relates to its transmission coefficient (τ) by definition, and that is the property of 8" brick, 4" brick, 4" glass, ½" glass, 2" wood, 1" plaster…, anything you name is the kind of material that has a certain kind of transmission coefficient. Now again this will be a function of frequency (and I pointed that out last time in this chart in the Time-Saver Standards), it is an increasing function, with very little transmission loss at the low frequencies and increasing as we go to the higher and higher frequencies.

And I believe I mentioned that this is a matter, again, of common experience because we all know that when we listen to sound through a partition what we hear is low frequency, you never hear high frequencies.

[Aside to class: There is space here if you want it. I'm sorry about this crowding in the room, I've been trying to get them to get some extra chairs in here, but apparently it is illegal, so I've been informed and also apparently we have no choice but to either have this one or go to one that holds about 180 and I just am not thrilled at the thought of that. So let's see; maybe I can scare some of you out of the course or something. The upcoming quiz we'll make extremely difficult and frighten you away or something, I don't know what to do. If it turns out that we are consistently having people who have to sit on the radiator (it can be quite uncomfortable in cold weather)—why, we may have to move to another room. I'm sorry about this but I don't make the regulations here. I would have to be too much of a troublemaker.]

Let's say that a partition has a transmission coefficient, e.g. $\tau = 10^{-3}$. What will be the transmission loss (TL) of that partition (and the transmission loss is in decibels again)? (And this is the sort of thing I've been talking about when we say we have a 40 dB partition, or 30 dB partition; it doesn't mean it makes noise, it means it reduces it by that much in decibels. Transmission Loss, τ, with this partition will be 10 log 1/τ (which is 1 over 10^{-3}), which is 10 log 10^{+3}, which is 10 x 3, which is 30 dB. Now, that is the transmission loss of that partition, not its sound radiation capacity. Now that is unique to that kind of construction and to that partition, and it may or it may not reduce the noise between two rooms by that much. You'll have to see how this all ties together.

Let's just take an example of two rooms in which we have, say, a 100 square foot partition; we have in this room 200 units of Absorption; we have an intensity in this room, let's say it's 10^{-9} watts per sq. centimeter; and we want to know what is going to be the intensity in this (other) room. And the τ (tau) of the partition, let's say, is 10^{-3}, just as we calculated it. We are told this is a 30 decibel partition then we find out the area of the wall is 100 square feet, 10^{-2} square feet. We have $\tau = 10^{-3}$ and we have 200 sabins in this room. What will be the intensity of sound in this Room #2, I_2?

That's what we want to know. And we have already seen that it's a function of all of these things. It's a function of how much wall there is; how much absorption there is; and what is the transmitting quality of the partition itself. Well, all we've got to do is stick the numbers in, and I_2 is equal to I_1 (which is 10^{-9} watts per centimeter); times tau, τ (which is 10^{-3}); times S (which is 200 units or 10^2). These cancel out and we have $I_2 = .5 \times 10^{-12}$, or 5×10^{-13}. That's OK: Watts per square centimeter.

Now you say: well what's that? That's not a very useful form is it, because we are used to thinking in terms of decibels when we talk about the levels of sound in a room. We can then just calculate IL_2 because we know what IL_l is, don't we? IL_l is equal to 70 dB, 10^{-9} watts per square centimeter. Yeah, that's right. And then I started thinking about 10^{-13}. Okay, so the intensity level in there is 70 dB. What's the intensity level in the other room? That's what you want to know. It is equal to 10 x log 5 x10^{-13} divided by 10^{-16} and that would be 10^3, this will be 3 and the log of 5, which is .7 isn't it? Yes, .7, = 37 dB.

In algebraic format: What will be the intensity of sound I_2 in this Room #2?

In Room #1: Intensity = $I_1 = 10^{-9}$ watts/sq cm
In Room #2: Intensity = $I^2 = P_2/A$ =

Where:

$P_2 = (I_1 \times \tau \times S)$
$I_1 = 10^{-9}$ watts/sq cm
$\tau = 10^{-3}$
S = 100 square feet = 1×10^2
A = 200 sabins = 2×10^2

$I_2 = P_2/A_2 = (I_1 \times \tau \times S) / A_2$;
$I_2 = (10^{-9} \times 10^{--3} \times 10^{2)} / 2 \times 10^{2 =}$
$I_2 = 10^{-10} / 2 \times 10^2 = .5 \times 10^{-12} = 5 \times 10^{-13}$

$IL = 10 \log (5 \times 10^{-13} / 10^{-16}) = 10 \log (5 \times 10^{+3}) = 10 \log 5 + 10 \log 10^{-3}$
$IL = 10 \log 5 + 10 \log 10^{+3} = 10 (3.7) = 37$ dB

Now the transmission loss of the partition is equal to 30 dB isn't it? We just got through going through that exercise over there. We have 70 dB, we have 30 dB transmission loss. If the noise reduction that we realize between these two rooms were exactly equal to the transmission loss we would get 40 dB in the receiving room but we only have 37 dB. And it's because of the absorption in this room being 200 sabins. And that adds another 3 dB to the actual reduction in sound that we get between the rooms.

Student: *(inaudible)*

Yes, it is. That's exactly what it is. It has a transmission coefficient of 1/10 of 1% ... In other words, 1/10 of 1% of it the goes through by moving the wall.

Student: *(inaudible)*
Yes, what I'm saying is that the average intensity or intensity level in Room #1 has already been determined by the amount of absorption. You don't put that into the formula unless you start with P_1. You start with the Power and then you've got to go I = P/930A to find what the intensity is. But the intensity once established—it already has the absorption in it. Now if I increase the amount of absorption, A, in the first room, I will reduce the Intensity of that the source of level. And that's another safe assumption. Because the deader we make the space, then the average intensity level goes down, and we try to talk louder, play the radio louder and do other things that then increases the power. So we may not experience any loss at all by increasing the absorption in the source room.

Student: *"Does it matter where you put the absorption?"*
To the first order? No. It does not make any difference where you put it. Now if you completely cover the wall with a very efficient sound absorbing material, it will indeed improve the transmission loss a little, but to the first order—and just thinking about transmission of sound between rooms—we think about the total absorption in the room and we don't worry where it's going to come—the floor or the ceiling or wall. And you can certainly check this out for yourself if you want to. If you have poor partition between you and some other room and you want to hang a blanket up on it or something just to check out to see whether or not it does anything for you. I think you'll find that it does not.

Student: *(inaudible)*
The only aspect is: does sound go more easily down than up? The impact noise on the floor is what comes down to you. That's a totally different game now. We are not playing "the impact game." We're playing "the airborne sound game." And then it does make a different noise.

Student: *(inaudible)*
No. All I'm saying is that you can hang up the blanket in either room. Let's say you hang up the blanket here (Room #2). I'm saying that it makes an improvement because it adds together with the absorption that's already in the room. You have to more than double the absorption that's already present for you to really notice it—that's only 3 dB change. But it doesn't really matter whether you hang it here or here, or put it here, or there, it's just in the room.

Student: *(inaudible)*
It would be exactly the same effect if you hung it in this room, assuming everything stays constant in the source room. If we were going to reduce this level, assuming the rooms are the same size, it will do exactly the same thing. Because it either reduces the source intensity or it reduces the receiving intensity.

Student: *(inaudible)*
No; very slightly but not significantly. Not enough to solve any problems.

Student: *(inaudible)*
That's a very slightly smaller number, yes. But the point is that if it makes maybe 1, 2, maybe as much as 3 decibels difference, and it just isn't enough. The point I made on Monday was that the order of magnitude

of transmission coefficient 1/10 of 1%, as compared to 20%, will we get through the blanket. It's just so different that it doesn't matter.

Student: (inaudible)
It is a very important part of the question. And this is why if you take heed what kind of a partition I need between these two rooms, I've got to ask you what are you going to have in those rooms? What kind of background level have you got to mask whatever does come through? What kind of usage are these rooms going to have? Is this a psychiatrist's office? Is nothing going to be in the next room or is this just an ordinary old engineering office where it doesn't really matter whether you hear or not? There are all kinds of extra conditions that can go on.

Let me just do one further extension of this to show you how the noise reduction works. And first let me comment on a piece of mechanics, because you will have to do this from time to time. If you are given the transmission loss of a partition in decibels, how do you find τ (tau)? And you can do it with no trouble at all: you would just do it the way you convert Intensity Level to Intensity. If transmission loss #1 equals 35 dB, that equals 10 log 1/τ; Just keep 1/τ as a number, don't flip it over; don't do anything with it, just keep it as x…or something else if you'd like. Is that all right?

The "number," 1/τ, whose logarithm is 3.5 is something times 10^{+3} plus the number whose logarithm is .5, which is 3.16, if I look it up here on the log scale... I looked up the number .5 in the log scale, and now the number "x" came out to be 3.16 times 10^3, which is equal to 1/τ.

(Now this just happens to be a nasty number because 3.16 is a square root of 10, so it's its own reciprocal. It's 3.16 one over 316 is 3.16 times 10^{-4}. Be sure you keep that number right.)

What this says is that the 35 partition is a better partition and has a lower transmission coefficient than the 30 dB partition (not quite as good as that 40 dB partition). The 40 dB partition would have 10^{-4} for τ, tau, and this three times 10^{-4}, so let's say it would transmit about three times as much acoustical energy as a 40 dB partition would.

In algebraic format: 10 log 1/τ = 35; what is τ?

10 log 1/τ = 35, then log 1/τ = 3.5

let x = (1/τ) = x, so log x = 3.5
that is: x = that number whose log is 3, and that number whose log is .5
the number whose log is 3 = 10^{+3};
the number whose log is .5 = 3.16 (from log table or slide rule)
therefore x = 3.16 x 10^{+3} (and log x = 3.5)

If x = 1/τ, then τ = 1/x
if x = 3.16 x 10^{+3}, then to get 1/x, take the reciprocal of x:

then 1/x = 1 / 3.16 x 10^{+3} = .316 x 10^{-3} = 3.16 x 10^{-4}

> and $(1/x) = τ = .316 \times 10^{-3} = 3.16 \times 10^{-4}$
>
> (note: the reciprocal of .316 = 3.16; 3.16 = square root of 10)

For comparison, 3.16×10^{-4} is <u>less than</u> 10^{-3}, so the value of TL = 35 is <u>less than</u> TL=f 40, which means that TL of 35 blocks or reduces less sound than TL = 40. [Higher values of TL let less sound through the wall and are better at blocking sound.]

Student: (inaudible
1/τ is $3.16 \times 10^{+3}$. Now 1 / 3.16 = .316 times; and $1/ 10^{-3}$, then that's 3.16×10^{-4}. I'm sorry I just skipped that part, yes.

Student: (inaudible)
The extra loss in that example was due to the fact that I had 200 sabins of absorption in the room. If I had only 100 sabins, let's just change it, if I had 100 sabins, this will be one times 10^2, and this would be simply 10^{-13} per square centimeter which would be 46 dB. And I simply doubled the amount of absorption in the Room #2 and lowered the average level by three decibels and as far as that room is concerned, we don't care where the absorption of sound is. It came through the wall but it's a new power in the room. That's the point.

Now the other point is that doubling the amount of absorption in a room is not easy. If you want to double the amount of absorption in this room right now we would have one hell of a time. Because we've got the whole floor covered with a very efficient fuzz and the whole ceiling covered with a very efficient fuzz, and we would have to add an area of fuzz equal to the top of the floor and the ceiling in this room of very efficient stuff, and I don't believe we could do it even [with fuzz] on all the walls:

Student: inaudible)
No, but you all are efficient. All of you, I'm looking at you as an area of fuzz and the fact is that anything that gets down through all you fuzzy people and comes back up again is very little. You have an absorption coefficient of about $α = .85$. And doesn't really matter because all of you down there are fuzzy on your sides, and your absorption just comes back so you're just a great big blanket here, equal to approximately four and half square feet of an open window each. I like to think of the open window. So just to kind of keep the mechanics separate and follow it through in the very order it happens, like that, and you won't have any difficulty at all.

Now let me develop one further notion here and we will see how this comes out explicitly. The Noise Reduction [NR], the noise reduction in these rooms is equal to the intensity level, IL, in the first room [Room #1] minus the intensity level in the second room [Room #2]. In our example here, where we had the 200 sabins we've got 37 dB in this room and got 70 dB in this room. The reduction between those two rooms, in that example, was 70 dB - 37 dB= 43 dB… Now this is a new number of decibels. This is the actual noise reduction [NR], not the transmission loss [TL]. It's not any level at all; it's the noise reduction between the two rooms and, in reality, this is what we care about, isn't it. This is the only thing we care about. What is it going to be, I don't give a damn whether the wall is made out of pie crust or concrete or what it is, I want to know how much I'm going to hear over in that room. That's all I care about.

Student: "Don't you mean 33 dB (70 dB – 37 dB)"
Yes, thank you. I'm not renowned for my arithmetic. My wife says all the mistakes that are made in the check book addition are mine. Whenever the bank says that we're wrong, it is I who is wrong, not the bank.

33 dB is the actual amount by which a noise is reduced in going to the next room. Now I'd like to formulate this a little more carefully so that we can use the decibel numbers rather than having to go back through all the τ's (tau's) and the I's and so on in to doing very simple calculation. Let me operate on this formula. Now this is just algebraic manipulation.

A person can divide both sides of the equation by 10^{-16}. Alright? Now let us take 10 times the values on both sides of the equation. That is a legitimate operation. I want to manipulate it into the form obviously, of 10 (I_o -I_1) over 10^{-16} plus 10 log t. I choose not to break this so I can recognize it as Transmission Loss plus (+) 10 log I_o-S/A_2.

I'm breaking this out. Now we'll multiply everything through by this; of course, this is IL_2 and this is IL_l. And this is all, I guess. Now I think I want to multiply everything through by minus 1. OK, let's do that first. Minus and we'll make this +1/τ and we'll make this A_2/S. And then we have -IL_2 - IL_l + TL; this is now the Transmission Loss +10 log A_2/S. This is going to work. Now I take IL_l over to this side of the equation and I'll end up with:

$$NR = IL_1 - IL_2 = TL + 10 \log A_2/S$$

In algebraic form:

$I_2 = I_1 \tau S/A_2$; now divide both sides by I_1, so :

$I_2 / I_1 = \tau S/A_2$; invert both sides of the equation, so:

$I_1 / I_2 = (1/\tau) \times (A_2/S)$; now take 10 log both sides of equation, so:

$10 \log (I_1 / I_2) = 10 \log (1/\tau) + 10 \log (A_2/S)$

Divided both I_1 and I_2 by 10_{-16} so

$10 \log I_1/10_{-16} – 10 \log I_2/10_{-16} = 10 \log (1/\tau) + 10 \log (A_2/S$

Note:
$10 \log I_1/10^{-16}$ = IL1, and $10 \log I_2/10^{-16} = IL_2$. and
NR -= $IL_1 – IL_2$, and
$10 \log (1/\tau)$ = TL, so

$NR = IL_1 – IL_2 = TL + 10 \log (A_2/S)$

That's just fiddling with the equation. The reduction is equal to transmission loss plus something. And the "plus something" factor is the ratio of the amount of absorption in the receiving room (A_2) to the area of the wall (S). Let's go back here and look at this example now. The Noise Reduction is 33 dB and 30 dB that was the partition value…and we said the partition had plus 10 times the logarithm A_2 (which is 200) divided by S (which is 100). About 10 log 2 is 3 dB, isn't it? You know that by now. So that the noise reduction is 33 dB and you can get it by taking the Transmission Loss and adding to it to the value of 10 log A_2 / S.

Now if the area of the wall and the amount of absorption in a receiving room happen to be the same amount; then that term disappears, doesn't it. Then it becomes 10 log of 1, which is 10 X 0, which is 0 and we have a Noise Reduction equal to the Transmission Loss. Now in real life, in real life—and that's all we are really concerned about here—A_2 and S happen to be very near to equal most of the time or within one or two decibels. And for a rough thinking about the performance of a given situation we simply say, well, if the level in this room is 70 dB and that's a 40 dB TL wall, we are going to have about 30 dB in the other room. We just don't fret too much about the fact that it might be one or two dB one way or the other. But if you are going to do a real calculation, if you are really interested in being a little bit more precise, then we go through this operation.

Student: *(inaudible)*
The fact is that in some cases the transmission loss can be greater than the noise reduction. Suppose we had only 50 units in the receiving room and we come out with l0 log 50/100, or 10 log of one half (10 log .5); that will give us -3 dB instead of +3 dB. And I said that the Noise Reduction would be only 27 decibels rather than 30. Now you say, well, how can that be? It can be because we're building up the intensity level of sound in the receiving room because it's so hard and reverberant, and we are actually increasing the intensity level on the average in the room. Because what causes it is the energy that goes through the wall into the room, and then the room operates on that by its own absorptive characteristic, as in any other situation, and establishes an average intensity level that is determined by the amount of absorption. So that we can have Noise Reduction less than the Transmission Loss if the receiving room is very hard and reverberant. But the noise reduction, you understand, is an intensity level, and that is what we are finally interested in for the real life situation.

So NR = TL +10 log A_2/S. Having to produce such a formula and having demonstrated that it works, I'd turn right around and say: don't use this except in a very special case of a single type of dividing element between the two rooms. In other words, if I have a door or a window or leaks and cracks or anything other than a beautiful perfect wall, then this won't work. We'll have to demonstrate now on why it won't. This is for single elements dividing two spaces: only one transmission loss, only one kind of material forming the divider. This is a very common situation. It's not at all unusual to find that, but there are cases where this doesn't work and then we'll have to go to a more slightly more complicated way of handling it.

OK. Anybody have any questions so far? Yes.

Student: *(inaudible)*
The latter. No, it doesn't really change the transmission, that's right. Yes, it's not a major sort of thing and again, as I've tried to say over and over again, the order of magnitude of reduction that we need to reduce sound to satisfactory condition, TL will be 10^{-4} or 10^{-5} or something like that. All these little dippings around with changing the absorption in the room a little bit is not going to solve the major problem.

I'll describe to you in some detail (maybe we'll get to it today or maybe we won't): the problems at the Graduate Center at Harvard and what we had to do to correct it, but the problem is severe enough so that the University was willing to spend a couple of hundred thousand dollars in remodeling a number of buildings and it could not be done simply by adding some more carpets or anything like that to the room. The room already had acoustic tile ceiling as a matter of fact. It didn't solve it and Mr. McGee I'm sure was the anti-noise carpet consultant to talk to them and probably could have sold them a good many hundred yards of McGee's carpet and in the end they would have found themselves right back smack in the same place where they were before, with absolutely no cure. Whether the McGee carpet should be put on the wall or on the floor it or on the windows or wherever else might be. Back to the same thing.

Let's look very briefly at the more complicated situation of a door or a window or a leak or a crack or something of that sort. Let's say we have a Room #1 and a Room #2. And here is another element -- a door or a window or something. Room #1 and Room #2, I_1 and I_2 with A_2. Now we have a complication because we can't seem to say that we have a full uniform wall surface. We've got to have S_l and S_2. For wall area S_1 we have τ_1, and for wall area S_2, —this is door or piece of paper or Japanese screen or whatever it may be—there will be a value of τ_2. OK.

Now then we use exactly the same argument that we did before, that the incident energy in this Room #2 is the Power that's hitting the piece of wall S_l will be I_1S_l, and a fraction power is going to be transmitted into this other room, isn't it? Coming through here into Room #2 will be I_1 (S_1 τ_1) plus I_2 (S_2 τ_2). What than is the total energy power that's being transmitted into Room #2 from Room #1 through this composite transmission barrier? [It will be] he area of each element (S) times its transmission coefficient (τ) multiplied by the surface area; this will give us how many watts per square centimeter flows through the wall. Now the total intensity in Room #2 is I_2 is equal to the sum of as many elements as we have contributing, dividing it by A_2 (absorption in Room #2).

If we rewrite this simply as I_2 equals Σ (τ_n x S_n)/ A_2., then $\Sigma\tau_n$ x S_n simply means add up all the contributors to the transmission picture.

Now let me immediately do an example. Suppose I should deal directly with transmission coefficients. Suppose this is a 40 dB wall and, therefore, $\tau_1 = 10^{-4}$; it could be a brick wall. Suppose this is a 20 dB door, and therefore, what would be its transmission coefficient be? 10^{-2}, so $\tau_2 = 10^{-2}$.

Let's say the door has an area of 20 square feet and let's say the wall has an area of 200 square feet. Let us say an A_2 is equal to 300. Let's say that IL is equal to 10^{-9} watts per square centimeter. Now all I've got to do is turn my numbers into the formula and turn the crank. I_2 will be equal to I_1, 10^{-9} times the sum of all of the τ_nS_n combinations: τ_1 S_1, τ_2 S_2, τ_3 S_3,. … And what kind of tau numbers we have is one transmission coefficient of 1? A τ = 1 could be any kind of an opening or a joint between two prefabricated elements that are rotting. We will have a very unique transmission coefficient that is called "unity" or 1 because there is no end to the difficulty of such an opening. In fact, it's the most difficult problem to have solved and we'll see how that works in a minute. But somehow Σ (τ_n x S_n) includes τ_1S_1 (10^{-4} x 10^{-2}) right on to τ_1S_1 (10^{+1} x 10^{+2}).

I'm going to go very specific (cough) divided by three times 10^{-2}. It's just algebra from here on: 10^{-9} x 2 x 10^2,10^{-4} will be 2 x 10^{-2}….

Will you check me on this? Plus 2×10^{-1}. Divided by $3 \times 10^{+2}$. Notice right off the bat what we learned. Just that it is very important to write this down like this. Through the wall…a fraction of the energy, 2×10^{-2} , is sent through the door which is 10x as much energy as goes through the area of the wall. The door is only 1/10 of the area, 20 square feet compared to 200 square feet of the wall. But its transmission coefficient is 100 times as great as that of the wall, therefore, the energy flows through will be 10 times as great. Yes.

Student: "Does it matter if the door is further away from say the center of the room?"
No. It doesn't matter at all. We're assuming an average condition over the whole thing. Well, I won't try to finish this, but this is $2.2 \times 10^{-1} / 3 \times 10^{2} \times 10^{-9}$ times 10^{-1} divided by $3 \times 10^{+2}$…(?) . You can finish that yourself, but the point is that very quickly you will begin to see that it's the weak element in the construction that will determine a performance and not merely so much the stronger element. And this would be 50 feet brick, you know, real thick and the door would <u>still</u> control because even this is adding only 2/10 to this whole number here.

Fine. I'll see you all on Friday.

End of Audio File 08

THE END

Robert Bradford Newman Lectures

9 October 1970

LECTURE 9

Title: “Newman’s Black Box”

Summary: In this lecture, Newman uses his famous ‘black box’ example to demonstrate modes of sound transmission through walls.

Start of Audio File 09

(Info on quiz and meeting place at Newman Residence…. We’ll meet the 18th at our place. I’ll get maps to Lincoln. Terry will organize rides.)

Today I'm going to show you my “black box” to make believers out of you. It affects a number of matters that I have been trying to show you about the modes of sound transmission and isolation. Let me just comment on a matter that a number of you have been raising: In teaching a course like this in order to cover everything that we want to cover in the field of acoustics, we necessarily have to over-generalize and I often make black and white statements about things that ought to be sort of gray rather than either black or white.

Now we have been talking about the business of the application of sound absorbing materials to walls and the effect that this has on the transmission of sound through the wall. If one examines this very carefully, that is to say that you have Room #1 and Room #2, you have the wall in here, and you have a source of sound in this room. I said that to the first order of approximation, it really doesn’t make any difference whether we put the fuzzy stuff here or here or there.

Now, let me be a little bit more exact about this and say, first of all, that at very high frequencies, 3,000, 4,000, 5,000 cycles per second, there can be partial increases in the sound isolating value at the boundary <u>if</u> you put the fuzz on the wall that is doing the dividing rather than elsewhere in the room. In other words, not only does that fuzz act to decrease the amount of energy in the sending room available for sending on through, but it also decreases a little bit the transmission loss of the wall itself because there is such a high energy absorption at these very high frequencies.

Now if you looked in the Time-Saver Standards at the curve to which I refer—to Figure 19—, we see that almost <u>any</u> partition has an increasing Transmission Loss at high frequencies. The partition already has a very high Transmission Loss compared to what it has at low frequency. So the fact that adding fuzz to the wall makes it even higher, it’s usually of academic interest because its already so high that we don't care whether it’s higher or lower by a few decibels. It’s the thing that keeps us from hearing whispers through the walls: “*SPSPSPS*” doesn't ever come through and “*BOBOBOBOO*” does.

The effect of the fuzz then might be (I'll just illustrate) to increase the transmission loss in some such fashion as this, but it’s already so high here that we really don’t care about it. Now where it is important is in the skin for airplanes for example. We are dealing with aluminum as our basic massive element, which isn't really very massive and that’s so the damn thing can fly. Then we can begin to use these very efficient sound absorbing blankets in the heat insulation structural sheet metal between the outer skin of the aluminum and then we can put in fuzz in here, and then we have our cloth inside which may be vinyl or something of the sort, and we add up every little decibel we can get a hold of, and if we can get an extra 10 dB or so at the high frequency we welcome it because we're down so low to start with that boosting it by 10 will be very, very important. And it’s in these specialized applications of aircraft, particularly aircraft and that's one of the few places where we really have a weight problem, or some of the lightweight trains, high speed lightweight trains on this and we use sound absorbing material as an element to serve both the heat insulating and the sound absorbing functions to improve the transmission loss characteristics.

If we can do it in [inaudible] try and forget it. It's like if you’re flying in an airplane at 1,000 feet and you suddenly drop 500 that could be pretty horrible, whereas if you’re at 10,000 feet, 500 feet doesn't bother you very much. It might upset you but it isn't so perilous. It's just a matter of relative importance. The mastic type “*DUM DUM*” or whatever you want to call it, is the damping of the metal so that it will not have a sharp resonance transmission loss efficiency and to bring it up to mass law behavior. You really cannot improve over the basic mass behavior and I'm going to talk about stiffness effects here, in the course of things.

I want to just get some real basics stuff first, but all of this business—the theoretical mass law assumes no stiffness whatever, and you know that that's not true of real structures. The only thing that you can think of that really doesn't have any stiffness at all is rubber sheet with loaded vinyl, the sort of thing that they drop over you when you are being X-rayed, you know when you don't want to get x-rays everywhere, and they plop this heavy rubber thing over you. Those are heavy because they are filled with loaded vinyl and you try to use that for partitions and you set it up, and it doesn't have any stiffness at all, you have to hang it up now as a curtain, that is just nothing but mass. It gives no stiffness but the minute we get into structures that will make decent partitions, like brick, concrete blocks or gypsum board, studs, or anything else, then we’re faced with stiffness which begins to introduce resonance and we have to damp it out.

Now, damping on a car is entirely a matter of getting rid of these things. Sound absorbing materials are used sometimes under the hood and that is a local absorber. I = P/A. It reduced the level of sound just a little bit that is available to send on into the body of the car.

Now I just wanted to verify that point because strictly speaking, the fuzz does have influence in ordinary building problems. It’s just not an important one and you should not make a judgment on where you put the treatment in a room on the basis of improving the transmission loss characteristics of a partition by putting it on the partition. It's OK if you want to, but don't expect it to do anything very miraculous.

Now I also wrote down at the end of the hour, last time, and I think we did one little example of a door and wall and we saw that even though the door was a considerably smaller area, it was transmitting ten times as much energy as the rest of the wall. Now let’s just look at even more elementary situation, and one that we have all the time.

What about leaks, and cracks and holes? Now we all sort of agree that the transmission loss for a hole is 1. It’s not 1/10 or 1/100 or 1/1,000 or 1/100,000 as we have for most decent partitions, but it’s 1. Open air has unity transmission coefficient (τ), and of consequence, the transmission loss of a hole is equal to zero decibels. Now I have a very simple example that I carry around in my head and you can carry it around in your head because it’s so easy to illustrate the disastrous consequences of any kind of a leak or crack; this is one of our biggest problems in modern building construction.

If I take a piece of wall that is ten feet squared (you notice I always use ten foot cubes or ten foot squares rather because this is so easy to multiply even for the simple minded). That's 100 square feet. This is a piece of partition in the abstract, surrounded by infinitely attenuated structures. Now let us say this has a transmission loss of 40 decibels. If it has a transmission loss of 40 decibels, what is its transmission coefficient? We know right away that tau, $\tau = 10^{-4}$ because we can look right there and see the number. This is the nice thing about the decibel system. So tau, $\tau = 10^{-4}$. Now I want to look at sigma total S, ΣS. We won't look at this; we just want to look at this number here because this tells us who is the culprit, where all the big energy is flying, where the big energy is coming through. We can catch it right here in this addition because, you remember, we had 20 parts through the door and two parts through the wall the other day in that example. Ten times as much energy going through the door as through the wall, having already taken into account both its efficiency and sound isolation and its area. So here we have—let's write down sigma total S.

First, we have 100 square feet X 10^{-4} for the wall; that would be10^{-2} won't it? That's τ_1 or τ_{wall} or some such thing.

Now let's put a hole in here. Now the hole has a transmission coefficient of 1, and I want to get the same product 10^{-2}, I want to have equal contribution from the wall as from the hole, just for this little example. What area must the hole have in order to give me a product of 10^{-2}? Well it's obviously 10^{-2} square feet. You say, well its 100th of a square foot and 144th of a square foot would be a square inch, so it's just a little bigger by 1.5 square feet.

Now this very crude approximation here says that if I have a wall (and this might be 4" brick) and you'd have a 40 decibel transmission loss in middle frequency. But if I put a hole in the middle of that wall, of just over one square inch, I let as much energy flow through that hole as I do through the rest of the wall. And very quickly as I increase the size of that hole it really doesn't matter what the wall is made of. The wall could be 8 inch spread or one inch spread or ... if I have a one square foot hole in it, it doesn't matter because the hole has a unity transmission coefficient.

There are all kinds of 'ifs' and 'buts' here. I said I had a 4" wall and put a 1" hole through a 4" wall, I've got a flood of air there that's going to resist some motion and it isn't going to count at all -- it will be high frequency cut off, it will transmit the lows better than the high. All of these things are frequency dependent, but for the moment I want to stay away from those computations. We're just getting a basic idea and then we will come to the frequency and then computation.

What would happen if you had a pipe penetration? I've got a wall here and I have a steam pipe go through the wall. Now is it tight fitting or is it loose? That's very important because if it's tightly fitted, and dumped it in here real well, stays tight, then the steam pipe will pick up very little energy to relate it to the next room. The problem always is that it isn't tight. The problem is that we surround the steam pipe with Tau = 1, we put a sleeve in here to make it convenient for the steamfitter to get his pipe in and the sleeve is always bigger than the pipe; a 2" sleeve for a 1" pipe or something like that. And he may stuff a little gunk in there.

Baker House is just full of these sleeves up and down particularly, and I've encouraged students over the years to stuff them with old socks, tee shirts or anything you can stuff in there. Now the tightness of the stuffing is very important because you want this to be an air tight stuffing and not to leak. We will see in a minute how sound absorbing materials do leak out energy. But the world is full of these little leaks.

In fact now, a shrinkage crack, for example, if you have a building that's concrete slabs we put up a masonry block wall here, particularly concrete block or something of this sort, almost inevitably after you put it in place—no matter how carefully you seal this joint with mortar—it will shrink a little bit as the thing cures and dries out. It will shrink a little bit, and you end up with a crack that will always happen at the top 99 times out of 100 and you have maybe a 1/8” of a crack here at the top, it’s open. You say an eighth of an inch isn't very much…no, but you add it up and multiply it by the length of the wall and you very quickly have got a leak that's equal to the wall in its transmitting quality.

At Harvard just a few weeks ago in the new Baker House one of our chaps went up to observe the construction and this was done because we had consulted on the job and this wasn't the case of a hole or leak but this is what they had. Here's the outside wall and then they put on the Styrofoam for heating insulation. Now Styrofoam is an absolutely worthless material from any acoustic point of view. It is not heavy enough to be a good barrier; it isn't soft enough to be a resilient isolator; it has no interconnecting air cells so it is not sound absorbing--it’s a real nothing material but it’s a good heat insulator. It's got some value.

The original designs called for the Styrofoam insulation to be interrupted at the point where the partitions came. The partitions come out to the outer wall here on some kind of steel studs II don't remember just what the detail was) and then the plaster wall for the room itself—the finish wall over the Styrofoam—OK that's the design construction. Now on the job, and this is always what happens—what they call site conditions and that’s the excuse for any kind of botch that is made by the builder, by the architect, or by the job captain or whoever is in charge. The site condition came up and a decision was made because the contractor said, gee architect, if you'd let me put the Styrofoam on the wall right on down the line here and run this plaster right through and then we'll come up with these partitions. You go into these rooms and turn on the noise source in one room and go into the other room and listen. The first thing you always do is not make measurements but go in there with your two bare ears and it’s also very handy to have a professional device along with you called a stethoscope…it looks very professional to come into a job with a stethoscope sticking out of your pocket. My father was a doctor so I learned how it’s done—just the right dangling angle, so you look extreme professional and it isn't a total fraud because it’s very useful. It makes an extension ear; that's what doctors use it for—just to extend the ears. It doesn’t really amplify it gives you a long tube on your ear.

Well, you stand in this room here and just listen to the sound coming from the next room and all that appears to be coming from this corner and you could get your stethoscope out and go over to the corner and run along the wall and all of a sudden—now we have a built-in situation with a very light weight stiff member on the outer wall that is giving us through this path and through this path—a τ tau = 10^{-2} more like 10^{-5}, a real serious leak, and we get a noise value whatever from the massiveness of the masonry on the interior skin.

I will illustrate several such examples as being extremely important, that if one alters a detail that has been carefully thought out, what are the consequences of the change? There may be changes that can be made and be alright.

We have a box, a plywood box with a noise generator in it and it makes the same kind of noise that that stupid thing did the other day. It’s heavy and bulky and cumbersome to carry around and you bang your legs when you’re going to airports to visit someone, it’s a nuisance. We are going to try to develop a solid case, now I want to show you, right at this point, this demonstration because we can illustrate here and let you hear the kinds of things that leaks and cracks do cause. Would you let me close the door back there please? I am going to make some noise and I'd just as soon not disturb the neighbors.

Any of you who have ever heard me as a visiting lecturer at a school anywhere in the world have seen this box. I always take it with me, it's my standard bag of tricks. I once had to pay duty on this in Denmark, I paid 75 cents. The only thing that the Danish customs didn't think that I should be bringing it in, and. I explained that it was scientific equipment, and now they thought to set some duty, so I paid 75 cents! Otherwise Id have just blustered through with it.

Now let's see… it's working! Now this gadget is a warning horn we put up in a factory to tell what time it is, if it's time for lunch or something of this sort. You couldn't miss that very well. It makes this noise by clacking a steel plate against a magnetic pole…it's a vibrator so it's got vibratory energy coming out of it as well as simple radiation of sound out front. Now I'm going to illustrate a number of points here because it pertains not only to the stuff we are talking about now but structure-borne isolation from machinery, from loudspeakers, from doorbells, from people walking around and almost any kind of activity that impacts the structure because it is the structure that vibrates directly rather than by the motion of the air molecules in the air, what we call airborne sound.

I want you to listen to the difference in the sound if I put it down on the table as compared to up in the air......"*THANGGG*". Now, the first thing we always do in a sound isolation situation for a piece of mechanical equipment or anything that's vibrating is to get it up off the floor. Get it up off the floor. Now if you do that and have some guys standing holding it, I'm a reasonably up off the floor construction. I mean I'm not all that rigid, and you can notice that when I'm holding it, just nice and quiet, and I put it down here on this table and we suddenly have coupled this to a great sounding board, and you must think of structural slabs in buildings, think of walls as sounding boards, as things that can actually amplify, or at least make the radiation efficiency much greater for the gadget.

Now what happens here is this. If we look at these—I'll just imagine something, I don't know what it would look like—but let's say "*AAAAA*" looks something like this, the sound belt. And what we did when we put it down on the table and picked up the bottom end here and it went "*BOOOOO*" rather than "*AAAAA,*" we build up the bottom end, and we do very little with the top end of the spectrum. Now I'm going to operate on this in a number of ways here and actually we're going to have it almost inaudible with just for simple things I've got here, without any cheating whatsoever. So I've got a squashy pad getting long-sighted, this is resilient material, this is rubberized hair that's used in horsehair. I do not recommend this as a permanent installation kind of thing, although I must admit this sample is about 12 years old, and it's stood up all this time under the impact of this gadget. But eventually this will settle down and permanently compress. But it's good enough for the present purposes.

This is squashy, this is resilient, this keeps the gadget from getting to the floor "*BANGTGGGGGGG*". Now that's just as good isn't it as up? I mean as far as you can hear. You notice this is connected up with a kind of a floppy piece of wire. One of the things that very often happens when you design a resilient mounting for a machine, is that it has to be connected to the electrical service through sometimes a conduit, and 9 times out of 10 the Code will call for a rigid conduit, all you've got to do to completely louse up a decent spring lining is to hook it up with rigid conduits back into the building again. This just short-circuits all your resilience, and you've got nothing left. Workmen on the job will stash beer bottles under resiliently mounted equipment, they'll sweep rubbish. What the hell, you've only got to sweep the floor up in here and there's an old brickbat, some concrete scraps, some old beer bottles and coke bottles and other stuff, and the guy says what the hell, sweep them under that machine, nobody will ever see them.

And one of the things, a standard piece of equipment on a checkout for a job is a yardstick, so you can reach round underneath and find all the junk that's been shoved under there in the course of construction. Now the architect can do this just as well as the acoustical consultant, and it'll cost the architect considerably less money if he does it, rather than hiring someone from Boston or San Francisco to come and look for a beer bottle under a piece of machinery -- it's ridiculous! The first thing you do when you inspect a job, inspect a piece of machinery that's been mounted, at least what I do, is to put my foot on it, and BANG give it a good shove, and see if it bounces, and hear it go "*BOOM BOOM BOOM*" when it bounces and you know something's under it – perfectly obvious, and if something's under it, it's not resiliently mounted and it's going to short-circuit, and it's going to make a noise in the building. So the first thing we do with anything from a water closet --so you can't hear people peeing in it-- to a machine or anything else: get it up off the floor onto something squashy.

O.K. Now this is a noisy gadget that's on my desk here, and I've got to work at this desk, and I just can't stand this "*BUZZZZZZZZZZZ*" noise. Well somebody says: "Why don't you put some insulation on it?" It's an absolutely universal suggestion, from Singapore to Boston, in Sydney, in Copenhagen and in several other places where I've observed it: you've got to put some insulation on it. Now here I've got a box made out of hair felt, this is ozite rug packing, ordinary old hair felt. This is a beautiful sort of material probably 85% absorptive in middle frequency. It's an inch thick, it has all the joints sewed up nice and tightly, no leaks or cracks in it, but listen to what it does to this noise "*BUZZZZZZ*" -- well that certainly is not a cure. There is an effect, if this be the noise "*AAAAAA*" like this, what happens is that we get the reduction at high frequency, 4,000 cycles per second, was maybe six decibels reduction.

But remember, a six decibel reduction is noticeable but not of consequence in solving this problem. If this noise had barely audible to start with when we put this over, it might have been rendered inaudible merely by this action. It depends upon how high you are when the airplane starts coming down, just how important the effect may be. So this doesn't do anything for what is a largely high frequency effect.

Now, I'm going to put on this box which is made of ½" plywood, if I could carry around a box of ½" steel this would be much more effective demonstration but I am not strong enough so I carry plywood. Around the bottom is a piece of rubber, soft rubber, and around the base here some more rubber. I have rubber here so that I can make a tight contact and air tight contact, or break it, and I want to illustrate to you that even with ½" plywood, which doesn't have much mass and we all know that ½" plywood barrier is not really soundproof. If I could choose strong ¼ inch plywood that I talked about before, you could hear everything through it or practically everything. Even ½ inch plywood is not going to behave up to its potential unless we make it air tight. Now, just let's listen to what this is about "*BUZZZZZZZZZZ*."

I'm compressing this so I just have contact with the rubber; the cord comes through here makes a little hole and it's not really a drop but it's a reasonably tight fit but not more than 1/32" of an inch anywhere. I'm going to press down on the sides of the box so that I don't affect the radiation through the panels and listen to the difference "*BSSSSSSSSS*" Can you hear that change? I'm about an inch of an opening at the top box. Until I get this thing absolutely air tight, even a weak system like half-inch plywood cannot perform up to its potential.

Now, let's put the fuzz inside the box where it can act on the sound in the box to make less energy available to send out. I = P/A, and the sound in this box is going 1000 feet per second just as it is out here in the air, and the sound will have many, many, many, many, many contacts with all this fuzz in the box. We are going to go from the condition of the <u>all hard</u> room to the <u>all soft</u> room, and maybe get as much as 15 decibels additional reduction. Now let's listen to what this does. Remember: this "*BZZZZZZ*" is the order of 10 to 15 decibels of additional reduction.

Now that's putting this fuzz inside the box and protecting it with the box. Now the point is that the fuzz alone does very little, but when we contain it within a massive container, so that the sound has to encounter it many times, it doesn't just get to bat right through. That's why we gain tremendously in the effectiveness of the treatment. Sound absorbing treatment is useful <u>inside</u> a space to reduce the amount of energy available for sending on out to the next space. We've said that a dozen times, but this is what happens.

Now this is almost a cure. If this had to sit here on my desk I think I could stand it, I wouldn't like it, but I think I could stand it. And again, though the leaks and the cracks just when I relax the pressure on the box as the noise comes out and "*ZZZZZZZZZZZ*" -- this makes it almost worth it.

Now, suppose I do everything right: I have the resilient mounting, I have the fuzz inside the box, I have the box air tight, and the box can be a room or anything else, the minute I press down on it, to stop the little bit of leak that is there, "*ZZZZZ*" suppose I forget the resilient mounting, underneath it "*ZZZZZZ*" I take the pad out from underneath it. Now what I've got left is the airborne radiation through the plywood box.

I saw a case, over ten years ago, a new hotel had been built in Philadelphia. The Sheraton hotel in Philadelphia is over some underground railroad tracks on the old line between 30th Street and the old station down Cross Street, and so there is no basement in this hotel, so all the usual basement activities have to be up above grade and one basement activity that occurs in all buildings is transformers, power transformers to reduce the line voltage to the building voltage. In this particular hotel, the engineers decided that the place to put these things was on the third floor, and on the second floor were meeting rooms where people had meetings and rented space. These wonderful things with Modernfold [manufacturer of folding operable partitions] doors between them, you know that you hear everything through, because they are such light weight and are not airtight but you rent them for a meeting ....

Now right above here was the transformer, and the transformer was set up on rubber pads as per the description of the acoustical consultant, which was us. Rubber pads. Now these rubber pads are ribbed rubber pads, they are not solid rubber but they have ribs in them going this way along side and this way along the other side, and they are about ¼" thick and sometimes you make a stack of these sometimes you may have an inch of these, you put a little piece of sheet metal in between and you put another one on and you make a sandwich and this makes a good amount of squish. We don't need to go into steel springs on transformer, we don't need to go into very fancy mounts, but we can do it sometimes just with rubber pads. They have to be properly loaded and loaded to the order of fifty pounds per square inch but they are a very useful sort of thing to do. We hook the transformers out with great loops of wire instead of conduit, we have great loops of wire big fat cables looped around so the vibration "*NNNNNNNN*" noise wouldn't go through.

Now we had a complaint; again, there must have been a problem because people said that we don't like that "*NNNNNN*" on all the time during our meetings so we won't rent your room anymore Mr. Sheraton unless you can get rid of "*NNNNNNNN*." Well, one way to get rid of the "*NNNNNN*" is to shut off the power and then you don't have any lights. (laughter)

What was the trouble? Well we went down to Philadelphia to see, and we discovered that everything had been done exactly properly only that when a job condition came up, a site condition, in which a switch gear had been mounted in the cabinet and placed between the two transformers (a switchgear is the switches and the fuses and the circuit breakers and so on that go with the transformer and have to be nearby). Since the switchgear is all passive plastic stuff, I mean the switches are not going "*CLEE KONK CLEE KLONK*" they are just going "*KLONK*" once and then you leave them alone and if the circuit breaker goes you get a "*CLANG*" and that's that. So if they don't make any noise they are just fastened in here like this in a cabinet, a metal cabinet between folded down from here to here. Now what the hell do you suppose happened?

Now one of the engineers involved on this project, this was a mechanical engineer, said "I know how to solve the problem, we'll put 4" of fiberglass on the ceiling in the room. Four inches will have to absorb all of the energy of the "*AAAAAA*." Now what would that do to solve the problem? Nothing. Just nothing. So the answer is to cut the case loose, get it up off the floor, they did and it worked, you don't hear the transformer anymore. Time and again we find this thing.

In the MIT Chapel, for the first fifteen years of its life, in the balcony of the room and all over the room, you could hear "*MMMMMMM*" from the transformer downstairs that was bolted rigidly into the structure of the building. Now I kept agitating and agitating to have this damn thing just raised up, put on some rubber mounts like this, and the connections changed from rigid buss bars to flexible loop of cables. Well, this meant shutting off the power for, I don't know, half the dormitories or something in addition and never was it convenient to do this. This was going to be an all day operation so we just suffered with it.

The organist said it was very difficult to play the organ up there with this "*MMMMMMMMM*" going all the time in addition to whatever he or she was trying to play. Now with a steady pitch like that it would drive you right up a wall. Finally, they have just disabled that transformer and brought in the power for the Chapel from the basement of Bexley Hall just across the street here. Now there is a transformer there that has enough spare power to feed the Chapel. So the thing has been solved by cutting it off and so we don't have the humming any more in the Chapel. That's one way of doing it by just cutting it off. The first thing you ask is: well, couldn't you just shut it off? That's the easy way of doing it, don't bother me to come down and look at your problem, just turn it off. We can, so we just have to solve the problem.

You may well have to have restraining construction here on this angle, with another piece of rubber pad here to keep it from sliding sideways. Now let me just describe here a very simple thing that I did in my own house, and you're welcome to look at it (I can't let you pull it out) when you come out on Sunday. We have a dishwasher in the kitchen, now this is a very common piece of domestic equipment, and if any of you have had any experience with dishwashers in general they are rather noisy and they are not excruciating they don't cause any permanent hearing loss and you can't make any claims under the Walsh-Healy Act for Damaged Ear Hearing but at least the dishwasher with which we have had experience in the kitchen, you have a noise level which makes conversation difficult and if the dishwasher is fastened down rigidly to the building, it's impossible to run the dishwasher in the kitchen if the kitchen adjoins the dining area while you're having dinner or entertaining because it makes so much noise that you can't talk.

We had a dishwasher in our other house in Lexington which was fastened rigidly to plywood cabinet work that immediately adjoined the dining area which was open to the kitchen, so we had airborne noise and structure borne noises. Exactly what kind of conditions I have shown you here, very, very, noisy and unpleasant. Well I modified the dishwasher there and I modified the dishwasher in the new house before it was put in so that it would not make this kind of noise, and I have measurements of the before and after. Not in the new house. I have some before measurements in a number of untreated dishwashers. That's very simple to do and it only takes about a half a day of your time and if any of you have dishwashers or contemplate having dishwashers someday, take note again of what we did.

Now the first thing: this is a Kitchen-Aid dishwasher, a very common variety. And the first problem was the cabinet where it is going to be situated. There is an opening with other things happening on both sides, and we very carefully measure this opening: precisely 24-1/2”. The machine is precisely 24”. All dishwashers go in 24" wide openings and it’s like getting the carpenter not to put the studs on 16" centers for some kooky reason. He can't do it, it’s his religion and cabinet-makers all have a religious belief that 24" is the right number of inches for dishwashers; OK.

We said 24-½.. Now I'm drawing what I meant, anyhow ½” wider. So the cabinet worker arrives on the job with a 24" opening, of course; thank you; (laughter) 24-½” specified. 24" they always put it 24” because they always make mistakes. OK this machine sounds without any cabinet work around it, it’s just bare on the back and face on the front.

The first thing I did was open up the package; I take it out and it has underneath it the four leveling bolts—those flat headed screws like this that are used for legs. A nut here and you can turn it in and out.

The first thing you do is take those out and throw them as far as you can into the trash. (laughter)
Then throw away the other clamps that are provided; throw them away (laughter).

Now it’s a plain machine and first you have to turn it over on the floor and glue on with good contact adhesive two layers of red rubber where the leveling bolts were, under each corner here so that there is a ½” of red rubber under each corner here. Two layers of ¼” red rubber... naturally.

You have to be very careful when doing this to use a small enough amount of material. It is much more important to use too little as to use too much. Any resilient material whether it be cork or red rubber or string or whatever it is must be loaded so that it squashes. If it is not heavily loaded enough, it is not going to squash and if it’s not going to act as a resilient mounting.

Red rubber, depending on what you use, has to be loaded as I said a minute ago about 40 to 50 lbs per square inch. Now the machine weighs about 150 pounds more or less and with four 1” pads under the corners we have it loaded at about 40 lb.

I'm talking maybe one, two, or three layers. If you need it, you’d better do something else because that will collapse when it’s not loaded. It just sits and there is so much of it; the worst thing in the world you can do, for example, is lay down a cork pad under a machine unless the machine is the heaviest damn compressor you have ever seen it isn't going to work, it’s going to be stiff and it will not give you resilient isolation. You can take out 90% of the cork and just have a few little pads then it will act like a spring. Let me just finish this very quickly: the pads go under here, the entire tub of the machine is coated with automobile body undercoating for the reasons that we mentioned before, so that it doesn't "*BONG*" and so that when the water splashes around, again it is nice and quiet and just goes "*SUDS, SUDS*" instead of "*BONG BONG*".

Now put all this black Sears Roebuck gunk, all over these nice new stainless steel innards of the machine. Put fiberglass blanket there and put all around in here just tuck it onto the drum….2" blanket, rubber pads at the top and bottom, and front and back to keep it from moving sideways. These are ¼" rubber pads so that they fit into exactly this 24-½" space and a set of rubber pads in the back and top to prevent the machine from falling out when you open it (and that was what the clamps were for that I threw away). And I put the rubber pads…. just to keep it from falling forward and not for anything else. I hooked it up with a rubber pressure hose instead of copper pipe, and that's about it; and just stuff it all into the space. Don't screw it in; it just sits there. And the spectrum of noise in this machine untreated and treated is here, and this change is in the order of 10 decibels, and it makes a tremendous difference in the level of sound in the kitchen and furthermore in the dining room which adjoins it. You don't hear a thing at all because it's not structure-borne transmission.

Well this is just one of many examples; see you all on Wednesday. …(Audio runs at higher speed.)

End of Audio file 09

THE END.

Robert Bradford Newman Lectures

14 October 1970

LECTURE 10

Title: "Noise Reduction"

Summary: In this lecture, Newman talks about how to make a perceivable reduction in noise and the benefits of fiberglass duct board.

Beginning of Audio File 10

(chatter about transportation to Newman Residence…)
What is noise reduction? Noise reduction is the difference in intensity levels in the two rooms in question isn't it? Think about what it is in English--not in formulas. This is not designed to test your ability to grab the formula but to do a little thinking and I think it may even be a teaching device. I hope that a quiz is a teaching device otherwise there is not much point in giving it. No need for it. Also, I will announce at this time that on Friday of next week which is the 23rd of October I have to be at another lecture down in Pennsylvania and I cannot get back. I have to give a lecture there at 1in the afternoon on Friday and I cannot get there and be here at 11. So we'll not meet in class. There will be no class on Friday October 23. I could send somebody out to fill in every time I do this, but it ends up that I have to do it over again not because other people can't teach but it just doesn't work in the continuity thing. As far as I know that's the only class I'm going to have to miss this term. Let's get on with acoustics.

Last time I showed you the black box demonstration. I don't know anybody who's had this course and seen that black box and still doesn't remember it because I see people who saw it twenty years ago in this class and I'll see them in Singapore and Stockholm or some place and they'll ask me if I'm still using the black box. Well of course. It's like Newton's laws in motion effect and all the invention of plastics, wonder drugs and so on, are not going to change these basic physical facts. The black box is a very good teacher and if you don't remember much else out of this course that we heard I hope you will always remember the sort of change we got when we put that felt box over the box and got almost no perceptible reduction. The order of 6-7 decibels at the high frequencies. Really that amount just doesn't amount to a hill of beans if that is you're going to cure that problem. Also the effect of the leaks and the cracks, the little opening up of the slightest little leak around that box, remember how the noise came right up. The final clincher was the removal of the resilient mounting material underneath the buzzer which gave us almost as much noise as without the enclosure when the whole sounding board here, the floor, this desk top was radiating the sound energy. Those principles are basic to any kind of mounting of mechanical equipment to handling of any noise problem.

I recently had a very interesting experience in my own house. I mounted all of the exhaust fans for the bathrooms on steel springs and there are some rafters here and we have some springs here, hangers and then we come down here to a little platform and here sits the fan and the fan has a motor on it and the exhaust side of the fan goes outside through a canvas sleeve to a duct that then goes on out through the roof and the intake side which comes out that end but I'll draw it over here comes into a canvas sleeve and then into a duct which is lined with fuzzy stuff which then it goes down into the bathroom. Now we talk about the use of fuzz in ducts a little later but this absorbs the noise from the fan so that in the bathroom itself through a grille here in the ceiling so that we don't hear any noise. I think this is a very pleasant as you to have extraction fans work turn them on and out goes the air and "*ZMZMZMZMZMZM*." The usual sort of racket. One problem is that you leave them on. I've discovered them on some two weeks after some guest had left one time in the guest room that we hadn't used and I thought about all that lovely heated air that we paid for that was being blown to the outside at 200 ecm and so on.

Well, this is connected to the source of box here with a piece of flexible material. Now in most respects when I have anything to do with it, I like to write that "conduits connecting all the electrical equipment shall be floppy." Now that's not a very elegant word for a specification. "It shall be flexible" is how you should put it in a specification. Flexible doesn't mean floppy. Floppy means that if you take it and shake it, it flops.

Now in this particular case the fan was connected through a piece of flexible conduit, some call Greenfield, you know that is armored cable that is called BX, it's a flexible metal conduit. Well I was annoyed by the humming sound I got there in this bathroom; it was a guest bathroom, but nevertheless, as an acoustics man, I like to see these problems solved properly. So every time you turn on the switch you hear "*HUMMM*," very faint, but "*HUMMMM*." So I went upstairs and I took off the canvas sleeve on both sides here that the contractor had put on he'd put on some rather heavy rubber padding, and I got some much lighter weight, but rather heavy muslin—just cotton cloth and I made a new sleeve. This took all Saturday morning - making new sleeves here. I checked the mount, and the way to check the mount, as I've said before, is to shake it "*CLUNK CLUNK* CLUNK" beautifully, and now we have flexible sleeves, and I went downstairs, and still the same "*HUMMM,"* not a bit better, not one spec better.

What I hadn't realized was that the sound was going down through this piece of flexible conduit. Now this is a very lightweight machine, it's a cage fan just no bigger than that horse motor, little squirrel…just a lightweight machine. And this rather big fat conduit, the size of my finger and my thumb came down here, and makes a considerable loop, and is rather soft, but nevertheless in its longitudinal mode, it's relatively stiff. And by taking it loose right here and letting the wires just run in here without this metal, I got rid of the hum completely. It was all coming down this piece of semi-flexible conduit. So what I did was to take this off and substitute a piece of rubber, a rubber cord and then go into a plug in the top of this box. I put an outlet in here, and now I put it up with just a heavy duty extension cord, with a ground wire in it which is a perfectly legal form of connection, and it has absolutely no hum. It's amazing the ends to which you must go sometimes to preserve the resilience of the mounting system, if it be a vibration isolation problem. It looks very simple in the black box, but you have to follow through with all sorts of detail and care.

Well, if I don't watch, we'll do nothing but talk about little bits and pieces of things, and we'll not talk about anything important matters. The thing that comes through from thinking about the black box demonstration, and it comes through from any consideration of the realities of getting sound isolation in buildings today, is that probably your biggest problem is that of getting airtight seal, airtight seals between the prefabricated elements that make up so much of our contemporary buildings, and between those elements and the building itself. If you have a dry wall, a pre-fab partition system, a removable partition system, all sorts of pre-fab panels and so on, we've got to connect them together, and the connections between these things must be airtight, and they must be designed to stay airtight throughout the life of the building. When the Time Life Building was built in New York, they had inside architects and outside architects ~ and they didn't even agree on the module and they had very neat site conditions, which means custom made panels to fill out the ends where things didn't come out right. The designers of the interior partitioning system, a metal partitioning system, said "We're going to have l/8" gaskets, l/8" soft gaskets to connect between the elements of the partition, between the panels, and at the top and at the bottom.

We were consulted on the job, and we said: “That’s not big enough, it's got to be as big as a finger, a 1/2" gap.” "Oh that's so gross" they said "so gross, imagine a 1/2"gap, yuck, if you do it with a neat clean 1/8" it'll photograph so beautifully for Architectural Forum!” Be quiet - So, anyhow, 1/8" gaskets were used. The owner moved into the building, and then began to bitch because the sound transmission between offices was so much. You could hear everything between offices.

What have we got for partitions? Seals… sure, you’ve got seals, you got 1/8” gaskets. Now the reality is that no pre-fabricated metal partition, no matter how carefully made, when delivered to the site, installed in the building, with imperfect slabs and ceilings -- no building has perfect slabs and ceilings—there are going to be variations in the order of a ¼” at least, and more like a ½”, the columns are not perfectly vertical, or perfectly smooth or perfectly true - nothing is perfect, it's rotten, and we’ve got to be prepared to make out with our factory-made relatively perfect things and the reality of the building itself. So the things were not tight; they were leaking all over the place, and the owner was facing the problem of going round with a caulking gun, and squirting toothpaste in to all these miles and miles and miles of joints throughout the building, in order to get it to work.

Now toothpaste would work for a very short time, if you’re up against it, and have to have something for a 2 hour duration, toothpaste is just great. There are better materials, made with all sorts of more permanent things, but caulking materials in general don’t last forever, and you have to re-do and re-do and re-do.

Some of the good caulks are quite good today and really don't show. But air-tightness has got to be achieved and got to be preserved throughout the life of the building. I mentioned to you the other day the business of shrinkage cracks at the top of masonry block partitions, where a masonry block partition goes up to a slab, and you rake the masonry joint there: here's the slab and here’s the joint, joining. And here you put in your mortar and stuff and you make this join up, and if you're a real slick architect you will rake it back a bit so that it will read as a reveal. You don't want to join this material to that material without a differentiation, and a reveal very, very important, so you rake it way back and you don't put anything in there, because who's going to see it? The architect isn't going to get up there, and until they begin to hear it between the rooms, nobody will know it hasn’t been filled in.

One job we did a while back, the architects decided that we had to have this revealed. We ended up in most cases with 3/4" of space here, and decided that rather than put any more in, we'd just fill it with masking or caulking. Now caulking, the most wonderful caulking in the world, isn't good for filling 3/4" gaps; let's be real, that's too much space, and you get all sorts of trouble with shrinkage, and of course it didn't work, and they had to take out the caulking, put in mortar, and then caulk on top of that. Now when you caulk on top of something solid like mortar that will then take care of the shrinkage cracks that appear above here. Yes, it's a urethane foam usually. Quite often it's a tube, a vinyl-covered tube, with urethane caulking in it. There are all sorts. There are some excellent caulking compounds for this that really do stay, but not 3/4", you’re asking too much when you overstretch the limits of reasonable use of materials.

Another very common source of leakage is all the spaces, and I mentioned this in Baker House, that the pipe sleeve problem, all the spaces around things that go through the wall, the penetrations for steam, for water, the under-window convector covers that you often find near buildings, where the convection goes along the upstairs building, and is covered with a cover of some sort with a top, and then we go right on to the next room, and likely as not they have a hole here, so that it's convenient for the seam-fitters to slip through here, and the sound goes down right through the into the next room. I think they take the cover off to shake hands - it's true, he told me. It doesn't really matter what the wall is made out of because the transmission loss equals one ($\tau = 1$) for that opening, times this area, will overshadow anything that's the rest of the wall.

Back-to-back convenience (a lovely choice of meanings) -- the electrical outlets that are placed back-to-back so that the mechanics can hand the screwdrivers back and forth through the hole, until such time as they put the outlet and the cover plate on, and that's really just his form of poker.

Now it's quite an old development, which was new back in the early 50's. It has a very neat detail for the bathroom. It had beautiful partitions, this is the medicine cabinet in the bathroom, here is a 2' x 4' or 2' x 6'. We have two layers of plaster and we put on stuff on one side and stagger them so that, so that they're all set, so that the two faces are not connected together with a common stud. We get a very much better performance out of the wall than if the two faces are connected together so that they move back and forth under the impact. In this case we have a, I bet some of you have been in apartments like this, it has little spot back here. These are adjoining tenancies, and you converse at an ordinary conversational level between bathrooms "Good morning, John, how are you this morning." Now why does this get through? Now this is a thin metal cabinet, not very heavy, not much mass, it's just pretty dry here against the wall and there's this razor blade slot built in the back. . .usually a few other incidental holes for an absolutely transparent situation.

Now what do you suppose? I guess this opening is framed, a framed opening, with a wood frame all round, and at the last minute when they are through handing wrenches back and forth through the hole, they slap in these little light-weight tin medicine cabinets with a mirror on the face here. What do you suppose they try? They put an inch of fiberglass in here, and what do you suppose that did? Nothing! Not anything! And then they tried some rock wool. Well if the fiberglass doesn't work, maybe the rock wool will work. No fuzz will work, no fuzz will work. And then they called for help, and I went up there, and we got a piece of slate that they had lying around, and we cut the slate to fit this opening, and put it in here and caulked it in place, and then, of course, you couldn't hear anything.

Then he said "What happens to the razor blades?" I don't know--that's their problem. And there isn't very much space left for the razor blades. But they then went around and did all these over with plaster in here, actually a piece of rock glass with plaster each side rather than fiddling with slate. But all it takes is something solid and heavy to get around this dreadful condition. Perfectly good plaster both sides, the wall itself was fine, but this idiocy knocked it all up. There are just oodles of cases of this sort.

Another thing, never count on clothes in a closet to do anything for you. Hancock Village also has this problem. They had a situation with staggered closets. This is the outside wall, and this is Bedroom No. 1 and Bedroom No. 2, this is the closet with clothes in it and stuff, and this is a 2" solid plaster partition, 2" solid plaster. It's a dry floor with plaster on both faces, and it's about as good as 2" plaster; it's no good for a common wall between apartments. But they convinced themselves that because there were clothes in the closet, and also they had sliding doors on the closet, that this would just do an easy job. It didn't. And the reason I was called out to look at that was the same reason I was called out to look at the bathroom problem. The tenants were complaining. And when the tenants begin to complain, all the tenants begin to complain, they're not all nuts. I don't think any of us believe that everybody's nuts. Some people are nuts, but not everybody.

So I went up there with one of my colleagues, and we went into two occupied apartments, and we had these two women just up at the wall before we'd finished, because we made measurements between this apartment and this apartment; we made noise reduction measurements -- NR -- we made a big loud noise in this apartment, and we measured the transmitted noise into this apartment. Now all we had was a loudspeaker which made the same sort of noise I made to you here in the classroom. If you're out on a desert island some time and don't have a noise generator, a vacuum cleaner is a very good source of noise for making tests, and we sometimes use vacuum cleaners, or a noisy mixer, or an FM radio tuned off station, if it doesn't have a noise suppressor. There are all kinds of things you can use.

Now we made measurements of the transmission between these two apartments: with the closets full of clothes, door closed; then closets full of clothes, doors open; and closets empty of clothes, doors open; closets empty of clothes, doors closed. And we had exactly the same answer in all four cases. It tested with measurements, it tested with listening. The clothes in the closet are fuzz, yes, and they're inside the space, and you'll think about the black box, and you'll think well gee whiz, that is something; but remember in the black box or in a room, we are asking that the sound has many contacts with that stuff that it's bouncing round. Here it's going right through to the wall and right through to the other side, with only one bang. Now there may have been four or five decibels of difference of high frequency, I don't remember, but it's not important. The sliding doors are not gasketed, they're not airtight and they're all cracked around the top and the bottom and in between, to the point that they simply don't do the job of providing an extra seal. So if you're ever thinking about construction, and that's the situation in an apartment house or a hotel, and are thinking of using the closets as sound isolators, FORGET it unless you're prepared to put gasketed doors on them.

The solution to this was to add a piece of plaster here, here and here, like this, onto these clips, and so effectively produce a double wall. But the woman who managed this, lived in one of the apartments, said that she as a manager tried to do everything she could not to annoy her neighbors, because it's wrong to annoy the tenants when you're the manager. And she said that if she went out in the evening, before she went out she opened her closet, because the sliding doors made so much racket in the next apartment, so that she wouldn't have to open it at 11 o'clock at night, or at midnight, or 1 o'clock, or whenever she came in. She pre-opened the closet so she could just avoid the issue. Well, I have to walk around like this all the time…it's a nuisance, now wait a minute. The only way to do it was to wait until the apartment was vacant. You just cannot come into an occupied space with plasterers. If any of you have ever tried it, you know that it's a bad thing. An unholy mess. Oh, urn, I really don't remember, it was much better - I really don't remember~ And this was an outside wall, but whatever it was, it was in much better condition in any case, this was the weak link. And 2" of plaster just isn't good enough for any kind of apartment wall.

I will illustrate a situation that we have here in our own office building here in Cambridge, which is a very cheap building. I wouldn't say it was inexpensive, but it is cheap. Metal studs and plasterboard, sheet rock, and we have a hung ceiling on a T-bar suspension system. And the T-bar is put down on one of those urethane gaskets connections, a little thing about the size of my little finger, ¼" urethane foam gasket is put in place, and then this T-bar is battened down there.

Anyhow, the lay-in ceiling system, which is of a very heavy, mineral fiber acoustic tile, with a foil backing, and the foil backing to make it so as you don't get air blowing through it, and so it has to act as a sound isolating construction. Sound absorbing material can act that way, if it's very heavy, and if it's impervious to air flow, and the air can't go through it. So we have this system running on both sides. Now then, we have ducts which lets the air into this room, and this room, and the duct is up here, I won't draw all the rest of it -- here's the duct. Now the dirty air from each room goes back through a space around the duct there into the cleaner, and then back to the fan room. So you can close a door to a room, air is supplied through a diffuser in the middle, and comes back around the side of the room; it's a very common way of doing it, so you can have supply and returned air, without two sets of ducts for each room.

Now then, you say it's a very big opening (transmission coefficient, $\tau = 1$) and noise is going to go up in the air and come down over here, isn't it? And why bother with this partition? Well, if you do a little calculation, and we did this very carefully, we find that this is a pretty well-balanced piece of design. The partition isn't very good, but it's some good. It has a transmission loss of circa 35 dB at 500 cps. And we calculate what sound will go through the ceiling here. Now that happens to be about 35 dB also, because we've got two passes through the tile—one through, one through, and it's a very heavy mineral fiber tile with a foil back on it, and you look up in the books, the Commercial Villager, on this material, you will find that it is indeed given a transmission loss of 35 dB through here. And then we calculate the effect of these holes.

We have a hole here, and we can say: well this hole is one square foot, one square foot in the ceiling, and then we calculate, on the basis of the average intensity throughout the room, how much energy is on this one square foot of hole. And we calculate the power that flows up here and then we know that that power spreads out in all directions, and a small amount of that wave power will come over here, and will find its way down this hole into this room. And again, by the time we get through with all this diffusion of the energy through the whole ceiling space, we find that it will also be about 25 or 35 decibels noise reduction. Now you say: "well that looks like a well-balanced engineering result." It is very satisfactory for our particular set of offices. We are not psychiatrists, we are not having confidential disclosures in the offices, we are dealing in ordinary engineering matters, and we don't require confidential privacy, and most of the conversation is at ordinary level, telephoning, dictating and small conferences. Now this is just fine.

In addition, we have a fairly noisy air-conditioning system, which provides a masking level, to mask any intrusions which come in at levels even higher than this fan. When the air-conditioning system is shut off, we can hear quite a lot between rooms, but the addition of the air-conditioning noise, which again I'm going to discuss in much greater detail, is enough to make it a perfectly private situation.

Now one day, one of my dear colleagues went up to the Harvard Medical School and Dog Farm. The dogs were making too much noise for the neighbors. The dogs barked and made a noise that bothered the neighbors. So we were trying to help them locate a place, a new location, where they couldn't possibly bother the neighbors and get them far enough away. The first thing to find out is, what is the source power of dogs barking? How many woofs do they radiate? $I = P/4\pi D^2$. Even then, even the most sophisticated acousticians would use the simplest formulas; they're very valid and very useful.

Well in order to do this you make a recording of these dogs, and then they brought them back to the office, called several friends into his office, and played these recordings. Boy this is it! And so they played the dogs barking recordings at full dog barking level. And you could hear it throughout the entire building! Because we're at a much higher level than we normally use, this is not sound proof against anything, it is designed £or a particular purpose. It's a well-balanced design, and this is the way we do engineering of buildings. But there are always going to be exceptional uses, and the building will likely fail the test, when we do put on an extreme use, such as dogs barking in offices - customarily not required, or expected.

With a lined duct, the air, of course, is going right through, that's a sort of DC blob, isn't it, in direct terms, and the sound is a modulation of that pressure variation on top of that indirect flow; Now, what happens is, of course you get some losses in lined ductwork, it's a frictional drag on the surface, there's no question that a lined duct offers more resistance to air flow than a flue does. It means you have to size it up a little larger. But the sound waves that come along here are constantly encountering this kind of material, and is losing air all the time.

Now if I take a piece of three-foot lined duct, and put it up by maybe 4" in diameter or something like that, and talk to you through it, maybe I'll bring one in next week, but it will drop the level of my voice by a good 10 dB at the higher frequency. We can get 2 or 3 decibels per foot of reduction in the transmission of the opening parts to get the sound reduction. And in the case of these bathroom exhaust fans, I have 7 feet of lined duct, leading from the fan down the opening into the bathroom, with one bend, and the bend is tremendously useful. Really top dog.

Sure, the bend is going to cause some problem for the air. The advantage with air pipes is that if we get a very quiet system, we pay the price in terms of higher resistance in the system and have to size the ducts bigger through the wall. That has to be consistent, and many times if we have an unusually noisy situation, it's too cold, either the duct is going through a mechanical room or other place in the room and the noise goes in through the wall, or the reverse case, we sometimes have to enclose the duct in plaster, to beef up the skin, and you'll see sometimes duct going through rooms that are plastic, just to keep the noise from all the machinery in there from getting involved.

Now one very popular form of lined ductwork today, and it's a very recent discovery, and we use it in our house, the duct-work is made of fiberglass it's made of an inch thick fiberglass board. And when I say fiberglass, I don't mean fiberglass batt insulation; I'm talking about a rigid board, that is bonded together with formaldehyde resin in a rigid board that is very sound absorbing, and the inner surface of this is coated with a sort of spider web of neoprene or something, I'm not quite sure what. But in any case this keeps the fibers from going out, and making a mess of everything.

This material comes in great big sheets, and is covered with heavy aluminum foil, and as it's quite heavy, I don't know what the fuzz is, but it's foil and not sheet metal. It is just very heavy aluminum foil. And here is the fuzz, and they you take a curve of 45°, or you make a 90° slot in the stuff, and then you bend it up, and then you fabricate it up on the site and then you have to size it up--the aluminum foil comes over the end, and all around, to make these nice rectangular ducts. They also come pre-fabricated round, 8", 6", 4" round ducts, for short runs and so on. Now this wall is very poor, it's very lightweight, it's very poor, if the problem is one of inter transmission through the wall or either way. But it's such a marvelous duct, and it's much less expensive to use to put lining into conventional ceilings. The duct is stiffer, lighter, and goes for longer distances than most. Our ceiling contractors were very, very pleased at the way it worked.

Student: (inaudible)

Well this comes in 8' x 4' sheets, flat, you have a big table like this, wider, and you lay it out and they bent them up, and the final seam is made at one corner with an aluminum face that you have to iron on with a hot iron the heat sealing the heat.

Now this installation has been 3-1/2 years, and there's absolutely no sign anywhere of trouble. Now in ten years' time, I may get another answer, I don't know. But two people make them. Cross is one manufacturer, they're fiberglass people; and Justin Bacon (like *bacon* for breakfast), they both make a fiberglass- duct; it's just called fiberglass ductwork. And it's just the greatest thing that ever hit the market.

The result is in our place, they've got an air system, a hot air heating system, and you just don't hear anything! When you get to the end of the line, now we have them blown up, so you don't blow hot air like that through the ceiling. We can louse up an otherwise perfectly good system quite quickly. Well I really got way up when I was in bad pain yesterday, and if you hadn't read my notes you would discover that is the end of the tape. But this is another very valid use for sound absorbing material, and if any of you have ever lived in a house and I hope you've all had experience in a house where the hot air system with a blower and a furnace goes on and off, as you need heat, and it's a blessed relief when everything goes off, I think I have experienced this, and it's such a wonderful thing--and it's just by using sensible materials. I know they cost, regular acoustics we can enjoy, without paying very much for it. I fancy they'd cost a little more, in fact a got a price for it - $65 was the difference between the cost of doing it this way versus putting in a whirring rattling fan right here in at the end of the house in this room. A real rattler "*W'RRRRRR*"-- like that - $65 difference.

O.K, that may be enough to frighten you, it may not be. I have to say these things. What you do if you're real fashionable, you won't have any space for this, because attics aren't fashionable at the moment. I lived for 20 years in a house with no attic and a flat roof, and my new house has attics, and they're vastly convenient for old beds, and fans and boxes and all sorts of things, but you do need some space to do this kind of job.

O.K. All these things, these under-window convectors and ducts and the like can be in this building here and these ducts are not lined, they are bare metal ducts, partly because of they keep this way, and also again, calculation shows that because of the very small area involved, and the fact that the energy goes this way and this way, and then spreads into this room about here, this again has about 35 dB. It's a well-balanced system.

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Let me describe a couple of other things that happen--the leaks and cracks in buildings. Some of them are concealed, a lot of them are concealed, and we can't even tell where they are. We're not using it so much anymore, but about 20 years ago, the curtain wall was all the thing, and all the big guys and so on were using it. And we did General Motors where that little metal shop was that I described, and here is a concrete slab coming out of the edge of the building, here is a curtained wall-that comes by on the outside, and here is a window sill and glass, and a window pane and glass, and a hunk of ceiling down underneath, and an enclosure here for an air conduction unit for air conditioning. Going to get the air up like this, and let the room air go up like this. Now this in a 6" slab, and if you look up in any books about 6" concrete slabs, you will find that it has a very fine transmission loss. And we very seldom hear much through a 6" slab. It's a very good piece of goods. I can hear everything that somebody down here says in the lobby to a funeral he'd been to the other day, and I went downstairs to find out who'd been to a funeral, and if he had been describing it to somebody on 6" slab, and I said to the architect, are you sure it he was at the end of the slab?

Oh yes, absolutely, absolutely sure. And here's the curtained wall, goes by over here. A curtain wall in this building has Portland enameled spangled panels and glazing in the window here, and they had lined it up very accurately so that it would look good from outside, and give a good smooth true reflection. I would do this, you would do this, if you go into a glass building, it might as well look smooth and not all wiggly-waggly. Again, we come back to reality. This concrete slab which was not perfectly true, it had variations of 3/4", and it went down the length of the building, and it is a good slab, it's as good as you're going to get. But it is 3 /4" and that simply went against this certain house at some kind of an angle I don't know how this works, but some sort of an angle here, but it is an open crack. It varies from I/8" to zero to 3/4" up and down the building. And this angle has only a point to hold it up at every module point, and make it a continuous angle. And some old socks and stuff stuck in there will make a beautiful job of the whole thing.

We'll have a quiz on Friday and proceed with this on Monday.

End of Audio File 10

THE END

Robert Bradford Newman Lectures

19 October 1970

LECTURE 11

Title: "Sound Transmission"

Summary: In this lecture, Newman discusses the solutions to a quiz over transmission loss and noise reduction, and he describes two of his experiences related to sound transmission between rooms.

Beginning of Audio File 11

Terry will return the quizzes that we had on Friday, and while he's in the process of doing that—do you want to call them out, or do you know everybody's face? While he's doing that, I'll just run over the problems very briefly. I hope all of you learned a little bit doing the quiz, and if you didn't do things properly, as I said earlier, please don't jump out the window or anything. It isn't that important. This is mostly to find out what you do know and what you don't know. One tendency we all have, I think, when we're faced with a quiz problem that isn't absolutely like something else we've worked on, is to go pawing through the notes and see what we can find that might be a suitable formula into which numbers can be stuffed and crank turned and so on.

The first problem is really extremely simple if you just keep it that way. Some of you chose to go to go into the Time Saver Standards and find a formula for the effective transmission loss of a complex construction and work out an effective average value, which is all right but really not as accurate or as easy a way as simply to consider the problem in its basic elements. Now, if you just stay real simple and think a little bit rather than stuffing numbers in formulas, life is just a lot easier. I would approach the problem in this fashion. We had a 20' x 10' wall with a window in it, 4' x 8', and the window had a transmission loss of 30 dB, and this means a τ for the window that equals 10^{-3}. Need I go through that the derivation of how we get there? I think you all by now know how to go from the transmission loss to the transmission coefficient, τ, and so this is 10^{-3}, and for the wall, TL wall, I guess we have to call this window, is equal to 50 dB. Therefore tau, τ, for the wall equals 10^{-5}. S_{wall} equals 200 square feet minus 4 by 8, which is 32 square feet, which is 168 square feet, and S_{window} is equal to 32 square feet.

Now then, here comes the first problem. You had a formula that we worked out that says that the noise reduction between two spaces is equal to the transmission loss—what is it now, minus 10 log S/A_2 or plus 10 log A_2/S, it doesn't matter which way it comes, and the temptation is to grab this formula and start cranking. Don't. This formula applies to, as I said several times as we worked it out, applies to a single wall without any kind of complications in it—no holes, no leaks or cracks, no windows or doors, just one kind of simple wall that divides two spaces. This is a very common condition in buildings. It's not at all uncommon, and there's no reason why we shouldn't use this formula in the case where we have a homogeneous construction.

But where we have a construction with a window in it or a door in it or a hole in it or some complication, this is no longer true. You can go into the formula in the Time Saver Standards article and figure out an <u>effective</u> transmission loss for the combination of the window and the door, but it's a lot easier not to bother with that, especially when you have such nice simple numbers as we had here. Now I_2 is equal to $I_1 \sum \tau$

S/A_2, or I_2 over I_1 is equal to $\Sigma\ \tau\ S/A_2$. And right away we see that what we're interested in is the ratio I_2 to I_1, and we know that the noise reduction between rooms is equal to $IL_1 - IL_2$, equals in this case 40 dB.

That's what we said we wanted to have, a 40 decibel noise reduction between the rooms, and I want to know in this case, if I have these two rooms here with a window in it, how much is A_2 in order that NR = 40 dB. The ratio between I_2 and I_1 will be 10^4, won't it? If the noise reduction is 40 dB, $IL_1 - IL_2$ is 40 dB, this is delta IL = 40 dB, then the ratio of I_1 to I_2 must be 10^4, mustn't it? Is that all right or should I—do I need to go through that? Delta IL = 40 dB = 10 log I_1/I_2. And then if we go to work, we can even solve this, and we can get 40 = or 4 = log I_1/I_2, and therefore $I_1/I_2 = 10^4$. 4 is the logarithm of I_1/I_2, therefore the number whose logarithm is 4 is 10^4, therefore I_1/I_2 is 10^4. Here I've got I_2/I_1. Well, that's all right, we'll just turn it upside down. So we have $10^{-4} = \sum \tau\ S/A_2$, or A_2 equals—I'll take 10^{-4} downstairs—now all I've got to do is stuff the numbers in. I've got 168 square feet, $168 \times 10^{-5} + 32 \times 10^{-3}$. I'm going to get A_2 right away. A_2 is equal to this, and then all I've got to do is do the arithmetic, and that will be 3, let's see, this will be, since I want them both to come out in the same form, I'm going to make this $.168 \times 10^{-2} + 3.2 \times 10^{-2} / 10^{-4}$, and that will be equal to 3.36×10^{-2} over 10^{-4}, or 336 units.

Is that all right? Is that clear to everyone? If we have any combination of things we want to know, for example, if we knew that the noise reduction must be so much between these rooms, and we have a given wall, and we already have the absorption in this room given, we want to know how good does the window have to be if it's only 32 square feet to satisfy our noise reduction requirements.

The point is, the window is only a 30 dB window, and yet we get a noise reduction of 40 dB by virtue of the fact that its area is quite small compared to the area of the wall, and that we have quite a lot of absorption in the receiving room, 336 units as compared to a 200 square foot gross area of wall. But we could have solved for the transmission coefficient of the window if we wanted to, if we'd known A_2. We can solve for any combination of things if we just go into this very simple formula here and start turning the crank. Putting in the things we know, we can always find any of the other components in the system. Now is this clear to everybody? Please, if it isn't say so, because I don't want to spend the rest of the term working on this idea. We've got several other ideas to introduce. Now as I say, there are other ways of solving this, but I think this is probably the simplest. Now the second problem apparently some of you got a little hung up on, but let's just run through it. No more questions on #1? Okay. I think Terry has annotated your papers pretty thoroughly anyhow.

Now the second problem had three rooms here in a line: A, B, C; and we said that in room B there was 101 dB, and this resulted in 76 decibels in Room A and 70 in Room C. Now one thing, apparently, that some of you didn't really grab was the notion that the noise reduction between two rooms, between any two rooms, will be the same both ways, and furthermore, I said these rooms were identical except for the construction of the party walls. They have the same amount of fuzz in each of them, so we have absolutely no problem about thinking of reciprocity in terms of noise reduction. So the first thing we want to do is get NR A to B, and that's 101 - 76 = 25. I think these are right. NR B to C was 101 - 70, which is 31 dB. Is that all right? If anybody—I can make mistakes, I do all the time, so please holler when I do.

Now then, I said, let's change the game now. We'll have A, B, C again, and let's put 85 dB in here and 85 in here, and they'll both pump noise into Room B. How much is there in room B? Well, what I have to do now is take the noise reductions that I've already found and apply them to these new numbers. I say that A to B is going to be 85 - 25 = 60, and C to B is going to be equal to 85 - 31, which is 54 dB. Now 60 dB + 54 dB is not equal to 114 dB. You know perfectly well that you would not have an excruciating level of sound in this room from the contribution of 2 (two) 85 decibel sounds on each side. So now, in order to add these two together, we've got to go back and find the intensities associated with them. So we have IL_A to IL_B is equal to 60 dB is equal to 10^{-10} watts per square centimeter, I won't go through the calculation of that, and IL_C to IL_B is equal to 54 dB, which will come out after we struggle through the numbers to be, let's see now, 2.5 x 10^{-11}. Then IL_B will be equal to 2.5 x 10^{-11} + 10^{-10}, which is 10 x 10^{-11} or 12.5 x 10^{-11} or 1.25 x 10^{-10} watts per square centimeter. Then IL_B, of course, will be equal to 10 times the logarithm of 1.25 x 10^{-10} / 10^{-16}, which comes out to be 61 decibels. Now there's precious little contribution from the 54 decibels, which is down 6 from the original.

Now again, there are charts in this Time Saver Standards article, which will tell you how much, if the difference between two levels is 6 decibels, it'll tell you that you add 1 decibel to the a higher level in order to get the resulting level, but I think it's important in developing a way of thinking about these things, so that you could always solve it out on a desert island without the Time Saver Standards reprint or anything else, to know how it's done from scratch rather than using charts. You can use the charts if you want to, but I think it's a good idea just to work through. Now Terry tells me there's some much more complicated way to work this that takes several pages, and maybe some of you would like to espouse the cause of the more complicated approach. This to my way of thinking is the simplest way to think about it and the simplest way to handle such a problem. Yes?

Student: "I put the percentage of change in the rooms."
On an intensity basis?

Student: "No, just on the percentage of reduction within the rooms, and then reworked the proportions with the new 85 dB from each side, and it came out all right, but I'm not sure whether it would come out right every time."
I think it must been an accident that it did, because—I don't know, I'd have to think about that. It's very dangerous to—well, there's several things that are dangerous to do. One is to average a number of decibels. You have 85 and 89 and 72 and so on, and you say the average level is so-and-so. Well, an arithmetic average of a bunch of logarithmic numbers isn't a terribly meaningful thing, and I think if you take percentages of decibel numbers, you may be safe within certain limits, but really you should add and subtract them rather than percentage them. Yes?

Student: (inaudible)
No, as long as everything stays put, you have a given set of conditions, then we're going to be all right. If the noise reduction is so much, then it is so much for that (inaudible). This is this is a hypothetical situation. This really isn't something that I ever remember having done in real life. I try not to drag in imaginary problems here for you and try to deal with real ones, but I don't think this is something you would do very often. But you are concerned sometimes about the two-way business. If the noise reduction is so much

here, is it the same there? Yes. Any other questions? I think you've all spent enough time thinking about this problem. I just wanted to be sure everybody is clear about it.

The last question I believe most of you answered reasonably satisfactorily. Terry says some of you wrote 5 pages and some 1, and either length is all right. I guess the only thing that I hope that you would talk about is what sound-absorbing materials do and where they ought to be placed and when might they do little good, and there are many places, particularly in very noisy industrial situations where a worker is very close to his own machine, where the use of sound-absorbing material on the perimeter of the room will have almost no value whatever in helping the individual person who is very near in the near field to the noise maker. I don't know whether anyone wants to discuss that one any further. If you have any complaints about the marking of your paper, see our Mr. Hartsedis, he's responsible for this. And again, it really isn't important. Unless he's really done you in and gypped you terribly, why, I wouldn't bother with it. As I've said before, the really important pieces of work this term are the two field studies. Those are the things that I really am interested in that I will read myself. Any other questions on this quiz?

Let's move along then, and also here are some problem sets that you can get at the end of the hour. We'll have one more set of problems and then that will be all for the term. As I announced last week, I'll repeat it today, we will not have a meeting of the class on Friday of this week because I have to be away and, well, we just won't meet. Very simple.

I'd like to discuss a couple of case histories this morning relating to the problem of how does sound get through from one space to another, and these are both fairly horrible examples, and I draw from the horrible examples rather than from the ordinary simply to make the points more strongly. Let me first talk about a case at the Connecticut General insurance building. I've already mentioned one problem there where we had a large open office area, where the only solution was to put in glass to stop the transmission of a very noisy machine operation to the adjoining spaces because absorption alone simply couldn't do it. Now in the executive offices at Connecticut General—this was a building that SOM did, oh, 10 years ago, 15 years ago now. Very slick, very all glass with the right amount of limestone and so on, gorgeous setting out in the countryside, and just a total disdain for some aspects of the environment, namely the acoustics aspect of the environment.

Now I say a total disdain, and I don't really mean that, because the architects came to us and said, what should we do about the general office areas for acoustics? We're going to have a lighting system that consists of fluorescent tubes to be shielded by some kind of baffles, and we said, why don't we make the baffles out of sound-absorbing material? So the basic scheme throughout the building, and I've shown you this before, was perforated metal baffles. These are fuzzy baffles with tubes in between, and these are on 2 foot centers and they're 2 feet deep, and these baffles run across all these rooms all over the place with tubes in between, and at least in one direction you get a cutoff of the visibility of the lights. Of course, if you look along the baffles you see the tubes. This is one fallacy of this approach to lighting. But nevertheless, this is what they wanted.

Now the executive offices, and it's extremely important for us that once in a building and you decide on a system, you have to go on with the system come hell or high water. I will just pause at this point to make a very horrible little example and observation. When we were doing the General Motors Technical Center with Eero Saarinen, we came to the medical suite in the engineering building where the clinic was located for the employees, and they wanted the examining rooms to have reasonable acoustical privacy between each other. They were using as a system a Hauserman [maker of office furniture] metal movable partition with a 5'-2" module. Now a 5'-2" module was set by the fact that they were using 5 foot fluorescent tubes throughout the building, and by the time you get the end fittings and so on, a 5 foot fluorescent tube, you're 5'-2" inch on centers, and this sets the module for everything in the building—doors, windows and partitions and everything else. So they had a 5'-2" metal partition made by Hauserman Company, and this was it. This is the system, and once you get yourself locked into a system there's nothing you can do except go on with it and crank it out ad infinitum.

When we got to the clinic, I said, those partitions are not good enough. The owner says, we want privacy. I said, they're not good enough. Okay. You're going to have to have something else there. We can't. Why not? Well, you know, we've got a system. You can't. It's impossible. What did we do? Let me tell you what we did. I'll draw you a detail of the partition. This is what is called 4" brick. Here's Hauserman metal. And behind this system of 5'-2" metal panels which looked perfectly consistent is a little heart of 4" brick, which is a very valuable kind of little heart to have in a metal partition if you want isolation between spaces. It's a lie, but it looks consistent, it photographs well, and the magazines will all exude over it and how consistent the architects have been in following their module.

Okay, back to Connecticut General. The columns here were on 12 foot centers, and great sheets of glass here, and the executive offices were 16' square, no, 18' square because the partitions came at midpoint of glass. We'll just draw one of these. Now you'd say, well, if you're going to have a partition coming to the middle of a glass window, you probably will put in a mullion. That's a common way of solving the problem. Oh no, not SOM. We just go up to the glass and touch it, just plug the partition into the glass, because on the outside you wouldn't want to see a mullion. Heavens! We've already gone to so much expense to get 12 foot glass.

Student: *"What's a mullion, for non-architects?"*
A mullion, for non-architects, is a metal post. It divides—you've got two sheets of glass with some kind of a divider in the middle. And a muntin, for non-architects, is an even smaller division, the kind of thing that you get in little panes of glass. The mullions separate the windows, and then the window can be divided with little muntins. Okay. But they didn't have a mullion, they just butted the partition into glass.

Now let me describe this partition. This is where the trouble begins. Now the reason I was called down here, we had been asked about the general baffles and so on, Messrs. Knoll Associates were assigned the interior design. We had one conference with Messrs. Knoll Associates and they said, oh, you people just want everything heavy, go away, you know, go away. So we went away, and from there on they did it themselves. You people just want everything heavy, damned acoustics people, as if we invented the laws of physics. We're merely abiding by St. Isaac [Isaac Newton] and the other saints of physics, what they discovered. Well, here sits a desk, and then over here is a rubber plant, and an old sofa, and a coffee table, and a suitable number of chairs, and a marble ashtray, and so on. Right out of the catalog. You can just read the catalog number of every piece of furniture in the place, you know. Now under the windows is a sort of a shelf that runs continuously, and here we have a grille for air and so on, and this of course goes right through here. Now I'll draw a section through here.

Now the reason I was down there was that the guy sitting at the desk in this office, which is exactly the same size and exactly the same furnishings, his secretary who sat here taking dictation said she couldn't tell whether she was getting this guy's dictation or this guy's dictation. That's the kind of communication they had. You could sit in there and talk like this between these offices. Now these have got $35 a square yard carpets, they've got teak walls, and all the expensive furniture, you just know the list price and they probably charged them at least that for it all, and terribly expensive offices, and not one whit of acoustical privacy. Now here's the detail. Here's the deck, here's the spandrel panel, here's the window and the sill, floor. Now here we have the convector unit, I don't remember just what it was, blowing air up, and this is open right through from office to office continuously down the building. Why is it open? Well, for the convenience of the mechanics and because you don't know, you might want to move this partition. Well, would you ever move it—where would you move it? An inch? Oh, no, no, we might want to move it to this column line. Well then, why don't we put in a barrier here to start with? Oh no, that's too much trouble. Just go away. You want things all heavy and airtight. Now then, here is a closure between the end of the partition, and here at this line cometh the baffle. There's a 2' baffle here that is a perforated metal sound-absorbing baffle. Now that's very sound-proof, isn't it? It's got insulation in it, and it's perforated metal and it's got fiberglass in it. How good is that as a sound isolator? Just about as good as this hole here, isn't it? Zilch. None.

Okay. Up above here, they had a Robertson Deck ceiling, steel deck, and they had quite a lot of guts and stuff running around, pipes and ducts and so on, and they filled this space in here with Homasote, and they trimmed the Homasote to fit the deck, and this must have cost a mint, you know, this Homasote piece, and this was in section just a little double Homasote panel on the top of this perforated metal baffle here which has fuzz in it, and now we have the deck and we have two layers of Homasote. Well, this is one of the better things in this partition, as I'll go on and describe here on a much superior detail.

Now then, down—this is at 9 foot height, and down to 7 foot height we have glass, plate glass, and there are some mullions that occur here and here and so on at the module points in the panels. Then we have panels here, and these are teak grain panels, and one very interesting thing is that this is a flexible system, and it's consistent with the system throughout the rest of the project, but the teak veneers in each office are very carefully book matched from one flitch, and they go right around here, ding ding ding, because when I proposed rebuilding the partition panels, they said, oh, how would we ever get the matched veneers again? I said, I thought this was flexible. Oh, not about moving, it's the system. Watch out for systems, especially these jackasses that start talking about the systems approach to design. You'll get yourself right into a snare that you'll never escape.

Okay, so we've got glass, quarter inch plate glass, we've got teak veneer, I haven't told you what's inside of that, and here we have a closure which is an aluminum closure piece because the glazing setting is all in aluminum, and this aluminum filler has a rubber gasket on the end of it, a very, very high durometer, just hard as a board, but it's rubber, and you know, rubber is good for making gaskets and pipe connections. It is, IF it's soft enough to make a connection, but if—as in this case you can slip a calling card or a piece of paper or even on some days when the wind's blowing right you could pass a whole book through—it's not sealing. I don't care whether it's rubber or cream cheese, it's got to make an airtight seal. That's all we care about is airtightness, and this didn't do it. Now then, but that's a minor problem because here we have a great big hole through here. You could lift these grilles off and reach through and shake hands with the guy on the other side, literally. So there's a wide open thing, and a little crack here is nothing. And here's a wide open thing here, but everything else is wide open, so why sweat it?

End of Audio File 11A
Beginning of Audio File 11B

The partition was made of teak veneer, quarter inch plywood, on a 2" egg crate. A 2" square grid of wood sticks, this is the 2" thickness here, so obviously this is a different scale. Don't worry about it. This is the plywood, and here we've got this 2" egg crate, an almost worthless panel, about as poor, I think, as you could build for sound isolation and still have it stand up there and give visual privacy between the offices. These were joined together here at these points. And these posts were aluminum, beautiful black anodized aluminum posts with bright anodized aluminum pitting to join the teak panel to the next teak panel. You have a bright aluminum and an anodized black aluminum in the middle. Oh, it was delicious, absolutely gorgeous detailing, sort of thing that you just want to eat, it looks so good. Right up here, right up through to this point. I won't even attempt to draw it because I would do it a disservice. It's beautifully detailed. All dry connections, slip, slide, and "whoosh" goes through the sound at every one of these points. A lousy partition, open here, leaks and cracks here, open here. The only decent thing is the quarter inch plate glass and the Homasote up here. Everything else is practically worthless.

This was built, my friends; and the solution that Connecticut General adopted for some time, at least until they needed the offices, was to vacate every other office. Now that is a solution to the noise problem. 18 foot square, $35 a square yard carpet, teak veneer, and all this aluminum, gorgeous stuff, and you just need that empty space for sound isolation here between these two. And one of these guys, one of the VPs down there when I went down was sort of, you know, saying, you guys are dead, you don't know it, I mean, you're hopeless. We'll have to rebuild this. It would have been better if we'd had brick walls between the offices, he said. I said, sure it would. But why in the hell have we got this stuff? I said, don't ask me, I'm not your Knoll Associates "*inferior*" designers. (Laughter)

Okay, so the first thing we said was, let's redo this. Why does this have to be here? Why does this baffle have to be here? Because it's part of the system. It's on a 2' module and we couldn't possibly have anything else there. Well, couldn't we fake it and put a little solid heart inside it, like out of 1/4" steel or something, or fill it with concrete, or just something nice and heavy. Well, yes, I suppose we could. And then couldn't we do something about this? The 1/4" plate glass is all right, and then we'll have to rebuild these partitions. We could fill them with sand. Well then, this gets to be a problem because they've got all this damn egg crate in them, and we'd have to drill down through every 2" all the way down through these things, and this was going to be a hell of a job, so they decided maybe it would be better to build new partitions, and then they got into this sweat about the fact that the veneers wouldn't match anymore coming right around the room like this all out of one piece of wood, and that would be just terrible, and it was just so important. The result is that they just sort of decided to live with it, and they're still living with this dreadful lousy condition, and they (inaudible).

Now that's one way to solve noise control—to cut out the source level! As a way to solve a noise control problem. I think it's a dreadful way. Well, there it is. This was in 1950 something or other when this was done, and you'll see equally stupid design in 1970, and I'm sure 1980 will continue to have people who crank out this kind of asininity. Just totally unrelated to the problem of creating an environment in which people can work and can enjoy a reasonable amount of privacy. These people were the senior officers of this company. They're not psychiatrists, they're not lawyers cooking up secret deals or oil prospectors or anything of the sort, but they do deserve a little bit of freedom from distraction so that the secretary at least can tell whose dictation she's getting. You know, it just should be reasonable. It doesn't have to be a super duper double floated skin and all that jazz, but it's got to be something just sort of reasonable.

Now let me recite one other case history in a little detail because it illustrates the same sort of point, applied in a completely different situation. This is the graduate center at Harvard designed by TAC [The Architects Collaborative] about 20 years ago, and the partitions between the rooms were done in cinder block because Mr. Gropius [Walter Gropius, founder of TAC, Dean of Architecture at Harvard Graduate School of Design] found some cinder block of which he liked the texture very much. He liked the texture of the cinder block, that's what got used. Between the rooms, in plan, up have here a brick pier and then another brick pier, partition, then a mullion here and a partition, and a partition. This is fixed glass, mullion, and an operable sash here, an operable sash here, a mullion, and fixed glass, so that the elevation of the building went "*BOING boing boing BOING boing boing BOING BOING*" and so on. Very important. Now here again, we have this usual lovely detail of—this obviously is related to this, and I can't remember just how, but here is a windowsill with radiation of grilling, and obviously this relates to this, let's not worry about architectural scale, and the pipes in here are carried up in a metal filler that goes between the end of the partition and the mullion of the window, and this is the cinder block partition, cinder block partition, cinder block partition. One room, another room, and so on.

The greatest leak here, one of the greatest leaks, was this pair of out-swinging awning windows, which swung out like this and formed a beautiful scoop for sound between the rooms. We don't think enough about how many times in buildings we see corners meeting here with two different occupancies with windows that open across the corner, or windows along the face of a building with out-swinging casement windows or out-swinging awning windows or any kind of operable windows adjoining each other in a common mullion, separating two rooms. The sound goes right out and comes right back in again with almost any of these, and it really doesn't matter what kind of partition we have. And we're not always going to have fixed sash and air conditioning, I hope. We're always going to be able to open up something and let in some nice outside air.

Now here again, the reason I was looking at this problem was not that it was okay. Nobody pays you to come and look a building that's just fine and everybody's happy with it. Why should they send you there to look at it? This was in trouble, deep trouble, because the students had complained constantly about this building from the very minute they moved into it. All sorts of complaints, and finally Mr. Pusey and Mr. Griswold got together and decided something had to be done about it. The partition, made of block, went up and met the slab here at this point, and a shrinkage crack, of course, naturally occurred at the top of the cinder block. It always does for Mr. Gropius and for you and me, for everybody who uses cinder block, it shrinks. So it shrank away. Now during the construction of this building, towards the end, they finally got a windfall of some sort on some acoustic tile that they could get for about 5 cents a square foot installed or something real cheap, and so they wanted to know if it would be all right to use acoustic tile throughout the building for ceiling finish and save a lot of painting and so on, and I said great. So now we have the condition, though, where the—here's the slab and here's the top of the partition, and it shrunk away a little bit, but we have an acoustic tile here which sits down like that and conceals that crack so you can't even see the shrinkage crack at the top, but it's there, and the sound finds it, because remember, the sound is a pressure wave, and it gets everywhere and finds every little leak and crack between the two rooms. So we have a leak here. Basically, the cinder block isn't very good, partly because it's porous and partly because it is a very lightweight concrete block with high stiffness, and we haven't even begun to talk about those problems, but—it's a fairly lousy partition, but this was not the major problem at this point.

Out here at the window, we have the convector, this is just a straight pipe convector. Now this is the metal closure between the end of the cinder block and the mullion out here, and here's the out-swinging awning window. The pipes go up and down behind here, in this thing. This metal closure unit was joined to the cinder block with a dry connection. In fact, it you stand in one of these rooms and wiggle back and forth, you can see right through. Well, okay, that's lack of visual privacy, most people don't investigate like this, but if you're an acoustics man looking for the leak, if you can see through, see light through, you know damn well the sound is coming through that spot. So we have a dry connection here with a leak. We have just some lightweight metal here, just enough to keep visually the pipes enclosed and to stay flat, but if this metal has been sealed here and here, it would have behaved as a reasonable partition. But down here, for the convenience of the steam fitters, they cut a great big hole in this metal thing, and this makes it handy for the steam fitter when he comes to hook up this radiator, and the pipes can come anywhere within 6" or a foot there, and it doesn't matter as long as it's in the cabinet space, and so this was just left open for convenience of connection.

Now what do you suppose they put in there to stop the flow of sound between rooms—down through here into this room and up into the next? What would be the natural material to use there? Fiberglass, isn't it, for insulation? We can sit here and laugh all we like, but this is the way the world goes, and I've seen this used everywhere in the world, not just in Cambridge, Massachusetts, but everywhere in the world. Fiberglass is stuck in for insulation, for sound insulation, my friends, and it doesn't do a damn thing here or anywhere else in the world. Somehow these things are universal, and the truths are all universal. Sound behaves just the same way in Singapore as it does here, but in Singapore, they stuffed in fiberglass, and in Copenhagen, they stuffed in fiberglass. Everywhere they do it, just the same. Well, here we have fiberglass doing nothing, here we have this open grille, here we have open windows, here we a crack, here we have a shrinkage crack, and a basically poor wall.

Well, to make a long story short, the university said, what can we do to make this soundproof? Well, the first thing you have to explain is that there isn't any such thing as a soundproof construction, no matter what we do. If we start testing jet engines in one of these rooms, you'll hear it in the adjoining room. It wouldn't be reasonable, we're not going to test jet engines, but if Joe Blow has his electric guitar here, strumming away on it, it makes a fair amount of racket, and this guy [in the neighboring room] would like to be able to sleep. Well, even the electric guitar we'd have to say, well, we're not sure about that, but let's make it a conversation. Okay. So what we did was first of all to say, you've got to move one of these operable windows. And this was the point at which some of my friends at TAC got very unhappy—"You're spoiling our building when you don't go "*BOING bing bing BOING*," you want to go "*BOING bing BOING bing BOING bing*." And I said, well, that's just as good a tune. (Laughter) It really doesn't matter. I must say my friends at TAC who were upset have since got un-upset over this because they recognized the truth of the matter, and so we moved the mullion down here, moved the fixed glass here and the operable sash here, reused all the existing stuff, there was (inaudible) new material needed, just a matter of shifting half the windows throughout the whole dormitory. Now this whole project cost upwards of a couple hundred thousand dollars to do, it was not a cheap little operation, but it was worthwhile because it did such a sensational job of improvement.

Now the next thing we did was to introduce a very tricky detail, and I can't remember just how it was done, but somehow we came in here at the point where we had the fixed glass and we came over a little bit with the closure here and we put in a new skin of plaster, which went right from the window back over the entire wall, right through here on back, including all this business underneath. A new skin of plaster was plastered around tightly around all of this and then stuffed and caulked. This skin was put on as follows. Here is the existing 4" cinder block. We put on strapping, 1" x 2" strapping, with a resilient clip system that supports glass and plaster, and then in here we put fuzz. Now fuzz in the inner space, in a multiple construction like this, can improve the performance. It effectively makes the separation between the two faces greater as far as sound transmission is concerned. We were trying to minimize the robbing of space from these rooms because these rooms were not large to start with and we didn't want to take out any more space than we had to, so we took out 2" of space, or maybe 2-1/2" of space, out of each room, and we added a plaster skin on resilient clips to one side of each partition as we went down the building. Every room there, then, has a plastered wall and a cinder block wall, but the point is we sealed it, we put in caulking up here, and then we made the new skin tight to the ceiling, cut out the acoustic tile, made it tight to the ceiling with caulking, made it tight, complete tightness clear out to the corridor wall and plastered in all of this underneath here, and the whole thing got closed up with a real nice honest-to-goodness layer of plaster. Plaster is awfully good. It's nice and heavy, it can be pushed into the corners and made completely tight, a plastic material, and it's just great.

Well, the result is that we did one room, mopped it up, and Mr. Pusey got in one room and Mr. Griswold in the other, and they hollered at each other for a while and were satisfied they couldn't hear each other, so they each believed the other to have been hollering, and so we voted yes. So we went ahead the next summer and redid the building. The doors to the hall were all gasketed so that the hallway noise wouldn't get into the rooms. This made the problem of intrusive noise nonexistent. We sealed the leaks around the door.

And one interesting thing that has nothing to do with acoustics: when the building was built, they had a glass transom above each of the doors, you know, you have a full height panel, you didn't want plaster above a door, so you have the door going out and the glass transom above, and the very first day that the students were in there, all of these glass transoms got covered with newspaper, several thicknesses of newspaper, to keep the hall light from shining in the rooms all night. Wouldn't you think that might have occurred to somebody? Well, in the new plan, these transoms were all eliminated. The newspapers had been up there for several years and went sort of yellow. They're not there anymore; the transoms were blanked out. You say, well, gee, that sounds kind of radical to do all that, it makes a terrible mess.

End of Audio File 11

THE END

Robert Bradford Newman Lectures

21 October 1970

LECTURE 12

Not available

Robert Bradford Newman Lectures

23 October 1970

LECTURE 13

Not available

Robert Bradford Newman Lectures

4 November 1970

LECTURE 14

Title: "Noise Suppression in Practice"

Summary: In this lecture, Newman speaks about some of his work experiences with noise suppression and some interesting solutions that he's implemented in the past. He also muses about his interaction with misleading "anti-noise" product marketers.

Beginning of Audio File 14

You remember some time ago I brought in this lovely ad of McGee Carpets. It says our anti-noise carpets and it says "They'll hush the screams of a jet. The honking of traffic jam, a 105-piece orchestra playing. A room full of kids making a racket, or just a plain shouting session…If noise is your problem in an office building, school, hospital, hotel, motel, church, concert hall, theatre, or what have you, call or write a McGee Anti-Noise contract carpet expert at 919 Third Avenue, New York City. He'll bring you "peace and quiet carpet in any size." So I proceeded to write a letter to Mr. Magee:

> *In the September 19'70 issue of PROGRESSIVE ARCHITECTURE on Page 17 is your advertisement for your "Anti-Noise Carpets."*
>
> *What in heaven's name is an anti-noise carpet? How do your carpets differ from other people's carpets of the same thickness and construction when it comes to sound absorption?*
>
> *Carpets are very useful as sound-absorbing material but they <u>do not</u> "hush the screams of a jet, the honking of a traffic jam, etc." You mislead the innocent architect with your advertisement. Why not claim for your carpet the virtue of any carpet—a very effective controller of scuffling noises on the floor, impact sounds transmitted to the floor below, and general reverberation control, but leave out all the miracle stuff."*

His reply --- and this is a very good reply….This is an ad man writing—the Merchandise Director for Magee, a Mr. Kressler::

> *The McGee Carpet Company*
> *919 Third Avenue*
> *New York, New York 10022*
>
> *October 20, 1970*
>
> *Mr. Robert B. Newman*
> *Bolt Beranek and Newman, Inc.*
> *50 Moulton Street*
> *Cambridge, Mass. 02138*
>
> *Dear Mr. Newman:*
>
> *We did not intend to mislead the innocent architect. You are quite correct. Our carpets do not differ from other peoples' of the same construction in their ability to absorb noise. But that's the problem.*

If we were to advertise the acoustical benefits of carpet in general, we would not be helping Magee specifically.

All we were trying to do was to make you think of carpet in relation to its acoustical benefits and think of McGee as a company that understands and can help you with some acoustical problems. We got over enthusiastic perhaps, but we did not mean to make claims that were false. We will take out the line "hush the screams of a jet." In advertising, we get carried away with the visual and that is why that line was put in in the first place. We used the photographs we did because it's very hard to picture noise. A jet and a traffic jam visually come across as noisy. Thank you for your constructive criticism and the next time you see the ad you will see the copy has been revised so it is not such an overstatement which, as I explained, was not intended to be deceiving in the first place.

Sincerely yours,
THE McGEE CARPET COMPANY
Richard N. Kressler
Merchandise Director

Well, I guess that is as good a letter as I could expect to get. At least we got the screaming jet off the ad. I have been engaging in this activity for some 20 or 30 years, and every time I see something like this I get angry, I write a letter, and nine times out of ten I get some kind of action out of it. Tomorrow I am going to be in Houston giving a talk at the Acoustical Society of America. They have asked me to be a keynote speaker on a session they are having at the National Convention on Household Noise, and I am going to harangue for about 25 minutes or so, as I do here, and yesterday I had some gorgeous grist set into my little mill and naturally I haven't decided what I am going to say yet (that will be on the plane, this afternoon).

This is an article from the Portland Maine Press Herald, and where they got their stuff I don't know. Thursday; October 29, 1970: This fellow says maybe you should stop worrying so much about the sonic boom of the SST and start worrying about racket-ridden hide-a-way in your home. And then we come along and we quote Dr. Herb Newton. (You can count on it if it's an article in the popular press: the quotes will all be the same people being quoted and the same garbage, because the garbage makes such wonderful quotes.) Dr. Newton, who should have shut up long ago, says "noise, like smog, is a slow agent of death. If it continues to increase for the next thirty years as it has for the last thirty, it could become "lethal." You can just image this lethal noise getting into our living, bleeding into here, throwing up. (laughter)

Now I just listen to this. He goes on about how your own home should be able to shut out the world, and noise can't be shut out, and so on.

First, from Dr. Leo L. Beranek of Cambridge, Massachusetts, one of my partners: "The noises, of our daily life have been variously blamed for the high divorce rate, social conflict, indigestion and other organic disabilities, nervous breakdown, high b1ood pressure, heart failure and even insanity." Now, what Beranek said following this, this is a lot of bull shit. But that is not recorded here. (Laughter) And it is a marvelous quote out of context. He was quoting some other jackass. Well, a wife who runs the vacuum in the evening (says Dr. Lee E. Farr of the University of Texas) may be contributing to her husband's ulcer and allergy.

Here in all the most obvious result too much noise, and then they talk about these Africans that aren't very loud and don't have any hearing loss, that's it every single time.

Now here comes the good one. Speaking of home again, Henry Still, author of a new book "In Quest of Quiet," Stock Books $5.95; $6.95. Excuse me. Have any of you seen the book or heard of it? "In Quest of Quiet." I've got to get because this is good. (laughter) "Home is no longer a quiet place. 90% of our indoor noise is a result of modern conveniences. He adds decibels this way: Refrigerator 10, meat frying an added 10, food blender 20, clothes washer 20, dish washer 30, hot air furnace or conditioner 10 to 30, then he concludes that here in the quiet of a modern suburban home the total noise level has reached 90 to 100 decibels. (laughter)

That's not cast at the increase in the newspaper in just the last week or two, my friends. Now I hope that by now you're all so sophisticated about noise and decibels and how you add up energy and what it's all about that you could just look at this and laugh. Now the teenager son of the house puts a rock and roll record on the living stereo set, and suddenly the sound level may be 120 to 140 dB. (laughter) And also associated with auditory pain. So they've got some hotter equipment then most of us have in our house with levels like that. (laughter)

I must say when my son turns on his electric guitar amplifier, I suspect that he gets up close to 110. Well, he goes on, this is just more of the same kind of garbage. But this marvelous quote from Leo Beranek, I showed him this yesterday. He just had to laugh. It just shows that you don't dare write anything in which you quote anything that isn't exactly what you want to say. But you always quote other people who are obviously asses in order to make your point stronger if I didn't take this baloney and then so on. Well, Leo Beranek none of us think that noise is the cause of insanity or divorce or organic disabilities, high-blood pressure, heart failure arid so on.

Noise is serious; noise· is something that we need to do something about. I'm not saying that at all, but it certainly is talked about in the most magnified: terms the popular press. And while I'm reading you press clippings, this other one to which I referred earlier in the term and I dug it out this morning because I want to use it in my talk tomorrow. "Tree barriers to help cut noise pollution." Headlines in a newspaper, April 19, 1970. And the scientists are adapting an old tree planting technique used by farmers to protect fields and buildings and in hopes of solving some of the countries noise pollution. Notice that word "hope;" that's a wonderful word, we can always hope it will work, the man who builds the concrete building with little poppers in the concrete hopes it will break up the sound and he won't have any noise problem and he won't have to cover up his lovely concrete with fuzz he hopes, but it never works.

Prescott (?) hoped that over in the dining hall, the little bumps on the surface of the concrete would break up the sound and he wouldn't have to cover the concrete with fuzz. The concrete covers itself now because it didn't work.

The agriculture department says that a three year study near completion indicates unwanted noise can be cut as much as 65% if trees and grass are used as barriers. Rows of trees that have been used for decades protecting sites from wind and so on, and so on, and then they talked about it with Professor Cooke, University of Nebraska who carried out this study. And it says here that using instruments, the scientists were able to compare noise effects in protected tree areas with the same sound in unprotected areas. When used alone, trees reduced noise levels up to 50%. In other words, if you have 85 dB from the traffic going by, it will be 42-½ after you put the trees in.

This is a row of trees 75 ft. wide. But when grass areas adjacent to the trees were included—now how they are included, I don't know, but when they were included—the noise dropped another 15%. That's how you get 15 plus 50 equals 65. And among the requirements for the best effectiveness is ample space the scientists concluded. Well, for sure, if you get the highway 6 miles away it's probably not going to be very noisy; ample space is a great thing. Outdoors. Well, this is absolutely hopeless. Totally hopeless.

Now what he found out, I'm sure and I wrote him a letter, and he wrote back. “You seem unduly concerned of the effect that a single newspaper article extracted from a news release based on preliminary letters…”. And so on and so on, “you seemed unduly concerned.” Well, I get concerned when we read here all about how this is such wonderful information it's going to be so valuable to the landscape architect and all these other people who are going to use this new found technique for controlling noise because this leads to nothing but disappointment.

Now trees, 100 feet of woods, will reduce the level of traffic noise about 3 dB in excess of that that you would get by normal inverse square law losses. You get 3 dB excess attenuation due to trees per hundred feet of wood. Now this is for 200 or 300 feet; now when you get up to several thousand feet this effect is less strong. And what no doubt this report said, though this man would never admit it to me in his correspondence, is that the energy level was reduced by 50% which is exactly what 3 dB is, and so probably the report is all right but the trouble is this is like reinventing the wheel. This work has been done and done very well, and the literature is full of it and our Department of Agriculture sees fit to send it here in contractual support of this jackass at Nebraska to study the effects of trees. This is no point in going on and on in making measurements hoping that maybe the Nebraska trees are going to be different from the Massachusetts trees or the Ottawa trees or other places where the study hasn't· been squared out. Well, once in a while I guess I get a little carried away with these things, but I think it's good to look critically at this and always ask the question: can this possibly be so, based on what you already know?

I spent a lot of time at our last meeting talking about doors and gaskets, special sound isolating construction. I would like to just say one more word about door gaskets. I mentioned them in connection with music teaching studios, radio studios, and other places where we really have to keep out the noise. I would suggest that in every house, in every apartment, in every hotel room there is a need for door gaskets. In the apartment house (if any of you live in apartment houses with corridors), you know the problem of corridor noise getting into the apartment. This can be almost completely eliminated with any kind of a half-way decent door that is weather-stripped, and has a gasket on the door. A weather strip on a door ought to be something that makes the door not feel very different from an ordinary door, not take extra pressure to close it, and be fairly serviceable and not require constant adjustment and so on. These are perfectly obvious things.

Any compressible gasket that engages the face of the door, and I’ve said this the other day, but let me say it one more time: a compressible gasket where we have the door here closing, here is the jamb and the stop and we have a gasket here which the door compresses when it· closes you've got to whang the door closed with a good loud ‘thunk’ in order to get it to latch because you're exerting pressure back from the door. If you just try to close the door gently it isn't going to latch and you have to give a shove to make it flatten the gasket. And for this reason we feel very strongly that the only kind of gasket that really works well is one that engages the edge of the door rather than the face of the door. You slide across it and this can be flexible bronze; it can be the sort of rubber bubble gaskets that I described to you the other day; it can be a great variety of things. Gaskets on doors inside the house—not only those that communicate with the corridor and circulation spaces, but inside in dark rooms, in bedrooms and any room where you'd like to shut the door and have the door act reasonably effectively as a sound barrier—ought to be used a great deal more than they are at this point.

Tom. I just want to underscore that no door is going to work as a real closure unless it is weather-stripped and that even the hollow ordinary kinds of doors can be made to be quite effecting sound barriers with gasketing around it.

Let me move to another subject and I've got a whole catalogue of things I want to talk about, and we have so many more things to talk about this term that I just hope we can just follow them; I'll certainly try. At times we have requirements (and some or you may run into this sometime) for really very, very high sound isolation in order to make things work properly. I'm thinking of the typical situation of a scene shop associated with the theatre. Strictly college level, the theatre often has a scene shop; and if it's a really active college theatre program, the scene shop is likely to be in use almost all the time because some people will be putting on a production and others will be getting ready for the next one and this scene shop activity must be able to go on all the time if it's going to be a really lively active thing.

Now at Harvard when the Loeb Drama Center was built several years ago, a scene shop was part of the program and the architect located the scene shop in a reasonably good place: stage off of the main theatre here and the scene shop is back here. And then there's a little theatre joining it back here so he's got it so that the main seating of the theatre is out here. Well, the scene shop is back here where it's not right adjoining the audience chamber but it is adjoining the stagehouse. And at first I suggested a solution which might work—if it's carried out—that is, that we make this scene shop a separate structure and separate it from the structure of the theatre itself. And there was a lot of flak about this because it's going to cost money. Very few things in life that are worthwhile don't cost something, money or effort or something. This is going to cost, so the first reaction of the owner and the architect was "we'll schedule the use of the scene shop."

Well, I've been through enough of these things to know that you cannot schedule the use of a scene shop and have it work at all as a scene shop for an active theatre program because the kids who are going to be building scenery cannot come at Monday; Wednesday, Friday at 2 o'clock for their scenery and stop at 3:30 when something else has been started. You've got to be able to work 24 hours a day.

Well, we did separate this scene shop and indeed I think that it's the best thing we did acoustically for the Loeb Drama Center to make it possible to use this space, day and night during performances, and this means hammering on the floor, dropping things, swearing, running buzz saws, stapling, painting, doing all the operations that go on in building scenery for a theatre. This happens here without any audibility, whether in this space or this space.

Now how is this done? Well, the rear wall of the stage house is a brick wall and goes on up. Here's the stage floor and the scene shop has a glass here and it has a brick wall that goes up about so high. And then it has a roof and has an ordinary expansion joint detail that joins the roof of this building to the wall of this building. It's a fact you get slick members in it so that it can come and go. There are columns in each of these walls and the space between the brick work is in the order of six inches. Now, at this point the columns or beams or whatever come fairly close together, in particular here at the sill, and you have an inch of fiber glass in here just to prevent anything from touching so they don't touch each other. Now at this point, the columns go down one floor below grade and they are sitting on common footing. In this case the engaged column and the brick work go down to a common footing here at just about 10 ft. below the stage floor level; and at this point they are joined together and they are not separated. It can be done but it's more difficult to separate at the footing because, well, partly because of the rock underneath here didn't make much sense and then you get some funny eccentric loading if' you start having your footing loaded on just one side with only a six inch space between the two walls.

And we find that this is quite adequate, since when you are hammering here on this floor it is not heard by the time it goes down through here, shakes Mother Earth all the way to Australia, and comes back up again here and out here into the theatre itself. In this wall we have a pair of doors and these doors are great heavy doors. You ought to go look at this sometime. It's really quite a nice installation. Textbook installation. Here is the door here and a door, here in this space, and these are great big doors. There are two of them; I think each 5 feet by 10 feet so that-the total opening is a 10 ft square.

And in plan, you say this is this scene shop and the doors swing like this, they are great big metal doors with tremendous heavy refrigerator door hardware, hinged and latched hardware with wedge action latches so that you really pull the handle down like that and there are other bolt gaskets. These have to be safe gaskets like the one I described earlier, but with all this fancy squeeze hardware and wedge action closing devices, you can squeeze against the gaskets. So we close this set of doors and we close this set of doors. The structural preparation goes through here and all the way around.

Actually, the building wraps around here some more, with some more space like this and all the way around to the structural separation. And if you look carefully there, you'll see there are some places where we made no attempt to put in a double wall here—we merely have a separation and you see an inch of fiberglass running along beside the wall here at the floor and at the ceiling where this building just comes up and touches the other one, but through fiberglass. There is no connection anywhere that is rigid other than that one. It works like a charm and it's really a wonderful thing because it means complete flexibility. This is building flexibility—not the ability to use the thing all the time anyway you like and thus not make it impossible to use any of the other spaces.

Now at Webster College out in Webster Grove, Missouri, we did another theatre right after the Loeb, and I went through my same song and dance about separation of the scene shop. I have a standard song and dance routine on that particular subject because I think it's the way to do it, and if you don't do it that way, you are going to have trouble and you are going to have to restrict the use of the space, and that's too bad. At Webster College we have the stage here, and I won't try to draw all the ramifications of it and the door here opening out into a loading dock with just ordinary doors. And then there was some space in here and finally we came to the scene shop, which is over here. It went, I don't remember just how, but anyhow the theatre really kind of wrapped around here in some such fashion as this

And we said: let there be a structural separation, and there was. And here is the structural separation: all around the scene shop, so it really comes up next to this building but just barely touched it. It doesn't come in rigid contact. And here we have two sets of doors with a great big space in between, and these doors could be much less good than the doors where they are just within a foot of each other; because where you have 10 ft. or so of separation, you can add together the transmission loss of this door to that one, and you can add decibels three times and a spare; if this is 35dB doors and this is a 35 dB door you get transmission loss out of the combination with this much space in between.

So I went out to visit this place and the theatre director said “I thought you guys said that this scene shop was going to be soundproof and we weren't going to hear hammering.” And I said, “I did.” And he said “But you can hear hammering.” “Well I don't believe it.” “Well, I'll show you.” So he sent a guy out here and he banged on the floor and I sat staring at the ceiling with the director and we could hear the guy hammering. It's no use to my sitting there and say I couldn’t hear it because it was very clear. You could hear bang, bang, bang, banging on the floor. So I turned to the architect and then I said: did you inspect all of these expansion joints? Are you sure it's all OK? Oh, absolutely. Everything is perfect. He looked at it all through construction. Well, let's go find out; there's a short circuit somewhere.

And we went out there and here we found it. The door, the personnel door that went between this space and this space, and we saw the concrete slab ran right through the sill at that 3-foot door. Everything else was separated. The whole breadth of the perimeter was separated except at this point, somebody forgot to put in an expansion joint and a slip sill of some sort, and so the floor went right through! That was the whole trouble, right there, just one little place, that's all you need. And then you can very clearly hear the hammering that's going on out here from your sitting out here in the theatre some distance away by structure born transmission. So we now have a concrete saw-cut here and everything is fine. You have to follow through every little crook and cranny in these things to avoid structure-borne transmission in these very critical situations.

Student: *(inaudible)*
Yes. Airborne sound-wise. Well, we measured it at the Loeb, and it's more than 70 dB. The background level in here is sort of say 20 to 25 and this can get up to 95 or more and not be audible. Now I'm sure it's conceivable that you could violate my statement that it's really soundproof, and if you turned off the air distribution system in here, and had no masking at all from the air movement (there is a little of that now), and everybody sat breathless, and somebody set off a jet engine out here or something like that, you'd probably hear it. But the way they do things, it's okay. And it’s the same thing at Webster; this is even better sound isolation, and it this could be more than 80 dB, because of the separation of space and the several layers of things in between. But even with that, if you have any structural continuity; you actually (bang, bang) bang on the structure like that, you can hear it right on through.

Student: *(inaudible)*
That is, I might as well talk about that while we're at it.

Student: *(inaudible)*
You know what it was upstairs? I think it was OK. That should do it. How did it start, what happened because I had endless details in mind. And it is drumming and dancing, jumping, that will come through.

Of course, I would always suggest, I think, that in the case of the scene shop there is some logic to having the scene shop next to the stage for obvious reasons of convenience, this carrying junk back and forth and scene wagons and everything else.

If you can ever avoid a shoe-horn job like Kresge's do so. A little theatre was placed under the big auditorium; this was because Mr. Saarinen could not accept the appearance of any other lump in that particular composition. This is the straight fact. The Little Theatre has a big house on it in which you can legally use painted non-fireproof scenery. You cannot use painted non-fireproof scenery upstairs. Downstairs, there is a smoke vent that satisfies the law and it's put in in the most incredible fashion. In section, it goes through the stage of Kresge's upstairs and I'll describe the noise in a minute. This is quite interesting.

Here is the stage downstairs, the ceiling of which is the underside of the slab of the stage upstairs. A one-foot slab separates the two theatres, one foot thick concrete slab, and then here, over the corridor space on each side, was a hard marble opening, and outside here is the brick pavement. And here is the glass wall going out to the side, I'm a little off on my scale because if you look carefully right here, you discover a double line in the aluminum trim and here is a flop-out panel and this is the smoke vent of the Little Theater downstairs, on each side. There is a huge length of panel that when it gets too hot, because of the great consideration of what's going on here, it will flop out and then the breeze will be encouraged, and you get greater consideration· and the smoke goes out in any case.

It's usually disguised and it's about three or four of the vertical panels wide. Look at it; it's right there. It's painted dark green; it's opaque and it's in the side of the business just in the opaque section and the bottom three feet will flop out. Well, this is a real piece of ingenuity to get this in here so that it will satisfy anytime the reasonable souls for public safety.

All right. Now let's not worry about that. The sound isolation: how is that done and how could it? The main house has an acoustic concrete slab and then there is an enormous beam here that turns up, that forms the floor. That is a beam of reinforced concrete and then here is the orchestra pit and here is the floor of the auditorium. Going on up, I've got it too steep, but let's not worry about that. This is an 8 inch slab forming the basic floor slab of the Kresge Auditorium on which you sit—8 " concrete. Now then, here is the pit of the Little Theatre downstairs, and here is a 12" slab.

Now we said we'd like to hang a resiliently supported plaster ceiling under this whole business to protect against airborne sound transmission from upstairs to down and down to up. This was not possible here because this ceiling is fitted with tracks so that the scenery and the loading capacity of this construction is such that you simply cannot have a resiliently supported plaster ceiling on 'wobblings' there; you've got to hook it right up to the concrete, and have it rigid.

The space plan is exposed in the room below. And we are going to make a field trip over there a little later in the term and see all this. I might as well tell you about it now. The stage floor is on fiberglass, exactly the way I was describing floating a lab the other day. Here is tongue-and-groove boarding and—enlarging it a little bit and so on, this is tongue-and-groove boarding that is nailed through into ½" thick plywood and ½" plywood is laid down here with 6 inch strips of half inch plywood at the joints to make a continuous wood raft and these were glued together, glued from top to bottom. I don't remember how it was done but in any case this is essentially a wood raft of ½ inch plywood. Under this is about 3" of fiberglass, and then the concrete surface of the actual slab.

Now this is all we could do. This floor slab—I mean for many reasons to mention there just isn't space enough to do more and actually we would love to have an additional of concrete slab on top of the basic one and then put our wood floor on top of that but there just isn't room enough for it. So we compromise on this and this is adequate for walking around and for cellos and for ordinary sorts of use. The minute you put a drum, and particularly if you start jumping on the floor, this kind of construction is not adequate to provide complete isolation. To get jumping and that sort of thing out, what you would have to have would be about a 6" concrete slab up there with some kind of topping on it, carried on steel springs like this on top or the 12" concrete slab and with fuzz in the inter-space just for sound absorption.

But then you take another 6" slab and then you have your wood floor on top of that with steel springs. This can be done, but this really begins to cost money and you are already spending money like mad here on some of the things we've already did. That's all there is and it is not drum-proof or jump-proof. It certainly is not.

In fact, if you want to look at it sometime you can lift up, there are some hatches in the floor you can lift up and look down in there. You can look in some of the places where electrical connections go and you'll see the fiberglass sitting right there and you can even feel it if you want to; it's soft.

Student: *(inaudible)*
Now the floor is connected at the leading edge here, there is a wooden member here that receives the floor and this is connected here at this point. So the floor floats up to here and then it is connected and it is connected at the walls with just no way sensibly to separate. But it's been very satisfactory as far as everything goes.

Now out here in the house, the 8" slab is reinforced with a 1" cement plaster ceiling and I say cement plaster simply because it's good and heavy. We wanted 10 lbs. per sq. ft. which you get from an inch of good heavy sand, cement plaster on metal lath that is carried on resilient hangers that hang down and that serve the Little Theatre and the lighting instrument serves the Little Theatre and finally the plastering with scoops and all that jazz which is honking risk.

But there's nothing in this space and the space is the order of 18" so kind of double construction of 8" concrete, resilient hangers and a 1" plaster and all this other junk that serves the Little Theatre from underneath, and there is no penetration into this space at all.

And I purposely checked the channels when it was in construction, getting up on the scaffolding and jumping up and down just to be sure they bounce. You know if resilient, it must bounce and you check something like this out and it goes 'screererer…' the side walls and the channels are touching the side walls and they have to be cut off. It must be resilient; it must be separate and you can check these things as you go along and avoid an awfully lot of trouble later on. The Fuller Company who built the building just hated to see me appearing on the scene. They knew I was going to raise hell about something and it's a terrible thing to have to do, just awful job to have to do because everything had to be shoe-horned into place.

You get back here and then there is some real fancy shoe-horning. We'll just cut a little bit out here and we now have the floor, and then we rise up for the stadium seating section in back of the cross aisle and here are some ducts, and this is where the air goes out. There are no mushrooms in the floor no air extraction was permitted through this floor because it is a sound barrier and the mechanical engineer said well we always extract the air through the floor, through mushrooms. We do not extract the air through mushrooms in the Kresge Auditorium because if you do, then all the noise is going to come up so you can't have it that way. (Laughter)

This is sort of standard stuff, we always do it that way and it's always wrong. The air goes out here, and here is a 2" plaster ceiling to form a top of the duct and then completely separated from it is the plaster ceiling of the rehearsal room downstairs, which is also 2" plaster and it's hung on some kind of resilient hangers and other stuff here. And then, this is the rehearsal room downstairs here, which is below each side of the back of the theater and the reason the ceiling goes down there is that the return air ducts go down and it had to follow that. It is all this absolute like a shoe-horn fit, and then the ducts that serve the Little Theatre had to snake in here somehow, I don't remember just how they did it, but around the edge and down and through and into this and no penetrations this and incredible loss of fitting and screwing around to get it in there to work.

Well, by and large I think the isolation has been reasonably successful, but as you point out there are times when it isn't and to make something absolutely totally sound proof is almost economically unfeasible to meet the general use requirements.

Anybody else have any comments or questions about corroborating reaction? Simultaneous use of and flexibility in a building, whether it is a college building or religious or domestic or whatever, I think simultaneous use of adjoining spaces is something that ought to be possible and that we should not concede the use of the space next to another space just because of noise leakage. But to achieve this we've got to apply all these principles I've been yakking about here at you for weeks and which I hope you believe to do this you've got to plan ahead and make these provisions at the outset.

So there is no use talking about hanging this here with ordinary hangers and then as the Fuller Company suggested, somebody suggested, well, why don't we use ordinary hangers and we can blow in some mineral wool for insulation. The great faith that is put in insulation by the building trade and by the designers of the building is incredible all over the world. Hanging with rigid hangers and blowing in some fluff, some fuzz or whatever you want to call it, will do absolutely <u>nothing</u> to the problem of getting a separate structure here. You've got to have the resiliency, the softness, the squishiness in-between, and it's got to be really free all around.

I guess the most radical case of isolation or two radical cases are: one, the National Film Board of Canada about, oh this is almost 20 years ago now. They asked me to come to Montreal to look at a situation they had. They were planning a new building studio for the National Film Board and had a site selected, and the site was six miles from the Montreal Airport, which sounds not so bad except that it was right on the direction of the principle runway and they wanted to be able to make films in this studio and have absolutely no intrusion of noise from four-engine jet aircraft taking off fully loaded for a transatlantic flight from the Montreal Airport and flying over this site. And at the time they got over this site they would be at 1500 feet. Now using the well-known formula, $I = P/4\pi d^2$, one can compute what will be the noise level at the ground for a four engine jet aircraft flying at 1500 feet.

And indeed it was a serious intrusion and, of course, when you are making films and so on you can spoil some sound track very quickly with an airplane coming into the middle of a birds and bees scene or something of the sort. This you just don't want.

So, my first suggestion was, why don't you put it someplace else. What you always start out with is: “couldn't you put it someplace quiet?” Well, no, it was politically expedient to put it where they were putting it and the site was determined, and they would appreciate it very much if I wouldn't raise any further questions about that. Let's get on with your work young man. So I did. I said, well, the only answer is to build two buildings. Two buildings? We only want one. No, but you have to have two, one inside the other to make this thing work. And what we did worked. And don't ask me if it’s any better than it needed to be, because any foreign engineer always designs things a lot better than they need to be, so he doesn't get himself hung (hanged?.. laughter)

A 6" concrete slab on a 1 foot brick wall. We use just ordinary nice simple vulgar material you know and steel structures. This is the interior of the studio and they hang from this all the lights and garbage along with the ducts and everything else. And then two feet away we build another building, just like it. One foot brick, two feet of air space, and then we go off here 10 feet and we have another set of·structure and we have another 6'' concrete slab. Here is the Film Board, here is the studio in here with insulation all over the inside for acoustical purposes. The air conditioning which has monstrous requirements in a filming studio or a TV studio where you have lights and everything else; the air conditioning comes in through great long sections of lined duct with turns and elaborate fans and everything comes in and out at the inlet and outlet ends of the thing so that the fan noise together with the jet aircraft noise comes in through this great labyrinth of fuzz.

They tested it by buzzing the building site with a fighter jet. They didn't hear it inside so they decided it was okay. We can prevent that (cough) That is expensive, but it’s the price you pay for the use of the site. Just as I said at the beginning of the term, for U. Mass Boston Campus Buildings, they are going to cost more money for the taxpayers of Massachusetts than everybody involved, it is going to cost more money because they are being built on a very noisy site. They've got to have double glazing, they've got to have all sorts of heavy airtight construction in order to work at all. If one selects a site where there is going to be noise, then the noise control issues have got to be faced squarely, and it may well cost more money. It may be worth it, it may well be worth it to put it there and I cannot argue that this is not a wise place to put this thing.

In a case like this, the addition of fuzz is very useful where you have a short airspace like 4” or 6” or 2” or something of that sort, and when the walls are relatively light-weight, because the fuzz effectively increases the benefit of the airspace and increases the softness of the spring.

Now if we go to a 1 foot break and 2 foot break airspace, I doubt that a little fuzz in there would have made any difference. We did not use it. Now they may have put it in for heat insulation in Montreal, I'm not sure, but as far as our acoustics recommendations went, we did not call for it.

Now the other extreme case, now this is really ridiculous when I tell you this one. This is the Port of New York Authority Boardroom, down on lower Broadway, and the situation was this. Here is a heavy concrete slab and here is a brick wall. This is the wall of an elevator shaft and in this elevator shaft go 3 or 6, 6 large truck elevators. Elevators on which you back a trailer truck; I guess you just send the trailer up, I don’t know; but it is an enormous elevator and then this is a warehouse up here for the Port Authority. This many floors, you see. And up here on top of the space, this is where the Boardroom is going to go, and here are the motors, and so on, which is for these big truck elevators you know, out here, just enormous. And every time one of these elevators starts or stops there is a certain ‘*ROOOOORR”* reaction and the motor

"'*ZOOOOOOOMZOOOOMS*" and the motor jumps up and down like this and the floor the slab "*ROOMROOOM*", and they have some light fixtures in there "*WHRRRRRRR*". (laughter) Incredible. We want the Boardroom *here*. There are also a number of other freight elevators and passenger elevators.

All the elevator equipment in the building was on the slab immediately above where the Boardroom is going to go. And again the question: couldn't you make that storage and go someplace else for your damn Boardroom? No. We want it there. OK, we'll make it for you. So we hung in some extremely resilient hangers and put in about a 3" plaster ceiling. You make the plaster 3" thick by having many layers of board, you make·a lot of mud and put on some more slab and more mud finally finished plaster and here 6" brick wall on a steel beam carried on a steel spring. And don't ask me all the details of how you do this but it is done and it can be done.

It goes all the way around this place, 3,000 sq. ft. of spaces and then the fourth slab came in here and it too was carried on some very fancy steel springs. This goes over here, terminates and, of course, the duct work has to be brought in and all protected and plastered and it was just an incredible job. 3,000 sq. ft. in building a new space inside an existing building cost $100 per sq. ft. and you can figure out what that then cost. Umm. This is an exceedingly expensive piece of construction. I think an extravagant piece of construction, but this is what they wanted and this is what they got. It's a quiet boardroom. It's a good space. Very, very expensively achieved in this case, but if you insist on putting it underneath the freight elevator machinery and next to the shops that carry the elevators up and down, then this is the kind of measure which you have to take.

I would recommend very strongly against ever doing this again. I would scare the hell out of them. The trouble is that somebody else who wants to do this can go there and see that it can be done and then he wants it for himself. So you have got to do it over again. I think it's a very unwise procedure. A long miserable life, this retched situation. Perhaps enough of these things of high sound isolation requirements are not something that come into everyday practice, but you ought to know about how you can achieve them in really solving these very difficult problems.

On Friday we'll begin talking about mechanical equipment. ·

End of Audio file 14

THE END

Robert Bradford Newman Lectures

6 November 1970
LECTURE 15

Title: "Mechanical Noise Control"

Summary: In this lecture, Newman discusses noise control and vibration isolation for mechanical equipment. He also talks about reducing noise and vibration from railroads and subways.

Beginning of Audio File 15

In writing up the last problems, I omitted a piece of necessary information. It is in Problem 2 where you need to know the dimensions of a window; I just forgot about the window or its dimensions. Let's guess that the window will have a 4' x 4' piece. That's as good as any other number; use the same one. If you have already done this problem assuming some other area window, well, leave it alone. This area will just have to work in lots of different problems, but if you haven't, let's all be consistent and use the 4' x 4' window. I am sorry that I made that omission but it's not the first or the last mistake that I've made in my life.

I didn't see anything yesterday in Houston to bring back to you to talk about. It just looked like Houston, it was a lovely day; I had a good time and enlightened my fellow Acoustical Society members about what could be done about noise in the house. They are a very wise bunch, incredibly unapplied. I also attended a session in the morning yesterday which I found most enlightening on the subject of teaching of acoustics presented by a bunch of physics electrical engineering types, and I commented to one of them afterwards that the way you get people interested in acoustics is to teach them a good course. He wanted to know if I taught a good course and I said I thought I did, but at least they seem to learn something and they were concerned because people didn't seem to be learning very much and I could quite understand why. Presentations gave me the clue.

Today I want to kind of wind up our discussion of noise control of mechanical equipment and so on, and so that we can go on on Monday to talk about room acoustics. The second half of our course, the design for good hearing conditions. When we begin on Monday to talk about good hearing conditions the first thing we are going to talk about is noise control. You go right back into the pot again because probably the most important thing you can do in any auditorium, any space of any sort in which you want to hear well, the most important thing you can do is to make it absolutely dead silent. Get rid of all the background noise from mechanical equipment, from other spaces in the building, from lobbies, from simultaneously-used spaces.

We talked the other day about Kresge Auditorium and some of the details there and their degree or lack of degree of success, but the reason for so much emphasis on noise here in this course and noise control and the principles that govern is that it is basic and fundamental to the achievement of good hearing conditions. And that the minute we have noise, we don't hear. We mask out what we want to hear; the very thing we do to achieve privacy is exactly what we don't want when we have an auditorial condition. We want an un-private situation with total communication. And if you think that maybe we spent too much time talking about this rather mundane aspect of acoustics, I feel it is terribly important and that we understand completely how to go about controlling noise before we start worrying about how we go about hearing.

Today I'd like to talk a little bit about mechanical equipment, which is something that is very much with us in buildings today, in houses. We have lots of mechanical equipment. We often have hot air furnaces, we have air conditioning systems (we have in larger buildings, certainly), we always have some kind of air handling equipment or some kind of comfort conditioning and this happens in all parts of the world to varying degrees.

One aspect of acoustics that I think is very interesting, and I would like if we have time for it at the end of the term to come back to, is the question of acoustics in the tropics. The problems of tropical architecture differ considerably from the problems of architecture in temperate climates. In situations where we have natural ventilation as the comfort control device and wherever natural ventilation occurs, there goes noise control. And it's not easy, I haven't got any magic answers; I have one little example that I'd like to show you just in passing, and it has nothing to do with mechanical equipment, but it does have to do with noise transmission.

Oh, it's been ten years ago now. My wife and I took a vacation down in the island of Tabago, which is off Trinidad, and we stayed in a very nice small hotel that had no air conditioning and it just had natural breezes through it. There were probably 15 or 20 rooms altogether and it was arranged in one-story sort of buildings around the grounds there overlooking the water and it was very, very pleasant. And we liked it because we had natural ventilation, no air conditioning and bottled-up feeling. And one morning about 7 o'clock when I was awakened by the chatter and clatter of the maids outside our room, I lay there in bed and quickly redesigned the building. And I moved one line in the design and I solved all the problems.

Now let me describe this to you. Here is a pitched roof building, and it's this sort of thing that we need to use our ingenuity about. This is the section through the building and here is a balcony and here is a screen opening, the door through it, and here's the room. And then here is another screened opening up to 7' high and there is a partition with a door in it and then there is a column out here, a column out here, the roof and this is the corridor. Now here is the bedroom and the breeze comes through like this and it's very comfortable; it's very nice, everything is very pleasant about it.

The bathroom was here and partial height construction also ventilated over and out here into the hall. Now in the morning here we are sleeping and in the morning the maids arrive at seven o'clock. Now one of the things that one generally likes about being on vacation is <u>not</u> getting up at seven o'clock. (At least that's one of the things I enjoy, or maybe at eight or something.) But at seven, the maids arrive and they are out here in the hall having a tremendous time and talking all about their dates last night and just thoroughly enjoying life and banging a few buckets around and so on around. And they just might as well be in our room you might say because here they are under the same roof, a hundred percent transmission here through a 3 foot screen hole and they are right in the room. Also during the night if anyone gets up and uses his bathroom anywhere up and down this hall, he might as well be in your room and the flushing sound will certainly wake everybody up. It's just a sort of a public arrangement.

Well, this is fine; you are at least visually protected from the passers-by. But as I lay there in bed that particular morning while being awakened, I thought, you know: what if they had just done this, how much better it all would have been. We have a door, this is closed, we get the ventilation. The corridor doesn't need that ventilation; it's open on the side anyhow. And if we just had had a roof here to keep this noise from coming in, how much more pleasant it would have been, how much less transmission we would have had from room to room by virtue of this containment of the corridor ceiling and we could have had all the same advantages of natural ventilation and just been a hell of a lot better off.

Well, now this particular case works in a single-loaded corridor scheme. I've had problems presented where dormitories, for example, were going to be built at the college in Burma where they were going to have double-loaded corridors and natural ventilation and want to stop the noise. Now that becomes another horse [of a different color]. The minute we start putting in noise traps that are efficient enough to stop the transmission of noise across a corridor through ventilation and other things, you'd have to put in fans to force the air to go through it because the noise traps become sinuous devious path sorts of things with lots of fuzz in the lining and they introduce enough static pressures so that natural ventilation doesn't happen.

Student: (inaudible)
Yes, this is exactly like somebody coming to you and saying, dear Mr. Architect, I love to look right through the roof and see the sky, I don't want any glass in there; I don't want any rain coming through. You can forget it. (Laughter) It's not going to happen. And where air goes, sound goes. There are oodles of these things so you just have to make up your mind that okay, that maybe is a solution, but it's not going to work if your requirement is of reasonable privacy.

Well, this is a non-mechanical equipment noise problem, but it's the sort of think that I hope you'll all come around to thinking about just as a way of thinking if nothing else from this series of lectures. Always try to figure out what could be done, what makes sense, what's likely to work, and what isn't likely to work, and don't get carried away by the anti-noise carpet or anything of that sort. Go back to Newton and forget about today.

Mechanical equipment, as I demonstrated with the black box experiment, must always be resiliently separated from structure. Whatever the mechanical equipment may be, whether it's a dishwasher in the kitchen or exhaust fan, a big circulating fan, refrigeration compressors in an air conditioning system, a cooling tower or whatever. It must be resiliently mounted. It must be on something that is soft and squishy. Now I brought in this morning in my shopping bag here some springs. I'll pass these around if you like. Now the first sample is the two little pieces of stuff that I'll pass around. This material is called Fab-cell. It's made here in Boston. This is the material I used under my dishwasher at home. This is a waffle neoprene and if you look you'll see that the voids are opposite solids on the other side. Not like a regular waffle, where the voids are opposite the voids. But this is a staggered waffle, since it's made out of neoprene and not for eating, we don't care about that.

Now, whenever we use rubber in a mounting for vibration isolation, we want to use it in some other mode than simple compression. In other words, this is a better piece of isolating material because it is <u>not</u> solid rubber, and the rubber is acting not purely in compression but partially in shear. Rubber-in-shear with shear stresses in it is much more effective as a vibration isolator than simple rubber in compression. Now rubber in compression can be used, but it's much, much less efficient. I'll pass these two samples around, and you can just squeeze it. Now that has to be loaded at about 40 to 50 pounds per square inch in order to be effectively resilient. Now here is another form of rubber-in-shear isolator. These aren't very clean; I'm sorry.

This one (I'll hold it up here and draw it), it has a piece of steel bent like this, then there is another piece of steel down here bent like this and in-between are blocks of rubber. What is it?

Student: "That's again in shear?"
It's in shear. This is practically a pure shear operation, not pure shear but you put the force on here and this is your base here so that the rubber is being acted on in shear. And this type of mount, this has a bolt in it

here for bolting a piece of equipment onto the top – bolt the legs of the equipment, whatever it is, onto this; this is the bolt and so on here. And then this goes on the ground and carries the machine very nicely in a shear fashion.

Now a mounting of this sort, a rubber-in-shear mount, is very good, as is that other type of rubber that I'm handing around for machines that have relatively high frequency noises. Not a compressor that goes "*CHUNKCHUNKCHUNKCHUNK*," but something that's going '*WEEEEEEEEE*," you know a high speed turbine or a high speed motor or something of that sort. What we have here, by the way, is another rubber-in-shear device – this is a ceiling hanger. This is what was used in Kresge Auditorium in the Little Theater downstairs. This unit has a rubber bell here and then we have a bolt coming through here with a hook on the bottom and a nut here and then this is carried in a frame. Goes on up like this to the hook up above and here is the rubber which is then pulled down, and again is acting in shear. Now there is some compression force there too, but the primary action is rubber in shear. This is a very standard sort of a mounting. I'm not sure just what sort of a load per unit goes on this, but when you hang a ceiling, a plaster ceiling, on these with normal channels and you see this is made to take that ordinary plastering channel. That kind of a ceiling will weigh 8 to 10 pounds a square foot, and these will happen about every 4 feet. So that's sort of 100 pounds or 150 pounds load on this is about what you have to have and again if you have too many of these you find that the whole thing becomes quite stiff and if you have too few it will bottom out. So you've got to load them properly for the application.

Let's see; pass this one down this side. I'm sorry I haven't got more of these. Now, in some situations we find ourselves wanting to use something considerably more resilient than a simple rubber-in-shear isolator, and I've got here a spring (damn, this is locked, *mumble, mumble…*) well, okay the load on this, this is a hanger spring but these can be made equally well for compression application. Here is a simple steel spring with the load applied onto this bolt here pulling downward so that the spring will compress. And you can isolate very much lower frequency sounds with a steel spring like this. You can get a static deflection on this of an inch or more.

This particular spring probably would have a static deflection of not more than half an inch or perhaps an inch when the load is first applied and the amount of static deflection, of course, will determine how resilient it is, how soft it is, how low will be the frequency that it will isolate.

But this is a typical hanger spring that we might use for a piece of equipment mounted on a platform and hung from the ceiling. We put another bolt up through here to hang this on up. Now my fans at home are all mounted with springs like this, hanging from the rafters above and another bolt coming down here, four of them supporting a little platform on which the fan actually sits. So that...

Student: "How heavy are the springs?"
Well, this spring is heavier than the ones I have at home. Oh, what do they weigh? 50 pounds, maybe for they are little fractional horsepower fans, you know. There is a motor so big and a fan on the end of it.

Student: "That other rubber one was less weight?"
For different application, I mean, that's a ceiling hanger, that's a thing that will work over a broad frequency range, sort of a non-machinery kind of isolation. When you have machinery with low rotational speeds then you almost have to go to something like this, a steel spring. You say, well gee, aren't those awfully

expensive? I'm not sure just what this costs, but I bought for $65 twenty-four springs for use in my house and so they are sort of $3 apiece, or $2, between $2 and $3.

Student: "So for the rubber pad, you said that was to stop the vibration carrying into the floor?""
That's from a machine like a dishwasher.

Student: (inaudible)
"If you had a piano, would those little rubber pads cover that?"
You'd do better, I mean they'll help. You have to figure out the loading. What you may have to do is to take a piece of plywood and if this is the wheel under your piano leg, stick a piece of plywood, you'll probably have to cut this a little bit so the damn thing doesn't roll off, and then calculate the area of this and maybe have two layers of this ribbed rubber underneath, like that, against the floor and calculate this so that the loading is at 40 pounds per square foot, no per square inch, I'm sorry. Thank you. Per square inch and it may take 2 or 3 square inches, you see, under each leg.

Student: "That would reduce the sound."
It reduces it quite a lot.

Student "Do you have to add a capacity for 2 mats underneath?"
No, they're in series and you can stack them up 3 or 4 deep and you get more and more effectiveness in the isolation. That is, the greater will be the static deflection of the pile of them. Therefore, the lower the natural frequency, the loading is the same. So that'll work. Now sometimes for pianos, I've done this, we take a rubber-in-shear mount, sort of like that one that's on the hanger like this, and we make up a cup. Here's a cup with three wheels, casters, outboard casters, and then we take the wheel off the bottom of the piano so we don't get the piano up so high that you play like this, you know, it is uncomfortable. And then we put in here a rubber-in-shear device, either like this or like this one or sometimes simply a gizmo like this would be, I'm drawing this a little bit small. But here's our rubber and this is a steel shank in here that we can put a bolt into or we can simply rest the leg of the piano on top of this. And this then acts in shear and it's even more effective than the simple sandwich like this. But this is an awful lot easier to do if you have the situation, you want to try it.

Get a hold of some of this stuff from Mr. Fabreeka [Fabreeka is the name of a cork-rubber isolator product] and, well, it's on the pad the address there right here in Boston. And I don't know what it is, I've never paid for any. I use free samples, but I'm running out of them so (laughter) but it isn't very expensive. This stuff is nice; it's better than some of the neoprene stuff that comes with ribs like this. I'm enlarging it; this is solid rubber and underneath is a bunch of ribs going the other way so that they are crossed at right angles. Now when you stack them up you have to put pieces of sheet metal in-between to distribute the load because otherwise, when you start loading the top of this one with this one you get a lot of point loading and it isn't as good. So when you stack up this kind of stuff you have to put a piece of sheet metal in, and then comes the next layer and the ribs and so on and then another layer of sheet metal. Whereas with this waffle stuff you are always on top of solid opposite void or void opposite void. It doesn't really matter, but it doesn't have to have this sheet metal sandwich.

Student: "When you stack it, you stack it void over solid?"
Yes, though I must confess that that isn't a major problem. Just stack them up.

Well, if you like, I can pass this around. It's kind of heavy. This hasn't been around has it? Steel spring. Once in a while we get into very severe problems and this relates not so much to the design of the mounting, but to the design of the building where the architect indeed has some influence. The State Street Bank Building in Boston has on the top floor a mechanical equipment penthouse. And the mechanical equipment there is big. Some of the fans have 25 feet diameter wheels, and 25 feet diameter wheels are not unusual in big fans in big buildings today.

Now a 25 foot wheel will be driven by a motor, electric motor. I don't remember whether it is 150 HP or just what. But they are big gizmos, this is not little fractional horsepower motors, and we design the isolation system for those fans and for the most part consisted of steel frames which are mounted outboard and one thing you have to be careful about when you use steel springs in compression is that they're fat enough so that they're not going to topple. And you don't want them restrained by some kind of metallic containment because then you short circuit the springs. You want fairly fat wide springs. You generally specify the diameter of the spring has to be greater than the compressed height of the spring. And then we often mount them in this fashion with a concrete base here which carries the machine itself, with the motor and all this jazz on it.

Now there are some very nice installations over in the basement of the Material Science Building, which is right in back of Building 7, and if some of you are interested I could certainly arrange sometime a field trip and we'd go look for these things. There are some very nice ones there. In any case, we generally try to have the mounting points for a big fan of this sort occur either very near the column or over a beam or somehow over some fairly massive and stiff construction and not out in mid-panel. In other words, if we have a framing system with fairly sizable spans and then we would like to have these points of mounting stand not in the middle of a slab. Remember, when we have a spring system and we push down on it, then the floor has got to be able to resist that downward force and we've got to push back with our floor. Otherwise, the whole thing is just going to move, unless we have a resistance. And one secret of success in any kind of vibration mounting is to have adequate resistance in the subsystem on which we are mounted.

Well, to make a long story short, in the State Street Bank there are three or four of these large fans. One of them through some job condition (and job conditions or site conditions always happen and you find in any building that when you go into it later you'll find that the drawings are not followed exactly for many, many reasons). Nobody can properly remember, but for some reason or other it couldn't be put there, so they put it over here instead. And one of these fans got mounted with one of its legs in a mid-panel point on a slab. And this resulted in the transmission of some very low frequency sound down three floors below and then into the ceiling structure of some offices. I don't know whether it was happening in the intermediate space but the guys that were complaining were down three floors and their complaint said to the owner, you either get rid of that vibration or we are moving out. And whenever you are a building owner and you have renting customers who say we are moving out; you generally try to do something about it. Because that's the whole reason for having a rented building anyhow is to have those people in, not out.

So we were called back to see what could be done and we did a very quick investigation and discovered the offending fan: we do this by turning off various units to see which is it that's causing the trouble. And we substituted for the steel springs, in the final analysis, air springs. And the air springs are more expensive; air springs are simply big rubber balloons so to speak, which have considerably lower natural frequencies than the steel spring. And has to be kept pumped up all the time; so you have to have a source of compressed air, which they had in the building for their controls anyhow. But we had to go to air springs on this particular fan that was causing trouble. All the others mounted exactly the same way but with different underneath conditions were perfectly satisfactory.

Student: "Is this the same category in which we would discuss a building built above a railroad?"
No, well, of course, the isolation of a building from vibration is the same kind of problem. It's a different scale and we never resort to keeping it pumped up on air springs. (laughter) With power failure, you know. The building vibration, let me just say two things about it. First of all, if you are going to build a building over a railroad track or a subway line or something, if you can possibly mount the subway line or the railroad tracks on a resilient mount, do so. That, of course, generally can consist of steel springs, we have done track isolation where we have steel springs and then the track is carried on a concrete slab in some such fashion as this. That's a beautiful way to do it. Now that can't always be done and we sometimes lay a concrete slab and we have rubber gizmos or rubber pads that are shaped sort of like this. And this is the track)it fits in here), the bottom of the track, and then there are some metal pieces that come up here and clamp this down to keep the track from going anywhere. I don't know whether this is clear or not. This is rubber and this is pretty much rubber in compression. It is pretty hard to get any shear forces in there and the track itself is simply cradled in the rubber.

Now if we can't do that, then we mount the building, and today—as in past years—we have used what we called "lead-asbestos sandwiches." A lead-asbestos sandwich is not for eating but for bearing pads under buildings. It consists of an 1/8" of lead and an 1/8" of asbestos and 1/16" of steel and an 1/8" of asbestos and a 1/16th of an inch of steel and an 1/8" of lead, etc., etc., etc., in a sandwich. The whole thing encased in an 1/8" inch lead box so that it is protected forever against water and so on.

Student: (inaudible))
The foundation is resting on it, now what you do is make a cup like this. This is the sub-foundation and then you have your lead-asbestos sandwich in here, and then you pour your actual building footing here. This is the lead-asbestos sandwich, and the column goes on up here. Now this is more than 40 lbs. per sq. in. and this is real loaded and if you take one of these pads you'll think it's just absolutely solid and stiff as a piece of wood or concrete. This has been done for almost all the buildings along Park Avenue in New York, above the railway tracks, and they are mounted on lead-asbestos sandwiches to minimize the transmission of railroad rumble in the buildings. There aren't any basements under most of the buildings, you know, and they just sit up there on feet resting on the tracks.

Student: "How much would you say of street noise is transmitted because the streets aren't resilient? Is most of it done through the air?"
I'd say most of the ordinary street noises that we get are airborne noises. So if you could somehow make the roads on lead asbestos sandwiches, that wouldn't make much difference.

Student: "What did they do to the Howard Johnson's on the Mass. Pike?"
I have no idea, probably nothing.

Student: (inaudible)
Down here in Newton, yes. No, I don't think they did anything there. You see when you have, well there is a railroad track there, too, isn't there. Yeah. Well, you can just ignore the problem, that's the way it's usually done. The hell with it, so it's lousy; who cares. What's one more lousy building? That's what said about the

Jordan Marsh department store. He was a guest professor here; I was a student then. We were chiding him that his firm had just done the Jordan Marsh store downtown and what does he think of that? He was doing the dormitory over here, as he always called it, and he said, oh what the hell is one more lousy department store. So I figure, you know, one more lousy building is just one more lousy building. There are so many that one or two more doesn't matter. But if you really want to go first class and do it right, then you have to take into account these things.

What I started to say is: you have all these other things (and none of this is in my notes), what we do today is instead of this lead-asbestos, we use neoprene. And we feel from many points of view that neoprene is a better answer, is a more resilient material and it's more likely to be successful over a long period of time. So we used asbestos in many buildings that have been up for a good many years and New York City along Park Avenue there is quite long term and quite good. I think I may have told you at the beginning of the term. [Would you please cut out the speech interference level in the halls by closing the door? (laughter) But maybe that won't help, I'm sorry. I merely identified this coming from that corner. (Laughter)]

I may have told you at the beginning of the term about a project in Toronto. Did I talk about the Toronto Project Canadian National Railway? Well, we were consultants on this job and I may have told you they were going to do it and now they decided not to because it is so expensive. Canadian National Railway in Toronto has a piece of land. The Canadian National owns a strip of land across Canada that's, I don't know how many feet wide, but it is kind of wide, and some of it's quite valuable because it is downtown Toronto and downtown Montreal and a few places like that and a lot of isn't worth anything. Queen Victoria gave them this land. In any case, here is an embankment and here are four or five main railroad tracks here. The Trans-Canada principle main line and freight is moved here all the time and they have three and four diesel engines pulling mile and two mile long freight trains through here day and night all the time.

The Canadian National owns this piece of land here and they want to put up some high rise apartments and other things here and they want it to be nice, first class rentable stuff. And we've been working with Canadian National now for several different places in far west of Canada and now in Toronto and other places towards building buildings that they will own on their land adjoining railroad tracks. And I think the conclusion that we about to come to is that it's just too expensive to make any sense; just damn well better do something else there like warehousing. But what we proposed here was that these buildings be on resilient feet. I'll just indicate that, but fancy neoprene pads, because the railroad track couldn't be lifted up even though it's their railroad track. They simply couldn't operate and they can't shut down because this is the main artery of freight transportation across Canada.

And so we said okay, if you can't do that, then what you've got to do is build a tunnel over this damn thing for two miles. You know I don't want to put concrete, build a tunnel over it. And we made very careful analysis of the noise here and we had guys up there all night measuring and so on and the answer is: you enclose this thing for two miles in each direction and put the buildings on neoprene pads, and then you'll be able to rent apartments in this area where people can open their windows, which a lot of people like to do, and maybe sit out on the balcony, and maybe even walk around outside under the trees and roll on the grass or something and be able to do this without the intrusion of intense and very high level of railroad track noise. Now this site is on Young Street, very much in downtown Toronto, very important and valuable site which is presently underdeveloped, underdeveloped for the reason that the railroad track is there and I don't know what they are going to do about developing it. But they have decided that this approach makes it just too expensive to be an economically viable situation.

Yes, Ma'am

Student: “Once it’s enclosed, can they build separate structures over it?”
They could, they could indeed. We investigated several years ago for Perkins & Will the feasibility here in Boston, you know the Employers Group Building that is coming up right now across the street from King's Chapel, the corner of Tremont St. and Beacon St. There is a great hole there right now, an enormous hole. They asked us to check on two sites for feasibility, one is that site and one was down as not an “air-rights” building, but an “under-rights” building at the central artery of the elevated roadway down at State St. And the question was: is there any insurmountable noise problem if this is the expressway and going underneath this expressway with part of the building and then going up here with building that overlooks the expressway. They wanted to have “under-rights” and “over-“ or “side-rights” but not “air-rights” over the thing. And the answer was that if the building were built separate from the structure of the roadway, which it would have to be, there would be no problem here any greater than the problem they would have at the other site where they have a subway running by. In neither case is it bad enough to warrant putting the building on resilient mounts.

City Hall in Boston has two subways going under it, one of which was built just before the City Hall structure was started and we kept badgering the architect about doing something about mounting that building, City Hall, on resilient pads because in other buildings in the area even as high as ten floors up you have people's desk drawers rattling and things like that, you know, from the subway passing underneath.

Well, this is one of those problems that kind of got swept under the rug. We kept hoping that the acoustics problem would go away and stop talking about problems, we don't want to hear about the problems. We want everything to be lovely and beautiful and peaceful and calm and they don't want to hear about the problems, we don't want to hear about the problem. And we said, if you are putting a new subway, couldn't we at least mount that subway track properly on rubber pads? These are standard railroad pads that I talked about for mounting tracks. And there was an old fossil in the MBTA, General or Colonel somebody or other (laughter) that said: No; you couldn't do that, and he kept saying No. And finally he got his subway finished and then Bill LeMesssurier, who was the structural engineer on the job, said well, we can't have any resilient pads under the building footings because this isn't an ordinary building that just goes up you know all uniformly loaded on the footings. We go up five stories with some columns and there is no load on it until finally we put some up here when we get up that high and then all of a sudden take up the load and then suddenly that column is loaded and he said this building is coming so near to being a “high-crack probability structure” that we don't dare put resilient footing underneath. And so the building was built without any precaution for subway noise. I do not know whether it's a serious problem or not. Maybe some of you know.

Student: “That’s such an extraordinarily heavy building, is it possible that you don’t get subway noise in that building where you might in a lighter building?”
Yes, certainly there would be less.

Student: (inaudible)
However, I just want to tell you, I know of a case in Philadelphia, City Hall, which is a very massive masonry building. Now whether it's as massive as City Hall in Boston, I don't know but it's a very, very heavy building. I was called down there to look at a courtroom which is on the third floor. And this

courtroom was above the arch that leads out towards Market Street going towards the Delaware River and the subway, the Market Street subway line, runs right underneath it. And the subway was put in many years after the building was built and this courtroom had four granite columns supporting its floor structure at both sides of the archway here. And these heavy granite columns went down and the subway tracks had been mounted on concrete that was poured integrally with the footings for these columns. So every time the subway train went underneath, the courtroom procedures stopped for ten seconds 1-2-3-4- and then they could go on. And it was an incredible thing, every time the subway would go under the things would go (loud knocking sound), everything would go *roootaaarrrooo* and then it would stop (laughter) What to do. I had them put the tracks on some neoprene, that's what you do. You couldn't rebuild the City Hall.

Student: (inaudible)
Well, yeah, I don't know, it hasn't been something certainly that has been bad enough to do anything about.

Yes.

Student: (inaudible)
Well, the placement of the spring….let's just consider that a spring under a piece of equipment ought to be over [supported on] as heavy and stiff a member as you can have.

Student: (inaudible)
The point is a 3" concrete slab under a piece of machinery and out in mid-span or carried over by bar joists simply is not even massive or stiff enough to resist the downward forces of a fairly heavy piece of equipment. It might be perfectly all right for a little fractional horsepower motor. But always mechanical equipment floors have to be heavier and stiffer and built a lot better than ordinary personal equipment.

Student: "When a site condition like that happens, who is responsible, the contractor?"
I don't know how this was finally settled. I'd rather think the owner paid for it. This was just one of those things. It wasn't a blatant case of negligence.

Student: (inaudible)
I guess he was, I really don't know. But you as architects are not the mechanical engineers, you are not designing all these mounts and so on, but you've got to set the stage for it and you've got to be prepared to look at these things and see whether they are being put in properly. Avoid short-circuits by other trades. There is always some clown that comes along and wants a light [fixture] or something on a piece of equipment, and he has to have it in rigid conduit [that is] coming over. And there is a couple of cases over here in the basement of the Material Science Building where everything is beautifully mounted and then somebody in physical plant decided they needed an extra light there so that they could see what they were doing when they were oiling it which is a reasonable requirement and then in goes this light and a piece of rigid conduit tied right over to the piece of machinery "*BZZZZZZZZZZZZZZ"* you've got yourself a path right on through the building to carry vibrations.

So just remember that the vibration isolation of any kind of equipment has to be designed for the equipment but you have to provide adequate underpinnings in terms of mass and stiffness. Probably, the worse sorts of equipment probably to isolate are big reciprocating compressors which just go chunkchunk chunkchunk chunk like that.

In fact, the worse one I ever saw in my life was a single cylinder compressor for an air conditioning system in the theatre at the auditorium in the University of Puerto Rico in San Juan. There's a tremendous compressor downstairs and it does *chunkchunkchunkchunkchunk* like that; it was tied rigidly to the building and to the whole back half of the auditorium. If you sit in any seat you get *whoompwhoompwhoomp* underneath like that (laughter). A very stimulating experience. (laughter)

Student: "What do they do to try to isolate mechanical equipment in airplanes?"
Well, of course, the airplane game is a whole new game because we can't have all new planes and a lot of stuff just simply isn't isolated and you can hear a lot of particularly high frequency "*WHOOOOOO"* things like that. A lot of it is isolated and generally rubber-in-shear is used for these isolations.

Student: (inaudible)
No, but the engines are carried. You watch when a propeller engine starts up, it isn't rigid; you can see the whole thing popping around. Just what a car engine does. Car engines are isolated with rubber-in-shear mounts. In fact, the very first application of rubber-in-shear mounts is automobile engines. I think the Plymouth is the very first automobile engine mounted with rubber-in-shear, and that was some 40 years ago, and I believe some of them are still in existence and are known still to be working. It's a long history of this particular kind of application.

Cooling towers are another very tough thing to isolate, especially where they have big fans, slow moving fans on the top. This is a kind of a whompitywhompetywhompetyhomp, and sometimes we mount cooling towers with 6" static deflections in the springs. Very, very soft mounting.

Another thing I might say just in kind of winding this up, is, for God's sake, if you possibly can, put the fan someplace else than where you are thinking about.

Student: (inaudible)
That's right, the other guys building. If this is an auditorium for example, this is a hall (blank) Damnit, it's awfully hard. Here are the mechanical equipment rooms; this is a transverse section through the auditorium, here is the stage down here and all the seats and people. And then this is circulation, you see, and it is a great temptation to say: well, this space up here isn't used very much for anything else, so you can call it *miscellaneous*, or *storage,* or janitor, that's for janitor. But that's kind of unhandy for storing and for the janitor and everything, so we'll call it that other thing we always put in there, mech. (laughter) That's the two sides of the auditorium. Now this is just about as hard a thing as you can find to do. It's really tough. We had to do a super-double wall here and everything is on sort of foot high springs (laughter), beautiful, lovely insulation and it's a textbook to look at it. But it took a tremendous lot of work to achieve it. This would just be so much better down here someplace or under the building next door. If you can avoid putting – I've seen mechanical equip also, this is a balcony, this is a great favorite space for mechanical equipment. Because this balcony under the balcony space isn't very good for much else and you might as well stuff all the fans and compressors and everything in there. And then it's real handy and you don't have long duct runs at all, you just pump the air *Pssssssst* right out there (laughter). Well, we'll come back to a few more of these things but we'll begin room acoustics on Monday.

End of Audio File 15

THE END

Robert Bradford Newman Lectures

9 November 1970

LECTURE 16

Title: "Flutter Echo and Background Noise"

Summary: In this lecture, Newman talks about what can be done to prevent flutter echo. He also discusses various sources of background noise and describes some of his experiences with noise problems in concert halls and theaters.

Beginning of Audio File 16

We'll have to work out the problems, like the ones you've been given to do here in class, and the answer was probably not, the purpose in asking you to do problems and in having quizzes and further such inquisitional procedures is, I hope, to educate you, that's the purpose of this course, the only purpose to teach you something about acoustics. I've no other purpose here, and I think it's a good idea perhaps to know a little more about the subject than you actually are using in everyday practice and to understand; and I hope that doing these problems brings you an understanding of the importance of various aspects of the real problem, the consequences of leaks and cracks, what happens when you fetch a sound source from outdoors indoors, what happens to the relative levels at certain distances away from these sources, and so on. It is really just a matter of getting familiar with the decibel, and with the way sound travels in buildings—not so much that you ever have to calculate any such thing, but at least you'll be prepared qualitatively to make judgments and to know when you see something that's really proper or that maybe doesn't just have any chance of working.

Now I had a call on Friday afternoon from a very prominent and well-known architect, whose name I won't mention, and he was talking to me about a new building he had just done, and one of the big shots was bothered because his office sounds like a barrel, his office sounds like a barrel. Now in plan, the office is as follows. Here's a glass wall, here's a plaster wall, here's a plaster wall, and here's a glass wall—no, this is plaster—and a pair of doors, wall, door here, door here, 30 feet long and 20 feet wide, nice sized office, and the man sits at his desk right here, I judge, if you tell by the description of the patient.

And I'm not sure just what happens in the rest of the space, and I said well, what are the finishes? He said well, we didn't do anything about acoustics in this building, didn't think it was much of a problem, and after all it's just an office building. It's been much photographed and published in all the magazines. This is glass and I said, well aren't there any curtains? Oh no, no, no, that's part of the scheme, no curtains. And are there any bookcases or other junk? No, no, no, he's got a low bookcase behind his desk, but no other junk. You mean just plain bare plaster? That's right, bare plaster. And the floor is, of course, carpeted? Yes, the floor's carpeted. And what's on the ceiling? Well he said, it's acoustical plaster, but it probably doesn't do any good!" he said, even before I could jump in to tell him that he was an ass for using acoustical plaster. It's just lousy, no-good, stinking material, never use it.

Well, I said, it's very simple, the man is suffering from flutter. He's got a serious case of flutter, and the only way you're going to cure that is to hang a blanket up on the wall here, and we'll try that first, and then probably a blanket up on the wall here, maybe one up on the wall here, and when you begin to get enough blankets hanging around the room he'll probably feel pretty good again, and it won't sound barrel-like. An office with hard parallel walls, all sound reflecting, 20 feet or 15 feet or 10 feet or 30 feet apart, with fuzz on only the floor and/or ceiling is going to sound like a barrel. It's going to sound like a barrel for you, and for the famous great architects of the world, and for anybody else who perpetrates a thing like that, it just won't work. You cannot expect people to sit in an office like this. I may be exaggerating some of this, this is probably more likely, looks a little better, doesn't it? In any case, it's 20 feet x 30 feet and the inevitable result of designing that room that way is that it sounds like a barrel, and is uncomfortable. And until he beings to get some fuzz, some books or some junk or some things on the wall, some paintings, some things that will disturb the complete total smoothness and slickness of this thing, it's not going to sound like anything that anyone wants to stay in very long. End of report.

I don't know what's going to happen, I presume they're going to try some blankets, they thought that sounded like a keen idea, something you could try out to see if it works, and they they'll have to come in here for some kind of elegant $10 a square foot, gold-plated fuzz on the wall, I wonder what it'll be, but I'm sure it can be done very expensively. This is an expensive building.

Student: *"This would still have happened had there been reasonable acoustical stuff on the ceiling?"*
Oh yes, the acoustic plaster on the ceiling I have to condemn just as a general policy of condemnation, but the flutter might even have been worse had the ceiling been real efficient, because once you get two modes of the room very dead, that is top and bottom, then the horizontal modes persist and you hear them more. We've talked about flutter, haven't we? No? Heavenly days, mille pardons. Um, well let's talk about flutter.

I guess some year I should write some decent notes, so I don't make these horrible sins of omission, things that I have not done that I ought to have done.

Flutter echo is something that always happens between parallel walls in a room. In this room here I think I can excite the flutter echo although it's not acute because of the amount of junk. Let's see: CRASH CRASH CRASH etc. Get up on the desk here. CRASH CRASH – I can hear some of that liveness that runs back and forth between these surfaces. Now up here, this room isn't very good, the one across the hall used to be a classroom – CRASH CRASH – I can't hear it very well here, but take a room with really slick smooth surfaces, this room fortunately is jiggly enough so we really can't have any persistence of sound reflected back and forth, back and forth between smooth mirror-like surfaces. The University of Pennsylvania, in its new architecture building, maybe some of you have seen it, and I've described it a few times, has a supermarket hung ceiling in each of the lecture rooms, is acoustic material in a T-bar suspension system laid in panels, and this sound absorbing ceiling, together with the sound absorbing people pretty well does away with any up and down modes in the room, and the rooms are beautifully square and parallel and very smooth, even the tack-boards are set in flush with the plaster, so that it is all very, very flush and smooth. And when you talk in those rooms, everything you say goes "*BOING BOING BOING"* and you clap your hands and it goes *BOING* and you bang something on the desk and it goes *BOING* and you say something and it goes *BOING*. Just anything you do is repeated back and forth between the parallel surfaces, and this gives what this man describes as a barrel-like sound, somehow he's down in the middle of a hard, barrel-like space and he says it sounds like a barrel. Flutter echo, and I guess we really haven't talked about it, because, we haven't gotten into room acoustics yet, so I'm not surprised, but nevertheless, flutter echo is an unforgivable sin, it's something you cannot live with. A good place to observe flutter echo—there are two or three places—one is if you can find a situation where you've got a couple of buildings outdoors, the ends of a couple of buildings, with fuzz all around in the form of outdoors, and stand in here and clap your hands together, and you get a most marvelous flutter between the parallel surfaces.

The new lecture room in the next building up the street here, what the hell is it called, "Advanced Engineering" or something of the sort – "Building Nine" – Thank you. The lecture room in Building Nine is a very good lecture room, we helped design it. We also asked the architect, please don't make the walls hard and parallel, and of course they did, because they are Skidmore Owings & Merrill, and things are parallel in Skidmore Owings & Merrill's world, and that's the way they are. Now when that room was first finished, Messrs. Physical Plan went over to inspect, and Physical Plan clapped their hands – crash crash – between the parallel sided walls. And if you go in there and stand up in the middle of the audience area and clap your hands you'll hear a very classical flutter; it's a beautiful flutter. Now they have cluttered up the wall with some TV things for some purpose, and those have mitigated the flutter to some extent, so it isn't quite as textbook as it used to be, not quite as good. Parallelism always gives us trouble, it gives us a sense of ringing, of repetition of the sound, of prolongation that sounds funny, and is not comfortable, and we have to avoid it, and the more we get into junk and stuff happening, the happier we're going to be with our rooms.

Paul Rudolf once called me and sent me some drawings on a room sort of like this, only it was—I can't begin to describe the discrepancies, and the things that were happening here—but there was a window finally that happened here somehow, this is some simulation of the scheme, and at the other end had similar, and then there was a door. These surfaces were parallel, and this was a room in which in a private house was the living room, I think maybe there was a window there too, or something, it was very, very bizarre , and these people gave concerts in their living room, and this living room was about 35 feet long by about 20 feet wide, and they had a pair of concert grand pianos, you know like this, anyway to play piano duos and so on, and these were concert grands not ordinary little uprights, or baby grands, and these people wanted to have concerts, and this room was 15 to 16 feet high, parallel white plaster walls, and the end walls real juicy with stuff.

And Paul wanted to know how the acoustics were going to be in there, and I said: Lousy, dreadful, you really ought to do something. Don't these people, people who have two concert grand pianos, probably have a few other things, like some paintings and some sculpture and some other junk, don't they have any junk? Oh God, yes, they've got all kinds of junk, and I'm afraid they're going to put it in the room. Well, I said, you're afraid and they're going to have to, and the more things they get happening in here, with pictures hanging on the walls, and stuff, the happier they're going to get the room, because we are beginning to establish some diffusion, and get rid of this simple parallelism that will drive them absolutely nuts and make it quite impossible to use the room.

Student: "If the wall had been glass, would the same thing have happened?"
Yes. Glass is beautifully reflective, just as plaster or wood.

Student: "What if the wall had been broken up with a window?"
If the wall had been broken in some way, that would be fine, or even if they had been a little askew, in plan, not parallel. It is the deadliness of parallelism. If we skew things a bit, or introduce patches of fuzz, or bumps and wiggles, just anything, bookcases, pictures hanging at slant off the wall, instead of flat on it, or even a very rococo frame, just anything.

Student: "If the two walls were parallel, and there were two windows in it, is that enough junk?"
If the windows were you know, had a reveal and were offset. This kind of business is enough to get rid of it. This room does not have flutter in it, I don't hear it, and once in a while I think I can, "*CRASH CRASH*" –

there's a bit of a *BOING,* that you can almost hear, at least that I can hear, but that's just a little bit in this room, this room is just fine. It's just the right kind of junkiness and even the front wall and the back wall here, the fact that the blackboard is offset a little bit and there is that projector back there, there's just enough going on, and then I'm down here near you, and you absorb sound as it goes back and forth, as we will see in a few minutes, that seems to do it.

Well, excuse me for dragging in this little subject at the moment, but I like to do these things while they're hot in my mind, and to let you know that these problems are today's problems, not ten year ago problems, these things are happening right now.

Student: "The Harvard Law school, in the new building, has classrooms which I worked on the drawings of, and you recommended I think that the walls tilt. Is that as effective as taking them out of the parallel planes?"
Yes, I did talk about empty swimming pools, didn't I? The empty swimming pool is a classic case of the barrel like sound, that comes when you have a space that's shaped like this, and this is completely open, or totally fuzzy, and if you're down in here, making a noise, this place sounds very, very live. If you calculate the reverberation time according to $T = .05\ V/A$, you will find that it has a very low reverberation time, and yet when you're down here it sounds quite high. Now you're getting a combination of real reverberation, which we're going to talk a lot more about, and flutter, which is just the persistence back and forth of the sound between the parallel surfaces. And I mentioned that the way to get rid of this, and this is very easy to do, is just to stand up a couple of 4 foot by 8 foot pieces of plywood alongside the room, and all of sudden the room goes quite dead. You've added no fuzz, you've got the pattern of sound so it isn't buzzing back and forth and the sound is getting out and…Oh I've had so much fun so many times in my life, having sent for a piece of 4 foot by 8 foot plywood, it's a marvelous tool, and you have the flunkies bring it in, and you show them where to put it, and you can just—it's like walking on water almost, it's a miraculous cure that it produces in very troublesome situations.

I cured a death rattle one time in a guy's teaching studio. He said, my room has a death rattle in it. And I said, well let me hear it, let me see it, and sure enough a piece of 4 x 8 plywood and he was all fixed, and we decided that a bookcase would be more elegant treatment than a great big bit of 4 x 8 plywood sitting up on the end of his desk kind of skewed like this, so he put books on it and he was very happy after that. There are lots of ways of curing these.

I promised that today I would start talking about hearing conditions, and somehow we've gotten into it down the line a bit, now let's come back to the start. In the Time Savers Standards Reprint, there's quite a little bit on hearing conditions, and a lot of what I'm going to say this morning is there, and maybe you say, well we can read that and don't talk about it. But I want to really underscore two or three very important points.

First of all it is axiomatic almost that for good hearing conditions anywhere, outdoors in Singapore, indoors in Boston or any other number of places, we have to satisfy four very simple requirements for good hearing conditions anywhere in the world. The first is silent background. The second is adequate loudness of the sounds you want to hear, and the third is good distribution, and the fourth is proper separation of successive sounds with a proper blending. Now I've used a lot of pretty fancy adjectives here, all of which are highly qualitative, highly subjective and a matter of interpretation. Adequate loudness, good distribution, proper separation of successive sounds with proper blending, adequate blending, or enough blending, or whatever little words you want to use. And it's our job for the rest of the term to come to grips with what do these things mean, how do we go about achieving them in rooms, and what are we going to do.

Well, I've spent a lot of time, and I want to spend just a little bit more this morning talking about the silent background. No background noise at all. There's a relatively new theatre in Houston, called the Alley Theater, that Ulrich Franzen [Ulrich Franzen, Architect] did. It's right across the corner from Jones Hall in Houston about which I am also going to talk this term. And the Alley Theater is run by a lady by the name of Nina Vance, who was a well-known "impresariess," or something, whatever a lady impresario is, in the theater game, and the theater was scheduled to open, oh, a little more than a year ago, and oh six weeks or perhaps five weeks before the opening, they began to have rehearsals for the opening production in the theater. And the theater wasn't finished, they did get the workmen to stop hammering and banging when they were rehearsing, and they started rehearsing at night, but they had to have the air-conditioning on, because in Houston everything is air-conditioned all the time, otherwise you die, and I just rediscovered that last week when I was there, it was incredible.

In any case, the air-conditioning was on, the system had not been finished, and had not been balanced, and this "not been balanced yet" is the excuse always used by the mechanical guys for the excessive noise, and bad performance and drafts and everything else that comes from a newly installed system. And it is partially true. In any case the air-conditioning system was turned on and Miss Vance and her troupe were there to rehearse, and they immediately decided that the theater was an acoustical disaster, and they had to get a sound system in.

First thing you do when you can't hear is to get in a sound system, because somehow a sound system will solve all your problems, and God's voice will be heard, and everything will be just great. Now the problem was not needing a sound system, but the simple fact that the air-conditioning system made so much noise that people couldn't hear, even in rehearsal, and the air-conditioning system had not been finished, had not been balanced, and when it was, it went down to its appropriate silent inaudible level, and there's no more need for a sound system in there than there is in this room for you to hear me, or to hear anyone talk in this room. We never would think of using a sound system when we don't absolutely have to have it.

Silence, silence, silence in the background from outside and from inside the building. There should be no noise whatever coming in. Now I would like to suggest that the criterion for background noise level, intruding noise level, in any legitimate theater or concert hall should be what we would describe as an NC-15 spectrum. Now the NC spectra, Noise Criterion is what NC stands for, Noise Criterion 15. This is a spectrum, and it's shown in the Time Saver's Standards Guide, and it looks something like this, and add about 1,000 cycles per second, it will have a level of about 15 decibels. This is merely a description of a whole spectrum of background noise. Where is it in there? If someone finds it, perhaps they would call out the page, the NC curves are shown somewhere there, well, it doesn't matter at the moment. In any case, this is what we call NC-15, and this is inaudible, it's very near the limits of audibility. People will say to you, and I've had this said to me, many times, I have measured the levels of audience noise in rooms, and audiences make more noise than that; they rustle their programs, they squirm in their seats, they scuffle their feet, they blow their noses, hack and wheeze; yes, it's true, and you measure the noise of an audience, and it is likely to be up in here somewhere, maybe five decibels above this background noise.

The point is, however, especially in a concert hall, and in the theatre as well, if the performance is really good, and is really gripping, if Isaac Stern has just been playing some magnificent violin concerto with orchestra, and he finally gets to the end, and the orchestra has faded away, and he's bowing that last, and you can hear the rosin scraping on the A string, and he's just—everybody shuts up and stops sniffling and wheezing and coughing, and shaking their programs and so on—everybody shuts up, and it's absolutely deathly quiet, and then you come down to this floor of noise established by whatever else is serving the room. but you can hear that final last scraping nuance that's so important to this part of the performance, you don't lose it in the hash, or if you get some very tense dramatic moment in a play, where a whisper is the thing that carries the line; everybody shuts up and listens for it, and then you've got to get down to this level or you'll miss it!

And no performance, of any kind, can be done in a noisy space; with amplification, certainly you can amplify up to any level you like, and override almost any kind of noise, but this is not what we're talking about, we're talking about good hearing conditions. I didn't even write that up there: Good Hearing Conditions—where you hear well, without any effort, you can talk to 2,000 people in an auditorium, if it's well designed, if these other things are satisfied, without sound amplification and can be heard clearly by everyone if you talk in a voice as loud as the one I've used in here, there's no reason in the world why not. In fact in the ancient theaters, the outdoor Greek and Roman theaters, as many as 14,000 people heard unamplified voices, and the Romans and the Greeks had no better voices than we do today, they were exactly the same kind of people we are today, the evolutionary process has not changed, we haven't gone downhill, or up very much; exactly the same situation, and this was partially because these places were absolutely silent and free from Lambrettas and Vespas and aircraft flying overhead, and all the other things that make noise in today's world.

I may have mentioned—did I mention Damrosch Park to you earlier in the term? Maybe not; I've given so many lectures I just can't keep up with them, with whom I've said what, but Damrosch Park in New York City. Here is the Metropolitan Opera House, and here is St. Philips house, and here is the corner, now this is Amsterdam Avenue, and don't know whether this is 65th or what it is, but it doesn't matter, it's right up there in the 60s someplace. And this is a chunk of land belonging to the city of New York, and Robert Moses in his infinite wisdom, ten years ago, did a stately pleasure dome decree, in far-off New York, and he said let there be created here a band shell, an orchestra shell in memory of Walter Damrosch. What a hell of a thing to do to a nice old guy! To give him an absolutely jack-ass memorial! If anybody did this to me I would rise up out of my grave (laughter).

And then there are going to be some trees. Now trees are, of course, to stop the noise, everybody should know that! Mr. Ralph Walker, of the then firm Vorhees, Walker, Foley and Smith, and now it's, I can't think of all the newer names, but it doesn't matter, Ralph I think at that time was president of the A.I.A., he may not have been; in any case he asked us would we help him design this orchestra shell. And we said no, because it is an idiot project. And he said, Well, will you write me a report? Certainly, we'd be delighted, sir.

So we went down here and stood in the middle of where the audience was going to be, in this outdoor music-performing facility, and there we measured the noise from traffic, and we took maybe a five minute sample which was quite enough, and the traffic noise sample looked sort of like this here, a function of time in seconds or minutes, anything you like, and we have "*WRRRRRR WRRRR,"* etc., and these are levels up here, 80, 90 decibels. New York City traffic, or Boston City traffic, or anywhere, and you have ever taken the trouble to measure traffic noise, you will know that this is what it is. And then we plotted on this same curve the opening bars of Beethoven's 5th Symphony, we put a 100 piece symphony orchestra assembled here playing to this audience. Now we know the levels we get from that sort of thing, because we've measured them a lot. Now what the hell is the use of even talking about it? I mean it doesn't matter, it's a simple, I mean it's hopeless. And he said, well couldn't you amplify the orchestra? Yes, sure you could get it up to 120 decibels – the level of pain and earache. Who the hell wants to go and sit there in the middle of traffic noise and listen to a cartoon of symphony orchestra playing at 60 times (laughter). And, of course, the headlines in the newspaper when this damn thing opened a couple of years ago, the headline in the New York Times said "Noise the Victor in Damrosch Park" and it was just hopeless.

Student: "Have there been concerts there since?"
No; it's just impossible, it's hopeless. Of course the shell they built is also one of the jackass style round shells like this, which Mr. Belluschi said he asked the architect. Oh, Mr. Walker said he wouldn't do the job, so Eggers and Higgins [Architects] said they'd be charmed, and they did the job, and I asked them, what's this kooky shape? I understand that's not a very good shape for an orchestra shell, and they said: Well, it's just sculpture, really, and we'll solve the problems of focusing by lining it with acoustical tile, we'll line it with acoustical tile. Can you imagine lining sound reflecting projectors with acoustical tile? This is like painting the inside of your automobile headlamp reflector with flat black paint, because you don't like that shine. You won't get it to shine, you'll get a little gleam, and that's all.

And the argument there was that they wanted to cut down the level of sound because of the echo problem off this building, so you choke it down, and don't let it out. They don't have any echoes or any kinds of problems.

Student: "They actually put up the tiles?"
I don't know, this was what they said. If they didn't then they have a serious focusing problem, but it's all academic, because they're not going to use it. And ten years earlier I dug out of the files a 2-sentence letter, which we wrote to Mr. Walker saying: "Enclosed is our report, which shows the absolute insanity of trying to do this project in that place. It's impossible, and we suggest that you don't do it either—we won't." But people are going to continue to want to do this sort of thing, and you may well get involved in equally stupid projects, and just remember that it's hopeless.

Have any of you attended the Esplanade Concerts down on the river? O.K. Now I can remember back, twenty or more years ago when I used to enjoy going to those, this was before Storrow Drive was put in, that was indeed all a park area, and you could listen to music, and Fiedler [Arthur Fiedler, Conductor, Boston Pops Orchestra] would conduct the boys, and it could be very pleasant. Also I was, at that time, like you are now, looking for free entertainment, and other things like concerts I could go to that didn't cost much money. And it was really good except when the blimps used to fly over advertising Coca Cola and so on, and then they would *BLABLA* right overhead, and you couldn't hear anything for awhile, but it wasn't bad. Now Storrow Drive was added, and more aircraft traffic, considerably, motor boats on the river, and the result is that amplification was put in a few years ago, not nearly enough to override all this, but you can only hear really right close up.

Student: "Last summer they put in more amplification."
Well you make as big a cartoon as you like, just blow it up, bigger and bigger, to override the noise, but it really is not, at least it's not my cup of tea, for going to a concert. Now if other activity is your objective, and you want some background music, that's fine, and I have no objection at all to that sort of thing. But it just isn't listening to a concert.

Rain noise, rain noise is a problem. Back almost, well it is over 20 years ago, we did out at Aspen, Colorado, with Eero Saarinen, a tent for a musical festival that was held in Aspen at that time. Aspen was just kind of coming on the map as a cultural centre, had been a skiing center for a while, Mr. Pepki of Container Corp. decided that he'd like to have some culture there too, and so we did this tent with a marvelous plywood canopy over the orchestra area. Mitropoulos [Dimitri Mitropoulos, Conductor] conducted the Minneapolis Symphony and Mitropoulos was ecstatic about the acoustics in the tent, and was running around saying that all music henceforth should be performed in tents, to hell with these concert halls, look what you can get with a tent. Now a couple of problems with a tent: one was that every time it rained, you just had to stop.

Now one of the purposes of a tent is to keep the rain off the people, keep them dry. It does that, it does that very nicely, but you can't go on with the music, because of the rain noise on the tent. We can't hear anything. So if it rains, the concert stops. Now you can wait till the rain quits, or call it off, just depending on how long the rain is going to be.

Oh, it has been almost ten years ago, I went to Singapore to help an architect there with a new building for the National Theater, and he'd won a competition with his design, and he felt honor-bound to stick to some elements of the winning design. This is always a very tough thing. How do you award the first place to a winner, and then discover that the design isn't any good, and won't possibly work, and some of those that you've passed by, and which weren't quite so sexy, would work, but can the winner be permitted to get into something sensible, or must you go ahead and build the insane solution? I've come across this several times.

In Perth, in Australia, the competition for a new concert hall was won by an architect with a circular scheme, a round scheme like this, and here's the town, offices, some kind of linkage, I don't know, and I was asked, would you help us with this on the acoustics? And I said, well, if you must, but couldn't you use a square shape or some other shape like this. Well, they supposed they could. And I went to Perth, this was 4 or 5 years ago, and was received by the Lord Mayor and the Town Council and this very posh do, and we had this tremendous discussion about the morality of the situation. Now Mr. Newman, we understand, perfectly clearly, that this is a dreadful shape. I said yes, the most dreadful you could think of. And that you'd much rather have a rectangular shape. But we awarded this gentleman the prize for his circular shape because it was different, he said, different. And we feel honor-bound to proceed with this. I said, even in the face of disaster? Yes, it's a moral issue. And we had a debate that went on for 2 or 3 hours, with the Lord Mayor and everyone else waxing more and more pompous about the morality of not building a disaster. But I don't know what they've finally decided, they're still stewing as far as I know.

In any case this theater in Singapore had a scheme with a stage house here, and a large audience, 3,000 people, and then the big gimmick was a retractable roof which would somehow retract, I don't remember just how he was going to do it, because I didn't study it very far. But the retractable roof was to be made of corrugated aluminum. Now corrugated, whether you call it “aluminum” or “aluminium,” when it is rained upon, makes a loud noise, in Singapore and in Boston and in other places.

So I asked Mr. Wang, I said, have you ever been in a building with an aluminum roof during a rainstorm? Well he had, as a matter of fact, and he said, It's frightful. I said, Yes, it's frightful. Now what is the purpose of this roof, Mr. Wang? Well it's so when it rains during a performance we can extend the roof, you know, put up the umbrella. It's as simple as that, put up the umbrella. And is it then your purpose that the performance continues or merely that the people not get wet? Well both, he said. I said, well you accomplish only the latter purpose, that of so the people don't get wet, because they will not be able to hear at all. Well I discouraged him from this and he abandoned it, even though he had won the competition with it, and we have a fixed roof, a solid heavy roof, made of wood wool slabs like the Tectum or Porex things, rendered on the other side carved with cement so that they are hard and heavy, concrete-like surface, and then there's waterproofing overhead. Now this is fine, you don't hear very much of this rain noise, in fact in his backyard he made up a little shack with a roof of this material on it, and we sprayed the garden hose on top of it, and went inside and listened, and we had a lot of fun, making rain noise of various sorts with garden hoses, and this roof was decided upon.

Now the problem is that the rain on the ground outside—this thing is open on the sides—the rain on the ground outside is enough to mask the hearing of quite a lot of people around the perimeter. Also as the rain tends to blow a little, they all move in towards the center anyhow. There's no sense in doing a thing like that, because it cannot work, anywhere.

Student: "This is an interesting problem because when I went to this theater, and I didn't have any money I sat up on the hill way behind it, way up on the hill."
Back here?

Student: "Right, right, and I could hear perfectly. It's quite a sort of democratic solution for a city to (inaudible)."
Well, the hill as you say goes on up here, and in fact I think there's a little wall here and then it goes on some more, it's very steep, and we do have provisions here, it's a very good sound system, and I believe this line of sight is quite a lot of this area from it, and it's a very good thing. But if it rains, you go inside probably or go home.

Student: (inaudible)
Yes, it had a lens-shaped roof. Well, let's just talk about that one, as long as you've raised the question. The theater died, for a number of reasons. One was that inflatable roof was so much trouble to store in the winter, and so expensive, and they had to find a big warehouse, big enough to lay it out in, apparently it couldn't be folded up, for some reason. It was lens like this, supported with steel, I don't know just what kind of, but anyway some kind of pylons with a ring around it, perhaps some of you remember seeing it, and this was kept, here was the seating and a stage at one end here, the Charles River down here—"*BBBZZZRRR"*—boats, Soldiers Field Road over here with cars going "*BBBZZZRRR*", and aircraft from Logan flying right overhead—"*AAAHHHH"*—and so on. Now when Carl Koch [Carl Koch, Architect] who did this asked me to help him with it, I said, couldn't you put it somewhere else? My standard question! Couldn't you put it someplace else, like out in the forest somewhere in Bedford, or just some place. Well, no this has got to be here. O.K.

Student: "Where was it?"
At Soldiers Field Road, you know, where the Institute of Contemporary Art is?

Right there, there's an old, there's some kind of paving next to it, there, that was where it was. The thing burnt down for some reason. It had a stage house down at one end. I have no idea, I don't know any of the facts, and I'm not even going to speculate on it. The question was asked, how did this work in the rain? The answer is, it was quite noisy inside when it rained, both from patter on the roof, and from the water on the paving outside.

Now in this particular theater, the second season we finally persuaded them to put in a decent sound system, which I will describe later in the term, when I will talk about sound systems, and we could override the noise of the rain, we could override the noise of aircraft passing overhead, but this thin nylon membrane gave us almost no protection from outside noises at all. And, in fact, it did one very interesting thing that I hadn't even thought about, and that is the undersurface of this was just beautifully set up to reflect traffic noise from the street down into the seating area. It was worse than had we had no roof, because it was an added reflector down, and we hung up a lot of heavy canvas back there to try to help a little bit, you know, I said heavy canvas is no good as a sound barrier, but it might be 10 decibels, and if you drop the traffic noise by 10 decibels, why goody for you, and you can get some points. It was an incredibly complicated effort. Unfortunately, it didn't last for two seasons, and as I said, one of the problems was storing this thing, but it didn't exclude noise.

Student: "I just went to Tanglewood some time ago, and I found that I couldn't hear anything sitting out in the shed in the back."
Well it depends on where you sit outside, and I want to talk about the Tanglewood Shed. The big shed seats about 6,000. The opening at the back of the shed is only about 20 feet high, the shed is 40 feet high inside, and one of the things that we have wanted to do for a long, long time is to open up the whole back of the shed towards getting better sound outside. Now as you stand facing from the stage out, stage right, the land is fairly level outside, stage left it falls away, so that you're sitting stage left, it's quite likely you can't hear very far outside. But I certainly have listened many times outside there, and heard beautifully on a quiet night, when everybody is spell-bound by the performance. I think it was Stern [Isaac Stern, violinist] actually fiddling one night that I heard out there. It was absolutely magnificent. It isn't as good outside as it is inside. Now the Singapore thing is considerably better because it is a steep slope, and if we could slope the land up there at Tanglewood, we'd have to chop down a lot of those gorgeous trees. I wouldn't want to be part of it, but if we could, then we could improve matters considerably. And this too we're going to investigate by the way the effect of an audience as a sound absorber.

All sorts of simultaneous activities in the building have to be kept out, and we talked about Kresge, and the kinds of construction we go into, when you have lobbies that are used by more than one auditorium. You have a very serious problem because the intermissions for the two auditoriums will never coincide and so you have to have at least two sets of doors to a theater when it shares a lobby with another theater because of the hubbub and the noise that goes on outside during intermission. At Kresge, there is a dreadful problem in the Little Theater, particularly if there are two performances on and you have an intermission upstairs, then people out there in the lobby make a hell of a fuss and bother the people sitting in the back part of the Little Theater. I don't know whether you have had that experience or not but it is a common source of complaint and when we remodeled a little bit over there a couple of summers ago we wanted very much to get in two sets of doors and we simply couldn't do it without coming out into the landing at the bottom of the stair and that was ruled out for a number of aesthetic reasons but it's a very bad situation. There is only a single set of doors. But doors you certainly must have.

At Bowdin College there is the Picard Theater which is in an old building where (inaudible), and there are some stairs that come up out of the lobby like this, up here to this level and there are no doors separating the lobby from the theater itself. You simply come up at the two sides of the stadium section of seats and the lobby is in the theater and this is always a disaster because latecomers arrive in the lobby. It is lighted differently from the theater, it's brightly lighted, you assume somehow that the designers have fixed it so your loud yacking won't be heard in the theater and the result is latecomers come in and stand down here—bla bla bla—they are usually late because they are little bit tight and full of food and having a good time so they are in a good mood and make a lot of noise and somebody has to be sent down to shush them. You shouldn't have to shush people in a lobby. You've got to have doors, solid doors, not curtains, but doors and doors with weather strips. I'll show you over at Kresge when we visit there. Weather stripping on the doors just for sound isolation requirements.

At Houston, in Jones Hall, we had a problem of fire engine noise. The main fire house for downtown Houston is just a block away from Jones Hall and the fire engines always go by there on their way to good big downtown fires and we said to the architects Messrs. Caudell, Rowdell and Scott, you've got a problem, boys, with this fire engine noise. We've measured it, we went to the site, had our sound level meters, and we found out how much is it. We measured just exactly how many decibels when the fire engines go by, you know, full throttle, full sirens, and bells, and everything going. It worked out that in order to exclude the fire engine noise we would need to go to double glass in the exterior glazing of the building, which would have cost an extra $200,000 over the cost of single glass. Everything else stays the same, we've got a lobby, we've got doors to the theater itself and then the theater chamber; doors, walls, lobby, and glass. The glass would have to be doubled—double glass—by that I mean with an air space in between, and this was going to cost $200,000 to get rid of all audibility of the fire engine noise.

Now the owner said that's a lot of money and we said we realize it is an awful lot of money and he said how much would we hear if we don't do that. Well, I said, once in a while when it's very quiet in the hall, very quiet passage in the music or in a play or something, a fire engine goes by you are going to hear it very slightly. Well, we'll take that chance. OK, as long as we all understand it, and you can imagine my pleasure and the owner's pleasure when we were sitting together in the newly completed hall in silence one morning, nobody making any noise in the hall when the fire engines went by and we heard it and he said, "Just like you said, isn't that great," not "You bastard; why can we hear that," we knew we were going to hear it and we heard it just a little bit and he was very happy and everybody has been happy ever since. A little bit of intrusion like this every once in a while isn't a disaster and I don't think it's worth spending the money to keep it out.

End of Audio File 16

THE END

Robert Bradford Newman Lectures

13 November 1970

LECTURE 17

Title: "Effects of the Audience"

Summary: Newman presents material introducing the principles of audience absorption and sight lines.

Beginning of Audio File 17

There is a book, a short passage out of which I would like to read. This is called "The Encyclopedic Guide to Planning and Establishing an Auditorium, Arena, Coliseum or Multi-purpose Building." It costs $45, believe it or not. Per pound, it's quite expensive. It's a fairly good book. It's a reference written by a Municipal Auditorium Manager about the design of the multipurpose municipal arenas, coliseums and so on, and all about the facilities that various and sundry people have had, and how they work. But this little particular bit is rather amusing, especially since on the previous page, he references a couple of things that I have written in Progressive Architecture, and a couple of other places, and he says "Acoustics cannot be treated too seriously" and reading my works: "It is showing more and more evidence of success that the modern building depends on acoustical accomplishment, etc. etc."

Now, then, here's the killer. He talks about sound amplification, which we'll come to in due course, and he says "Throughout the planning and construction of the building, sound engineers should be requested to aid and give guidance. Often acoustical paint, acoustical backer boards etc. are needed to give the best results. Blank rear walls, even though treated with acoustic paint, may cause echoing feedback. To offset this condition, some buildings bend a cloth drape along the rear wall to prevent echoes." Well, he says, often acoustical paint and so on is needed. And in the next sentence he says: "if acoustical paint is used, you get annoying echo." Isn't that alarming and surprising? Acoustical paint, as I've told you before, and I was interested in talking to one of my colleagues this morning to discover that acoustical paint is not only an American phenomenon, but he went to school in Russia, and remembers the Russians were working on acoustical paint, and had a lot of important people pursuing the problem. Well, acoustical paint is an absolute quack product, and you'll see it referred to in books and other places. It still is not possible to get sound absorption, except by having a porous fuzzy layer of material at least 3/4" thick.

This colleague told me another amusing story. This happened in the 30's in Moscow. They were building some of the new subways, and they were quite concerned about the noise in the tunnels in the subway, and so some of the best brains in the country were put to work on developing an acoustical plaster, to line the interior of the subway tunnels. And they formulated what they thought was the very best possible acoustical plaster, and they proceeded to plaster the interior of a section of tunnel, and they measured levels in the trains before they did the acoustical plaster, and then they measured after they did the acoustical plaster. Before they put in the acoustical plaster, they had about 98 decibels of level in the trains, and afterwards 102. Which was a great embarrassment, and which was never published. Of course, the acoustical plaster was like all acoustical plaster—absolutely no good, and furthermore, as he said, the tunnel was full of all sorts of little crevices and nooks and cracks and accumulated dirt, and pipes going off here, there, and they just sealed it up and smoothed it up so beautifully with this hard plaster that the sound level in the tunnel increased 3 or 4 decibels, with the application of this vile, worthless material. There's just so much of this in the world, and it's good to know that it isn't an exclusively a North American phenomenon, as most things are.

In order to wind up our work on noise control, we're going to have another quiz. I would like to have it on Friday of next week; is that a convenient date? Is there any big panic that would make that an inappropriate date? I'm always willing to be reasonable on these things. I hear no violent objection. Other than on general principle. Again, this will be open book, and will cover the material up through our beginning of room acoustics discussions. If any of you have any questions about the stuff that we've done on noise control, or the problem sets that we've been doing, please don't hesitate to ask about them, I'm sure you're all... Yes?

Student: *(Unintelligible)*
The quiz will not be on the discussions on hearing conditions that we began last Monday, just on the noise control aspects, the stuff that we've covered in problem sets and in discussions in class on control of noise….

Student: *(Unintelligible)*
It will, with perhaps a little bit of extension into some ideas that we've introduced since then. I haven't covered anything in the hearing conditions end of things that will be "quizzable" yet, though I might just be moved to ask a question about it.

Last time I talked again about noise control, the importance of it in any space where you want to have good hearing, and the need to achieve absolute silence of background noise, so that we don't have any masking, the masking which we tried to achieve in situations where we're asking for privacy.

I want to talk today about the propagation of sound in a room, in an audience room, and to discuss at some length today and Monday the achievement of the 2nd and 3rd sets of criteria that we talked about last time: the uniformity of distribution of sound in the room, and the adequacy of loudness of sound in the room. How do we get these things? Let's first look at an audience and sound being propagated over the audience outdoors. If I think of some kind of a source of sound, the person's talking say here, this person's talking radiates sound out into free field. As we've described it, the sound is a wave of sound moving out (not a little ray of sound, and it moves out at 1120 feet per second). Now if on level ground, I arrange an audience—these are heads, and we can put fuzz on them, we won't render all the hairs here, but you get the picture. This is a fuzzy field of absorption, just as we are here in this audience. And if I know the power of P in Watts radiated by this person talking, I could say that at some distance, X feet, d feet, or whatever I like, let's say 50 feet away, I could calculate on the basis of $I = P/4\pi d^2$; the intensity of sound that I would get at a given distance, d.

Suppose I make a measurement here at that distance, d feet, and I find the certain density I in Watts per square centimeter, and suppose then I go down into the audience, the same distance, and make the measurement again.

I first make it up on the top of a tall stepladder, and then I come down into the audience, and I make the same measurement. I will find considerably less sound down in the audience than I found up in the air, the same distance, and one of the first things we learn about audiences, is that an audience is indeed a sound absorber, and that we get a considerable loss over and above Inverse Square Law by having the sound traverse the audience.

Student: "Is the element of traversing over the audience what makes the sound diminish?"

Yes. The audience is an absorbing material, and the sound is more or less grazing the audience here. That is, if I draw some ray diagrams, illustrating the directions of the sound wave, the sound is grazing the audience, and you will find that people at the back are getting considerably less acoustics energy than they would get in free field or if the rest of the audience weren't present in front of them, because of this audience absorption. Now this is exactly the same thing that you've all observed from time to time outdoors in the winter, when there's new snow on the ground. Everything is quiet. You will really observe that things are quieter, and isn't that the noises of motor vehicles and other things are muffled by the snow on the ground, it's the fact that the snow is between you and those sources. And the grazing incident sound, when we were outdoors, we don't have any overhead reflections or anything to build it up, you get less sound outdoors over new snow than you do over hard ground. And this is just grazing incidence absorption; snow is a very efficient sound absorber, it has got just the right degree of porosity into it, and you get this loss due to grazing incidence.

Student: *"Does vegetation do the same thing?*
Yes, vegetation does do the same thing. The problem with vegetation is that you don't have the right scale of interstices for efficient absorption, and the excess absorption due to vegetation, due to trees, to bushes and so on, is of the order of 3 dB per 100 feet excess attenuation over what you'd get in free field losses. In an audience, however, where we have a very efficient sound absorber, the interstices between the elements of our clothing and out hair are the right scale to be very efficient sound absorbers, and snow is a very efficient sound absorber. We could get excess attenuation of the order of 1 decibel per row of people, in fact 10 rows you're going to be down 10 decibels, or what you would get in free fields, if the sound source is exactly at the level of the audience.

Now usually the sound source is a little bit above the audience, and we're usually not sitting outside on level ground, and we find many things which mitigate this effect, and it is not as strong as that in most cases. Now there's one very important aspect of this audience attenuation business. We call this Audience Attenuation. I believe we've used the word attenuation before, attenuate is to thin out, or to reduce, in quantity—so it's an audience absorption loss. An audience of people is not simply a blanket of fiberglass, it is not a flat thing. The reality is that an audience occurs in rows, in discrete lines of absorbing material, and here we have a row of absorption, and this is usually sort of three feet on center, and this is sort of four feet high, let's say, orders of magnitude. So every four feet we have an occurrence of a thing, a sound absorbing thing, "*PLONK PLONK, PLONK*," and this is what we call a <u>periodic structure</u>. It's a regularly occurring thing, that happens every 3 feet and it's four feet high; Now if you're studying the behavior of periodic structures of that sort, as sound absorbers, particularly for grazing incidence of sound, you'll find that there is an increased efficiency because of the size of the objects, an increased efficiency in the region of 200 to 300 cycles per second (Hz).

What this means is that this audience is not only absorptive as if it were a flat layer of fiberglass or carpet or something else, but it is even <u>more</u> absorptive down in this range of frequencies than you would predict from ordinary absorptive characteristics of the surfaces, because audiences are not padded with materials that absorbs sound efficiency at 200 cycles per second (that would take sort of a foot of fuzz), to get really efficient absorption down at these low frequencies, at these long wavelengths. But because of the periodic arrangement of the audience, and the resonance effects, 1/4 wave length resonances and so on of the height of the audience and the spacing of these elements, you find that we get several decibels more absorption per row at the low frequencies, at this range of 200 or 300 cycles (Hz).

Student: "How many dBs would you say in general though of noise can be absorbed in a room?"
Well outdoors, without any buildup by the room, you can get between 1 and 2 decibels per row of excess attenuation over inverse square law when the source is in the plane of the audience. I'm making everything as bad as I can; that's the worst you'll get.

Now the fact is that this audience attenuation has been understood for years as a basic phenomenon, but the frequency dependence has not been understood until a few years ago. The fact is that in the direct sound field, that you get directly from the source in any audience situation, is quite likely to be very poor in the frequency range of 200 to 300 cycles per second. That is, there's more taken out there, selectively there's more taken out than in the remainder of the range, and you find that sound to be bass weak, "bass poor." And we simply do not hear much bass sound in a large audience situation in the direct field when we're seated down in the audience. It would have to depend on other sources for it—we do hear it, but we don't hear it in the direct sound field.

Everything we do in the design of a room for good hearing conditions, especially for music and for speech, must take into account the fact that the direct sound field is going to be weaker than it might be at three feet, and that it is going to contain even less in this particular frequency range, which is an important frequency range, at least in musical sounds—and the result is that music heard outdoors tends to be very thin and fragile. And, of course, bands, marching bands and other such groups that are designed to perform outdoors tend to compensate for this with tremendous quantities of "*OOMPAH"* and big bass drums and big tubas and so on just to build up the lower end of the spectrum. An outdoor marching band performing inside can be quite a deafening and a soul-stirring experience.

Student: "If you were playing the music on a very steep slope, you wouldn't nearly have that problem??"
That's exactly right, that's correct, and in fact we might just talk about that right at this point. If you slope an audience on a steep hillside, as did the ancient Greeks and Romans, and if you step the people up 2 feet per row, 30" every 36", that's about a 45 degree slope, you have no audience attenuation at all, because the sound is now not at grazing incidence, it comes in over the heads of the people in front of you, and you get very little loss. Now the secret of good hearing conditions that were obtained in the ancient theatres—some of which still exist today, in Greece and in Southern France and in Italy—the secret of good hearing conditions in these outdoor amphitheaters is very, very simple to understand. First of all, in ancient times the background noise was very, very low. They did not have aircraft, they did not have motorbikes and minicars and maxicars and trucks and buses, and all the rest of the things that contribute to noise today; they did not have these things. The audiences were placed on steep hill sides, with minimum audience attenuation. Now this I'm sure was not something that was understood clearly, but they found out that it worked, and they had the good sense—once they found that something worked—to use it. They could see better, and they could hear better, when they were seated on a steep hillside, and then you make the theatre into that shape.

Secondly, in addition to being steep, you arrange people in a semi-circle, so that they are maximally close to the performance: that is, you get the most people possible closest to the performance by arranging them in a semi-circle, and you don't try to do it in a complete round, because they found out that people don't radiate sound out of the backs of their heads. Even in those days; they didn't have angular mouths! People are one-sided sources of sound, they always have been, and likely will be for some time to come.

So we take the audience, we put them as close as possible to us, we have an outdoor situation with zero background sound if possible, steep hillside and good loud voices. There is nothing else to it. All the poetry of Vitruvius and the other boys, and all the stuff that has been written about the resonating urns and jugs that have been found in the ancient theatres is sheer hogwash and poetry.

Let us think for a minute upon this matter. Suppose I had an urn, somehow buried here in the ground, and I don't know just how they were buried, but they'd been found in the ruins and it was assumed that they were for acoustics, just like acoustic paint is for acoustics. Anything you do is for acoustics, and let's have one of these jugs here now in the audience area, and it's supposed to amplify the sound somehow, make it easier to hear: that's why they were put there. And what do you suppose this would do? Now you blow across the top of an empty bottle and it goes *UUMMM* or some other sound, depending how full it is and how much bierschaum there is inside, but you blow across and *UUMMM*. Now that's resonating, isn't it? Whence cometh the energy to make it go *UUMMM*? It cometh from the air-stream that you blow across the top, doesn't it? Now, let's assume we don't blow on the thing, we just let it sit there and quietly go UUMMM all by itself. It will do that. If I set an empty beer bottle right here on the table, and I stand here and talk in the room, this beer bottle, if I go down inside, with some kind of a probe microphone, I'll find out that the beer bottle is going *UMMM* all the time.

Where is it getting the energy for that? It's getting it from my voice. I'm pumping energy into it and it is an absorber. It must be an absorber, a Helmholtz resonator as they are called, after the great German physicist Helmholtz. Helmholtz resonators absorb sound and we sometimes use them to absorb sound selectively at a given frequency, at the *UMMM* frequency of the bottle, of the Helmholtz resonator. Therefore, *quod erat demonstratum*, an empty jug or an urn is an absorber. How can it possibly be an amplifier?

The ancients did not have electronics and other devices to plant in these things to amplify this particular frequency. It would also contribute absolutely nothing to speech intelligibility, because we know that speech intelligibility is all contained in the higher frequency of the voice. What the urns or jugs were there for, I don't know, but it wasn't for acoustics, so don't let's perpetuate that line of bunkum any further. Every time we try to do performances outdoors, and we forget about what it was that made the ancient theatres work so well for 14,000 people to hear well in an outdoor theatre, and we start trying to do 14,000 people on level ground in the City park, and then we wonder why it doesn't work. It can't work, because we've forgotten the fundamental reasons, and the thing didn't work in the first place. All right, if people would find out these things.

Student: "This summer I was at the (unintelligible) arts festival and they had 200,000 people flat out in front of the stage, and then those people (unintelligible) a quarter of a mile over on the side of a hill, and by the second day everybody was over on the side of the hill."

In Melbourne, a few years ago the Meyer family, who are the big department store magnates in Melbourne, old Sidney Meyer left a big fat sum of money to build an outdoor music bowl to entertain the public in Melbourne, and he endowed the costs of the concerts forever, in addition to giving them the facility. He gave them the concerts, and a huge sum of money. Millions of Australian pounds were put aside for this purpose. And the architect, Sir Roy Grounds, came to see me here in Boston, and we were talking about this facility. And he said, it was mostly for Sunday time-killers. And I said, well, if they're Sunday time-killers, they deserve to hear, don't they? Absolutely. And he said, where shall we site this outdoor theatre? It was for 100,000 people, but they were expecting to have some amplification, which they would have to have, and they didn't have any acoustic paint. And I said, well, Roy, if you get yourself a nice hillside…He'd been to visit all the ancient theatres in Europe, and he'd observed what they were like.

Now he was about to decide that that was OK for the ancients, but today we're so much smarter than they were, and we can toss aside the rules under which the ancients operated, and we're not bound to chariots and walking and so on, and we zoom around in jet aircraft, and therefore we're better. And so he and the committee selected a site, in a park, right in the middle of Melbourne, on a fairly flat site, and decided that this was where it should be, and he sent me the preliminary schemes together with the newspaper announcements in the Reviewer Section, with the artist's conception of what it was going to look like and everything, and asked that we analyze it acoustically. And I cabled him back to say that the site was impossible; and he cabled back that the site was politically expedient, would we please proceed! Well, we did our best with artificial earthmoving, and made a sort of a hill, and did a lot of other monkeying around, but it just is a lousy situation, and it can't ever be anything else but lousy. Time and again we try to get away from the basic facts, but audiences do soak up a lot of sound, and if they're on level ground or mild slope, the people at the back simply don't hear very well, and it happens today as it has happened from the beginning of time.

Well, outdoor music performances and theatres and so on are not one of our principal efforts today. It becomes increasingly difficult in the modern world to find places that are quiet enough to do this sort of thing and to get people there. Tanglewood and some of these places manage to be far enough away from the hurly-burly of the world to work pretty well, but these are places you have to drive several hours to get to, and they're certainly not going to be found in any of our great urban centers. I think we should address ourselves then to the problem of what we do inside.

Student: "Can you get the slope effect by having the performers up on a watchtower?"
Yes, if the performers are up very high you certainly can. You get into a problem then of the performers being more than one thick. If you had a quartet you could spread them out straight, and have them on a tower, yes, that would be great, but you get them very far back, and they get out of the line-of-sight by virtue of the platform, and the fuzziness of the performers in front of us.

This effect can be very pronounced. I don't know that in this room we can notice it very much but maybe if I get here—I won't get up on the desk again, but if I get down at this level—do you notice anything, any decrease in the back of the room, as I'm down at this level, out of the line-of-sight, over a lot of fuzz up front here, and I'm continuing to talk at the same level as I go up and down and get down at your level? Now does that work at all? O.K. The ceiling is not helping us very much in this room. This is a nice backwards design for a plaster sound absorbing ceiling, you'll see very shortly, typical, but stupid, nevertheless. Audience attenuation is a reality: it's something we always have until audiences begin to shave their heads and come in the nude to performances, and we're going to always have this effect. And I'm not expecting in my lifetime to see this happen; it's rather unattractive. Or maybe all wear heavy plastic raincoats and hoods that would help quite a lot in livening things up.

Now let's go to the ordinary, everyday reality of an auditorium in which we're going to seat people indoors, and we're probably not going to seat them in an amphitheater unless we have a lecture room, or medical operating room, where what we really want to have superb visibility of what's going on up front. If this room, in which we are now, were a demonstration room for a physics class or a chemistry class, it would not be very good, because you at the back simply couldn't see what's going on. And if you remember the day we had the black box, a number of people in the back of the room stood up, so they could see what was happening. There are cases where visibility calls for a very steep slope, but in ordinary auditoria, concert halls, we don't have quite so demanding an environment.

The very first thing we do when we begin to design an auditorium, of any sort, is to concern ourselves with not only the acoustics, but with the visual aspects of the relation between the performers and the audience. This is extremely important. What and how shall the performers and the audience relate to each other? Do we want a very intimate close feeling? Do we want a distant feeling? What do we want? How well should we see? Must we see the tabletop? Or is belly-button visibility enough?

The answer usually is that we design for visibility of the front edge of the stage. If this is any kind of a performing facility, every member of the audience should be able to see the entire performing area, and that means the whole stage. It may be ballet performances, in which case you want to see the feet of the performers, not just the top of his head. It may be that all sorts of situations might arise where you'd want to see this particular area.

Now in general, we design auditoria for what we call “every-other-row” visibility. We do not today, nor have we ever designed, for every row visibility. Every row visibility means that you see over the top of the head of the person in front of you to the stage. That would happen in a very steep amphitheater-type stepped seating arrangements. It will not happen in a room with a sloped floor, without steps, in which you can achieve what we call every-other-row visibility without much trouble. Every-other-row visibility means that this person, with his eyes, can see over the head of this person. Now you see (I haven’t drawn it very well, but you draw it properly in your notes), and presumably you can dodge enough back and forth, you, yourself, can move a little bit, so that you see between the head of this person and the person next to him, but you run out of dodging ability when you get two rows ahead, and so you design it so that you can see over that person's head the next row in front, two rows in front. So we call it every-other-row visibility.

And although you can do sight-lines with computer programs today, I recommend very strongly to you that the first time you lay out an auditorium, you really do it graphically. There is no substitution for straight graphic construction of sight lines to really understand what's going on. And do it at the scale big enough to come out with some kind of accuracy. I say minimum scale for laying out sight-lines is a 1/2" to the foot. It is a big drawing you have to do, you cannot do it in sixteenth, eighth or a quarter scale because your precision is too small. And you'll find in all the books on human anatomy and standards and so on what the average height of the seated person’s eye and the height of top of the seated person's head. Now this is going to vary, of course, from person to person, but there are averages, and all the world we can do design for averages. There are some short guys and some tall guys and they will be outside the range of averages that we designed for average. And we go along the line, we put this guy in place, and we put this guy in place, and then we put this guy here, and we fix his height so that he can see the front of the stage, now I haven't got him quite high enough, we'll have a higher stage here, maybe that’s what we’ll do.

Student: “Is that the design criteria the front of the stag? Sometimes I’ve run across the question as to whether you only need to see the top half of the lectern, or the person speaking?”
It depends on what you’re going to do. If you're ever going to do any dance in the place, you must see the floor. Good practice is to see the floor. Now you may have to compromise. You may come out with something so steep that you simply can’t do it, but you start that way, with visibility of this front edge of the

stage. That's good practice. Now, as with many things we talk about, what is good practice isn't what we always do. We have to learn how we can back off from good practice, and do something practical.

Student: "So theoretically, when they have those theaters where every row is set off from the seat behind it, then theoretically you should have visibility, every person… ?"
Well, staggered seating is not used very often because you find that almost every seat is staggered for part of the stage, and if you stagger the seating, it only works for straight ahead, and it really isn't worth doing. It gets you into so many problems of aisles. Aisles by law, for reasons of public safety, must be straight, or pretty straight; you can't zig and zag in very much, because it begins to clog up people if you're escaping in a panic. You have to keep in mind that panic happens, and for God's sake, let's never forget it. And we ourselves can be in a panic situation, and so generally you have to justify the ends of the rows, so that they come out fairly straight, and staggered seating gets us into trouble on that.

So we go on back here, and we put this guy so that he can see over this fellow, and so on, back, back, back. And we'll come out with a sloped floor of some sort, and it'll slope: it'll continue to slope up as we get farther and farther back. Now whenever I see an auditorium design, in which the front of the stage is level with the back of the house, I know that this person has not considered sight-lines in determining that floor slope. You say, how come that the back of the auditorium is level with the stage? Well, it's for convenience of circulation outside the auditorium. And I say, does that dictate the sight-lines in the auditorium? Well, we're not worried about sight-lines, you know, you've got to be able to wheel the piano around from one end to another. Well, to hell with wheeling the piano around. Now this room is for seeing in. And if you see an Auditorium with a 3 foot rise to the rear, matching exactly the height of the 3 foot stage, you know that it's been designed by a jackass, and not by a thinking person, or by a lazy ass, an ass nevertheless.

Now we've got this situation with a nice steep slope, and we find ourselves coming into a legal problem. Now this again is a problem of public safety, and it must be taken into account, if we're going to have people come in and out in a public assembly area safely and comfortably. And that is that the ramp here—the ramp which forms the aisle—may not have a slope, under most codes, of greater than one in ten (1:10). If you get a slope of greater than 1:10, it really is quite an uncomfortable thing to walk down. The O'Keefe Theatre in Toronto, do any of you know the O'Keefe, has very steep aisles. I find them uncomfortably steep, and in fact I've watched ushers in smooth leather soled shoes ski down the aisles, they're carpeted. And they literally go whizzing by and you wonder what the hell is happening, what shoes has he got, jet-propulsion or something, and those aisles, I don't know what they get to, but they're considerably steeper than 1:10. I'm sure there was some exception made for that particular situation.

But normally, if we're going to have really safe comfortable rooms, what we do is when we get to a 1:10 slope, and this is somewhere near it, we put in a cross-aisle, and then we go into steps, which continue to approximate the line that we I've drawn from our sight-line construction. Now the law says—and this is with very good reason—that when you change from a sloped floor like this, a ramp, you must approach the stepped section of the seating through a level cross-aisle; you must come to a pause area, you must come to a total change of pace. You may not go straight from a ramp to a step. Because what happens to people is that they always fall down when they come to this. Have you ever gone up or down a flight of stairs where suddenly the top riser or the bottom riser is a different height, quite different in height from what you've been used to? You always fall, you've tripped your foot, or you fall, you step like this, because you've stepped on something this high instead of this high, so we're stupid, you're a block, we're dumb, we're people.

This is not the way people behave, and once you establish a rhythm when you're walking up an aisle, and suddenly you come to a step, you fall right flat on your face. So instead of that, we give you a cross-aisle, an area, a pause, a big open space, where you can see and sense that something is different.

Now mistake number 1 (which has been made in real auditoria, and which I see in fully half of the designs of auditoria that I have looked at in all parts of the world), has the same error. This is the cross-aisle error. Notice what happens here. When I put in a cross-aisle, I step up an enormous amount in order to get back up to where I was, and then I go on with smaller steps, and this riser here is almost always three times as high as the risers in the stepped area above. Mistake number 1 that is so often made, is that we go back here and then start up the steps like this. The only problem that these people have is that they cannot see, or hear very well, otherwise they're present in the room, adding heat, noise, and so on. This mistake has been made in some real auditoria, and they've had to build wooden platforming on top of the existing concrete platforming, in order that people could see.

Please remember that once you construct a section for sight-lines (this is the first thing you do, when you start designing auditoria), that once you begin to construct the sight line sections, that is the section that you must preserve if you want to have the sightlines that you predicted. And anything you do in monkeying around with steps or ramps or anything else, must be with respect to that original line. These people have got to be right up there where you've drawn them, and in order to do that, you usually have to go up here with three risers here to get up to this point.

Now this first row may lose a seat; you can't put these steps out in this cross-aisle, because that, too, is a hazard to public safety. People will fall over these steps, they'll trip on them, and you have to put this back to this line here, and cut out this seating here, and then we go up three risers, and then we may lose a seat, because we have to go back into this first row of seats, which are protected with a rail. If we go over to Kresge, or if you are at Kresge at any time before we make our field trip, look at how it's handled there. It's handled very well, but you'll notice that it is a considerably greater rise—I think it may be only 3 in 2, or something like that—but you've got extra steps to get up from the cross-aisle to this first row of seats, in order that people can see. Please don't make that mistake; it's very, very commonly made. There's all kinds of different ways to handle it, but it must be handled. Once we have designed this seating section, to give us the kind of relationship that we want between the audience and the performers, we are now ready to start worrying about what is the roof going to be like, what is the enclosure going to be like.

We may have already decided on some kind of plan configuration, we may want to have the audience more or less wrapped around the performers, around two sides, three sides of the performers. We may decide we want to have a long skinny arrangement where everybody looks straight on at the performers, there are all kinds of things that will determine this, but somehow we have to come to grips with this question of what is the performance going to be? How are we going to see it, and relate to it? Now, people have at times made rather arbitrary decisions about these things. Mr. Scharoun, for example, an architect in Berlin (I guess he's Professor Scharoun, everybody in Berlin who's anybody is Herr Geher, Herr Doktor, Engineer, Professor so and so), Scharoun said, in designing the new Berlin Philharmonie, 'I would like to have the people arranged as on the hillsides in the vineyard…. and here comes poetry again, architects can get so carried away with poetry, and mellifluous words, they print so beautifully, and photograph beautifully, and in your memoirs they read just so magnificently. I personally don't give a damn how my memoirs read, I'm around here today, and I'm going to enjoy it.

But Scharoun said, let us arrange the audience as if they were on the hillsides in German vineyards. Now apparently he'd been out having some Heurigen wine or something, and had been sitting in the vineyards, and had been having a good time, and maybe some kind of a performance, some accordionists, and so on, and discovered that you can hear quite well up the sides of the hill in the vineyard, as if he had just rediscovered the wheel, as the Greeks and the Romans had done. And he said, also let us arrange the audience all the way around the orchestra, so it's an orchestra in the round. Now its 2/3rds out front of the orchestra where God intended that the audience sit, and l/3rd around behind the orchestra where God didn't intend the audience should sit. Now what's God got to do with it? But the physical fact is that musical instruments, like people, have directional characteristics.

The modern musical instruments that we have, the modern symphony orchestra, whether it's good or bad, I'm not trying to make any judgments, but the fact is, it's the way it is because of the way it's been performing historically through time. An orchestra performs <u>to</u> an audience, not <u>in</u> an audience; it performs <u>to</u> an audience. In the Symphony Hall in Boston, the orchestra's up front, the instruments either face the audience or face away from it. Professor Kramer in Berlin, was the acoustics consultant on the Berlin Philharmonie, and he told me that the very first thing he noticed when he went to a concert, sitting behind the orchestra, was not that the strings were weak, or that the brass instruments were particularly overpowering or anything, except that the French Horn came in like a ton of bricks, the French Horn. Now, the French horn you know, faces back, it developed that way over a period of time, to present a rather muffled, distant hunting horn kind of a sound, that's what it is for; and yet if you put somebody behind, back up here, he's going to hear that instrument.

Now then, here comes the vocal soloists, and they're doing Beethoven's 9th or something, and you've got the 4 soloists and the great chorus, and the soloist sings, and the soloists always stand up by the conductor, don't they, but in any case, they face outwards towards the audience, where God intended that they should face. And this is the 2/3rds area out front, they face this way, and the people behind don't hear anything. They hear the accompaniment, but the singing is totally lost. Oh a little bit of sound gets back there, but none of the articulateness, none of the quality of the sound that's intended to be heard. You say, well, have them rotate, or something—it's impossible to hear a vocalist from behind a vocalist. It can't be done. It can be done with electronics, yes, fix him up with a microphone, and shoot him back there, and I will describe a sound system later in the term where we've done this in a theatre-in-the round and it works beautifully.

Then comes the next number, it's a piano concerto, and the piano concerto is performed, always, with the piano lid at full stick. Full stick means that the lid is up at full stick, and that's about 45°. And the pianist always sits with his right side towards the audience, that's the way the piano is designed, with the low strings on the left. I've seen architects who couldn't accommodate a piano in that way, and drew it backwards, so you go *OOERERRRROMPH* like this, ridiculous – the kind of people that walk around upside-down, doesn't happen. And here's this lid of the piano sending all the articulation of the piano sound out towards the audience in that direction, and the people again behind and up the sides simply don't hear it. You say, well why don't you take the lid off? Well, then it doesn't sound right to the pianist. It isn't right at all; he can't play that way, it won't work, and again the people seated around behind just miss that part of the performance, and again the only way you could possibly do this would be by electronic reinforcement, which I'm sure will come, as audiences get bigger and bigger, and we demand more and more tricks. But it's definitely a trick and not part of this basic natural acoustics we're talking about.

Student: “Weren't the Roman and Greek amphitheaters in the round?

No Sir, no Sir: semi-circular. Orange in France comes a little bit around, perhaps another 10°, but to my knowledge, none of them were in the round. In fact, theatre in the round can’t be done for more than 200, 300 people, just because of the basic directional characteristics of the humans. Now maybe we could devise some kind of hats for the actors to wear—that’s a good project to work on, an omni-directional hat, you could wear kind of a Chinese hat, with some kind of reflector to shoot it back. I don't know just how this would work. Maybe somebody could work on this. Of course, what goes back doesn't go front, remember, so you're going to cut off the coverage potential for the front side. Well, what I'm getting at is in deciding how the audience is going to relate to the performance, you, the architect, cannot be totally arbitrary, whimsical and poetic in making this decision. You've got to think about the sources of sound that you're dealing with, and how they radiate, and what their directional characteristics are going to be, and if you decide “I want omni-directionality”, then keep it very, very small, so that there's some chance that the sound will indeed fill the whole space and give everybody a chance to hear.

Now, we come to the important decision, what shall we do for a ceiling? Shall we use acoustic tile, or what shall we use? Our time is almost up, but let me just say that the thing we want to do is to put in some kind of a surface here that will reflect the sound down on top of the audience, as if the audience were up on this platform that you asked about a while ago. Then we would have the performer, his image, way up here, equidistant behind this thing, and now the sound is coming down on top of the audience, with no audience attenuation, whatever. And of course this is a very efficient way to increase the loudness of sound heard by the audience. This is why it is absolutely immoral and wrong, ever, to make the ceiling of an auditorium of a sound absorbing material. It always should be a sound reflecting material and never something that absorbs sound energy.

We'll proceed with this on Monday.

End of Audio File 17

THE END

Robert Bradford Newman Lectures

16 November 1970
LECTURE 18

Title: "Auditorium Design"

Summary: In this lecture, Newman discusses floor slope in auditoriums, as well as sound reflection and diffusion.

Beginning of Audio File 18

Terry has returned the Problem Set #4 here; you can pick them up after class. Apparently there were some discrepancies in interpretation of some of the problems. This is my fault, and I apologize for not writing clear statements of exactly what I have in mind. Terry has also said that a number of you were asking about just what we expect on these Field Studies in the way of reporting. Now, I've said at the outset of the term that I think the Field Studies are probably the most important part of the work this term.

This does not mean that you have to turn in a great tome for a report. Great length and padding and double spacing is not impressive; content is, and substance. This is true in everything. What I would like to have, and what I think you would find most useful in doing (that is, what the more important thing), would be a brief report, perhaps two or three pages, either typed or written, just as long as it's legible, of what the noise problem is that you've observed, some drawings or sketches showing what the conditions are, what's the construction, what are the finishes, and if it's a machine, how is it mounted—just describe it as fully as you can, analyze the situation, is it well solved, or isn't it well solved, and what could be done about it to improve matters. If it's a transmission problem, do they need to tear the whole place down and start over. If they do, well, tell me what you would do better next time. In other words, a fairly careful considered analysis of what is the existing situation. If it's well done, why was it well done, what did they do to make it work, or what did somebody do to make it work, and just sort of a straight-forward basic engineering report.

Is that clear, or am I still being too vague? There's no, for God's sake, special form or anything, just something that makes some sense, and I think that most of you are architects, and find sketches and drawings the easiest way to convey your ideas. Just tell me about the problem. And the same applies to the problem set, to Field Study #2, which is hearing conditions, for which you have to have some drawings of some sort to describe the space, sections, transverse, longitudinal sections and plans. And if you can't get these, pace off the room and do some scaling with vertical heights of the doors, 7 feet and it's 2 doors high, and 6 doors wide, or something, but you could very quickly come to grips with how big a space is, and draw it up for us. And again, a very simple report on what you found, what were the hearing conditions, what were the difficulties, why was it that you could hear, or that you couldn't hear. And there is always a reason, and this is what we're trying to trace down.

Is that clear to everybody, is anybody perplexed? Just some half-way decent, legible sort of account of what you've been up to is what I'd like to see, and I will read all these and ponder them and weigh them and comment on them. I will do these and relieve Terry of the job of the field studies, he can read them if he wants to. I'm very anxious to see them, because I think they're by far the most important thing that you do. I've got to leave a little early today, because I have to catch an 11:30 airplane, but we'll buzz right along here for a while.

At the end of that last hour, I was asked two questions both of which I realized I perhaps had been ambiguous about in my presentation. In the first one, I said something about if you see a floor slope (we were talking about floor slopes), if you see a floor slope in which the stage is level with the back of the hall, this being about 3 feet, I said that this was almost always a jackass design, not thought out, and quite obviously done for reasons of circulation, and apparently some of you thought I was talking about air circulation. What I was talking about was circulation outside the hall, so that the floor level outside here stays the same the back of the hall around to the stage level; I hope that makes it clear. If that is the way it comes out for anything larger than a couple of 100 feet, you haven't got enough floor slope.

Now the other question concerns a matter that you will find in some of the books. I'll tell you the most horrible manifestation of this that you can imagine, absolutely true, as is everything I tell you here. It's wonderful, you don't have to make up these things, because they happen in real life. In Timesaver Standards, not the Reprint part I've given you, but in the big book (at least I think it's still there), is a section on the design of cinemas. And in the section on the design of cinemas is the so-called reverse slope of the floor. Now Ben Schlanger, who is one of the many people who work in this field in New York, is a great pusher of this particular concept.

Now if you design a cinema, here's the screen, and here's the floor slope that you've worked out for whatever condition you may have, and this means that the level at the front of the theater is considerably lower than that at the back. And for reasons of circulation of people and so on, it often is convenient to have the level of the front of the theatre at street level and the screen business also at alley level on a level piece of ground. So what you do is simply take this whole section and tilt it down so that the floor goes down like this. Now then, these people down front here are sitting way back, like this, you know, you've just tilted the whole thing down, at about this point, and you keep the screen here, you probably raise the screen a bit, and then it has to be at a different angle, so that it'll work to these people, but it's just a regular auditorium tilted downwards, so that at the back and at the front you have the same level, but at the same time you've gotten yourself a fairly decent bunch of sightlines.

Now, this will work quite well, if it is done properly, and if the screen is high enough, and is orientated towards the audience. You see these in a lot of the Trans Lux movie houses, I presume they still exist, they used to exist, maybe they're out of vogue now; that just shows how little I know about the current cinema. In any case, these narrow, skinny news theaters, there used to be lots of places in the city where you go right in off the street, you'll find that the thing goes down and comes back up again, being built in an existing store, or something of that sort.

Now the manifestation I saw of this was in Rio a few years ago. I was asked to give a lecture in the Engineer's Club in Rio on the 25th floor. And it was a brand new building, and they were very pleased with their building, but a number of people there assured me that nobody would be able to hear me very well in the auditorium on top because it was so bad. The architect, a good Brazilian architect, looked in Time Savers Standards, being a North American book, and it being printed ink, and in English, and therefore true. All of these things you must learn to doubt.

He was doing a 250- or maybe 400-seat auditorium, a relatively small auditorium, and he saw this business about reverse floor slope for cinemas, and he thought, Gee Whiz, that sounds great, this'll solve some of my problems, so he needed only as many rows as went half-way back here, so he cut off his theater at this point. Now this was not cinema, this was an auditorium, a lecture room. And then he needed some more seats, so he did a balcony, which is up here, like this. And then he decided that he'd seen somewhere, (it happened, maybe Kresge Auditorium, yes it has happened), but anyhow, he did a dome overhead.

Now here we have this lovely set-up. You have the stage here. Now in order for these souls down here, these galley slaves, to see anything, the stage front has to be five feet high. So these guys were way up here, you know, and you'd sit back here looking up like this at the speaker, and the speaker has to kind of stand right here on the edge in order to see these people because if he goes back very far he's going to be hidden from view. An absolutely incredible situation. I asked someone why, how on earth anyone could construct such a sight-line, and do it so completely ass backwards. You look down instead of up from the front, and the architect explained that he'd seen this in Time Savers Standards, and it showed this floor slope, and he needed only half of it, so he just used that part that he needed.

And it didn't make a speck of sense. That the blackboard was way up here and you had to step up two feet higher on another platform in order to write on the blackboard so these people could see. You're just barely getting clearance here of the balcony front. It was an absolutely monstrous room. Now of course the ceiling was such a dreadful shape for focusing sound that it had all been covered with, guess what, acoustic tile! So you had the ceiling doing absolutely nothing for you but soaking it all up, and here are these poor people sloping away from the lecture platform, and the lecturer way up here on a 5 foot high Bishop's throne sort of business—an absolutely monstrous sort of situation.

Well, I always enjoy giving lectures in very bad sort of rooms like this, because you've a got a clinical case right in front of you here. The dead patient is laid out here and we'll do an autopsy. And so we did, just that. And when the lecture was over the President of the Rio Engineering Club came to me and said the first time they had some money, he thought the best thing they could do would be to gut this place and start over again. And I said that would be a very fine thing to do. I suggested doing this, you know, just forget about these souls here and just put in a floor that slopes right on down to the front, and lower the stage to a decent level. The people in the balcony were absolutely on the level of the guy talking on the platform here. Here were these privileged people, and then way down underneath were these poor lost souls. Well watch this sort of stuff, don't just, hell, of course you wouldn't do such a thing. Don't copy stuff out of the books, it's almost always wrong. Well, maybe enough on floor slopes. The main idea is that people should be able to see with their eyes, and when they can see with their eyes, if they have good sight-lines, they're going to have pretty good ear-lines, because our eyes and our ears are very close together on our heads, and the two go together. And in general, the steeper the floor slope, the better are going to be the sight-lines, and the better is going to be the perception of direct sound.

Now, last time, at the very end of the hour, we had begun looking at the effect of the ceiling in a room as a sound reflector, and I've drawn this floor slope of some sort with an audience here, and I had put a source on stage, and said if we have some kind of a big surface up here we'll make this like a sound mirror, and in fact, I'd like that you learn to think about auditoria, or rooms for hearing conditions, good hearing conditions, always as being finished in sound mirrors. Things that <u>reflect</u> sound, not things that <u>absorb</u> it.

Let's examine this for a bit. The wave which goes up here like this, increasing, grazing over the heads of the audience, strikes this surface, and is reflected down again on top of the people. Now I should keep the same wavelength, there is no change in wavelength on reflections. The energy which is reflected from the ceiling comes down on top of the people, comes in at a very favorable angle, comes in at anything but grazing incidence, and we find in many situations that you, sitting in the audience back here, are going to get more sound by reflection from the enclosing surfaces than you get from the direct sound field.

And you say, well isn't that going to sound funny? Am I not going to imagine that the source is up in the ceiling or in the walls? Not if the dimensions are kept under control, and this involves a whole series of propositions, arguments and theories that I'm going to present at this point. Actually, what we have, of course, is an image of this source back here equidistant behind the source. And somebody's already drawn a circle up there, maybe I did that the other day, I didn't know I could reach that high; but there's our image. Now this image (this guy should be upside down, but never mind about that), is what's called a virtual image. It's exactly the same sort of image that you see when you look at yourself in the mirror, you see yourself behind the mirror at the same distance that you really are in front of the mirror, left is on the left and right is right and so on. Now you're not really behind the mirror—I think we all agree about that—there isn't anybody back there, especially when you know it's you, and you're out front. But the light seems to be coming from back there; it's a virtual image.

And exactly the same thing happens to sound. The sound that comes down here on the audience appears to have come from back there at the position of the virtual image. Now if we draw what we call a ray diagram, and we've done this before, but let's do it just one more time: the ray diagram describes the radial direction of this sound wave. It is not a little line of sound going out, it is merely the direction of the whole wave front.

And I'll draw a couple of these, a couple of rays, which are radial lines on this expanding wave front. Now I put an arrow on it, and say this is the way the sound's going. Now the sound will be reflected from this surface at an angle equal to the angle of incidence. In other words, if this is the angle of incidence, this would be the angle of reflection, just as in the case of optics. So this follows all the rules that you learn about optics, geometric optics. Angle of incidence and angle of reflection are equal. And all in the world this does is to describe the direction of the new wave front, which is reflected from this surface. And if our graphics are any good, these should intersect back here at that virtual image.

One way you can—I rather like to do this sometimes when I'm analyzing an auditorium—is actually to draw or to project backwards the images that I am going to have, and then flow the sound out of those images to the seating area and get very quickly an idea of the pattern of reflections I'm going to have. This particular image is behind a flat, level, hard, sound reflecting surface. This surface could be plaster, glass, plywood, metal, it could be anything other than acoustical plaster, and even that is a pretty good reflector because it's such a lousy material, but certainly not acoustical tile or anything of the sort.

Now the shape of this surface, and its size and its height, and everything else, are going to determine how much sound is reflected, and where it's reflected, and what the distribution is going to be. If you asked me, what is the very best shape that I could have for the ceiling of an auditorium, if I had only one shape to choose, I would say let it be flat, horizontal and without any interruptions, perfectly smooth, white plaster suspended absolutely dead level over the whole space. If you have no choice but to select one particular shape, then that would be it.

Now you can do better than that, but that's a good start. This is the start here. Now you're sitting here somewhere, and you get this reflection from the ceiling here. You first, however, have received the direct sound, haven't you, even though it may be decreased in intensity by the intervening audience, by this audience attenuation; you get the direct sound first.

Now you, as a human being with two ears, will always decide for yourself on the basis of the very first signal you receive, that that's where it's at, up there. The first signal you get is the one that gives you the clue as to direction. Now with two ears, and I assume all of you have the use of both your ears—if you don't, and are deaf in one ear, you do not have the ability to do very much of this directional orientation towards the source of sound—with two ears, however, we have a very strong sense of localization in a horizontal plane. It is because our ears are in the horizontal plane.

Now if you want to determine whether something is up or down, you have to turn your head sideways to do that—you can't do it by simply looking straight at the source. If I blindfold you, and if I put you outdoors and then we have something going *"WHEE"* or "*PPHHSSTT"* or something of the sort, we move it around left and right, then you'll point back and forth to it as it moves. But you can move [the source] up or down, but you won't have any very strong sense of this up and down motion. Of course, if it gets right overhead, you will begin to have some.

Student: *"What about front and back?"*
Front and back some, because we are more sensitive front than we are back because of the way our ears are shaped, and you can very quickly decide this even sitting in this room, or if you're at a concert or a play or something by increasing your ear flaps with your hands or by decreasing them in this fashion, you'll get nothing but backwash of sound from the back of the room very quickly. You can discriminate against what is coming from the front and what is coming from behind. But the main localization sense is a left and right one, and certainly some difference in back and front. That's considerably less important.

Now this first signal that comes in will give you the sense of where the sound is—that's the direct sound—and then if this later stuff, this reflected sound comes in quickly enough, you will not hear it as a separate thing, a separate echo, *'bla/bla, bleep,/bleep bla/bla'*, like that that, which is an absolutely, absolutely *inexcusable/inexcusable fault/fault* in a *room/room/ flap/flap flap/flap*. There are rooms like that, and when we go to Kresge, I'm going to show you one of the most gorgeous echoes that exists in Cambridge. Absolutely, just beautiful to hear. It does its academic demonstration, because it doesn't happen the way you normally use the auditorium, but you can misuse any room.

If this comes in quickly enough here, you will hear this sound as part of this sound but increased in intensity. Now the rule of thumb, and a pretty good one, is that the useful reinforcing reflecting energy must come in within the order of 30 to 40 milliseconds after the original sound has come in to be useful. If it is delayed very much more than 40 milliseconds, it's going to contribute not clarity, loudness, articulation and so on, but will contribute fuzziness and confusion. And when it's delayed as much as 150 milliseconds or so, you begin to hear it as an echo echo echo echo…like that, instead of being just nicely integrated.

Now what is 30 or 40 milliseconds? Sound goes 1120 feet per second and therefore approximately circa 1 foot per millisecond. If you want to get technical, it's 1.12 feet per millisecond, but I'm not going to worry about that; it's the order of a foot per millisecond. And this means then that if we want a 30 or 40 millisecond maximum delay between the arrival of the direct sound and the sound by reflection, this path must not be more than 30 or 40 feet longer than this path. You, as a listener, don't care when the sound started. You're interested in when you first get some of it, and then what happens after that, because until that point your ear isn't stimulated.

Student: "In a very large room, would there be a problem of lip synchronization?"
Yes, there is, of course. But this gets to be so only in a case where you really can't see the lips. You know we're lucky. If you could wear opera glasses you might have it. Lip synchronization is not generally a problem, nor orchestral bowing or other things that you associate with the activities of the performance, playing the piano. Symphony Hall for example is the order of 150 feet long from the rear most seat, I think it's that long up to the front, and there is no problem there of synchronization with what you see and what you hear. Now if, for example, this person is seated 40 feet away, then this path up here and back again shouldn't get to be more than 75 feet to give us an order of difference of between 30 and 40 feet. It's not an absolutely hard number; it's an order of magnitude of 30 or 40 milliseconds equals approximately, about generally, near 30 to 40 foot path difference.

Student: "Up and back?"
Up and back, in other words, let's say that this ceiling were 30 feet high, a ceiling in the order of 25 feet high, and suppose this distance here were 30 feet, and let's just say this was 30 feet, I don't know what it is, but let's just presume we have some such geometry, then 60 feet is the distance which this sound has actually travelled. And the sound keeps going, at 1120 feet per second, it comes up here and gets binged off, and it comes down again, and it just keeps on going at 1120 feet per second, because that is the velocity of sound in air and nothing changes that except temperature, and then we have this distance, which is 40 feet, so the <u>difference</u> is 20 feet, and that is a very satisfactory reflection, one that will be added in by your ears, integrated with the original sound, and you will not hear it as something separate, or distinct.

And this is very, very important, because you asked a question a minute ago: what about when you get very big? Don't you get in trouble? Yes. If this ceiling were sixty feet high, it would be almost impossible to get any useful first reflections from the ceiling, because if we have to go up 60 feet, and some down 60 feet, that's 120 feet, and then almost any distance that we have here short of about 80 or 90 feet back in the house would not get a useful reflection, but would begin to get a "fuzzying," a peculiar sort of sound that is associated with unclarity. That's not distinctly an echo, but what we call 'dead spots' often in halls. You find that many times in the places where people don't hear well, there are areas where there's confusion of sound due to the long delay of travel from reflecting surfaces.

Student: "Building Seven is like that."
Building Seven? You mean the lobby out here? Yeah, well that has many problems; it has a reverberation time of 8 seconds. (Laughter)

Student: (inaudible))
Step ceiling? In what? Oh all right, I want to get to that in just a minute, the elaboration of ceilings.

Student: "In old auditoriums with (inaudible) a mile and a half high, they aren't serving any purpose?"
Sure aren't; they cause trouble. Symphony Hall has a ceiling that is 65 feet above the floor, and if the truth be told, the people down here in the front part of the main floor seating in Symphony Hall get some pretty punk sound. It lacks clarity, it lacks articulation. Now when you get great big full soupy stuff, it'll just

surround you, swallow it up, and that's great; but if you're interested in clarity and articulation, then you don't sit in the front part of Symphony Hall.

We did an experiment one time at a Thursday night open rehearsal several years ago, in which we hung up some reflecting surfaces to give us these early reflections, and they worked beautifully, but they looked like the wrath of God, and people in the top balcony looked down on top of them. It's just that the dimensions of things are all wrong there, and the only way they'll ever do it is in plexiglass or something.

Student: "The thing is, when you were towards the back of the symphony, by then the angles worked out such that it was within 40 milliseconds.?"

That's right, and in the balconies, the ceiling is close enough so that you get these early reflections that are very useful. I'm going to work on this idea quite a lot, because it's one of the most important notions that we have today in the business of room acoustics, is the balance between what we call the early sound, the stuff that gets to you directly and gets to you within the first 30 or 40 milliseconds, which is useful added energy to give clarity and so on to sound; and loudness, and this is establishing adequate loudness, which is one of the things we set out to do. The balance between that bundle of energy which you use initially without any confusion, and the remaining stuff that comes in later, the reverberant energy.

Student: "How short a time interval can you detect?"

Well it depends on how loud the sounds are, but when it is the order of magnitude of 50 or 60 milliseconds, you can begin to detect or separate these things. This has been done in the lab, many times, in laboratory experiments with simulated sounds, simulated echoes, and then we checked it out with the real thing. This is one of the few things we can measure with any precision in a model of an auditorium. We're going to talk about that as well. We can model the time of arrival of signals in an auditorium and get a very good idea from scale models, even as small as half-inch to the foot. That's a 24th of full size, and if we interpret the frequency range as 24 times, well you get the picture, we scale the frequencies up, and the size down, and then we get a very good picture of the way the hall is actually going to behave. But this notion of designing the enclosure, treating it as a series of mirrors that reflect sound, and getting this pattern of reflections to behave the way you want it to, is one of the main things that we can do in auditorium design. [Airplane noise) – Excuse me, there's a high speech interference level.]

Student: (inaudible)

Oh yes. I don't know exactly the thinking that went into the Tyrone Guthrie Theater, the question is, is the breakup there for this purpose or what? This is one of the things we still have to talk about. [And I wish I could give you an auditorium pill at the beginning of this thing, and then we could develop all these lovely refinements, but we have to keep feeding in things.] This is the notion of a <u>diffuse</u> reflection as compared with a <u>specular</u> reflection. And whenever you talk about gold and gewgaws and stuff and all the wonderful Baroque decoration in halls, and the sort of thing that's in the Guthrie Theatre – lots of stuff going on – is that we get a diffuse reflection of the sound rather than a shiny one, or a specular one.

It's exactly like the difference in the reflection of light from a matte paint and a glossy paint. The glossy paint gives you glare, and gives you hot spots; whereas the matte paint of the same color, exactly the same degree of whiteness, will give you a uniformly <u>diffused</u> reflection. And what these irregularities do is to scatter the energy – rather than have it come off '*ping, ping*,' you get a whole raft of energy, and you have a *'whump'* up here rather than '*zing,*' a single kind of reflection.

Student: (inaudible)
I think that some of the rationale was that in the Guthrie theater, as in any thrust-stage theater, the actors are likely to be facing away from quite a lot of the audience, part of the time, and there is some argument for a lot of stuff up here, audience is back here, and I'm an actor facing this way talking, we have a lot of stuff here that might scatter energy back to these people, and there is some argument for that, if you can have the stuff in the right places.

Student: "Diffused sound, are you saying that's better or worse?"
I'm saying that, in general, some diffusion is probably a good idea. On the other hand, if I'm designing a lecture room, or let's say I'm designing a pulpit canopy for a minister to talk to a congregation, and he is going to stand in this position at a lecture desk or a pulpit or something of the sort, and I'm going to put some kind of great reflector here to reflect this sound down to the congregation – I might as well make that [reflected sound] perfectly smooth, because I have him in a fixed in position, and then I can work out exactly how it is going to be distributed. All of this needs a lot more talking about before we have a real clear picture. I have diffusion later this morning, but the question has come up, so if we have to answer it, that's quite all right.

All right, the first notion then is that of the conservation of the energy that is available in the room, reflecting that energy to the listeners soon enough, so that it will be useful to them in increasing loudness and improving distribution to overcome the basic fault of all audiences, which is that of sound absorption by the grazing incidence of sound field. And a well-designed auditorium makes use of all the energy that's available, and doesn't waste it in soaking it up in sound absorbing materials, and reducing this useful sound energy into heat rather than to the stimulation of the eardrums of the members of the audience. So that's what I meant at the end of the hour last time: it is absolutely immoral and stupid beyond belief to cover the ceiling of an auditorium with sound absorbing material, and there are dozens that you have seen, I'm sure, particularly back in the old high school, where acoustic tile salesmen got in, and sold them the whole acoustic tile ceiling. Quite often a hard rear wall that gives a gorgeous echo, and then a PA system, public address system, two little squawk boxes, one at each side of the proscenium opening. There you have about as ignorant and stupid an auditorium design as you can think of. Everything about it is wrong: where the speakers are, what the materials are, it's just incredibly stupid, that's all I can say about it.

Well, let's go back now and see what we can do to not be incredibly stupid. First of all, it's quite likely that we'll want to shape the ceiling. If this were just a simple lecture room, say for just 300 or 400 people, and this was the end of it back here say, now what do I do with this ceiling? Now I'm going to be the lecturer, and I'm going to stand up here on a platform, and this is the simplest kind of auditorium that you can think of, and that anybody can design very, very well, there's no need for any guess work about it.

What you do is to it start out with something here, a sloped surface, perhaps this angle – you have to fiddle with this, this is something you experiment with. And somebody will say, well couldn't you do a computer program? Well, I suppose you could, but it's like artificial insemination, you know, why bother? Here we reflect the sound from here, and sit back here fairly far, and I say well, maybe that's not far enough back, I might like to tilt it a little bit more. Now every time I tilt this thing one degree, I'm going to go 2 degrees on the reflected sound, and I might decide to have this first surface cover the whole house clear to the back, so I do it backwards, I draw it back here, and see what do I get for an angle, well I need it a little steeper, OK, so it's like that.

And then somebody comes along and says, “What are we going to do about lights, we've got to have some lights.” O.K. we’ve got to light the stage, we'll have to have a gap here, and we put in the gap, then we’ll work out here and we'll discover that the ceiling in this section probably ought to be fairly flat in order to reflect sounds down into the audience. The ears will tolerate many of these signals, in fact, it's better if we have a lot of them coming in, not just “*Plonk Plunk*,” but “*Plonk Plunk Plunk Plunk”* all over the place, from the walls to the ceiling and many surfaces. And then we might well decide to come down here towards the back of the room with a ceiling that looks like this, I don’t know – again, something that is usefully in reflecting sound down. Now this will result, sometimes, in a sort of a stepped ceiling. But it’s another sure sign of ignorance on the part of the designer. If you look at an auditorium, here's a typical thing we see. Here's this three-foot slope back there, and maybe we've got a little reverse slope in front, which is dead wrong for a natural sound house, we don't pay any attention to that.

And then we see a ceiling which does this – you can draw as many yards of that as you need, and you’ll have to think, what' s wrong with that? Well, it’s just scooting all the sound energy that strikes it back to the rear wall, where it might very well come back to the front of the room as an audible echo, and it's absolutely dead wrong. We see this over and over again in the approach to auditorium design by people who don't know what they are doing, and you say, what's that for? And you get, well, “it's for acoustics.” Well what does it do? Well, that's the shape of an auditorium ceiling and that is the way it ought to be. And it's dead wrong. You find that the first surface would in general slope up, but from then on you don't do that, you tend to come down again if you're going to conserve this energy.

Student: “How can you tell what the angle would be?”
You use the method of successive approximation, which is you draw something, and then you try it, and if that isn’t good, then you draw something else and you try that, and you keep fiddling with it until it's right, using a protractor and straight edge.

Student: “How do know what the angle of reflection is going to be?”
It's equal to the angle of incidence.

Student: “All right, that's where I stopped, but how do you tell the angle of incidence?”
Well, you assume some source position. Now you say, well, this guy is not going to be clamped right here, it's going be a theater, and he's going to move all over the place, you know he's going to act over here, he's going to be acting here, he's going to turn round, and you say, well I can’t select just one position. Well, you’ve got to select something! So you select what’s the most probable position. Most probably in most auditoria you'll find that most of the action takes place in the middle. You know, you don't generally have all the action on one side, unless it's a very peculiar production. So you say, well let's make it the center of the house. And then you say, well I don't know if he's going to be way back here, but you'll find again, if you examine the way things are staged, that actors in general don't talk when they're way back 20 feet, they generally say their lines up here in the front. You can find pretty soon an area that's a few feet across, then you just take the middle of that and say that's the source position, I'll design for that, and I know that it's not going to be right for a lot of other positions, but it won't be too far off, and this is where diffusion begins to come into the picture.

Student: “When a person radiates spoken sound, what is the angle up and down?”
Assume the front hemisphere is uniformly strong. Yes, fairly strong. And you might find that if this has any height at all, this is a nuisance, this distance is so short here that even if there's going to be more than 30

or 40 feet difference, if this is 20 or 30 feet high. And you may well want to tilt this so it can't get to this first row of seats, just to avoid this fuzzy business.

Student: (inaudible)
No, if it gets to look like a dome, destroy the design and start over. Seriously we'll talk about this problem, but it's a very serious problem, any kind of curvature, or even approximation of curvature gives us serious focusing. What we generally do is to go straight over to the sidewalls and then come down, and you could use those right-angled corners that come out up there. The plan shape is less critical than the section shape, because the plan reflections, the reflections from the walls in plan, experience the same audience attenuation that the original sound does, whereas the stuff from overhead comes in with much greater efficiency.

Student: "What about the stuff overhead that's coming off the wall?"
Well that's one more kind, you see, and you have lots of these in the room.

Student: "And when you said that we're trying to conserve the energy, in other words, we're trying to equalize the sound overall so that if we're going to have four or five reflections toward the first couple of rows over here, then you want to have (inaudible)?"
That's right, what you'd ideally like to have would be uniform intensity throughout the house. You can't get that. But to improve considerably over being outdoors, to improve enormously over being outdoors, and to overcome the effects of audience attenuation, we conserve energy by reflecting it from the enclosure.

Student: "Assuming that the last sloped part of the ceiling there is a balcony, understanding that a flat far-thrusting balcony is bad acoustically, what's the minimum that the slope can come down approaching the flat ceiling?"
Let's have this be a balcony. I would say that to start with, that this person seated back here under the balcony should be able to see ideally at least the front half of the ceiling in the main room, to see it with his eyes and his ears, to receive sound energy from it. And it's absolutely hopeless (and you've all experienced this), when we have a balcony that does this, you know, and you're sitting back here, you just don't get anything from anywhere, all you get is audience attenuation, and you're just out of it, really out of it, and you can't solve that with loudspeakers, it's just a dead duck. Better tear it down. I will speak about a couple of miracle cures, but let's not start out with miracle cures, let's have your patient real healthy and not needing any cures.

Student: "What is a good reflecting material to use on the ceiling?"
I enumerated a minute ago all the things I could think of, gold leaf on plaster, platinum leaf on plaster, concrete, glass, wood, almost anything that's non-fuzzy, just don't use fiberglass.

Student: "What about metal?"
Metal is great if it doesn't *bong*. You sometimes have to put gunk on the back of it so that it goes "*THUD THUD"* instead of "*BONG BONG*."

In the Airforce Academy Chapel, the architects were going to use aluminum on the inside as well as the outside, and I scotched that by saying you wouldn't want the music to sound tinny, would you? So they went and put plaster inside, it still leaks, but that's beside the point. Well anything, just so long as it's hard. Now you'll see sometimes the use of small areas of peripheral sound absorbing material for reasons of reverberation control and so on. This is all right, but the main thrust of the ceiling—the main surfaces—ought to be hard and sound reflecting.

Now the minute the echoes (and all these things are echoes when they're reflected like this), the minute they begin to be delayed very long, as coming from a rear wall or something of the sort, being delayed the order of 100 or 200 milliseconds, you're going to hear them as separate sounds, and these have to be destroyed, and got rid of, and are absolutely inexcusable, and totally useless. Only the early stuff is useful in increasing the intensity of the sound.

Well, I'm going to have to run if I'm going to make an 11:35 plane, and I'll see you all on Wednesday. Your problem sets are here.

End of Audio File 18

THE END

Robert Bradford Newman Lectures

18 November 1970
LECTURE 19

Title: "Balconies and Reflecting Objects"

Summary: In this lecture, Newman discusses the effect of balconies on acoustics, and he talks about the ideal size for reflecting objects. He also explains how to make sure the performers can hear each other.

Beginning of Audio File 19

Last Summer, oh sometime along in July, I had a call one day from a young man who said that he was a writer. He was doing an article for Playboy, and would I talk to him. And I said certainly, I don't know just what I have to say that will be of interest to Playboy, but nevertheless, I know the mag. So this sounded intriguing. And he said he had been talking to Chet and Joan Sprague [Chet Sprague, Architect, member of design faculty at M.I.T. School of Architecture], and they had suggested he ought to come to see me, and maybe I would show him my house, because they said it incorporated a lot of technological things. And he was going to do an article for Playboy on "What's coming in House or Housing Environment in the 70's," in the next decade.

So he came out, and I spent about an hour and a half with him, he brought his wife along (she was interested, too), and one of the things that disappointed him was that the technology that I had incorporated was mostly sort of invisible, like silent plumbing, quiet exhaust fans, and so on. You don't see them, you don't hear them, you're unaware of them; and what he had hoped to find was that the place would all be lit with luminous walls, that it would be all electrically controlled, that I'd have all sorts of closed circuit T.V. all over the place, and he couldn't even find our T.V. And I explained it was a Sony portable and it was some place or other, or somebody had been looking at something and I didn't have a clue where it was. And we didn't have a radar oven in the kitchen, and I said what would we do with that? Well you'd heat up T.V. Dinners and so on. I said if my wife gave me a T.V. dinner I'd slit her throat. We eat food in this house! Well, he went on at some length, and he thanked me very much and left in due course.

And I've been looking for his article, and sure enough, I found it. Wednesday after I left here. I rushed to the airport, and I had a minute, and I went to the newsstand, and quickly looked through Playboy, and here was the article, and so I bought it. And what I found was absolutely amazing. Fortunately, my name isn't mentioned here, I'm so glad. Chet and Joan Sprague are quoted – and I called Chet yesterday, and he hadn't seen it yet, so he rushed out and bought a copy, too, so at least we have 2 copies of Playboy sold as a result of this guy's article. It's called "Leisure in the 70's". It's a three-part article. This particular one is by Alan Adleson, and it's called "At Home" and then there's 2 other articles "On the Town" and "Out of Town." One is about travel, and one is about entertainment. And they all come down to entertainment, because that's really all that he cares about. The essence of this article can be found in this little paragraph: He said that some of the coming developments sound like futuristic fancy, such as the pleasure centers we may plug ourselves into for living dreams of sex, violence or just plain serenity. So you just plug yourself in and have any kind of experience you want, and it does it all electrically or somehow. Again, I just do not understand the need for that sort of thing.

Now he comes along here, and he has a section on acoustics, which is why I brought this in to read to you, and I don't know to whom he talked, but he didn't get this from me. He quotes Joan Sprague as saying that the house ought to fulfill all of our needs, our atavistic needs for water, fire, sun, quiet space, etc., and that it shouldn't just be a tranquilizing place where we sit glued to the T.V. and sort of Ha Ha once in a while with a canned audience. And I quite agree. And then he quotes Nuetra about incorporating nature in the house like a bird's nest and so on, securely wedged in the forked branches, and strategically positioned to yield the desired amounts of sun and shade, and then he quotes John Carlo who talks about the intelligent home, a living apparatus that understands its occupants, its occupants' wants, and is so totally versatile that it can accommodate those needs immediately. Walls would spring up or disappear when the dweller felt the need for insulation or openness; areas would be illuminated or darkened as an automatic response to the approach or departure of a body. Though this ultimate goal sounds beyond reach, some basic accomplishments in that direction have already been made.

Now, here beginneth the first lesson. "The greatest task for an architect is to arrange home space so that specific activities won't conflict with one another, and to do without subdividing the entire home into claustrophobic individual rooms. Somehow privacy and sound insulation have to be provided, while giving inhabitants a feeling of the space beyond them." Now I don't disagree with that. "Within the decade, that crucial problem will be solved through the development of air walls, somewhat like the gusting currents of heated air at many department store entrances. Air walls will stop the flow of sound without blotting out space or sight." In the next decade this is going to happen. Also in the next decade we're going to develop pills for eternal life, we're going to be able to jump out of windows and not go down, we'll go up, or straight out, any direction, just name it and we will.

Yes Sir?

Student: *(inaudible)*
Air, I see, maybe so. And then he goes on in the next sentence after "this air wall will be developed to stop sound without blotting out space or sight," in the same paragraph, "but, lacking these, Joan Sprague and her husband Chet, an MIT architect, have already mastered a good deal of the problem by cutting windows, skylights and shafts through their old three-story house." And Chet said, what the hell's that got to do with air walls? Not having this they put in skylights, not having eternal life I die! This is discouraging.

The rest of the article is given over to development of the "feelies" for home consumption, and all these sex plug-in centers, and contraceptives to be mass administered through the water supply, and cheap non-narcotic drugs other than alcohol would be available to produce specific mood changes, bringing on euphoria, non-aggression, heightened perception, increased attention spans, and other drugs maybe to alter our life-styles totally. Well, he's on that kick here – and let's have air curtains too. Well, he quotes a lot of people in here, and if his other material is no more factual—and I venture it probably isn't—then this business about air-walls is just another Playboy article which is for the amusement of men, it says here Entertainment for Men, and Women. Well the air curtain is not now, nor ever will be, nor ever has been a barrier for sound, and I've already talked about this here in class.

If you kindly go to a place where there is an air curtain, a department store entrance, or an office building entrance door, and stand there, and have someone else stand outside and talk, or watch the traffic or do anything else, you'll find that it doesn't do anything at all to the sound coming through. And unless it were going at Mach I, the speed of sound, which would make the most fearful noise itself, and would turn to hamburger anyone who ventured through it—you'd get pushed right down through the grille at 700 miles an hour, the wind-stream would be something monstrous—that would have some effect on sound that would stop it.

Well as I said at the beginning of this term, the purpose of this course is largely to make you sophisticated enough to be able to see through this kind of garbage whenever you read it in an ad or in an article, and know what the real facts are, and just have some kind of basic understanding of what this physical business of sound control is all about. It really is very simple.

Student: "When we first started, you said that sound was propagated through air…."
That's right. Sound depends upon the presence of air. You remember in physics class – I'm sure you saw this demonstration of a door bell sitting in a glass bell jar – there's no relation between the two – and all the air was pumped out. And when finally the air was down to a few millimeters of mercury pressure, nearly all the molecules gone, you didn't hear any more sound. You cannot transmit sound in a vacuum. It depends in the presence of the molecules in the air, and these molecules being pushed and pulled one after the other. Now I'm talking to you, I'm moving your eardrums in and out, but there are no molecules going between us, there's merely the motion of the molecules, caused by one pushing the other in an elastic wave that goes out at 1100 feet per second.

Student: "If the air somehow is moving, wouldn't that disrupt the pattern so there would be some kind of effect?"
Yes, there is a little effect, of course, due to an air curtain. Outdoors, when we have sound being transmitted from one place to another, there are tremendous effects, due to thermal gradients, and due to wind, and you have great wind fronts. Now suppose that sound is going 1120 feet per second, and you have a wind blowing here at let's say 30 miles an hour. And 30 mph equals 44 feet per second, you should remember that from physics class, 44 feet per second. So a 30 mile an hour wind added to 1120 ft. per second will make the velocity of sound 1164 ft. per second.

And if you have a wave that's moving here from some kind of a source, and here's the ground, and have this wind going along here, it's going to speed up the top of this, and it's going to bend it down, it's going to conserve the energy, and will make it louder than it would be with just ordinary inverse square behavior. We conserve the energy. On the other hand, if the wind is blowing against us, it may well force it up, and we don't hear nearly as well as we would in still air. But this is great fronts of air, great huge movement.

Now these air curtains are….I don't know what velocity they operate, does anybody know? It certainly isn't as much as a 30 mile an hour wind, 44 feet per second, that would be 2,400 feet a minute – it might be that much, yes, it could be that much. And it would certainly have a slight deflecting effect on the whole wave as it goes through. So just one passage like that is going to have a slight shifting of some sort of effect on the sound wave, but it's going to do nothing at all to its magnitude.

Yes?

Student: "What about difference in thermal variation in the air?"
The same thing happens because as the air gets hotter, the sound speed goes up, so you get increased ve1ocity, and when you have cool air on the ground, as over a lake or something, and warm air above, you find that you get a lot more sound at a greater distance than you would get with just normal inverse square expansion; you get this conservation of the energy, exactly the same effect as wind.

Now in the book that Sullivan and Adler wrote about their Auditorium (or some article, I can't remember just where I've seen this), but the Auditorium in Chicago I shall talk about a little later because it is anything but perfect, despite the poetry about it. Adler said that he was going to introduce the air into the auditorium for creature comfort above the proscenium opening in order better to waft the sounds to the audience. Baloney, it's just sheer baloney. It is poetry, it's like the urns and the jugs in the Greek Theatres, it's just poetry. Let's not get carried away with poetry when we're dealing with physical facts, the truth.

Well, let's proceed to develop some more physical facts and truth, and forget about air-curtains, even if it's in Playboy and even if it's printed, it's absolute hokum. I haven't decided just what kind of letter to write, but you can be sure there's going to be one that will cut this guy down to size. I'll have to be very careful that he doesn't think I'm angry and mad because he didn't quote me, because I couldn't care less.

Last time we were talking about auditoriums and reflections of sound. I'd like to continue this discussion. We had shown a number of typical sections. One of you asked, I can't remember who it was, what about the usual zig-zag section of ceiling that one sees in an auditorium, and I showed you a zig-zag section that didn't make any sense, even though it's often said it's zig-zag because of acoustics. We have to be very careful what we're doing because of any particular physical phenomena.

We talked about balconies, and I believe I illustrated—I'll just say one more word about this—the fact that the balcony has to have some kind of an upward tilted soffit, the underside must be tilted upward, and not—well, if its flat it's all right—but then it's even less extensive than this. There's no harm in it's being flat and it's that height—the point is that these people back in here, must receive sound from a good part of the ceiling area up here, if they're going to have a sense of being in the room. If they're going to get the early reflections that we consider to be valuable in increasing the intensity of the sound, and if they're going to feel the reverberant qualities of the room (which we haven't even begun to talk about), they've just got to be able with their ears to receive sound from the room, and not be cut off. Yes?

Student: "If the underside is tilted like that, wouldn't they get some reflections from it?"
That's right, they will, there's an added *ping* there, possibly. The Air Force Academy has an auditorium, it's not the Chapel now, but the Auditorium, and it seats 3,000 people. As I remember it, they have 2,000 on the main floor, and 1,000 in the balcony, I don't remember the exact division, but it's a sizable balcony, and we made the soffit of the balcony there so steep that the projection room is in here, and you can project the movies out at this level to the screen. And it's very amusing; the people in the SOM [Skidmore Owings & Merrill, Architects] Office in Chicago where this was designed were concerned, because they said that the people seated up in the balcony would have to look through the light beam.

Everybody looks through the light beam, below or above the movie, and you don't see any light until it strikes something. Now if the room is filled with smoke, you have a big white cloud, you see it from the top side just as well as from the bottom side. It's perfectly all right to look at the light. It's funny what bothers people. But if you can put the projection booth in the soffit of the balcony, it's quite likely that the balcony soffit will be steep enough, and it's a peachy place for it because it's right at the right level, and you don't have to have all these correcting prisms and everything that you have to have when you work from way up high and try to get a rectangular picture on the screen. Sometimes we go into many balconies.

In the new Uihlein Hall in Milwaukee which Harry Weese [Harry Weese, Architect] did and which opened last fall, the first balcony did that. The main balcony is up here, and then we have a little balcony tucked in here, kind of floating, just two or three rows of seats. And there's a little bridge across here for the circulation behind, but here we have a situation where sound comes down and sort of flows into this space and reaches these people back in here, who don't really have a good line-of-sight on much of the room. But they experience it because this is all that there is in the way of an obstacle, and they do get quite a lot of energy sent over the top. It's another approach to this sort of thing.

Sometimes we have multiple balconies, as in some of the opera houses in Europe particularly where we go off and up and up (and up and I'm being kind to them when I draw these soffits level because more usually they're very steeply downward soffits and anybody seated behind the first row really doesn't get very much in the way of a listening experience). In Paris, in the Opera House, I had an experience one time – the first row of boxes doesn't overhang the house very much I think as I remember it, but in any case there is kind of a thing like this, and then the next boxes are up here and this is a red damask covered divider. It divides all the boxes. These things go all the way around here. These boxes creep around the room and we popped into the Opera one afternoon to see if we could get tickets that night, and sure enough we got two seats and they happened to be in the first row of boxes in the center and I thought, oh boy, these will be tremendous; they were $6.00 a piece or something but I said we're not in Paris every day so let's blow ourselves to some good seats so we got two tickets.

And I was horrified to discover when we got there that the plan of the box was like this. Here is the railing and here is this divider dividing off the next box and here is one seat and here is another seat and another seat and we had these two seats and I, being a gentleman, let my wife sit in this seat and I sat in this one. Well, it was sort of: she is here and I was back here, back here in the subway telephone booth with these damask covered padded walls at my side and I was at the same level that she was, but we had no great amount of audience attenuation between us and the singers because we were up in the first row of boxes. I had a hell of a time hearing and the only way that I could really hear and enjoy the show was to lean out about like this you know, get myself outside this thing, and all I could say was that I was glad it was my wife in the seat in front of me, not a total stranger because it would have been ... I just wouldn't have done it.

There are lots of situations like this where you have this local fuzz and from here on back it's very fuzzy and you're sitting back in this little dead chamber and even though you are able to receive direct sound, that's all you are getting and there is no reflective build-up or anything and you are not receiving sound from the room, you are cut off from it and you have to lean out in order to get this general build up of sound energy which you do get from the room even in a horseshoe opera house situation. Many, many people seated in balconies have poor vision of the stage in some currently built theaters.

In the Metropolitan Opera House in New York, and also in the State Theater, tickets are sold marked "limited vision," which means you don't see the stage. And this is an absolutely stupid way in the 1960's and 70's to build theaters. We don't have to duplicate the mistakes of the past unless we're fatuous and doing a simple eclectic imitation with no thought whatever. It's just perfectly dreadful of Saint Phillip [Philip Johnson, Architect] and Saint Wallace [Wallace Abramowitz, Harrison and Abramowitz, Architects] to foist these things off on the public in the name of accommodating a whole lot of money-paying customers for the money-grabbing management of the damn place. Jackasses.

My friend George Izenour [George Izenour, Theater Consultant, author of “Theater Design”], who is also fed up with them, sat in a seat. He and his wife went down to New York and sat in the State Theater in one of these limited visibility seats, and they had to stand up in order to see what was going on on the stage through most of the performance. And afterwards, he put the two tickets in an envelope and sent them to Phillip Johnson with some things that I wouldn’t even want to repeat here—what Phillip could do with the tickets and his general disregard for mankind, and such.

Sight lines, good sight lines can be designed, ahead of time with pencil and paper, with models, with all kinds of graphic devices, we don't have to do it with computers and we don't have to do it with anything fancy, we can do it with the simplest of cardboard models. Sometimes the graphics of sight line construction at diagonal directions in a hall is difficult, and many times the simplest thing in the world to do is to build little scale model and get in there and see if you can see with your eye; and if you can see with your eye in the model (coughing) you can see in the finished hall. There is no excuse for not being able to see and if you can see well and if there is good clearance downward toward the stage and upward toward the hall, and you’re not way back underneath the great big balcony even though you can see, then it’s quite likely that you are going to hear well.

In Symphony Hall in Boston {which is, of course, perfect), if you sit back under the balcony on the main floor, way back in the corner or under the balcony on other floors particularly way back in the corner, well it’s only the first balcony that you can do this, but way back underneath the first balcony in Symphony Hall.… Here is the soffit in the second balcony, here's the first soffit going down, and these seats are just great out here, these stepped seats, but people back in here are really out of it. They're spectating through an opening, through a slot here, which is the heads of all these fuzzy people, and they really are getting a very poor quality of sound, a very poor sense of the room itself. And on the main floor the same thing happens, down here. You have people sitting way back under here, and they're just not in it. I don't know whether you've ever had an opportunity to sit in one of those seats, but try it out sometime. Yes Ma'am?

Student: “I think once I was up against the wall in the first balcony, and I’m wondering if that’s something you’ve tested.”

No, I have sat in those seats. Well let me not knock Symphony Hall. If you'd been sitting down here, it would have been absolutely sensational by comparison. What we find, and this happens especially in Symphony Hall, here in Boston, where at least until recent times it was almost impossible to get another seat until somebody died. And people sat in the same seat throughout their lives. And you get very accustomed to listening, and very happy with it, and Lord knows the performances are great, and I have enjoyed every performance I have ever heard there, sitting in some of the bad seats and some of the good seats.

Now way down front, this is Symphony Hall here (we're getting back to the Paris Opera House), way down front the stage is about 4 feet high, and these people sitting down here are just about stage level, and these front rows are perfectly awful places to listen. And yet you can thoroughly enjoy the performance because you can watch the conductor, and hear him swearing and so on, it's great right down there. But out here in the middle, you can see pretty well, and you get an awful lot of long delayed stuff from the ceiling, you get some long delayed stuff from the rear, you get very little early infill; it’s very soupy sounding, it's different. And the thing to do if you have an opportunity (an especially a good time to do this is during a rehearsal)…. to just walk around. And this is the way you begin to evaluate the hearing conditions in a room—move around, and sit here for a few minutes, and then quickly get over here and sit here. And do it quickly,

quickly, quickly so you can make these comparisons, and remember what it sounded like here and there, and you'll find that if you do this in Symphony Hall, and it's difficult to do it because when they have a rehearsal, the room is so reverberant, they put up a great big curtain here, and you can't see very much from behind the curtain, thought you can still hear all right. But if you can move around, even exchange seats at intermission and sit in a different place you'll discover that there are some very marked differences and non-uniformities.

I'm not quarrelling with your enjoyment of the show. The top balcony, on the other hand, way up here, you'll get the whole works, anywhere: it's marvelous. The interesting thing, Symphony Hall was repainted about 3 years ago, 2 years ago – I don't know, within the past 2 or 3 years, and oh they called us and said, you know, is paint going to hurt the acoustics? Well, it’s painted plaster now, and another coat of paint isn’t going to do one goddam thing for the acoustics in that hall. It just won't have any effect.

O.K. So they printed in the program the first night of the new season when people came the first time to see the new paint that “special care had been taken in the painting not to destroy the perfect acoustics of Symphony Hall.” And then, one of our brilliant local music critics, and they're the most brilliant people on earth, attended this concert and wrote a criticism in the Globe the next day, and he said, “Despite the efforts of everyone not to destroy the beautiful acoustics of Symphony Hall, there has been introduced the most horrible echo.” And he was seated (I'm sorry about this drawing here, but you get the general picture….). You know Symphony Hall has these balconies down the sides, and the orchestra's down here, and he was seated in the middle of one of these side balconies.

Now there's always been since 1900 when this place opened, an echo that can be clearly perceived in the front half of the side balconies coming from the rear of the hall. And you hear it on sharp “*BLADIDIBLABLA”* trumpet stuff, you get an extra sound—instead of triple tonguing, you get quadruple tonguing of the trumpet. And the organ plays, he plays sort of “*BLUMBLUM PLUMPLUMP”* and you get this extra stuff coming from the rear of the hall, it's always been there, and this jackass just said all of a sudden; well, we must find something to criticize, and they must have goofed up somehow on this paint, because acoustics is just a big guessing game anyhow, and you can't possibly know what you’re doing, and so let's find an echo, and so he found an echo. He rediscovered the wheel. Marvelous round things, and it’s been there right along. Well, all I am trying to say is that if you really want a person in the audience, in any kind of theatre, concert hall or anything of the sort to participate with the performance, to get the whole thing, he’s got to be out in the open, he’s got to be where he can receive some sound and get it fairly quickly, and this will set certain dimensions, and will determine overhangs of balconies, heights of ceilings, widths of rooms and so on.

Now let me say one or two words about the size of the reflecting object. We've already talked about this in connection with the design of facings, of sound absorbing materials, the design of grilles that go in front of organ pipes and loudspeakers and so on. The grille being something like my fingers here, as contrasted with the solid hand which is larger in dimension, and compared to the fingers which let almost everything through. I think you experience very little difference in the sound of my voice whether my fingers are in front of my face or not. Is that true? I hear very little back from my fingers, and therefore I assume that you're getting it all. When we design surfaces in a room, and when we draw a ray diagram and the sound goes like that, we are assuming always that the object doing the reflecting is large compared with the wavelength of the sound that's being reflected. Now this is true in any kind of wave phenomena, heat, light, radio waves and so on. We cannot operate on a wave with an object that is small compared with the wave, the wave simply doesn't see it.

Let's look at the three cases, and I think we've been through this before, and certainly is discussed in the Time Savers Standards Reprint, so I won't do it again very much, but we have three conditions. We have: (1) object large compared with wavelength; (2) object equals the wave length; and (3) object small compared with the wavelength, λ, lambda being the wave length of the sound in air.

Now what do I mean by these things? The wavelengths of sound, and I tried to give you some feeling for this the day we did the demonstration here by having you wiggle your heads back and forth.

Do you remember the standing wave that we had in the room? You've got the feeling that at the very high frequencies, "*SSSSTT*," the wavelengths were short, you could move your head back and forth, and every half-inch practically hear it up and down, whereas at the fundamental frequency of the voice, 100 cycles per second, we have a wavelength of about 10 feet. So the sound waves of interest in listening to speech and music are somewhere in the 10 foot to 1 inch range of size. They're not in microns, and it isn't miles, it's things of size that we are accustomed to having in rooms. If I expect that this surface, let's suppose, for example, this was a pulpit canopy of some sort. I'm going to put a pulpit canopy above a man who's going to preach a sermon, and I wanted to reflect the sound of his voice to the congregation; this is the way it's going to be reflected off.

How big does this thing have to be? Can it be a foot square? Will that do it? Well, first of all a foot square doesn't intercept very much energy reflected down, does it? The solid single interception of a foot square thing up here is pretty small, so we just take a tiny little squiggle of the energy and reflect it down. So from a mere point of view of reflecting a lot of energy, we'd like it to be about 10 feet square or something of that order of magnitude, just to capture a lot of the energy, and not let it go up to the ceiling, and instead force it to go down to the people who are listening. So if we wanted to do that as a mirror, it's got to be about 10 feet square, in order to be large compared to the wavelengths of the sound the sound we're trying to reflect.

And you say, well 10 feet square isn't large compared to a 10 foot wavelength. Granted, and this will not reflect in a specular fashion – by specular, I mean like a mirror where the angle of incidence equals the angle of reflection. It will not reflect in a specular fashion a ten-foot wave length, but we don't need a ten-foot wave length, we don't need a 100 cycles per second for speech intelligibility, we can be satisfied with 3-foot wavelengths to get good speech intelligibility, and a 3-foot wavelength is small compared with this object, therefore we will get specular reflection. When the object is about equal to the size of the wavelength, we get very wild scattering, and I can't even begin to draw for you the kind of reflection that we get. We do not get a specular reflection; we get a strong amount of diffusion or scattering and the sound goes off in all directions. When the object is small compared with the wavelength, then the sound simply goes right around it, and doesn't pay any attention to it. Just as the sound goes right around my fingers, and pays no attention at all to the presence of these small objects. You have all seen this, I'm sure, when you look at a wave in the water, a little reed, or a pile or a stick or something standing in the water, the wave comes along here, and goes right by. And if you look carefully you can see a new wave radiated off this, coming out on top of the first wave, the first wave will be like this, and the new wave that comes off the post will be very, very slight amplitude but it'll have the same wavelength as the main wave.

Look at this some time, and you'll see it happening. But the wave goes right by, and you hardly notice the effect of it. If I had a column in the middle of this room, people behind the column would not even notice it acoustically. At Robinson Hall at Harvard where I teach in the Spring Term, there is a column in the middle of the Lecture Room that we always use, the seminar room down in the basement, and it's about a 6 inch steel column. It's right smack in the middle of the room, and it's the most annoying feature of that room I can think of, because somebody's always behind it, and I'm always having to get around so I can see everybody. I like to see everybody, but we also have observed many times that it doesn't do anything at all to the audibility of sound behind there. If it were a 3-foot column, and if the walls were all dead, and the ceiling were dead, and we were only getting the direct sound, it would make it almost impossible to hear behind it, at least the intelligible part of speech, but it's small compared to the wavelength.

This is valuable to know, because when we begin to design reflectors for sound, sometimes we want them not to be totally reflected but to let some sound go through, perhaps into an upper space or something. Then we have to think about how big these things should be. Must they be 10-foot square? Must they be 3-foot square? Would 1 inch things do, or what? Ed Stone [Edward Durrell Stone, Architect] did a Recital Hall at the University of Arkansas, many, many years ago, and when I was in Architecture School, many, many years ago, it was in all the mags, and we were all looking at it, and gee, great stuff.

And there was one of Stone's early screens, he was in his "screen phase" at that time. The section through the ceiling of this hall is as follows: great big beams, concrete, painted white, with some ducts, and so on up here. Now in order to hide all these guts and so on up above, he hung a mesh, like this, and this mesh was made of wire, 6 inches on centers, a fish net of wire, 6 inches square. And at the intersection, I'll draw it full scale, of each of these wires, he had little aluminum things that looked like a clover leaf, and interestingly enough, these were stampings from motion picture film reels, the things that you cut out to make the motion picture film reel not solid, you know.

You've all seen this. And these were the stampings from these, and he had one of these at each intersection here, so it was a whole ceiling covered with these aluminum clover leaves, and quite, quite elegant-looking. I've been there, but all the mags said that the reason for the good acoustics in this room was these aluminum things, you know, and the fact that they were from motion picture reels had even more to do with acoustics, special dispensation from God to make them…. But this is full scale. Now what the hell can that do to sound? Nothing! The thing is: it's an acoustic nothing, and it's great. The ceiling is really good here, it's concrete, and it's got very big bumps on it in the form of beams, great big two or three foot things, scatter the sound all over the place, diffuse it like mad, and it's a marvelous room, it's great, but let's not get confused about what it is that's great about it. This is entirely visual, as one would say. Entirely visual, and nothing at all to do with the sound. In the MIT Chapel, the Bertoia Screen behind the altar block, or whatever one wants to call it, the block, is an acoustic nothing.

Now I was consulted about that, how big should these things be? Saarinen [Eero Saarinen, Architect of Kresge Chapel] wanted it the way it is, a very small-scale thing, and I wanted it the way it is, and Bertoia [Harry Bertoia, sculptor of decorative screen in Kresge Chapel] wanted it the way it was, so we didn't have any trouble at all, a five-minute conversation over the telephone about how big should they be. And I said, oh an inch or so, you know in width; and you can make them any length you want them; but keep them down to about an inch, and so they are, they're down to about an inch. That screen you know curves around here in plan, follows the plan of the base/ And had it been a really acoustically reflecting object, it would drive every celebrant, of any kind of service, of any religion whatsoever involving the use of the human voice….it would drive him absolutely up the wall, because he'd be standing right at the center of this dreadful focusing thing. Instead of that, it's a nothing, it's a visual thing, but it's an acoustic nothing.

And you have to be able to design acoustic 'nothings' lots of the time, because we may want things in places where they shouldn't be for sound reflection. We may want to let sound go through to something else. We may want to let organ sound come out. And we've got to know how big we can make the thing.

Student: "What does the wave look like the other side of a large-scale structure, for instance, in a three foot column, if there were a three foot column here, what would be the sound shadow passing behind it, would that be a straight line?
It's a function of frequency. At very, very high frequencies it would be a completely black straight line shadow, just as for light.

Student: "Radiating from the source?"
That's right. Assuming no reflections now from the rest of the room. And, of course, the great thing about being inside is that we don't have that condition, we always have some other stuff being reflected so that usually these things aren't very serious. Except that when we're under a balcony or something of the sort, and there aren't all these other things being reflected, it is serious.

Well, lots of times when (and we'll see these things as we move along here, talking about pipe organs and loudspeakers and other things that we may want to hear, but we may not want to see them), we may want to cover them with some kind of grille or something: what do you make the grille out of? How big can it be? And you'll find that if you really want sound transparency you've to stay down to elements of the order of one-inch or smaller to get everything, one-inch wavelengths through it. Whereas if you want to reflect, you've got to get up to the order of three- or four-feet. And that kind of order of magnitude size. Transparent things are down the order of one inch or so, and reflecting things are up the order of three or four feet. Now in between there's a great grey area. It goes all the way from light grey to dark grey, and we have to think about each particular case as we come to it.

One very important aspect of the design of a room for good hearing conditions is the hearing conditions for the performers themselves. I don't know how many of you have every performed in an orchestra or a chorus. If you have, you begin to know what I'm talking about, but I think we can all imagine it. If I'm playing in the Boston Symphony Orchestra, and I'm Mr. Silverstein [Joseph Silverstein, concert master] sitting in the first chair fiddle section (and he is one of those who complains vigorously about this problem in Symphony Hall), and I'm playing away here, and the conductor is up here telling us what to do and when to come in and everything, but if I'm a real musician, I would like to hear the rest of the performance and feel it, and make my playing fit the performance. Good musicians do more than just follow the conductor. They themselves add something of themselves to it. When we did a new orchestra enclosure at Tanglewood some ten or twelve years ago, the first performance was Beethoven's 9th Symphony, with Pierre Monteux conducting, and Adele Addison [?] was singing that day with the orchestra, and I asked her afterwards how she liked it. Well, she said, I have sung Beethoven's 9th with the Boston Orchestra I can't tell you how many times, this is the first time I've ever heard it. And how marvelous it was to be up there singing as part of this great chorus and orchestra, this magnificent Beethoven's 9th Symphony, and to be able to hear it.

In Boston's Symphony Hall, they don't hear each other. They have what is called "poor on-stage communication." And on-stage communication is something that we simply must try very hard to provide whenever we have a group of musicians performing together. What do we mean, on-stage communication, and what does this imply? I have said earlier, that in order to get articulate reinforcement, in order to add clarity to the sound that the audience hears, that the reflected sound energy which comes in, should come in, you remember, within 30 or 40 milliseconds. The same thing holds true for the orchestra.

If I have a group of musicians here on the stage, some of the sound they hear will be from adjoining musicians. Certainly they'll hear this, and if they were outdoors that's all they'll get; it's what comes to them from the other musicians. Now I illustrated already to you that when I get down here in the plane of the audience, you people at the back of the room will begin to miss some of the sound that I have. Now I'm playing a fiddle here, and you're way the hell back there on the other side of the orchestra, you're not going to hear very much of what I put out. And we depend upon overhead reflections, and reflections from the side walls. Assuming that those reflections can come down on top of us, we depend on these things to give us the on-stage communication.

And we find, by experience (and this is borne out in every part of the world—it comes out to be the same answer, which says that is probably is basically so), that some kind of ceiling, some kind of sound reflecting surface, whether it be continuous or partial, must occur at a height no greater than 30 feet above the floor. Now I haven't given you very many hard and fast rules in this course, but this is one of them. You must have a ceiling above a performing group not more than 30 feet high, if the performers are going to have good on-stage communication, are going to be able to hear each other well. In Symphony Hall, the ceiling is 42 feet high. That's too high, that's why they don't hear each other well.

At Tanglewood, in the big Music Shed--maybe some of you have been up there—we built about ten years ago: a new enclosure that came in at 25 feet with 50 % coverage. And it's at 25 feet. Now the musicians at Symphony Hall didn't realize how badly off they were in Symphony Hall until we did the new enclosure at Tanglewood, and then they came back after the first concert at Tanglewood to Symphony Hall, and discovered that they couldn't hear each other as well as they could out there in the shed. And it's a very simple matter of the presence of a reflecting surface here.

I mentioned to you the other day that we tried, at a Thursday open rehearsal, a canopy in Symphony Hall at 25 feet, in order to improve on-stage communication, made out of pieces of Masonite, draped between steel pipes, hung up with great heavy lines from the ceiling. It looked like hell. And the top balcony was just about here, and these characters were looking down on top of the thing, which was just awful. But it did a beautiful job of providing on-stage communication, and fill-in of early sound for the front section of the hall.

Student: "If it's at 42 feet and you get such a delayed reverberance, does it actually begin to, you know, make muddy the sound they hear, or is it too low?"
I think it's too low. If the ceiling were 80 feet high it would, certainly. It's kind of on the edge, it's past being useful.

Student: "But it's not quite destructive?"
Yeah. Now there are a few little surfaces on the sides of the enclosure at Symphony Hall that are paneled, and there's some richness and depth to the paneling, and so if instead of just having (I'm not good at drawing paneling) a flat surface but if instead of just this much, we had a kind of protrusion that stuck out a foot here between each of these panels, then we would begin to get some stuff off these shelves that we have, even at high frequencies. I can recite….I can begin to tick off all around the world the rooms in which

remedies have to be done. In the Radio House in Copenhagen, which looks acoustic as hell….when you look at the pictures, it was done by Erikson just before the war, balcony, second balcony—I'm getting out of range of my height, anyway the ceiling is wave-like, so it must be acoustic, it's slightly bowed this way, and it's actually longer than this. The ceiling is 20 meters high, 60 feet approximately—it’s too damned high. The orchestra sits here, and they can't hear each other. So at 10 meters, or a little bit lower than 10 meters, they hung in a series of panels. These are glass panels, because the lighting is from up here, and they wanted to keep the lighting and everything, and the Danes would know how to keep the glass clean—it's an unknown art in this country, but in Copenhagen, it's well understood: it’s called “washing.”

I believe, I've not gone back into Radio House in my last two visits to Copenhagen, but when I was living there in '59, these were installed, and they were made of ½” *Herculite* glass. *Herculite* is tempered glass, and the idea was that if any one of these things fell some time, it would just come down as a snow shower of glass and not in straight, jagged, decapitating slices. And it was put up most elegantly with brass fittings, oh, and suspended with wire and so on, but one of these fell, about 3 years later during the intermission, and ruined one bass fiddle. Nobody was on stage, and, of course, they immediately cleared the house, and the next day they took them all down. And I believe they've replaced them with plexiglass, which has less good cleaning properties, but much better properties for not falling down and hurting people. But this is at 10 meters, and this is the sort of thing you find in Stockholm, in Munich, in many, many places in the world, where the ceiling has been much higher, and the on-stage communication has been very, very poor.

Well we'll see you all on Friday, and we'll proceed with this on Monday.

End of Audio File 19

THE END

Robert Bradford Newman Lectures

23 November 1970
LECTURE 20

Title: "Reflectors, Flutter Echo, and Reverberation Time"

Summary: In this lecture, Newman continues to discuss how on-stage communication can be improved using reflecting surfaces. He also describes two of his experiences with flutter echo and discusses recommended reverberation times for various types of spaces.

Beginning of Audio File 20

The 2nd of December, which is a week from this coming Wednesday, we will make our trip to Kresge Auditorium. Wednesday, 2 December. Usual class meeting time, we'll meet over at Kresge instead of meeting here. I'll remind you again, but I just wanted to get it into your thinking process. We'll do both the Auditorium and the Chapel, if we have time, and there are a great many things that I can show you there and let you hear that I can't persuade you about by just talking about them. So we'll do that. Terry says he hasn't quite finished reading all your quiz papers, but that, in general, people seem to have done pretty well. And one consistent error that he noticed—and I might just comment on it, rather than trying to go over the whole quiz this morning until you have them back—is that of forgetting to take into account when you figure out the absorption coefficient of a material, forgetting to take into account that when you hung that curtain up on the wall in the reverberation room, you've covered up some concrete, which was there absorbing sound, even though very little.

Now you may say well, that isn't very important. No, it isn't very important, but as long as you're going to do something in an engineering way, it's a good idea to follow through in as much detail as you possibly can, and with as much detail as is significant, so that when you cover up an area of 100 square feet with a curtain, that area has an absorption coefficient α, of .02 to start with, and .02 x 100 is 2 units of absorption that should be taken out of the room. Then, take that into account in figuring the absorption coefficient of the drapery. Well, I'll go over this in more detail when we actually come to do this, but if you are ever thinking in a more critical case of covering up some area of material in a room with some other material, you've got to remember that you take the first one out when you add the second one in.

At the end of our class last Wednesday, we were talking about the need for good on-stage communication, the need for early reflections to the performers themselves. And this is an extremely important idea, one that I'd like to spend a little more time on before we actually start talking about reverberation criteria. I mentioned it to you through a picture here of the Radio House in Copenhagen, which had this great 60 foot high ceiling, very wiggly-waggly. I didn't really mention that this Radio House, big large studio, is for broadcasting symphonic performances with an audience present. There's some audience here and then they have this balcony, and then there's another balcony up here, and then a room like this. And for many years (this building was built about 1939), and up until about 1959 they put up with it and this dreadful lack of good on-stage communication.

Now this doesn't say you can't perform in the place, it simply means that it isn't as good as it ought to be, and the orchestral performers continued to complain: when we're seated here on the stage, with a ceiling 60 feet high, we can't hear each other, we cannot hear each other. And so finally (I described this to you at the end of the hour), in 1959, a whole series of glass panels was hung in covering about 50% of the ceiling area, and suspended from the ceiling above and down here at the 10 meter height, or about 30 feet above the musicians. And this gave a vast improvement as far as the musicians were concerned in the quality of their sound.

Now this is a broadcast studio for the orchestra, and primarily for the musicians. Now whether it improved things for people in the audience was of no concern whatever in this particular case. But it did, it helped at least the people down here on the main floor (nobody sits up here), and people seated here reported some improvement, though not as much as these people. The thing is that when you get near the back of an auditorium, even with a high ceiling, you'll find that the difference in the time of arrival of signals is almost always fairly small, simply because this distance is so great, and the difference in distance between this path and this one is seldom more than 30 feet or so, and the farther back you get, the less and less and less become these differences, and therefore the earlier these reflections come in, and the greater the clarity that you experience.

So the panels here don't help the people back there very much, but they do give a great improvement to people down in here, and a tremendous improvement on stage. Generally, we find that these arrays of reflectors, in this case they were squares hung up sort of like so, we would cover approximately 50% of the area with reflecting panels to give an adequate amount of on-stage communication. Now you say, well, would 40% be enough? Yeah, 40% would be enough. And would 60% be too much? No, 60% is all right, too, but in the range of 40% to 60% coverage, about half, in other words. Somewhere in that range. We need to obscure here in order to reflect sound back down. And these panels have to be the order of 3 to 10 feet in size in order to give enough energy reflection over the desired frequency range.

Yes?

Student: *"Why can't it be greater than 60%?"*
It can be. It can be 100%, and I should qualify this immediately, because what we want, in a case like this instance, where we have a whole room here acting as a reverberant volume (and I want to talk about reverberation time too this morning), but if I covered this completely with a solid thing here, I would effectively cut off this volume from participating in the sound field of the room. I would effectively reduce the volume of the room, and I might well effectively reduce the reverberation time that I have.

And what I'm trying to do with this partial coverage is to give enough early reflection down to these people, at the same time as letting energy go through and become part of the reverberant field in the room.

Now if, excuse me just a second, this were a stage house, and we're going to talk about multi-purpose auditoriums, where we have a stage house with a proscenium wall here, then you would never do a partial thing. You would always do a solid one because you don't want the energy going up into the empty stage house, where it can't get out again. So it all depends on what we're trying to do.

Student: *"What would be the optimum size for these panels?"*
Oh, anywhere in the 3 to 10 foot size, I think they were sort of 2 meters square.

Student: *"Would you get a largely different sound if you had 3 to 10 or 40 to 50?"*
Oh, 40 to 50 foot isn't in the range of 3 to 10. I'm saying 10-ish max size.

Now at Tanglewood.… Yes?

Student: “Is that 10 square feet or….”

Ten by ten, 10 foot dimensions. Now let me immediately now recant, and tell you a case where we went to 30 feet for some of the elements. But when you say 30 feet it's like saying, if I have something 100 feet long and a foot wide, you know, what is its characteristic dimension. We’ll, the one foot is kind of the size of it you know, even if there's 100 feet of it, as far as the waves that approach it are concerned. At Tanglewood in the Big Shed, we did a canopy, oh it’s been ten years or more, fifteen years ago by now I guess, over the stage; and at Tanglewood the situation is that here’s the big shed and here is the roof. The roof in this case is only about 45 feet high, and there are a lot of trusses up there. Trusses don't do anything do they? They're just things with elements of a few inches in dimension, and they just act as some sort of sound scatterers to the higher frequency sound.

Well, for many years, the people at Tanglewood, the orchestra, the Boston Symphony Orchestra, had struggled with an old orchestra enclosure that came from the tent that they had at Tanglewood before they built the big shed. This is like building a new house and moving in the old furniture and gradually getting rid of it as you can afford to buy new furniture if you want it. And so they had an old piece of furniture. And this enclosure consisted of a plywood thing about like this, they put an organ up here—we’re going to talk a lot about organs—essentially here, pipes were up here, and here sat the Boston Symphony Orchestra, clear out to here, the fiddles out here, and his blasting trumpets and everybody back in here.

Now all the percussion, all the big boys were in the back here, with this marvelous sound reflecting thing, and the weak guys with the strings and so on are out front here, and Koussevitzky [Serge Koussevitzky, Conductor of BSO] had a hell of a time trying to get any kind of orchestral balance and Munch [Charles Munch Conductor] had a hell of a time trying to get any kind of orchestral balance, and anybody else who conducted there had a hell of a time getting any kind of balance, and they said they couldn’t hear each other, the strings were weak and the brass were strong, and there’s a limit – and if you played instruments, you know there's a limit as to how softly you can blow a trumpet, and really have it be properly stirring, and there's a limit to how hard you can bow your fiddle without “*SCRARCHSCRARCH*,” you know, terrible rosin sounds and so on. So you just do the best you can, but it was always bad.

So Mr. Munch tossed in some of his millions, and some other people tossed in some money – it wasn’t millions, it was something like $50,000 that this cost – and we together with Warren Klappner in the Saarinen office [Eero Saarinen, Architect of the Tanglewood Shed] designed a new enclosure here. And we said, let’s make it about 50% open, because that's as good a guess you can make when you start deciding, to make something sort of open; 50%. So we design something here, which went out way out here, about this far into the audience. One interesting aspect of the organ being above this plywood enclosure was that the people in a chorus on stage being accompanied by the organ could never hear the organ, so they had loudspeakers in the ceiling of this shell to fetch down the organ sound, and give these guys a clue as to what was going on up topside and what the audience was hearing. You do have to hear your accompanist if you're going to perform with him.

We said, well, let's open it up so the organ sound can drizzle down through here to these characters, and so that this space will participate in the volume of the room in creating a reverberant field and we'll get some on-stage communication. This thing came out to be about 25 feet high. Now the point I was about to make was that because of the design of the thing, some of these elements out here did get to be about 30 feet long. Because in the plan, you may remember, that the shed has a very wide fan plan. We did the same with a series of radial sections, and these were great triangles of plywood, not quite, I mean there were several more, about 6 or 8 across here, but some of these got to be 30 feet across, and 10 feet in this dimension. And this will be a reflector, this will be open, and then in the next range, this would be a reflector, so this would be solid, solid, solid, and void, and solid and so on. It was an alternating pattern of triangles, decreasing in size as we got down here towards the apex. And down here they were sort of 6 foot by 3 foot triangles, 3 foot altitude, and out here they were about 10 foot and 30 foot.

But it still is in the right order of range for this purpose. And it does let a lot of sound energy get through, up into this upper space to become part of the reverberant field. True, not quite as effectively as if there were nothing there, but we've got to have something there to give us this immediate reflection to the positions of the stage. (Airplane noise) Damn airplane. The fact that the Boston Symphony players perform underneath this canopy at Tanglewood, and then have to come back to Boston in the winter and play under a 42 foot high ceiling, is why they're unhappy in Symphony Hall. They know how much better it can be if they have these early reflections, and it's a constant source of complaint at Symphony Hall that the on-stage communication is lousy, just plain lousy, and you ask just anybody that plays in the Boston Orchestra, and they'll confirm what I say.

Student: "If they used glass panels in Symphony Hall, would they cut out the balcony view?"
I think some glass panels could be done, so as not to cut out balcony view. I think if it were done very carefully, it could be. You know doing anything in Symphony Hall is like tampering around with the Apostles Creed or something in Church; it would have to be done by all the Bishops and other clergy together in congress for several generations, because it's already perfect, why do you want to twiddle with it? I mean, it really is tampering with one of our monuments, it's questioning the divinity of God, and you just don't do it.

And you know, after several generations, maybe some of you noticed, last year a new loudspeaker system appeared in Symphony Hall. It's right up near the ceiling. It's a bunch of horns, and for many years they've been using loudspeakers at each side of the great proscenium opening, and getting Grade 'C' results. This always happens when you put loudspeakers at the sides of an opening. You get "C" or "D" or usually "F" for that. Never possibly you get "A" because the loudspeakers are in the wrong place, no matter how high quality. So they finally admitted, they kept saying to us, can't you do something about the loudspeaker system? Yes, it's got to be in the middle. Well, we can't have it in the middle, because God never intended it to be there, or he would have put it there in the middle of 1900 [when Symphony Hall was built].

Well, they didn't have loudspeakers in 1900. Well, nevertheless, it should have been foreseen, and it's obviously against God's will, and so on, you know, and on and on we went. Well finally after years and years of talking and argument, they said, well O.K., we've just got to get some decent sound in this place, because the customers are bitching, and some of the paying customers don't want to rent the hall because they say you've got such a lousy sound system. O.K. so we put in a decent one, and we put it in right where it belongs, right up there in the middle. It's on a winch, and when it's used, it's lowered down to about 30 feet above the stage, which is where it belongs, and then it's used for announcements and non-symphonic events, all sorts of things happen there in Symphony Hall.

And maybe someday, we will get the same kind of reaction about some glass plates or something above the orchestra to give them some decent on-stage communication, because it's not going to happen until we do that. It's just very simple. Just as if there's a hole in the roof, water comes through, and until you plug up the hole, the water doesn't stop coming through. You can't just say: "stop coming through, water," and have it stop. We’re not Moses. We just can't do that sort of thing. Well, end of story. Simply some kind of reflectors have to happen in Copenhagen, in Lenox, Massachusetts, in Boston, Massachusetts, in Singapore, and everywhere in the world in order for musicians to hear each other. Something has to happen roughly 25 to 30 feet above the performer's heads. It can be lower than that; though for large groups, anything much lower that about 25 feet begins to be almost overpowering in the amount of containment of sound that it gives.

Student: “You seem to be stressing the fact that it's important to keep an open barrier over the stage that makes use of the reverberant sounds above. When you build an auditorium, how come you don't make a huge opening above the stage and then just use the alternating glass panels, instead of just building reflecting surfaces?”
Well, we do.

Student: “You do leave it open up there?”
Well, it all depends. You're getting the cart before the horse here. If we're dealing with a multi-purpose auditorium, in which we've got to be able to do ballet and opera and drama, and so on, with a conventional stage house, then we don't generally have the option open of leaving things open up above, because we can't get the sound energy out of it. Now the new Uihlein Auditorium in Uihlein Hall in Milwaukee, has an approach of this sort, and a couple of other halls built recently. In Uihlein Hall, we have a removable stage enclosure that comes up to about 45 feet, and then the proscenium goes on up from there, a very high thing, so we make one end of the room into a proper area, and then we have other things hanging in. We don't have them back here with a spot like this, we have some things that come in here and give us the early fill-in that we want.

Now this is a real mechanical marvel, and this all goes out of the way completely, and it stores out of the way so that the stage house is available for hanging scenery for operas and so on, and the proscenium gets teased down to here, and it’s a real piece of equipment. It was designed this way, right from the start.

I will come back to talk more about a multi-purpose auditorium. I want to finish something about reverberation criteria first, and then we can put this whole package together, and I think it will begin to make some sense.

Now I mentioned to you the other day something about flutter echo, my friend with the office, where the guy said it sounded like in a barrel. I was personally rather surprised that I hadn't talked to you about flutter echo, and then I realized that, of course, I wouldn't have at that point in the course. I want to say just a word or two more about flutter echo this morning. We've talked about echoes. All of these reflected sounds that come from surfaces in the room, that is, that come in after the very first sound arrives at your ears—these are echoes of some sort. There are the good echoes, and there are the bad echoes. And the bad echoes are those that we notice, those that we hear, as something separate, discrete, different from the original sound— “*BLAHBLAH, BLAHBLAH, BLAHBLAH”*—when the sound is delayed so long as to become separated in your hearing, then it's a useless echo, and you never want to have it, and I'm going to show you an echo over at Kresge so that you'll never forget what an echo sounds like. I want you to remember, because it's absolutely ghastly.

The useful echoes are those, as we've said, that come in within the first 30 or 40 milliseconds or earlier, and after that, they gradually begin to become less and less useful. Pretty soon, they become muddying, and then you hear them as separate sounds, there's no sharp point where it ceases to be muddying and starts to be separate. It depends upon how loud it is, and how long delayed. If it's delayed 200 milliseconds, it's always going to be "*BLAHBLAH BLAHBLAH"*, because that's a fifth of a second, and you'll hear it *as "BLAHBLAH BLAHBLAH"* as a separate thing. If it's delayed only 60 milliseconds, and isn't very loud, you may not hear it as a separate echo; it won't add anything to clarity, or distinctness. But it may not muddy things very much, but if it's 70 milliseconds then it's beginning to get muddy, and by 80 it's pretty sure to be muddying, and so on over this whole range of reflections.

Now flutter echo, which I described to you as the reflection back and forth between parallel surfaces, and I hope some of you have had a chance maybe by now to observe flutter echoes—in a stairwell, or maybe some other place where the walls are quite parallel. Flutter echo is simply the reflection of sound back and forth back and forth between two parallel surfaces. And you get instead of a single "*BLAHBLAH"* you get a whole series of "*BLAHBLAHBLAHBLAH*" and it begins to sound like "*BOING BOING BOING"* or "*PPRRRR"* or depending on how far apart these are.

If they're 100 feet apart you get "*PLONKPLONKPLONK*;" if they're 3 feet apart you get "*BOINGBOINGBOING*," you clap your hands and it goes *boing*, and you say this and it goes "*BOING*," anything you do in the room will go *boing* right back at you. And if it's 10 feet across it will be a lower frequency *boing*, but nevertheless, it's a very *boing-y* kind of a sound.

Now reverberation, which we're going to talk about, and we have talked about before, is quite a different thing from echo, or from flutter echo. Reverberation is the prolongation of the sound in the room after the source has stopped, that comes in as more or less a continuous decaying tail at the end of a sound. You go "*OOHH"* and the room goes "*OOHHHHHH"* and it dies away like that, you know, this "*UMMMM*." Now the reverberation that we hear is really a series of echoes. It's made of a series of reflections, and if we look at it on an oscilloscope screen, where we can really see what it looks like, we'll see that it's a whole series of spikes, the sound being reflected many, many, many times. And gradually the energy is used up by the absorption in the room, and we don't have any more sound left, so we don't hear anything more. Now that is a kind of sound we hear in a room and call reverberation, the prolongation of the original sound. Often true reverberation, however, is mixed up with flutter echo.

Now let me describe two very simple case histories. At the University of Oregon in Eugene, there was an old music building, music auditorium, that had in plan, a parallel wall stage area, and then the thing went out here, and they had the rest of the auditorium out here. The auditorium had…. somebody in his infinite un-wisdom, had put up acoustic tile all over the place. I know what it was, they had windows, and they got tired of the light problem coming in through the windows, so to blank the windows out, they said, you know, the acoustics is here isn't very good, so in order to improve it we'll use acoustical material. So that bothered them not a bit. Acoustical materials would improve acoustics, or do something to it, and so they put in acoustic fuzz all along the walls here. So this place was just dead as a mortuary. Really just well padded.

Now the conductor of the orchestra, the head of the school there, told me that it was very reverberant on stage, and very dead in the house. Now you really don't have a true reverberation time when you have a room that's as open to the main part of the room as this is. But what he was getting on stage was flutter. And you sit down at the piano here and bong some notes and the sound goes back and forth, back and forth here, and would appear to last longer. Now the fact that it comes at a musical rate doesn't always come through to you, because if you're making musical sound yourself, you may not hear this little "*BOING"* sound on top of it, whereas if you clap your hands, you will hear the *boing* sound.

By the way, never clap your hands in an auditorium, or slap boards together, or anything else, when any of the clients are standing around. I did this one time, and it took me two weeks to remedy the problem, which they never would have found if I hadn't been so stupid as to clap boards right in front of them. It didn't make a damn bit of difference in the auditorium, but once you hear these things, and you always can hear almost anything by clapping your hands, it's a very sharp and good sound for testing, once you hear these things, then you get all upset about them. Do your handclapping alone, and discover these things by yourself, otherwise you may get into trouble.

Well, I demonstrated to this fellow what his problem was because I could stand here and clap my hands, and we would get this "*BOING"* sound, and indeed the stage was quite reverberant, and he said they couldn't seem to play softly up there because it seemed so live, and it seemed so loud. And indeed they were getting sort of a containment of sound here, but they were getting very strong flutter. And we merely stood a piece of plywood up here, and it all disappeared. Just amazing what you can do with a single sheet of plywood.

Now here the obvious thing to do was not to do it that way, but to put several sheets each side, of plywood, which would encourage the sound out into the room, to become involved in the whole field of the room, and get rid of this local feeling of loudness and liveliness. It's a real thing, I'm saying it's not true reverberation, but as far as these musicians were concerned, it was a very strange and uncomfortable phenomenon.

Now down at Salem College, in Winston, Salem, North Carolina, we did a school of music several years ago, with a number of rooms in it—a large recital hall and then a small recital hall. And the small recital hall was the only room in the building that they didn't like. They liked everything else, they were just tickled to death with it. The dean called me up one day, he said we just love this building, except in the small recital hall, we can't seem to play anything but fortissimo. And I said, well don't you guys know how to play pianissimo? and he said, yes we do, but we can't in there. I said, well I think I'd better come down and see you. So I made a journey to Winston, Salem. And I walked in, and they had the faculty all assembled. Not all of them, just half a dozen, each was going to do a little ditty, or a little performance for me, I was the audience, and having assembled them all, we had to go through with the show, even though in about a minute I knew what the trouble was. It is very simple to diagnose these things, if you just know your onions.

This is a plan of the room. A smooth plaster room, without any interruptions whatever. Not a terribly handsome room, but nevertheless smooth. And the doors to the stage were set flush here, so that when they were closed they were absolutely flush. This is the edge of the platform, and back here is the pipe organ here, and then there were some pockets back here into which some draperies went, and could be drawn out here to each side if you wanted to deaden the stage area.

There were a number of areas of draperies in this place. Now here were the seats, and it only seated about 300 people. It had a straight rear wall, not this curved rear wall foolishness—we never permit curved rear walls if we can possibly help it, because all they do is focus energy back towards the front of the room, and make any incipient echo into a real echo by increasing its level to the point where it becomes quite audible. Flat is an awfully good shape for rear walls. Don't use your compass too much.

Now here again, they had the piano on the stage, and the dean sat down at the piano, and he bumped a few notes, and said: you see what I'm talking about? Now I heard immediately that they had a flutter. And he said, how can you have a flutter when you have that shape? Because one way to get rid of flutter, we always say in the books, is to skew the room in plan or in section. Now how can this happen? Well, let's just look at what happens here. Let's make X the source of sound, the piano. The sound goes over to this wall—I'm going to draw ray diagrams—and then it goes to this wall, and then it goes to this wall, and it's gone, so it keeps getting farther and farther back very quickly, and we don't have any trouble.

Angle of incidence = angle of reflection, it's the same. However, in the other direction, especially if you're out in front of the stage, here we go, and it's coming across here, and pretty soon we're coming across here, and then we're coming back again, or we can go back here, and go back, and maybe something like this. But in any case, when you get into the shallow end of a truncated shape of this sort, with this plan askew, you find that the sound walks in there and walks out again, and you get sort of a delayed flutter, that makes two or three trips before it gets back here to you. But indeed all of this energy that walks back here comes out again, and so you're getting a conservation of energy even if it isn't a simple straight across, nevertheless it is a conservation.

Well, this can be cured very quickly by having set in six sheets of plywood. We went out to lunch and came back, and here were the six sheets of plywood laid out neatly in the lobby, and then the question was: how were we going to get them on the stage? Answer is, we'll carry them in ourselves. So the Dean, and the President of the College, and several music faculty and Mr. Flentrop, the Dutch organ builder, who had built this instrument that was there, we all hauled in plywood, then we got some chairs, and we stood the pieces of plywood up on some chairs, alongside the stage. Well we did this first, and then I asked them to try it out, and they said, it's completely fixed – my God, it's completely fixed, you know, you have done a miracle, it's great, it's wonderful.

It makes you feel good once in a while to be able to pull off something like this, and have the clients just enraptured. So with this state of euphoria, I thought, well, let's give them one more jab. So I got Flentrop [name of organ builder] and the President of the College and another faculty member and I, and we took two of these, four of these pieces, and we took them down off the chairs and the vocalist was singing here to the accompaniment of the dean and we got plywood here and here, sort of two pieces.

The sheets of plywood looked like this with fingers coming around the edges, we were holding them. These people were just performing, and really not paying much attention to the environment, and suddenly this woman who was singing stopped, and said: what on earth have you done? It's magnificent, just magnificent. Well, we'd brought in some stuff within 10 feet or so, this is a fifty foot wide stage area here, and what you do out here may be to prevent trouble, but you don't often do anything very positive to help. And when we brought the plywood things in closer, just 4 x 8 pieces of plywood, they suddenly had something in close in giving them some very useful early reflection, and a very fine sense of their own performance. Well, these six pieces of plywood were immediately the next day mounted on dollies and have been in use ever since. I presume maybe they've painted them or something, but you know, you put a piece of plywood on a dolly, and couple of concrete blocks here, wheels and a brace here, and you've got yourself something that can move around, and they use these all the time to form a local enclosure for any kind of small group that's performing on stage. Single soloists or recitalists or a string quartet, any of these things, just feel an awful lot better with something close by, a security blanket if you like, but nevertheless, it's very real. And if you know anything about performing music at all, you know you've got to feel right about the performance, or you just cannot give a decent performance, it's impossible.

We have some similar things at Kresge [Kresge Auditorium, at M.I.T., designed by Eero Saarinen, Architect] that very seldom get used because they're not conveniently stored, and that's one of the many problems of that glorious design, structural statement.

Yes?

Student: "Would it have helped if you had put the piano farther toward the back of the stage?"
It probably would have helped, yes it would. But that's not where you perform with a piano. The piano's always at the front of the stage, in a well-organized school of music. Yes, the farther back you get, the less of this [flutter] effect there is.

And the organist didn't have anything to complain about at all. He couldn't understand what the rest of them were talking about. Obviously, these other musicians are all nuts anyhow, and they all think the organist is nuts, so not much feeling of respect in the musical community.

I tell you these two tales in some detail merely to help you see the sorts of problems that we can get into. If this hall had had a diffuse side wall design, if, for example, we had had just some kind of wiggly-waggly in the wall (I don't know what they might have been, ….some coffers, some bent panels or something happening rough at a large scale), this never would have happened. There still would have been the desirability of screens close in; that's another problem, but we would not have had to do this rather gross business at the sides of the stage, if we'd had some diffusion in the room to start with.

And this is another very strong argument for not having smooth slick things, but having a diffuse scattering of energy to avoid these simple reflections and these very simple sort of problems. Any other question or comment on this flutter business? Have any of you had a chance to hear flutter? Please try to listen to some in a parallel-walled room with relatively simple geometry, and clap your hands first to get it, and then you'll hear it on anything you do in the room,…. speech sound, or any musical sound or anything else, even whistling sometimes. If you can stop the sound quickly enough, will induce a '*boing'* kind of a flutter.

And that is not reverberation, but simple back and forth reflection at a regular rate. Because reverberation takes place with decreasing intensity, when the pattern of arrival of signals is totally random, and has no musical quality whatsoever. Now we've talked about the reverberation formula quite enough, and I told you about Professor Sabine, and going over to Hunt Hall.

By the way, I had a consultation last week at Hunt Hall with some planning office at Harvard, and when the School of Architecture moves out of there, the School of Design, moves out into its glorious new building, (I use the adjective advisedly), and the University is going to take over Hunt and Robinson, and guess what? They are going to fix the acoustics in Hunt Hall. And the fix is very simple. Hunt Hall has this section, a cornice line runs all the way around, and there's a ceiling like this, a ceiling like this, something of this general sort, and it's round in plan, you know, semicircular in plan. And what they're going to have done is a ceiling hung in about this height, over about this extent, enough so that anything that goes from here up is cut off, let's go farther than that, is cut off from any possible reflection from this surface. And then the entire side walls are going to be covered with fuzz, because that's the only way you can cure a monstrous shape like a semicircle, is just to make it fuzzy. Diffusion would have to be of such a gross scale, and you'd have to have a full profile model of the Rocky Mountains or something like that, to begin to do it, to get rid of the circular problem. Or the kind of grossness we have in the Chapel [Kresge Chapel at M.I.T., designed by Eero Saarinen, Architect] over here: big, big scale undulations might begin to do something, but that's going to be fixed up anyhow, and I'm delighted to know that at last it's going to happen.

It's too bad that we've all had to suffer through so many years of attending lectures in that hall, and with the really monstrous hearing conditions that follow. In any case, that is the hall in which Sabine [Wallace Clement Sabine, Professor at Harvard, and first developer of architectural acoustics and reverberation time formula] first found out that the reverberation time is equal to .05V/A.

We've been over this many times. Now I'd like to talk about criteria for reverberation in auditoria, because while up to this point we've talked about reverberation as something yeah, it's there, we calculate it in a big empty garage or something of the sort, or in a concrete test chamber, we determine absorption coefficients with it, but what the hell use is it in everyday life?

In the Timesavers Standards Reprint, if any of you have it with you today, on Page 618 (and if not, I'll talk about it in any case), is a chart showing criteria, it's called "A Guide for Determining Optimum Mid-Frequency Reverberation Time for a Variety of Spaces", It's this little bar graph that's in the Time Saver's Standard Reprint. Now this chart is not an absolute must. It's not really anything more than a general guide towards what has been shown, in practice, in a lot of existing halls, to be satisfactory reverberation times.

Now the reverberation time, for example for opera—it says here that opera houses, in general, will have a reverberation time ranging from somewhere from about 1.4 to 1.8 seconds at mid-frequencies. And there are some opera houses that go lower and some that go higher. It's unlikely, this tells us, that an opera house with a reverberation time of 3 seconds is going to be very good. And it is unlikely that an opera house with a 1 second reverberation time is going to be any good, because all of the good opera houses are up here in the range of 1.4 to 1.8. It's merely the order of magnitude that we're talking about. Mind you, an opera house can have a reverberation time of 1.6 seconds, which is right smack in the middle of this optimum range, and be a dreadful opera house, because of background noise, because of focusing, because of unequal distribution, deep under-balconies, all sorts of things can be the matter with it, and it can still have the optimum reverberation time and be perfectly dreadful. This is only one of the 4 conditions that have to be satisfied in order to achieve good hearing. An opera house can be quiet as hell, have no focusing, have no deep under-balconies, and have a one second reverberation time, and also be lousy. It can fail for many reasons, any one of the 4 tests, but this is only one.

I was just reading this morning the requirement by the General Services Administration (G.S.A.) in all Federal Court Houses that are built in this country, that the architect must get from an acoustical consultant (supplier of materials not acceptable) a statement as to the reverberation time in the courtrooms in the newly designed building. The architect must get some kind of a consultant to tell him what the reverberation time will be as it has been designed. Well, that's all very interesting, but if he covers the whole ceiling with an acoustical tile to give him that reverberation time, he'll have a lousy courtroom. And if he has hard walls with flutter, and all sorts of things, he'll have a lousy courtroom. It's a very narrow view of acoustics which is held by our Federal Government in the General Services Administration, a very narrow view that the only thing you really want to know about in acoustics is reverberation time. Useful, but only part of the story.

We have liturgical music, chorus and organ, beginning at about 2 seconds on out, we have churches and cathedrals beginning at 1.5 seconds, depending on just what brand it is, and going on out to 4 something as far as you want to go. Well, what brand it is is important. I would design a Christian Science Church very differently from a Roman Catholic Church as far as reverberation time is concerned. In one case, speech is very important, and the Christian Scientists have a special problem: on Wednesday evenings they have testimonial meetings, and people stand up and talk from any part of the congregation to everybody else. The first Christian Science Church I ever visited professionally had this problem; it has a balcony here, and then the main floor, and they had me come down to Baltimore, because the people up here couldn't hear what the people down under here were saying, and I said I can't do anything about that either. I mean, you know, you're trying to violate physical law here, you wretched people.

Well, they got me tapped off at first because they asked me if I was a Scientist, and I said no, I'm an Episcopalian. And I said in this case, OK, you've got a problem, I admit it, I'm sorry, I can't do anything about it, because I cannot make sound go around the corner. But you can put microphones down here, and put loudspeakers up here, and transmit what these people say by means of *materia electronica*. And they were happy, so it was fine. There are some things that you just can't do. But in this kind of a church where speech is primarily important, and liturgical music is not so important, you would select something with a considerably lower reverberation time, whereas in a highly liturgical church you might well want to have two or three seconds. That's just a matter of judgment.

Have I told you about Coventry? I might as well tell you my Coventry story at this point, because it relates precisely to this thing here, selecting a reverberation time, and then designing to it, and not using your brains. The use of brains is I think terribly important. This chart is just the beginning to start you, and then you've got to think.

You know that Coventry Cathedral was destroyed during World War II, and was rebuilt and finished and dedicated in the new Cathedral alongside the old one in 1962. Sir Basil Spence was the architect. Now the organist at Coventry said: "I want the new Cathedral to sound like Durham," he didn't say to have specifically the reverberation time of Durham, just: "I want it to sound like Durham." So Her Majesty's Government Building Research Station packed a van-load of equipment, and they drove from Watford near London to Durham. And they went into the Cathedral and they made all kinds of noises, they shot a cannon, and they shot pistols, and they burst balloons, and they "*PHSST BANG*," and all sorts of noises, and they made miles of tapes, magnetic tapes.

Then they went back to the laboratory, at Watford, and reduced the data. And when the data were reduced it was found that the reverberation time at mid-frequency was 4.23578 seconds. Then they took the drawings that Basil Spence had prepared for the proposal for the new Cathedral at Coventry, and they did some calculations, and they said T = 05 V/A; V is so many cubic feet. And we'll have some audience, and then we'll have such and such a T, and they found out that A wasn't going to be big enough with just the people there, and so they decided to add some more A to the room.

Now here, this is absolutely monstrous to think about. Adding any sound absorbing material in a cathedral—because if you look here you'll see that cathedrals go on out to infinity—and the only reason they sound like cathedrals is because they don't have any fuzz in them. The minute you start tinkering around with God's will and putting fuzz in cathedrals you're in trouble.

These guys calculated that the entire concrete roof, the soffit of the concrete roof should be covered with cork, brown cork, 1” thick, spaced 1-1/8” from the concrete on furring strips. This would be concealed. You may remember the design at Coventry has some great tree-like forms that rise up from some very thin wood columns, and there's a trellis that hides the actual ceiling from view, so that it wasn't visible. Then they had decided that instead of stone for the walls, because of economy, they were going to use plaster, and these guys said, aha, you should use acoustical plaster. That evil, immoral, dirty, filthy material—never use anywhere, not even in a whorehouse! They put acoustical plaster on the walls of this place, over the whole thing, and this should have Alpha = .153 seconds at mid frequency. So a sample was made up, sent to the laboratory, tested, approved, and it went in. And Lord only knows what kind of absorption it gives. Well, I was asked in ‘62 to go and look at this place because they were having complaints. When the cathedral was opened, they had a tremendous festival service. The Queen and all the Bishops and other clergy, and great choral groups and choirs and everything, and they all sang. And they said, why the voices of the choir boys don’t float as they should in a proper cathedral, they don’t float.

Well, of course they couldn’t float. How the hell is any sound going to float when you grab it every time it touches anything that might make it float, and suck it into it, and heat up the plaster, and heat up this wretched cork on the ceiling? How on earth could it work? Well, we drove up there from London, and on the way up I heard this hairy tale about how they’d done all these experiments, and I said, did you guys, did you chaps, excuse me, did you chaps look around when you went into Durham? Did you see any cork? And did you see any acoustical plaster? No, it’s all stone, isn't it?

Well, of course, we didn't look around very much, we were making measurements. And how the hell did you think you were going to produce a cathedral-like sound with all this wretched acoustical plaster and cork? Well, this is what the figures show, you know, the calculations show. If you are working on a building, and you have a consultant, and he comes in and tells you something like that, just either throw him out, or have a good fight with him, or argue with him; and for God's sake, don’t follow his advice, because it's wrong, it's dead wrong. Since then, they've removed the cork, they've painted the plaster, and the place sounds like a cathedral, and the choirboys’ voices are floating around upstairs. I haven't a clue what the reverberation time is, it doesn't matter, it's something greater than this, it may be 8 seconds it may be 10 seconds, but it is characteristic of that kind of big hard space. And you don’t start tinkering around with that with acoustical tile.

Well, end of today's first lesson; see you all on Wednesday.

End of Audio File 20

THE END

Robert Bradford Newman Lectures

25 November 1970
LECTURE 21

Title: "Adjusting the Reverberation"

Summary: In this lecture, Newman discusses reverberation time and the fundamentals of adjusting it with reflective and absorbent materials.

Beginning of Audio File 21

….about the Coventry Cathedral. I guess I made the point I wanted to make; I just would like to underscore it. Namely, in connection with any of these technological aspects of architecture—or of anything for that matter, but where you are involved as the designer, as the decision maker, for God's sake don't follow blindly advice that's given to you but make it make some sense. And if you are doing a cathedral and somebody says "put acoustic tile in it," then throw him out because that's obviously wrong. I don't care what the numbers come out to be.

Now these chaps who did the acoustics at Coventry tell me that they measured the reverberation time in the cathedral <u>after</u> it was completed and indeed found the numbers they were looking for, that is, the numbers toward which they had designed. I have to assume that this is true, but no matter what the truth is, the fact is that it cannot sound the way that it is supposed to sound if it has a lot of sound absorbing material. Because the reason cathedrals sound the way they do is that they don't have sound absorbing material in them, and they are, indeed, all of hard and sound reflecting materials. And you are just never going to get that marvelous sound that comes in that kind of a room if you start tinkering around and putting fuzz on the surfaces.

So fuzz is out for cathedrals; not that most of us have a chance to duplicate those, but also here's another interesting commentary on this which relates to reverberation. A fellow came into my office…Oh, this has been 10 years ago; he is an architect from Florida and he is doing a small Catholic Parish church and he happened to be a member of the parish and the priest had told him, look architect, you give this cathedral acoustics. You give this cathedral acoustics. And I said to my friend, what kind of ceiling height are you thinking about in this church? He said about 20 feet. I said, well, you are going to get about 1/5 cathedral acoustics. I said first of all cathedral acoustics would be inappropriate in a small parish church, you wouldn't know what to do with it. You couldn't use it and besides that, you only get cathedral acoustics with cathedral volume. And cathedral sound comes with 100 foot high ceilings.

Now why do I say that? Let's just look at a very basic concept and one that very quickly lets us narrow in on the order of magnitude of what we are talking about. If I have a section through a hall and a floor is covered with people—this is, say, a transverse section through an auditorium—then this will have some volume, V; and let's say the absorption, A, is all due to the congregation present. And that everything else is glazed concrete, α = .02. And I'm going to say let's neglect that [the absorption of the concrete] for the moment, even though on the problem on the quiz the other day we said don't neglect it. The reverberation time, RT, will be given by .05V/A. And the A, which is the audience in this hall, will determine what the reverberation time is as well as will the volume. The absorption, however, which limits the reverberation time, is all contributed by the audience.

Now suppose we say we'd like to increase the reverberation time in this hall; let's double the reverberation time! We have two choices: one is to take all the clothes off the audience, shave their heads and make the audience bodies shiny and smooth, and then they won't absorb very much sound and maybe we can cut A in half. If we cut A in half, we are going to increase T by factor of two aren't we, perfectly straight forward. The other thing we can do is to double the volume and we might just increase the volume by making it now into two pieces.

And if we have the volume 2V, and we don't change the absorption in the room at all; we are going to have twice the reverberation time. And right away we see that V, the volume, is a function of the height and, therefore, *quod erat demonstrandum*, T is a function of the height. If T is a function of V, if the Reverberation Time is a function of the volume, and if the volume is a function of the height, then the reverberation time is a function of the height, assuming a constant absorption in the space. And all I'm trying to say is that pretty soon you'd get a feel of the fact that unless you have a height in the order of 100 feet, you are not likely to get a reverberation time of the order of 6 to 8 seconds. And if you have a height of only 20 feet, and if you have the space pretty well occupied by people, then after working through a few of these examples, you'll find that you can't get much above 1 second with a 20 foot ceiling in a room covered with people.

And that in a concert hall, if you want to get up to 2 seconds [RT], then H must be in order of magnitude of 60 to 70 feet; and we simply cannot do a hall with a 30 foot ceiling and expect it to have a reverberation time of almost 2 seconds. There are just a whole lot of things like this that come clear to you as you work with these things, but after working with them for a few years you discover that it always comes out the same way. Just as I keep telling you about holes in the roof, where the rain always comes in, we learn pretty soon that you just cannot do a hall with much less than 60 or 70 ft. of height if you are going to cover it with fuzzy people and expect to get up to a couple of seconds of reverberation time.

Now, of course, the great reverberant cathedrals with 8 seconds—St. Paul's in London has 8 seconds, I don't know what Notre Dame in Paris is but it certainly is in the same order of magnitude. These have great volume, great height, greater absorption in the perimeter and in the surfaces in the room, and very low population density. They are not covering the whole floor with people, there are great areas of aisles and marble slabs with people laid under them who aren't absorbing sound anymore. So that we are able to build up to these tremendous levels, these tremendous reverberation times.

And in talking last time about this chart for optimum reverberation in the Time Saver Standard reprint, I was trying to make the point, two points: 1) that those numbers in that chart for optimum reverberation time are just good guides toward which to start designing, but they do not determine excellence by themselves. And that (2) if we want to have real excellence in an auditorium of any sort we are going to have to go to all the other factors that we discussed first in order to achieve those qualities of excellence.

Now there is a problem (…. where is that wretched chart?, oh, page 618). There is a problem in the multipurpose auditorium and I'm not going to discuss the multi-purpose auditorium very much today in detail, but there is a problem even in a sort of a single purpose auditorium, of wanting to perhaps have an adjustable reverberation time. For example, if you're to take the concert hall and I'm talking now about a non-drama room, a non-speech room, it's a concert hall at Oberlin College in Ohio …They have a School of Music and they have a concert hall which seats about 700 people. And even there they have a variety of musical performances. They have a big organ. They do organ and choral work and we look here and we see chorus and organ, and we'd like to have upwards of two seconds reverberation time. On the other hand, they do a great deal of individual instrumental recitals: that is violinists, pianists, flautists and other individual performers, and for these people we have recital and chamber music, contemporary orchestral works, we say it ought to be down somewhere around a second and a half.

And even if we are only going to have music as in the Oberlin Concert Hall, we want to be able to change the reverberation time from quite reverberant to rather non-reverberant and more intimate. A violin recital, a flute recital or a piano recital in a highly reverberant hall is not very successful. It doesn't sound right, it's much more of a chamber form of music and by chamber we mean a living room kind of environment.

So when we designed the Concert Hall at Oberlin, of the things we didn't get in there (and someday they are going to have to put in), and here comes the vanity of the architect. To the floor, the ceiling in the Oberlin Concert Hall is a very, very slight barrel. All forms of concave geometry are forbidden in acoustics but they get used. Very, very slightly barrel ceilings and it's 42 feet high and the people on stage do not have good on-stage communication, even though it's Oberlin College and it is a school of music. And the Dean may say, you guys hear each other, but can't, because the ceiling is too high and you've got to have some reflectors at an intermediate height. And someday these will be put in spite of Mr. Yamasaki's [Minoru Yamasaki, Architect] wish that nothing occlude the beauty of the clear pure space that we have created.

However, we did get into this room provisions for varying the reverberation time. Now let me look back at this example again. Suppose [looking for an eraser; there it is], suppose we go back to this earlier example here and suppose I say that this space as it stands has a reverberation time of two seconds and I want to reduce the reverberation time to one second, what do I have to do? Well, you say you can squeeze them down, lower the ceiling and have a piston [piston noise], and down it comes. Well, that's one way to do it, but let's not change the volume. Well, what can we do by adding absorption? How much absorption do we have to add to drop the reverberation time from two seconds to one second? Well, we have to add A don't we? We have to make the absorption go from A to 2A.

Now this is a very important concept, because what this says is that if I want to change the reverberation time (this is hard to do with varying the reverberation time; we put a control on it), if you want to drop the reverberation time in a given hall from two seconds down to one second, then we must add sound absorbing material to the room equal to that given now by the audience or roughly equal to the area. And my friends, when you start out to do that, you'll discover that it's almost impossible to add that much fuzz to the room. It's almost impossible to find places to put it. Now at Oberlin we were able to vary the reverberation time from the order of, as I remember it, it is close to 1.9 down to about 1.4 seconds, the order of a half a second variation. It's not 100 percent variation because we were not able to find places to put in variable treatment equal to the area of the audience.

Now there are two or three things we could do. Not very many. Somehow fuzz has got to be brought into the room. It's got to be brought into the room in places where it can work on the reverberant field of the room. And when it is not in a room, it must be out of the room. You say, well, that's redundant. Well, okay but it gives you this sort of thing. For example, if I have a wall that looks like this along the side of the room here. Say my seats were in here and I have some draperies here, I have some big heavy draperies. Big draperies—we very often use as the element that we introduce into the room to change the reverberant characteristics. We can introduce draperies; we can unroll carpets; we've done this. We rolled a great roll of 40' high rolls of carpet so it will roll up into the ceiling and unroll it like a window shade comes down and so we covered the wall with carpet or sometimes at Wesleyan in Middletown, Conn. they are getting a new Fine Arts Building and the variation there, we've got some wall pockets like this and we've got some doors here. I think this is the way it's going to work, heavy doors that swing out like this. No, they are not going to swing all the way around. I can't remember exactly, but in any case, we've got fuzz back in here and we've got fuzz on the back side of the doors and when we open the doors up we expose the fuzz to the room.

There are several different ways that you can do it, but the point that I was about to make here before I started on Wesleyan is that just taking this curtain and either extending it out like this or drawing it back here into the corner is not getting rid of it. It's still in the room. It's not quite as effective but it's very effective still in a little patch like this, a little patch like this. It's difficult to draw a drapery into much less than a third of its extended length or a quarter at the very least of its extended length, and if it still is there, and a quarter of its length; it still is going to be quite effective in the room.

Now let me just digress, and I have to keep digressing to fill you in on little facts that I may have forgotten to tell you. One of the things we learn when we start using sound absorbing materials in rooms is that when sound absorbing materials are used in little bits and pieces, little square, little strips and so on; they are much more effective per square foot of exposed fuzz that when they are used in a great field, as in the ceiling of this room. For example, if I take a sample (I'll get back to Oberlin, I won't forget it), if I take a sample of acoustic tile 10' X 10'. You notice I always use 10', because it's so easy and I put this on the floor of a reverberation chamber as we did in the second problem on the quiz. But on the floor instead of the wall—doesn't matter—and I'll make a measurement in the room, I'll find that 100 sq. ft. of tile will give me approximately 70 units of absorption, or alpha α = .70, okay or we might say .80. I don't care what it comes out to be. Let's say .70. Now if I go into the room and physically lift out alternate rows of tile so that I have only left 50 sq. ft., but the rest of it is staying where it was, so that I have alternating rows of soft, hard, soft, hard material, or I might do a checkerboard, which would be even more effective unless you take out alternate rows. Now I find that I may have as much as 60 units in the room from 50 sq. ft. or alpha α = 1.2.

And you say "how the hell can you have an absorption coefficient greater than 1?" This is a phenomenon of <u>diffraction</u>. It is more effective at the lower frequencies than it is at the higher frequencies. And at very high frequency and we get almost no effect and the wave lengths get very small compared to the size of these strips. But at lower frequencies you'll find there's a tremendous sort of tributary-area affect. An effect of almost attracting sound into the material by using it in discreet areas. Notice I get less total absorption when I take out part of the stuff. I don't get more absorption by taking some out, I merely increase the efficiency of what's left. Now the same thing applies to this drapery notion. If I have a drapery bunched over here into a quarter of the area or it extends out over the full area, the change here will not be as much as 100 to 25. It will be more like 100 to 40. Because it still is very absorptive and it becomes more and more efficient as I get it into a narrower, a narrower strip and per square feet of exposed stuff.

Well, the answer is that we must get rid of it, and in Oberlin what we did was a partial solution. The ideal would be to have a pocket back in here and the curtain goes back into this pocket and if we didn't close the door. Well, that's easy to draw: we have the door here and it's hinged like this. The trouble is it is 40' high and just the physical facts of life begin to face us after a while. You just can't open and close a door 40' high at least not reliably and not to be absolutely airtight and everything so what you finally do for it is to relax and say well hell we'll just leave it open. So at Oberlin what we do is to pull the curtain back until we still have exposed the order of 6" to 8' of fuzz in the corners willy-nilly because we simply can't physically do anything about closing them.

The Oberlin scheme is the rear wall here, sidewalls here with these alternating pockets and this of course is done partly for diffusion. The big scale "*UMPH, WHOMP, WHOMP, WHOMP, WHOMP"* anti-smoothness and I won't draw both sides; it is the same on both sides. And there are curtains here and each of these things that should be drawn out across the panel and then the rear wall has a most marvelous design, it has curtains here and here behind the scene. It can be drawn across here because basically the rear wall is a very bumpy surface that gets the high order *of* sound diffusion from the sound that goes back from the front of the room area of the performing area. Here are all the seats, in here and by the way the seats are upholstered fabric—upholstering minimizes the variation in reverberation time with occupancy so that the fabric-upholstered seats look more or less like people; and then there is carpet under the seats to increase the total fuzziness of that area that's going to be fuzzed up by people or not people whatever the case may be and the aisles are hard and non-sound absorbing to minimize the amount of "A" in the room other than that provided by the audience, which is an essential part of an audience room. So that we can—by pulling all these things back—have nothing but the audience absorbing energy.

The rear wall is made up in elevation of a series of—here is the size of the rear wall behind which the curtain goes, and the middle is made up of a whole squared off business like this of plaster pyramids, which are eccentric and they rotate. That is, they don't move but they are set up in rotation so that you have a pyramid which instead of being the proper Egyptian pyramid is eccentric like this and so you high point over here and then the next one will have the high point down here and then the next one will have it up there and then the next one will have it over there and so on. So it's a real wiggily, woggily; these things have-are 4 foot squares, sticking out a foot … good healthy scale of relief. And this then allows us to have a hard rear wall, it's straight across- thank God it isn't beam compass design, which is a gross sin—straight across and it enables us to have the rear wall hard and not get a discreet echo that's going to bother us at the front of the room because the hall is in the order of 80 or so feet long and if we simply had a flat smooth wall 40 feet high we'd get a great big "BINGBONG BINGBONG BINGBONG BINGBONG" off the back wall and instead of that this thing diffuses the energy and scatters it around so that the level of the returning sound is low enough not to be heard as a discreet echo.

Then if you want to deaden the room down, we push the button and there are four settings; you have "*Palestrina – Bach;*" and then you have "*Wagnerian*" style; and then you have "*Late Classical;* and then you have *"Contemporary*." You have four different scales of reverberant energy. No, they are just marked 1 - 2 - 3- 4. But the curtains can be centered zip or zip or zip or they are all tied together, it's all mechanized. A little motor drive, and backstage you just push the button where you want to.

I find that there is no sense to really having more than two positions of the curtains out or in. The intermediate ones just don't make that much difference. You either want it deader or liver.
And we're not all that fussy whether it's 1.6 or 1.5 seconds, towards 1.5-ish seconds or up towards 2-ish seconds, and we're not awfully critical in between. I think we sometimes get carried away with flexibility and infinite degrees of variations whereas most of us would be satisfied with maybe on/off or dim/bright, or something of that sort. And the result is they use them either all the way out or all the way back. Also they don't look so good when they are only partly out, the curtains. These curtains are black; Mr. Yamasaki chose to make them black, quite in contrast to the room itself that is sort of this goldy white tone, and the curtains are quite contrasting and show very distinctively when they come out. I find at Oberlin that they use them extended and the room deader more often than they use the room fully reverberant, and at the upper

end of the scale. But if it varies this order of magnitude, and you can see here that we are limited to rather small areas on the wall that are available for doing anything and this is the greatest variation we can get.

Yes?

Student: "Yeah I came in a little late so I have some questions. 1) Was all this planned before or after…?
Yes, before.

Student: "And was that shape therefore in order to incorporate the curtains?"
Yes, partly and then we sort of capitalized on it to give us added diffusion while we were at it.

There was a scheme incorporated into the O'Keefe Auditorium in Toronto, I don't know if any of you know that one or not. I've talked about its very steep aisles and the ushers skiing down the aisles on slick leather shoes on the carpets, it's quite steep. They had a very tricky arrangement in the side walls of the auditorium. The auditorium is done in cherry veneer plywood. Very handsome, very nice, cherry wood. And then in the walls they had a lot of areas where, full scale, they drilled holes about one inch holes, 3 or 4 inches on center, and in the full auditorium there are two or three balconies, two balconies at least.

There's an area about like this on each side, something of that order of magnitude, a few hundred square feet in any case. And behind these holes drilled into the walls of the auditorium was another board with exactly the same pattern of holes which could be slid up and down so you'd have register or non-register of the holes. That is, here is a hole in the facing board and then here is another board immediately behind it with a similar set of holes, and this board can go up or down. And you put it down and then you have all wood in the room; you push it up where the holes register and then presumably you go through to the fuzz behind. This is put in at great expense. You don't fiddle around with cherry and all this jazz for nothing and it's beautifully done. The woodwork and the craftsmanship and the cabinet work…. just lovely.

But, unfortunately, whether these things are registered or non-registered, you can't tell any difference in the hall! Why? The area is just much too small. In order to do anything to the reverberation panel of the hall you've got to operate on it with changes of the order of magnitude of the audience area. Now, you say is half the audience area "in the order of magnitude?" Yes. But it can't be a tenth, you know if it's a half, three quarters of the audience area itself.

Yes?

Student: (partially unintelligible)
The problem with livening it up is that sheets of things won't do it. You've got to have heavy surfaces that will reflect particularly low frequency sounds. And it has to get up to the order of magnitude of pretty heavy plaster, and this gets to be difficult to do.

I would say that experience tells us that it's much simpler to add fuzz then it is to add reflective material. This is the approach we almost always take. Another point in this providing variable control of the reverberation is that the material that is going to act on the reverberant field of the room must be in the reverberant field.

And you say, well, that too sounds redundant and obvious. Let me talk about the sorts of things that won't work. For example, I wish I had a whole semester to teach you about room acoustics for there are so many very interesting things to talk about; we don't have it.

Now for example, if you have a situation in an auditorium with an under balcony, something like this. Let's say you've even been able to get a decent slope to your balcony, you tilt it up, you put it out like this, and here are people, here's the hall, here's the stage, and so on. Now what are you going to count as a volume of this room: How do we count the volume? You say, well, you figure it out. O.K. But this is all filled up with fuzzy people and if we should draw a curtain across the rear wall here, will this have any effect on the reverberation time of the room? The answer is no, not really. The sound in the room really sees this opening here with that height H as having almost 100% absorption coefficient, whether we've got a curtain back there or not. The sound simple doesn't come in and out of this little space as freely as it circulates in the major space in the room. And a square foot of fuzz in here isn't nearly as effective as a square foot of fuzz up here would be in the major space of the room. And there's some disappointment from this: people have added big areas of draperies at the rear wall under balconies, behind a lot of other stuff that's going on in the room, and they have not gotten very much change in the reverberation time and they have been disappointed.

Now there's an argument for putting this stuff here <u>if</u> I have a potential echo from that surface, and an echo is just a one shot deal and doesn't demand the total involvement of the room in the reverberant field. If I'm getting almost an echo on the face, then a curtain here will suppress that echo, will get rid of it. It will absorb the energy and not reflect it and it can be effective in that sort of mode. Sometimes these materials are put up above a visual ceiling and if the visual ceiling happens to be 50% or 60% closed and only 30% or 40% or 50% open, then it's quite likely that draperies drawn out in that upper space will not do very much towards controlling the real gut-feel reverberation of the room. The stuff has got to be out where you can really see it and where it can affect the whole behavior of the room. And the Oberlin situation is one in which that happened because a section of the hall is a 40 ft. high business here, with these pockets happening every so often and full 40 ft. high draperies drawn out here in discrete chunks right in the room, and on the walls that are contributing reflection to the reverberant feel. So, if you are going to start using things of this sort for producing variation, put them out where they can be seen, where they will show.

Yes?

Student: *"In a situation where the main seating area was very steep and the back wall was not particularly loud, very similar to the … but up above, on the second level in the back… "*
It's up here now, this is the main… I'm exaggerating a little.

Student: *"Up above the top line. Let's say there is a catwalk or a mechanical space- mechanical spaces that are open that the sound passes through to a ceiling even higher, and again, there's probably a back wall about the same height as the lower part. Now, what would the effect of drapes at the top and bottom be—would that be much more effective…*
It would depend entirely on how open this is. Entirely how open that is. And I cannot say yes or no; this is a very tough question. We talked about facings for sound absorbing materials. We talked about the size of the object and how, if the object is very small compared to the wave length, the sound will go right around it. And I illustrate with my fingers here. Now this is true on the one pass situation. That is, I have a loudspeaker. It's speaking out and the sound goes through once, and that's it. I have an absorbing material

and I'm interested in what is its absorption coefficient, the sound strikes it once and is reflected, and that's it.

Now then the reverberant behavior of sound in the room is quite a different thing. The sound doesn't strike every surface just once. It does it many times because the sound is going at 1120 feet per second. And remember our dimensions of the room are likely to be 100 ft. maximum, or that order of magnitude. And so the sound is whipping around many, many, many times and what we hear as reverberation is a series of spikes. We hear the original sound and we hear a whole batch of stuff that's reflected from these surfaces and it keeps being reflected and reflected and reflected and reflected until, after a while, it dies down to nothing because the energy is gradually absorbed, equally, by all the fuzz and stuff in the room.

Now if that sound has got to go through any substantial amount of barrier in getting from the room back to some alternate surface to be reflected back to the room again, that is, if there's any substantial amount of closure, then it really doesn't participate 100%. And I have observed this over and over again; and I'm coming to be more and more disenchanted with the notion of the possibility of using a great deal of attic space for very much useful reverberant contribution.

First of all, some of these things just come down to what's really happening, and how is it in reality, in life. The attic of an auditorium serves a number of functions. It carries ducts for one thing—for air-conditioning (and hardly an auditorium is built in the world today that isn't air-conditioned). The attic has catwalks in it. The attic has lighting instruments in it. It often has heat insulation or fire-proofing insulation. But it's almost impossible to get that attic space above the ceiling here really free of all the junk that is bound to happen. Because that's what we have it for—it's necessary for junk. We have it because usually we have to span the space with a truss of some sort. In Kresge, as we'll see when we go over there next week, we created an attic by having the necessity for sound reflecting panels to overcome the horrible geometry of the dome. And so what was an acoustical necessity became a tremendous convenience because you've got to have lighting instruments up there, you've got to have ventilation up there, the air has to be introduced at that position. You can't blow it all from the sides of a wide room like Kresge and have a non-drafty distribution of air.

And even in Kresge, where the attic space is really quite open to the room, that space above those sound reflecting panels does participate 100% as part of the volume of the room and contribute to the reverberant sound. Now you asked me a very simple question and I'm giving you a terribly complicated answer, but I can't say yes or no. I can say that <u>if</u> this ceiling, for example, were series of little wood slats, 1” x 2” on one foot centers to give a visual ceiling, then yes, that would be just as effective up there as down below. But that is precious little disturbance to the sound, and the sound will go in and out very readily.

I observed this in a very interesting way, and again I want to digress as I constantly do. One of the things we are going to observe in Kresge when we go over there is a very interesting flutter echo between the dome and the floor. Now flutter echo—as I’ve described to you before—is set up been between plane walls. Once we curve one of the walls we now exaggerate the flutter and then we can get something that's really quite horrible.

The first time I ever heard this was on a job we did (it's always nice to discover one’s mistake on one’s own work). Every year students ask me “why the hell do you stand up there and admit to so many errors”. Well, because that’s where I've learned something and I might as well save you from these errors.

This was a dome for the Ford Motor Company. It was 120 feet diameter space in which new Lincolns' tail fins and so on were going to be shown. This was back in the finny era. This dome, 120 feet in diameter, is lighted with 250,000 watts of incandescent lighting. Make a sky effect, you know. And guess what the architect used to finish the dome because acoustics was important?

Student: "Acoustical plaster!"
That's right, that's the spirit. The real batty of batty material, acoustical plaster. And we said, oh, for God's sake don't do that; you should use perforated metal and fuzz and they said that's too expensive. And we said: for Ford Motor Company, my God. But it was for them, and so they used acoustical plaster and they took out the form work and it didn't look very good. And acoustical plaster never does, so they painted it right away to make it look good, because it's a lighting surface.

Well, H. Ford II walked in here one day and he got about this far and he was speechless. He couldn't talk anymore; and so, the very next day I was out there to be shown this phenomenon; it was my job. And I walked in here with one of the VP's in charge of things and we were speechless when we got about this far. What happened? I walked in and I said you know what. And that's as far as I got. I was going to say what seems to be the problem. But I couldn't say anymore. I was struck dumb. Well, this is what I heard. *"WHAT, WHAT, WHAT, WHAT, WHAT"* (continues to echo). (laughter) This went on for twenty-five distinct repeats. (laughter). Spaced 1/3 seconds apart (laughing) lasting for a total period of time of 8 seconds (laughter) "*SECOND, SECOND, SECOND*…." several words repeated over and over again to demonstrate the echo.] (laughter) Now this is the first time I'd ever observed this phenomenon. I'm not saying this is the first time it had been observed; this is the first time I had observed it or any of my dear colleagues. We were all "babes in the woods" on this.

Well, the answer is very simple if you begin to draw some ray diagrams, you'll find that the sound goes up here and goes along like this: "*BONG, BONG, BONG, BONG, BONG, BONG"* (laughter) and if it's acoustical plaster up there that's absorbing maybe 3% because it's been painted, why this all gets reflected. If you draw all the simple optical analog…. if you remember your optics: center of curvature C is here there and the focal point F is here. Remember that? The focal point F is the point to which parallel rays from infinity are focused by the new curve. Or vice versa, if we begin a source of sound or light of spherical nature here it will come off as a plane wave. This is the automobile headlamp, analog. Now if we place a reflector at this point, a plane reflector, and we've started something here "*TOOOT"* it goes up and comes off with a plane wave. Now what happens to a plane wave when it strikes a plane surface? It goes back to the plane wave.

And the mirror says, oh, here comes something from infinity, you're focusing (laughter) and then it starts up again. Back and forth, pulling it in, pulling it together. This happens in domes, this is one of the horrors of domes and it only happens though in a very short flat dome where we are <u>within</u> the focal distance. And in this case, this dome has a radius of 120 feet, yes a radius of 120 feet, and we were only at about 40 feet here. So we were about 1/3 of the radius. You know along in here somewhere and what we found was that it took five round trips before the sound got back in the focusing again. "*WHAT, WHAT, WHAT…*" and between each *what* was "*BRRRRIPBONG*." There were 125 round trips before this energy got dissipated.

Kresge Auditorium has the same thing, and we'll listen to it. You ought to go over there sometime by yourself, down in front near the orchestra pit, stand in the aisle and just say "*BOMP*" and you get "*BOMP,*

BOMP, BOMP, BOMP." And that' is what's left after all the seat absorption, after it was taken out. The dome is concrete, so the seat absorption will take some of it out, but there still is enough left so that you will hear this "*WHOMPWHOMPWHOMP."* And if you stand in the two aisles and talk to someone [on the other aisle on the other side], you get the most incredible garbage of speech you have ever heard. I advise you to try it with just two people or something, because if you get all these fuzzy characters in there [i.e., more people in the room], then the effect disappears because we begin to "SSSSSSSS" (suction sound) soak it up down here. This job was solved by changing this ceiling to perforated metal with fuzz. GM [General Motors] then did one, Mr. Saarinen [Eero Saarinen, Architect] did it right after this one and the poor people said hey, you've got the same lousy acoustical consultant, those people over there at Ford; we don't want any of that repeat jazz. And so they went ahead and did perforated metal to start with, with fuzz.

Now I was about to tell you of another situation at Illinois Urbana. You've heard of Illinois. It's has great basketball palace called an Assembly Hall, and it has a domed roof and the floors. And the domed roof is a folded concrete dome. (We call it "folded in and out" and the formwork is Porax, which is wood wool slab like Tectum) That's in place, so it's got fuzz and it's got some gazoots like this. So I went out there early in the game and when nobody was around. (Be very careful now, don't do these things when the client is standing around because if there's any trouble, you want to know about it in your own heart; but if you can keep it from him, then do so. Otherwise you are going to have to solve it.) And I went (clapping) the high frequencies disappear and you hear "*WHACKWHACKWHACKWHACKWHOOMPWHOOOMPWHOOMP,"* you know like that. The "*TTTTTT"* part goes off and then this low stuff keeps going. So I had a beautiful flutter here, up and down, up and down, up and down and I knew it would happen because the geometry showed it in the drawing ahead of time.

Well, there's not much we can do about it. They've given us all the fuzz we could get, and there was not much we could do. Now there is no flutter there now but here's what happened. They provided in this place a fully rigged stage to sit on. They bring in a stage in the middle of the floor and put on dramatic events—at least for one quadrant, and so they hung in here a whole batch of junk, junk, I mean catwalks, lights, all kinds of things, winches, chairs and cables and lines and the full junk that happens in the stage house. And I stood on the floor after that was put in and the flutter is all gone, the flutter is all gone.

There's not a thing there that is really absorbing sound energy in the fuzzy sense of dissipation. There's just a tremendous amount of stuff happening on a minor scale of diffusion, and also a little occlusion coming off of the free passage up and down for this sound. Every time you go through this, it loses just a little bit (as Stan Laurel would say on each banana split). Just a little bit, and that's enough so that very quickly this violent repeat business disappears and is not a problem.

Well, I was trying to say (and I always end up with the most complicated possible explanation) is that almost any surface you put in the way will interfere with free access of sound in a volume, if you're going to ask it to go zinging back and forth many, many times. And I would recommend that if you're going to start introducing variable things in a room, that you do it if you're going to ask it to be visually opaque; and you are going to do something behind the scenery, then what you've got out in front; the scenery has got to be almost nothing.

At the University of West Virginia, we've just used a 1" square grid wire as the interior surfacing for the auditorium. These are 1/8" wires, 1" on center. It's actually material that's made for reinforcing water pipes and sewer pipes, and so on—steel mesh 1" square 1/8" wire. That's over top and beyond, so that if you have that forming the interior of your room, then you can have the curtains and the gazoots and things going on and they will indeed be in the room. But if we decide, for example, to use something like wood slats that may work perfectly well as a facing for a sound absorbing material in the room, it will not be at all satisfactory in terms of letting the sound go through and come back again.

Just be very, very open. Well, maybe enough of that. My point is: don't count on throwing in a few little curtains here and there, opening up a few little doors, or sliding a few little panels. If you are going to bother with trying to change the reverberant character of the room to make it conform more closely with the acoustical desires and the optimal reverberation time as indicated in the chart, then you've got to have a very strong hand and with a very large scale of materials. There's just been much, much disappointment on this score.

Now one thing we found recently is that when you try to roll something up like a big roll of carpet, you've got to be sure that your roll is maybe 6" wider than the carpet, because you've all had experience putting up and down window shades, and you know they can get off just a little bit by any kind of irregularity of dimension, or just the thing sags a little bit in time a little more one way then the other. And we've had trouble with these things binding at the end, so if you start doing something with a roll-up system, allow some extra slack at the end just for the imperfections that are going to happen.

I would recommend very strongly that if you ever get tinkering around with any of these aspects of putting curtains in or carpets into a room or out, get the advice of somebody who really knows his theatre rigging, because it is not an ordinary structural or architectural matter. It's a theatre matter, and somebody who really knows his onions about how to handle these things can be of great help to you.

Well, we'll see you all on Monday, and I hope you have a very pleasant Thanksgiving Holiday.

End of Audio File 21

THE END

Robert Bradford Newman Lectures

30 November 1970

LECTURE 22

Title: "Use of Canopies"

Summary: Newman lectures about the use of canopies in Concert Halls and shares his experiences with many real-life examples.

Beginning of Audio File 22

Was there anything in general that should be said about the quiz?

Question:- (Unintelligible) … the hundred feet of concrete that was covered up by drapery that everybody forgot about. That was pretty tricky.

Well, you've got to be a little bit tricky in this world. The issue, and I think I've already spoken about it, that when you cover up the concrete in a room you have to take that into account in calculating the absorption coefficient status. I think Terry has probably pointed that out. Does anybody have any questions about the quiz? Is anything not clear? Otherwise, I won't take your time here going through it. But if you do have any questions, please come around and get straightened out. I read over the weekend all of the Field Study #1 that had been turned in on time to make this record response.

These [sound isolation] situations described are the usual tear-jerkers. A perfectly horrible, hopeless situation in which some of you have to live, in which there is just no way on earth to fix it so that you won't hear the guys in the next room. One fellow says that the kitchen wall separating his kitchen from the next kitchen is such that if he got down low he could see the people in the next kitchen because he can hear them so clearly.

Student I was in New York in a very soundly built brick apartment house. It was my sister's and I went into the kitchen where there are heating vents and it was like a microphone, you know, it had a cut out at the low tones or something so that you just got a minimum tone. But it was like the radio at a fairly good volume from above. I couldn't tell where it was.

Oh really, I think that all of you, I hope, you had profited from this study. I felt that all of you had learned something and had had a chance to look at some real situations and really analyze what's going on. This is a very valuable exercise, and I've always felt that these two field studies, this one on noise and one on room acoustics, were probably the most important part of our work here together. I was just as much amused by all of them.

Somebody commented about insulation of acoustical plaster that seems to work. Now I have not really said that acoustical plaster never works; it almost never works, but once in a while it does. And the cases where it usually does is on the ceilings of church auditoriums where, of course, it shouldn't have anything like that at all and the damn stuff is just contrary enough to start soaking up sound and not reflecting it. That's when you have to apply the paint on Coventry Cathedral or some other such place.

We will meet on Wednesday as I've noted on the blackboard here, over at Kresge. Terry, would you be so good as to come by here on the way over and put up notice for those people who forget because a lot of people will come here anyhow; it's just sort of automatic. But we'll meet at Kresge and do some looking around. I still haven't found out whether there is anything going on in the Chapel but I'll find that out today. I want to continue this line of argument or discussion on which we were headed last Wednesday, having to do with the number of sort of facts-of-life about auditoriums, things that we can't do very much about because sound only goes at 1100 feet per second.

We've talked about reverberation time, the criteria for reverberation time; in auditoria we've talked about varying the reverberation time and what tremendous areas of fuzz you have to drag in and out in order to produce a very substantial change in the reverberation time and, in fact, if you want to change the reverberation time in a hall from what it is to half that much, you have to add an area of absorption equal to the area of the audience. Which is a huge amount of drapery or carpet or something to drag in and out.

Now let me kind of see if I can tie this business together a little bit. We've talked about two aspects of hearing conditions. One is that of providing clarity, immediacy, and sort of distinctness by getting to the listener at some point here problems the source at some point here whatever it is a person or an instrument or whatever can get a direct sound and then by some path or other or series of paths to get additional sound and we've said that we would like that additional sound which comes in on first reflection or perhaps second or third reflections if we can do it that long so that the delta time of arrival between the time T1 and the time T2 delta T is in the order of magnitude 30 to 40 milliseconds max. And that we try to keep those reflections that we are going to use for building up the loudness, clarity, the distinctness, the articulate quality of the sound.

I haven't said 'fullness' and I haven't said 'richness' but just the part that gives you the clarity. That stuff is a bundle of energy, it comes in on the initial signal and then it's back to the stuff in here and that happens in the period 30 to 40 milliseconds. Now after that stuff has arrived, you've now got your initial impression of sound, you get a sense of direction for the sound from the very first signal that gets to you. So sitting here in a seat, the very first thing you come to is the direct sound because that's the shortest distance and that gives you your cue as to what is the direction of the source and where did it come from. After this stuff comes in there then follows a whole rack of stuff that keeps coming in from all over the room and this will go on for the order of seconds or up to two seconds depending what the room is like but this is one second plus. This is what we call the <u>reverberant tail</u>, that is, the reverberation persistence; in Danish it is called "Efterklang" and it's after "*clang"* or whatever you like—it comes after the main sound has stopped and then you have this "*HUMMMMMMM*" dying away, the reverberant sound.

And these two parts of the sound that reaches our ears in an auditorium have to be in the right balance, in the right relationship, if we are going to have the kind of quality that we have come to associate with really fine listening conditions. Now this is principally true for music. For speech purposes, for theatre or for any kind of situation where you are interested in clear, articulate speech intelligibility, you want very little of this reverberant energy and very much of this early stuff. You try very hard to have great clarity and great reinforcement of everything you possibly can to bang it right into the audience and then have no reverberation at all because reverberation for speech only begins to provide masking noise for successive syllables, and the speech itself provides the masking.

One of you in writing one of your reports commented that the people noise seems best to mask people noise. Yes, of course, in eating places and so on, the principle noise is that we have is other people talking and this is very successful at masking speech nearby because it's exactly the same kind of sound. So in reverberation where we prolong the sound, any reverberant energy that persists takes away a little bit from articulation and clarity.

Student: “You're talking about beyond the 40 milliseconds?”
Beyond the 40 milliseconds. Up to that point you can tolerate a great deal of this and your ears do not distinguish this as something separate but as within the initial clarity.

Student: “….-that makes it fuller?”
Yes. Well, not so much fullness but loudness. Now these adjectives that we're using mean different things to different people. One we call “fullness” or sometimes “warmth” or sometimes “feeling of envelopment by the sounds.” In other words, if I'm sitting in Symphony Hall I see the orchestra up there playing but I would like to feel that I'm in the Hall and the sound is surrounding me, that I'm really being swallowed up in it. When it gets up to one of these real good soupy passages, I'd really like to be involved, be in the midst of the sound and not have them playing off yonder in behind the proscenium opening in Symphony Hall. Now that part of the sound comes from the reverberant field, comes from the sound that is being reflected all around the room over a period of more than a second—a second to two seconds. And that part of the sound has to be balanced with this furry stuff if we're going to have a successful combination, a successful hall for listening to music. And it is the imbalances that we sometimes find between this [early]sound energy and the rest of the energy that may sometimes [make the acoustics] less good than it ought to be.

There are auditoria in the world in which music is performed, in which the music is just all soup. Royal Albert Hall in London for example: for many years until quite recently had a very soupy sound, very lush kind of rich sound with lots of schmaltz and so on. Quite a long reverberation time, and almost no early reflections so that articulate music was not very well heard. Royal Albert Hall also had a marvelous dome overhead and the dome was so high that in many seats in the house you got a real echo. I've heard this echo. I remember taking my wife there one time to a concert and she said: what’s that double business you hear all the time? I said that's an echo. Oh, that's an echo: “*PUTTPUTPUTPUTPUTT*.”

I don't know, Sir Thomas Beecham or one of those great English conductors said that Royal Albert Hall is the only hall in England in which a composition is bound to have at least two hearings. The first performance you hear it twice, so at least you will get two hearings. And in order to cure that problem just a couple of years ago—I can't draw Royal Albert Hall very well—but it's kind of a place with a lot of balconies and so on and some kind of little didily-winks of a shell or something up here, but there's a great dome up in here and in any case they've hung in here a series of reflecting panels which got rid of the sound going up to the dome and force it down onto the audience with some reasonable time delay.

Now the point I'm trying to get at here, and I want to just work on this a little bit, is that the physical reality of the fact is that sound only goes a foot per millisecond, 1120 feet per second, and that tells us something about the height at which some kind of reflecting surface has to happen if we're going to get these reflections to come in to the main body of the ceiling within this period of time. And we'll find in almost any hall, in almost any part of the world, that even without all of the Royal Albert Hall problems that this somewhere in here the order of 30 feet plus a little bit, 35 feet maybe, maybe up to 38 feet or sometimes even 40 feet, depending entirely on the way this thing is oriented and so on. There must happen something in the way of a sound reflector if we're going to get an adequate chunk of energy here in this early range. If we have too much of that early stuff, the sound is going to be dry, it's going to be overly articulate, it's going to be terribly clear and it's going to lack guts, lack body and fullness, which comes from the reverberant field.

You may remember in our very first discussion of the distribution of sound over an audience, I pointed out that the audience actually is selectively absorptive at the low frequencies. And that you get even less energy than you would expect if the audience were merely a carpet or a big sheet of fiber glass. You get more absorption in the audience because it isn't a flat sheet but it is a series of things down in the low frequency range, in the range of one, two or three hundred cycles per second [Hz]. That is more effective there than it is at the higher frequencies, as an attenuator as an absorber of the sound that grazes over it going out in this direct field. In other words, we have all these other characters here and they deprive this listener of more sound energy down in the range of 100 to 300 cycles per second then they do at the higher frequencies and therefore, Q.E.D., one never hears the low end of the spectrum in the direct sound that he gets from an orchestra.

You just don't get it because it's taken out by the audience in front of you. This assumes that you are seated in a big audience chamber of some sort, and we do get this full rich warm base sound in halls and it must then come from the rest of the stuff that comes to us. The reflections that happen from on top that don't have the problem of audience attenuation but we find, much more importantly, that we get our sense of fullness and richness and warmth, and—we are basing this entirely from the reverberant field and not at all from the initial early sound—the articulate stuff. When you use the initial stuff (the articulate stuff at the higher frequencies) and we get the rest of it from the reverberant field, and it's the balance between these two things. The early energy <u>compared</u> to the reverberant energy that has to be right. Now I cannot tell you precisely what it must be because it varies in halls, but certainly there are examples and I'll tell you a couple of them where the balance has not been right and the acceptance has not been good.

Now, I've also said (and I mentioned it the other day and got way off on talking about flutter echo) that suppose this is my platform and this is my hall and I have a balcony. Suppose I've got enough volume here. V (volume), V is established. I start off with this in mind knowing that I'm going to have an orchestra here, an audience here and an audience here. Now somebody may say, well, this is all irrelevant because all the symphony orchestras are going broke anyhow. Well, let's hope that at least for another generation we have a chance to hear symphony orchestras live other than on a recording. But I'm not arguing this for nothing; I'm just talking about physics, sticking to the facts.

What we'll find is that the ceiling in the hall (if we assume everything to be concrete, $\alpha = .02$ and nothing else in the room absorbs sound except the people), that the <u>ceiling</u> is going to come out and have a height H equals the order of 60 to 80 feet. This is depending on what the configuration is, how wide the aisles are, and a lot of other things. But it's not going to be a 30 foot ceiling—here is my point—it's a 60-ish foot ceiling; it's high.

Now if I put on the floor a bunch of musicians down on the stage, then the sound that goes up to the ceiling and comes back down here is going to be delayed a hell of a lot longer than 30 or 40 milliseconds and this will not be useful energy, it will be destructive energy. It will cause muddying of the listening experience and will not cause any clarity. Now the front part of Symphony Hall has exactly this problem in some degree because the ceiling in Symphony Hall is 65 feet high. It's that size because they knew (the designers of Symphony Hall were McKim, Mead and White) and they had Wallace Sabine as their acoustics consultant, but they also had as a model the Leipzig Gewandhaus (which has since been destroyed), and they had the Großer Musikvereinssaal from Vienna, and they had several very well-known examples of halls that worked well and had certain dimensions. And these boys being clever, being highly educated, knew that when something works in Vienna or in Leipzig, it's just as likely to work in Boston. Because the air isn't all that different and so why innovate, why not copy something that you know is good.

So they did, and it, of course, has a 65 foot high ceiling because that's what it took to give the kind of reverberation that you want to have. And that hall has at mid-frequencies 1.8 seconds with the hall occupied. If you read in the book, you'll find 2.3 seconds is sometimes quoted but that's empty with hard seats.

And it's so reverberant that the orchestra cannot rehearse in the hall empty; and what they do is to pull up in Symphony Hall a great big rehearsal curtain here, about 1/3 of the way back. A great big heavy piece of cloth, a great massive thing that sort of cuts off the reverberant energy from this end of the room and it adds quite a lot of absorption and makes it feel about the way it does when it's occupied by an audience. One thing that should be crystal clear by now, I think, and maybe I haven't underscored it, but always the seats in a theatre, or a concert hall or any kind of a room in which you are going to have a variable audience or you may only use the room empty for rehearsals and that sort of thing: the seats should be fabric upholstered. And I say fabric upholstered because I don't mean plastic; and I don't mean leather; I mean cloth. Now there are some perforated plastics now on the market (which I hate to think are available) and if you have to use plastic, then there are some with very, very fine pinhole perforations, with a kind of a rough texture that will admit sound energy into a fuzzy padding underneath.

And I say fabric again because I did a hall not too long ago in another part of the world in which we kept talking about upholstered seating and the architect just kept saying yes, yes, yes and I got there and I discovered that he had used plastic upholstery. And I had sort of assumed that when you talked about upholstered seats we were talking about cloth. I was thinking cloth and he was thinking plastic, and neither of us ever asked the other: do you mean plastic or do you mean cloth? Well, it's not a disaster but the hall is less flexible than it might be simply because it sounds quite different when it's empty as compared to when it's full. And there's nothing so ghastly if any of you have had the experience, as to rehearse in an empty hall with plywood seats and everything just sounds great, and then the night of the big performance, and in comes all the mamas and papas and other people and all fuzzy and padded and they all sit around and soak up all the sound, and the thing is just a disaster by comparison to the way is sounded in the empty place.

O.K. Let's get back to the problem in Symphony Hall. Symphony Hall has a ceiling up here that is 42 feet high and then we go on up to 60 feet. and its longer than this but I drew this pretend (unintelligible). And we have already talked about the problems of on-stage communication, they don't hear each other very well and the people down in the front here get a very soupy sound—a sound with a great deal of reverberant energy, a tremendous amount of surround and envelopment and almost no articulate quality.

Now these are relative things, and people pay money to sit in these seats and they enjoy the concert. All I'm saying is they would get their money's worth a little better if they were back here or up here than sitting down here, but if they don't move around so they'll never know it. Let's just assume that that's what Symphony Hall sounds like, and everybody says it's perfect and this must be it because—oh, it's perfect and I paid money and I'm in Symphony Hall in Boston; I've talked myself into coming here and I'm in a holy place and it's good. And other people say, well, I've enjoyed thoroughly concerts seated way back under the balcony, and I'm sure they have, but again it's better in some other places.

Now the essence to what I'm getting at here is that somewhere is the order of magnitude of 30 feet or 35 feet we've got to have something that's going to reflect some sound down to the audience if you're going to have this articulate quality, and they got to worry about this down in the front part of the auditorium. As we get further and further back (if you just work out the geometry) you'll see that it almost automatically solves itself because the distances are so great so the initial sound that even stuff that comes off the ceiling doesn't go more than about 30 or 40 feet more to get to those seats. And it's these people down in here that we have to worry about.

Now having said that, we have V (a given), we have T= .05V/A, and A is fixed by the audience, V will be fixed by the dimensions of the space and we'll have a certain achievable reverberation time set just by those two quantities. Suppose I say now I'm going to put in a big reflector here, then I've got to scratch that V, that's gone, and I've changed my volume. I've reduced the reverberation time because I've reduced the numerator of the equation. I've kept A constant, the audience is still the only absorber and, therefore, my achievable reverberation time may well be lower. And the point is that we've got to keep this thing [i.e., the canopy reflectors] quite open in order for energy to get on up in here and to let this volume really participate as part of the reverberation controlling volume.

Student: "Is there a factor in which you apply to an absorbing surface if it's not staged directly- suppose it's way in the back. (RBN Drawing) Then it wouldn't be so valuable?"
Yes. That's right, that's right. I would tend—in calculating a room like this, even with this kind of an under-balcony—to take the audience, put it in there and measure this distance here and not count this volume in the room at all but count this as an opening of the room with an absorbing area with almost 100% absorption coefficient because very little is going to come back if this rear wall is soft and the audience is soft. This is a refinement, it isn't going to make very much difference in the overall calculations because that's a small volume and it's a small [area of] absorption, but you are absolutely right: materials that are not really in the room don't really count at full value. And it takes a very sharp pencil to decide how to figure this. That's part of the art, I guess, not the science. Yes.

Student: "So then by having those openings, that's where you're going to get back the stuff that may take that second and get that much cooler sound."
That's right. So what we do is to back some of this stuff down here and let the rest of it get up in here. Now this dimension [the height of the auditorium], though is something that's very compelling, 35 feet, and it can't be really 40 feet, it's getting too high. And yet we must have the order of 60 odd feet to get up with our volume. Another reason we like to have something here about 35 feet is that in a large hall if we're going to have a sound reinforcement system as we'll see, we are going to discuss that very soon. The sound reinforcement system belongs somewhere about 30 feet above the stage floor and it finds itself very neatly as part of this array of things happening here because it must be at that height, it must be in the middle, it cannot be to the side, and it cannot be higher or lower. It's got to be right there if it's going to work well. Once again, it's kind of a fixed rule that we really can't do much to violate.

Now, the first experiment of this sort that we did in our own practice, well, I'll use Kresge maybe. But the Kresge canopy is really quite solid by comparison to what I'm talking about and we have a perfectly dreadful shape of the dome in Kresge, which necessitated largely occluding big areas of the dome with other reflecting surfaces so sound simply couldn't get there and get back. So the spaces behind the sound reflectors in Kresge—those over the stage and those back in the house—that volume really doesn't participate 100% in achieving reverberant energy in the space.

Now I described to you the Tanglewood experiment in which we did a canopy occupying half the area 50% closed and 50% open, above the performing end of the house and out over the audience about this far. And that canopy is about 25 feet high, it's a little less than this because the overall height is only about 45 ft. And this canopy was put in principally for on-stage communication improvement and for string balance improvement for the front part of the house because the strings were very, very weak. And this canopy was highly successful. It never has had anything done to it since it was put up, and everybody that's used it—at least everybody that I've ever heard talk about it--finds it to be a very, very successful thing.

Now I'd like to talk for a few minutes about the famous case of Philharmonic Hall [New York City] in which we were involved at the early phases and to quell a whole lot of false rumors because I've never heard a hall about which more bumpkins were said and more untruths told; and which there's been more stupidity on the part of the moneybags who control the funds in that hall. There's just nowhere in the world where there is such gross stupidity and politics. Now Philharmonic Hall was a derivative of Tanglewood. It was designed in about 1960 or '59, '59, when the design was going on.

The design of the hall as it finally was built was quite different from the design that was in hand at the time we finished our active participation. Well, that's just a historical fact. Because in the New York Times magazine section, before the construction was started and before the drawings were all finished, was one of these artist's conceptions, you know, those renderings done by the architect of what Philharmonic Hall was going to look like. And it was quite a different hall from what was built. The balconies had wiggily fronts on them, it was all bumpity, wiggily. The ceiling extended only just past the orchestra and then went up full height. The hall was more rectangular, and many things about it were changed as the design progressed.

The rear wall of Philharmonic Hall is a spherical segment, and I did not say cylindrical but I said spherical. It actually curves in section as well as in plan, and it's a spherical segment with balconies. You can't think of a better way to induce echoes then to make something concave and focusing. Guaranteed to give trouble. The only civilized shape for the rear of the wall of an auditorium is <u>flat</u> and get rid of your beam compass once you get the seating laid out, and then just make it nice and straight, flat and it's perfectly great.

Clowes Auditorium in Indianapolis, Butler University, was a descendant of Philharmonic Hall as was Salle Wilfrid Pelletier in Montreal, and a great many other halls around the world, all of which had derived from it and almost all of them have flat rear walls. The principal problem in Philharmonic Hall was that at the opening…. (oh, first of all there's some politics in it, very very political). The Hall opened in September, '62, and in June they had a series of test concerts; New York Philharmonic was under Bernstein [Leonard Bernstein, Conductor] and had some rehearsals, which they held in the new hall.

Now the new hall hadn't been finished. There was no stage floor yet. They stretched out some plywood over the framing; the seats were in, there were many doors not in yet, workmen banging and hammering and so on. But they went on and rehearsed for a week and they had Leopold Stokowski and all the big boys came in to listen. Test the acoustics. And this concert, this series of tests was to be done in absolute secrecy; there was to be no press release about it. The press was not to be called in and not to be told anything. The purpose of the concert was to see whether there were any changes that should be made during the last few months between June and September to bring the hall up to snuff.

And in the course of the week, a number of experimental changes were made and some of these were incorporated in the hall after this series of test concerts. But the PR people at Lincoln Center were just like all PR people. They just had to tell somebody and so they rushed out on Saturday of this week and gathered in all the music critics and announced that perfection was at hand; that the hall was perfect, and that it was going to be absolutely perfect when it opened and that acoustical science has triumphed and all this dreadful PR type garbage. Slop, dribble.

Then when the hall opened, of course, in the New York Times—the week before, there was more of this slop and dribble put out by the PR guys about perfection. And acoustical perfection and so on is now at hand. I personally don't even know what it means, acoustically perfect. This is a matter of opinion. It's a matter of how I feel, what I had for dinner. Whether I have a cold or not; whether I like the program; maybe I don't like the conductor's hair or there's lots of things that could turn me off. And I could say the acoustics is lousy or I could say the acoustics is good depending on a lot things other than acoustics. Well, during the course of development, the architect decided that he didn't care for the design in which the canopy or the ceiling stopped here; he wanted the ceiling to go all the way back.

So he hung the ceiling all the way back and I haven't drawn in all the balconies and everything but imagine what it looks like. This is essentially it. All these panels in the original design would be movable with winches. That proved to be too much of a task for the architect to figure out, and so they decided to weld them all in place and they put them up there in the most incredible heavy steel work, and they were all welded permanently in place, which reduces flexibility. I would say that if you ever want to move the ceiling of an auditorium (as I said the other day about moving sorts of things in theatre, moving big curtains or curtains or anything else to change the reverberation time), get the help of a theatre engineer.

Somebody that knows how to do this particular kind of thing very well, because this is not a very tricky thing to do, as we demonstrated in Jones Hall in Houston and other places—to move the ceiling in the auditorium around isn't a terrible trick. It can be done; it just has to be done by somebody who knows what he's up to. It’s not a bridge. It's a movable ceiling; it's a piece of theatre, and it's scenery, if you like, and it moves in an entirely different way. O.K. So all this is fixed. Then remember that at Tanglewood one of the things we did was to fill in a couple panels here full 100% because we wanted specifically to favor the string tone for a particular area of the main floor. The strings are at the front of an orchestra. And we just beef them up another 3 dB by putting in a solid layer of panels behind the opening in two rows. Everything else is 50% open, two rows or something.

If you go out there and look up and you see these [i.e., reflectors behind the panels]; they are painted black; they don't show very much and they don't interfere at all with the general pattern but they are there. Having had that experience we decided to let's try that here, and so we did some filling here, experimentally during this first period. And some of my brilliant colleagues decided, you know, that soup certainly was improved with a little salt, maybe the whole box would make the soup real good, and so after this initial trial period the permanent changes were made. And for some reason, which nobody wants to take the blame for, quite a lot more stuff was filled in than really was necessary. And in fact, this was the whole problem.

When we have an array of reflectors that is at the right height, it gives us the right kind of early sound down here. We have a two-edged sword now at our disposal. If we start filling in that array, we both increase the amount of direct sound and decrease the amount of reverberant sound. And the thing we are trying to operate on is the <u>ratio</u> of these two. So the minute we change this, we change the reverberant field as well. And the problem in Philharmonic Hall very simply was too much early sound and too little reverberant sound. The hall had what some people described as a “hi-fi” sound, hi-fi being an exaggerated clarity. Something that isn't quite natural in a hall. There is no amplification going on, but it sounded almost that way. It sounded hard. It lacked fullness and warmth: fullness and warmth coming from the reverberant ceiling. Well, we then proceeded to do a number of experiments in the hall after this initial criticism and prepared to report the recommendations to the owners, recommending that quite a lot of this stuff should be taken out that had been put in. And a couple of other minor changes to help combat an echo that came from the rear wall, which had to be solved now by absorption since the shape was already there, and it wasn't very easy to reshape.

Now at this point the late George Szell [George Szell, Conductor of the Cleveland Symphony] entered the scene. George Szell once performed in a high school auditorium, Lakewood Auditorium in Cleveland. Maybe some of you know that auditorium. It was designed as a high school auditorium, not as a concert hall for Mr. Szell and his orchestra, and they were prevailed upon to open the Lakewood High School Auditorium. And he didn't think it was a very red hot auditorium in which he should be leading the Cleveland Orchestra and indeed it wasn't, and shouldn't have been because it was then a lousy high school auditorium. And he decided that Messrs. Bolt, Beranek and Newman didn't know very much and should, therefore, not be trusted.

So he decided that he would dislike Philharmonic Hall from the start, and even before he heard sound in it, he got Irving Faloden and couple of others boys down there, the music guys aside, and gave them a two hour diatribe on how dreadful this hall was going to be, how it couldn't possibly work because Leo Beranek had been involved and he didn't like blue and he didn't like gold; the colors were all wrong and hall could be nothing but a disaster. So he decided that it was going to be a disaster and did everything he could to make it one. Time Magazine had an article about him two years ago and one of the members of the Cleveland Orchestra describes him as a cold, hard, SOB.

That's exactly what he turned out to be. Now here we have the intrigue beginning. George Szell went to Schuman, Bill Schuman who was standing in as the head of the Lincoln Center for Performing Arts, and said: you ought to get rid of those idiots from Cambridge because they don't know what they are doing and I've got just the guy for you, he's a German. (speaking in German) He is named Heinrich Keilholz. And some of you may have heard about him; he is an absolute fraud. And I'll say this in public. And no fear of a suit. He is a fraud. He even said: "I know nothing about acoustics, I just know what to do." One of these pipelines to God; Godness.

And he was formerly a recording engineer with Deutsche Grammophon in Hanover and did some recording with George Szell, and as my friends at Deutsche Grammophon tell it, he knew when to take coffee to the maestro and endeared himself to the maestro and thus became a great acoustic expert.

And Szell said you should get rid of those people from Cambridge, don't pay any attention to them, they don't know what they are doing and get my man Keilholz and he'll fix it up. Well, then they decided they shouldn't trust just one guy so they got a committee and you know about the camel and the committee and so on. They got a committee of three other people in this country; one of whom made a public statement that he was going to save the science of acoustics. And for this he was discharged from his position as Architecture Acoustics Editor for the Journal of the Acoustical Society of America and formerly reprimanded for making an unprofessional statement like that. Well, a whole lot of non-professionalism went on and these guys set out to prove that Messrs. Bolt, Beranek and Newman didn't know what they were doing, were wrong and they would change things and make the hall right. Their objective was not to make the hall right but to prove somebody else was wrong. And my friends, nothing ever gets accomplished when you go at something with that kind of an attitude.

They were told by the architect and by the owner not to consult with us on what we had done or what our thinking had been or anything of the sort but to conduct a separate and new investigation. As you know, the first changes they made were not successful. They were curing a migraine headache by trimming the toenails. You don't trim toenails to cure headaches unless your headache is entirely psychosomatic. If that's the case, maybe that would work. They raised the ceiling. They said any idiot would know those panels are too small to reflect low frequency sound. We knew that. We know that you don't get low frequency sound off panels; you don't want to get low frequency sound off panels. You want the low frequency sound to get around and up into the reverberant field so that it can build up this sense of fullness and give you the kind of sound you want.

And then they decided to fill it in solid, they raised the ceiling, then they spent I don't how much. I can't even remember the fantastic amount of money, and then the next year that didn't work so then the next year they threw out two of the guys, two of the Americans and they kept two Germans on the team now. One's name is Manfred Schroeder from Bell Telephone Laboratories who works with the computer. And all you need is the computer and you get everything right. All the answers are right. Garbage in, garbage out.

And he's never done a room in his life but he did know how to simulate certain parts of rooms with his computer. And so he and Keilholz then proceeded to make two more sets of changes and Keilholz—just last year or the year before last—did still a third or fourth modification; it's just ridiculous and they threw Schroeder out because none of these things were working. They couldn't work because they didn't understand what they were up to; they didn't understand the problems, the original design intent. And now the old ceiling has been taken out, the seats have been changed, the walls have been changed and it still doesn't work. And it's not going to work until sometime, maybe in the future when all the present morons with money down there are out, somebody will say: well, why don't we see what maybe could be done to this hall. It could be a very fine hall. No trouble at all. It could have been done for $50,000. At the outset.

After the first round of things for removal of some of this, they had estimated that it would cost about $50,000. Instead of that, they gladly spent $1/2 million at the direction of some quacks. Well, I tell you this story simply to point out the horrors of real life….the way things can go and that it is a tricky business. Since that time we have done, oh, I would say 50 halls at least in this country, in Canada, and other parts of the world as well. And they have all worked with varying degrees of success, again varying with personal opinions of the local critics and whether they like the colors and so on.

But halls that I would say, from a professional point of view, are very adequate halls. All of them utilizing some form of this notion of reflective ceiling panels in this general front area. Now there are other acoustics people (we are not the only ones in the world), there are others who feel that they would prefer to take what they call the 'eyebrow' approach. Unfortunately, these panels have gotten to be called clouds because Eero Saarinen called them that in Kresge and they were about the first "clouds" that were hung up. And since then, they have been called "clouds" and I don't think you'll have to worry. But there are people who would: say we want to put up an "eyebrow" here in the front. Well, if it's done carefully--not too much of it--this can be an equally effective thing.

But the point is it's got to happen here; it can't happen up 10 feet higher, and it shouldn't happen more than about 10 feet lower. It's something that happens at the 30-ish foot level and it simply must happen in a multi-purpose auditorium or in any other kind. And we know from the experiments that we did at Symphony Hall that the listening conditions on the main floor and on stage are incredibly improved with the addition of just a sprinkling of panels. But they change the appearance as you well know; that is sacred and you cannot do it. How they did it in Royal Albert Hall I don't know except that it's such a monster; I think they decided it would be better to make some changes and make it come out right. And they did indeed hang up some great big round reflecting panels all over the middle area and it made a remarkable improvement in the listening conditions in that space.

The knob that we have to turn, the "quality knob" in a concert hall, that knob had to do with the balance between the early sounds and the reverberant sounds. Not too much and not too little, but just the right amount and that right amount comes at something of the order of 40% to 50% reflectivity in this area. Now you say will 30% reflective work? Yes. That'll work. 60% is too reflective, I'm sure, but this order of magnitude and with things the order of magnitude in size of 4, 6, 8 feet, but not 30 feet.

Student: "That eyebrow that you drew up a second ago, what does that really look like? Is that a hundred feet long?"
Yes, maybe if the hall is that wide or 80 feet long.

Student: "No, that's no longer…. (trails off)"
No, that's a real reflector and is anything but half open. And what is does is to make this space—this volume—is not very effective in the room. If it's done right (especially if you curve it and they almost always curve them so that you defuse the energy), and so the level of sound reaching you is down lower and this is spread out all over the whole house. It can give a very good result.

Now you notice that I talked all together about the ceiling. The walls are not unimportant and one of the reasons you hear as well as you do in Symphony Hall is that the place is fairly narrow, that the walls (we draw a section through Symphony and there are these little balconies sitting on the sides) and out of the soffits of these balconies reflect some sound down.

And that hall is only about 70 feet wide and so you get quite a lot of energy reflected from the side walls, from the balcony sides, and from the general diffusion of sound in the room. That doesn't leave you totally devoid of any kind of early reflections even though the ceiling is 65 feet high. So it's not a disaster. If it were a disaster we would have heard about it long ago. It's obvious that the hall works; that the hall has a high level of public acceptance. It's just that it could be a lot better if we could only diddle a little bit with some thingies down there in the middle of space. I don't know if I'm going to live long enough to see that happen. It's just one of those things that there is a lot of resistance for doing it, and this is a fair exposition of this philosophical point of view.

Has anybody any question about what I'm trying to say here? It's a difficult thing and it can only be said after a great deal of preamble about all these other things that we are trying to do to achieve this quality. Now you go into a space like a cathedral church or something of that sort, then all these bets are off. We are not anymore talking about giving concerts on the steps of the chancel or something, though this has been done. When we talk about speech articulation in a great reverberant space like that, we talk about doing it with electronics. We don't try to just blow up the sound louder and louder because speech would be absolutely impossible if it were made generally audible with the "Voice of God" system in one of these places. It would be absolutely impossible to hear anything. Just "*BLOOLOOOOLOOO*." Or get out here in the main lobby of Building Seven [main entrance to M.I.T. at 77 Massachusetts Avenue, Cambridge] where the reverberation is 8 seconds and just try shouting from a balcony to somebody down below and you'll discover that you have almost no articulation at all. So we do that with electronics and try to speed things up with just the straight volume reverberation of music.

Well, we'll go over to Kresge then on Friday oh, Wednesday, Wednesday.

End of Audio File 22

THE END

Robert Bradford Newman Lectures

4 December 1970
LECTURE 23

Title: "Remodeling Auditoriums"

Summary: Newman discusses his experiences with remodeling existing auditoriums.

Beginning of Audio File 23

Mr. Harris has brought in an interesting little piece of literature here published by "Audio Lab." You will hear about this. This is an article that says that engineers are still searching for an answer. Good sound is an art, not a science. Now we have the prime example, of course, in the Lincoln Center for the Performing Arts. There is an unfortunate story which illustrates our point. Several years ago the City of New York hired the worlds…. the City of New York mind you, begin right off with faulty information, like most articles that you read in print. The City of New York hired the world's best acoustical engineers to design a concert hall which would be technically perfect. These engineers travelled around the world, measuring all kinds of concert halls, and eventually they came up with a formula for what was expected to be an auditorium unparalleled in acoustical design. They were so proud of their achievement they even wrote a book about it. The renowned musician composed an original piece to be played on opening night for an audience of dedicated music lovers. The renowned musician is Daniel Pinkham who composed a short ditty of about ten measures to be used, called "Catacoustical Measures," and it was to be played to get some data on reverberation time; it was designed to have some great, loud chords which would suddenly stop, and then we could measure the reverberant decay. It was a controlled gimmick.

Now, we go on. At last the-long-awaited moment arrived amidst the glare of television lights, the famous conductor raised his baton and began his symphony. To everyone's dismay the worst sort of discordant sounds echoed throughout the hall. Now this makes interesting printing and interesting writing. But it was anything but the worst sort of discordant sounds, and even that great critic of the New York Times, whose name I can't even think of at the moment. What's his name, no it wasn't Barnes, it was another guy, anyhow even he wrote an editorial, which said he liked the sound, after he decided it was a little bit too hi-fi. But that is not the point; discordant sounds echoed throughout the hall. The whole effort was a colossal failure.

Why did this happen? More acoustical engineers from all over the world—that's from Germany—struggled to solve the problem. Over the next few years a number of corrections were tried, as each scientist attempted to prove that he had the right formula. That's true. In the end, in spite of all this expensive high-powered effort, the hall still didn't sound as good as many of the old classic theatres that were designed by artists strictly by instinct.

Who believes that anything successful can be designed by instinct? I don't. We have one over there who does? O.K. To further illustrate our point, can you imagine any one questioning Stradivarius about the harmonic distortion and transient response of his violin. This Stradivarius bit, of course, is exactly what the musicians say when they see a hall finished in wood. They say, "Ah, just like the Stradivarius." Yes, so what. That is what they call a non-sequitur argument. Wood is good and sound is round. I can think of a few other little aphorisms. This is unfortunately the sort of thing that has developed in the almost 10 years since Philharmonic Hall opened. You keep hearing about this disaster, this colossal failure, this dreadful sound, the worst sort of discordant sound, and you ask anyone who tells you this: Have you been there, and the answer is always “No, but I've heard….” I've heard. It’s cocktail party conversation. Well this is just one more lousy little article; thank you for bringing it in. I shall see that Audio Lab gets squashed.

Does anyone have any further questions or comments about our visits to Kresge and the Chapel the other day before we move on? Yes?

Student: (Unintelligible)
The panels? Yes. Oh that's architecture. Let me get some chalk here. I think I get your question. There- it's not altogether just architecture, but you have a stage and a pit and the floor, something of that general sort, not quite like that. We have these reflectors over the stage, and they have surfaces like this, and we've got the stage out here, and the orchestra pit's here. Your question is what are these for? They're for two things. One, in order to get the pitch of these surfaces about right to project sound to the audience and to, well, mostly for balance, and put strings on and so on down, these areas you could go on up with this thing quite straight, but for visual reasons and for reasons of height and so on and for maximum masking of the dome itself we wanted to get this down again and these surfaces are merely to give the architectural continuity of going up and coming down and up.

Now they do serve an additional function of providing some reflections back from musicians on stage to others back here, for on-stage communication.

Student: “There are some further back that slope away and look to be about the same angle as the floor.”
Those are entirely architectural. Obviously the projection booth isn’t above those, so my drawing is just way off, but back here, these are merely to get them back up again, so that these can continue to come down at an angle that's useful, and it’s just a visual filling.

Student: (Unintelligible)
This one is up, isn’t it?

Student: “No, that one down there, yeah, no in between those two, there is just straight reflectors without going back up.
No I think they both up again. Why don't you check again, and then let's talk about it. I think, if I remember correctly, they both go up slightly here. Now what we really wanted, and I hope someday to live to see it, is not the simple bent plane surfaces, but pyramidal surfaces. That is, in plan to have these things and sections come up again, and in plan to have them like so, so that they have sides on them that kick sounds sideways, because the side-to-side reflection is not good in Kresge, and you find that if you sit over at the left hand side of the house, you hear the left hand side of the orchestra better than you do the right hand side of the orchestra, because these reflectors are fanning out, and are sending that side to that side and this side to this side, and not much cross-room reflection.

And we originally wanted this to be pyramidal and not this way, but the architecture predominated, as it did in almost all aspects of that building. It still works pretty well, you know it’s about a “B+”. I wouldn’t give it an “A-“ but “B+” it’ll get. Any other comments? Well, I’ll hope you'll all remember the echo, and I hope you've all had a chance to hear that flutter between the dome and the floor; that's really something.

I spent yesterday up in Burlington, Vermont, at the University of Vermont, on a clinical visit to look at a number of sick patients. It's quite fun to do this, and I do it once in a while, go to some university and they'll have half a dozen auditoria, all of which are bad and have been bad for generations, and suddenly they discover that maybe something could be done about it, and so we go and have a laying on of hands and general curing of things, and this wasn't quite that simple yesterday.

And if you know the University of Vermont, know about their chapel, which is McKim, Mead, and White, 1925 Georgian. That's a particular period of architecture, and it has the dome over the middle, and has barrel ceilings, and guess what the dome and the barrel ceilings are treated with? Acoustical plaster. Right, Right, OK, dead right.

And the walls were all hard and sound reflecting, and the room has almost no reverberation and the funniest sense of being in a barrel that you can imagine. There the worst sorts of echoes and flutters and things across the room from all these big hard vertical surfaces, and then the dome overhead and the barrels, it's a cruciform plan of course, since it's a chapel. And the dome's over here, and it's all acoustical plaster, and then there's a little well at the top of it. It comes up like this, and then there a baluster up here with an oval and a platform up here, then some more stuff up here, and this finally goes up like this to a cupola you know [cough] light comes filtering down through there. It's really classy.

There's a dome up in here too. We went up in here, and this is all treated with acoustical plaster, it isn't absorptive enough, but what you get are some perfectly marvelous sounds up in here. Just great, to be up in here, and talk, and hear yourself coming back and refocused and everything. Well, all this is just as dead as it can be, and then the walls here, in section, this thing goes on back, these barrels go up here, and then these great high walls (unintelligible) and so on, and then there's a great window here, you can picture the thing. Great big solid walls of plaster on masonry which reflects sound like mad. And it's just got abominable acoustics, and it's had abominable acoustics since 1925, and now they want to do something about it. And they also have an old gymnasium which has been abandoned, isn't used any more. Perfectly marvelous building, with great wood trusses across the top, spanning the space, and it's all done in wood boarding. Very thin wood boarding, you know the kind of stuff that was fashionable in the end of the last century, with the tongue-in-groove, extra *gazook-gazook*. I'm sure you have some of this in your kitchens where you live. You know, looks like two boards, narrow stuff, it's all over the place, varnished pine. You can just imagine; it's just great.

And so they wanted analysis or a discussion of the converting of these two buildings, and what could be done. They wanted one for a theater, one for a concert room, and they're willing to do either of them as a theater or either as a concert room, but we've got to make up our minds which is best for what. And it was a fascinating day—to spend the entire day with the drawings and discussions and clapping hands, and listening and thinking about what we could do, what would be the least expensive, and so on. I think we're finally going to decide that the Chapel is the better concert hall, and the old gymnasium is the better theater, because the theater program is one that is towards the experimental end of things. They like to be able to have a great flat floor, and do almost anything they want in this great space, and have marvelous hanging facilities overhead for lighting and scenery and almost anything. They've got good shop space, and I think we can make this into a first-rate concert room.

The big disadvantage of this shape is that this is about 85 feet across. Now this dreadful problem is that if we extend the platform out here, and make this into a music performing space, the religious implications are no longer [valid]; it is not to be, [though] it will still be called a chapel, but there is not to be any sense of chapel kept in it. We'll have to get rid of this ceiling~ this great dome, have some kind of a flat ceiling~ and they say that even the alumni probably won't get unhappy, if we desecrate the McKim, Mead, and White building with a flat ceiling in there.

Well, I said we could get some architect who still knows how to draw egg-and-dart moldings and so on to do some fancy egg-and-dart for the perimeter, and we might even put in a few (unintelligible), imagine me suggesting such papering, but it looked like 1925 Georgian. I passed it up as an example of its type, and the big problem is going to be: how do we get rid of the long delayed reflections that come back like this? And out in here, the listening is perfectly frightful from the stage. You can hardly understand a word that's said, because of this side stuff. You get back here in the back of the room, and it's not bad, and up in the balcony it's not bad. Yes?

Student: "Are the sides facing the hall (unintelligible) the center part?"
Yes, within three feet. It's literally the side barrels up, spring from the same height as this, and then there's a cornice, and you know, I don't even know how to draw that stuff.

Student: "How high would the flat ceiling be?"
The flat ceiling will be the order of 35 feet. It's now about 38 feet up to this point. So it's about right, it'll seat about 800 people when it's all done. There is now a balcony back here, which comes down like this. The floor is dead flat, and we'll probably maybe get rid of the balcony and pitch the floor up, and maybe keep the balcony and get rid of the under balcony seating. And the balcony then goes back over the entrance foyer, which, of course, has this barrel ceiling, this is the back of the building. Maybe keep the balcony, and then we come in here and come up some steps to this seating incidence. It takes a lot of work to think these things out, but I guess the purpose in talking about this is to say that you will all be faced from time to time with situations where a lousy auditorium exists. It's a sound building, it isn't about to fall down, it represents a tremendous investment, and something has to be done about it in order to make it possible for people to hear, what kind of renovation costs are we up against, and does it pay to do it?

I went down last year to Dallas, to look at the Fair Park Music Hall. Do any of you know that space? Well it was built about forty years ago, and it's in the State Fairgrounds area. And it's a great big barn of a building that seats about 4,000 people. Visiting symphony orchestras use it, and it's really booked quite a lot of the time for entertainment of 4,000 people. It is a perfectly dreadful room from the acoustics point of view. It has an acoustic tile ceiling all over the space. It has a very primitive public address system, and, by the way, this hall has the most marvelous P.A. system, consisting of two little boxes, one here and one here up high, sort of an idiot approach, just grade "F" right off the bat, without even listening to it. I didn't want to hear it. I know exactly what it would sound like.

And this Fair Park Auditorium was under consideration for remodeling, more than a paint job. They really wanted to make it a first rate facility. air-conditioned properly. It's air-conditioned now with some machinery that sits downstairs and when the compressors come on you can just feel it in your rear end, "*BBZZRRRRR"* –massage—which is better than that [horrible] compressor I saw down in the University of Puerto Rico, where it goes "THUMP, THUMP, THUMP, THUMP." You can really feel it; it's a one cylinder 1934 air-conditioning compressor; that just really is something.

But this one in Dallas just gives you general massage, instead of a thump, and a whole lot of things were wrong with it. Well, Don Jarvis, an architect in Dallas [Jarvis, Putty, Jarvis, Architects], who graduated here from MIT a few years ago, is in charge of the project, and he engaged me and a lot of other people to make a feasibility study as to what it would cost. You'll find that today, to build—this is 1970 I'm talking about—to build a new performing arts kind of auditorium, an auditorium with a stage, with a pit, orchestra pit, with good sound amplification, maybe with some theatre effects in it and so, will cost you upwards to $2,000 per seat, to build. So if you are talking about a 1,000 seat auditorium, you must have in mind a budget of something around $2,000,000 dollars, certainly not $1,000,000 dollars, not $700,000 dollars, and it might well be $4,000,000 dollars not $2,000,000, depending on how fancy you get. This is just the reality of things.

I'm doing a hall right now at Ball State University in Muncie, Indiana. The architect, Evans Woollen [Evans Woollen, Architect] came here to talk about it, and he said we are going to build a 1,000 seat auditorium, and we've got a million dollars. And I said Evans, you're dreaming, you can't do it. Well the price has gone up to $1.6 million, and the seating has gone down to 800, and we come very nearly back to $2,000 dollars per seat. This is the reality, and this is not a fancy auditorium, there's no stage house, it's just for music, lectures and so on, so it's just kind of a bare-bones sort of a job.

Well the thing in Dallas with 4,000 seats. It turned out that in order to remodel it, it would cost about $4,000,000 dollars. Now you say, how on earth could you spend $4,000,000 dollars remodeling? Well, it's 4,000 seats, it's big. All the seating has to be replaced; the floors are all right, but the ceiling has to be taken out; the walls have to be redone; the duct work and air conditioning has to be redone; the lobbies and all public spaces are totally inadequate. It's one of these concrete-floored-with-vending-machines kind of lobby, you know reverberant, General Electric best green high gloss enamel is use on all wall surfaces, and you can just picture it. With bare fluorescent tubes providing the light in these spaces, and industrial steel sash at the windows—in Spanish Renaissance 1920 style—just real juicy, and the whole thing is so horrible that it has no appeal whatever to people, you'd ·never want to go there or feel good about going there, and so it's going to cost about $4,000,000 to do it. And then of course the question comes, what would it cost to build a new one? Well, only another $4,000,000, only $8,000,000, and you start throwing millions around, and what's the difference between $4 million and $8 million, you know, just a little bit more debt, and shouldn't we just tear it down and start over again and build something really good? And they're still arguing about that, and I don't know what will happen. By the time they get through arguing, the remodeling costs will be up to $5 million, I'm sure, and I just don't know what will happen.

All this in line of talking about auditoriums, multi-purpose auditoriums: what's involved in making an auditorium serve many purposes, what are the criteria that we must meet,? Is flexibility a necessity or is it merely a frill that we can do without? These things I think can be answered, and I'd like to try to address myself to these questions today, if we have any time left. But don't throw in the rag when you are faced with some monster like this McKim, Mead and White 1925 Georgian thing, which is just dreadful acoustics, because 9 times out of 10, with some care and thought, you can make it into something really quite useful to the community, and not simply tear it down and start again with something else. And you may quarrel with the style of the exterior, if you like, or over the style of the interior or anything else; but it's kind of pretty good, and it's become a symbol, and maybe it deserves to be fixed up, so that it will be a useful symbol, and not just a building that everybody bitches and growls about.

We talked a lot earlier about changing the reverberation time in a hall, to accommodate a variety of performing conditions. This I still feel is very important in the multi-use auditorium, and I even cited the case of the Oberlin College Concert Hall, which is a concert hall, it is not a theater. It is not used for ballet; it's used sometimes for a concert opera, but is a primarily music performing space, and it has variable reverberant control even for music, because for music we have a tremendous range of desirable reverberation time. I don't think maybe we need to talk too much more about the business of varying the reverberation time. Yes?

Student: "When you set your standards for reverberation time, are almost everything else in terms of hearing quality, is it in terms of the professionals (unintelligible) who have music students and professors at Oberlin, and they tell you that something's wrong and then you tell them this is wrong or it should be wrong (unintelligible)."
Let me see if I can get to the core of your question. First of all, let me answer a slightly different question, which may help a bit. How did these numbers get arrived at anyhow in our chart for optimum reverberation time? Those numbers were arrived at by making measurement in the existing halls that were considered to be good. At least there were no complaints, and you find a lot of halls, like Boston Symphony Hall, that a lot of people like, and a lot of people aren't usually all wrong. And it is a good hall, so we go there, we measure its reverberation time, we measure a lot of other things about it besides its reverberation time, but as long as we're trying to narrow down to that constant, we say that is its reverberation time.

We know the Academy of Music in Philadelphia for example, and the Academy of Music in Philadelphia is an anomaly. It has a reverberation time in the order of only 1.3 seconds, and yet you talk to any Philadelphian, and he'll genuflect and cross himself at the very mention of the Academy. It was built in 1870; it's been there a long, long time, 100 years old. Philip Johnson redid the interior decor in his best decorator fashion a few years ago, and I must say, it looks pretty good. We put in air-conditioning a few years ago, and our job was to see the air-conditioning didn't change the acoustics; that meant you don't hear it, so it's absolutely silent air-conditioning, nobody even realizes that it's been done, except that they're more comfortable now than they used to be, and yet that hall, with only 1.3 seconds is below the range we say is optimum, simply because it's an anomaly, I'll admit that it is well accepted. And yet when I talk with Stuart Louchheim (?) and other people down there in Philadelphia who are responsible for that place, they'll say, our acoustics are sacred, not perfect. Sacred acoustics, I'm using the precise words, sacred acoustics, and we don't want to change it, but we wish it were a little livelier you know. Of course, they go to places to hear it.

Now I don't want to spend too much time on this, but there are hundreds of halls around the world which have been measured, and we know their reverberation times, and we put them on a chart, and we find that they tend to cluster around these numbers that we have designated in this chart. So this chart, to start with, is a compendium of known halls of good quality, or of not bad quality. So then we go, let's take Oberlin, and they say we want a hall in which we're going to principally perform concert music, we're going to have an organ, we're going to do oratorios and big choral works, and we're going to have big symphonic works down here. And we have a recital hall in here that you're going to do for us, which will be for small instrumental groups for chamber music and recitals. O.K. Yeah, yeah, yeah. But you'll probably end up doing a lot of recital work in the big hall, won't you. Oh no, never, never, this is only for the big stuff (and, of course, the answer is they do a great deal of recital work in the big hall).

After a while you get to learning that when people say “never,” they don’t really mean “never;” they mean “I think never,” but people will perform anything that’s possible in any space in which people can be assembled to watch and listen. Mark my words, everything will be done.

So we said, well, let’s see now. You guys have got, you’re going to have a symphony orchestra and an organ. We’d like to have about 2 seconds in this hall when it's fully occupied at maximum conditions. Now why do we know that? Well, we just know so many halls that are in about 2 seconds that are good, but that’s as good a guess as we can make. We know that if it goes to 4 seconds, which would be achieved only by doubling the ceiling height or the pit or something, that it would be too live to suit them. And we know if it's only going to be one second, it'll be much too dead to suit them, just on the basis of experience. And then we say, well, if you've going to ever have any recitals of single instruments, violin, flute, piano, or whatnot, harp, that you're going to want something down around 1-1/2 seconds. And then we work out how much fuzz we're going to add from 2 to 1-1/2 [seconds]. And that's what determines the area of the curtains. Now when they move in, they may not agree that they like it best that way and they fool around with it, and fiddle around with it until they find some conditions that they like. And they have done this. In the hands of a sophisticated user, like the faculty of music, I think these variable provisions are great.

I have long since decided that it is insanity to put in any kind of variable provisions in a municipally operated facility, because you just won’t have the people who will bother to learn how to use the variable features, and nine times out of ten, Parkinson's law will tell us they'll do the wrong thing. If they have the opportunity, the wrong thing will be used. Even in Philharmonic Hall, in the original design, the orchestra people the manager, the late George Judd and others, were very anxious to be able to vary the reverberant characteristics of the sending end. So the walls around the performing area were made of some wood slats, sort of to give this transparent grillage. Now inevitably they got denser than they should have because of architectural considerations. Architecture somehow always gets in the way of technology. Not always, but sometimes, often. In any case, curtains were provided back behind these, which could be drawn out, or drawn back in pockets. And there was a program set up, for if you're having Mozart chamber music, then curtains are set in Position A; for full symphonic, Position B, for Liszt, Position C, and so on, a whole chart was given. And we found out in the first few weeks that the curtains had been set at one of these many positions, extended not retracted, and that they were not moving them at all for any of the performances.

You couldn't see them because they were behind this grillage. So we asked some of the stage hands, how come you guys don't move these curtains around? Ah hell, you know, who wants to bother with that. O.K. so what? Hell, who wants to bother with that? So who does? An acoustics consultant. But he can't go down to New York and yank curtains around; besides he's not a member of the union. It's kind of discouraging sometimes, I can tell you. I don’t know whether that answers your question or not but...

Student: “Well, my question was only related to one thing. The other day in Kresge when we were there, I was really amazed to the extent that we have to be sensitized and told what to listen for in order to hear anything in particular, even hearing that last major echo, if it wasn’t pointed out to me, and so forth and so on, my hearing just glazed over. Well I used to play a classical instrument and I’ve heard a lot of musicians perform in a lot of strange places and actually I’ve never—unless it was really miserable—I’ve never heard anyone even mention the acoustics of the place they were playing in.”

Of course. I think this is a very important point, and it's a great blessing to all of us in this way. In all aspects of our environment—visual, thermal, olfactory, acoustical and everything else—we can ignore many things. With our two ears, the great blessing of fine aural hearing, you have no idea, unless some of you have lost the use of one ear, what a blessing it is to have two ears. It isn't to hear twice as much, but it's to get this marvelous ability to localize the source of sound and to filter out and not to pay any attention to stuff that you don't want to hear.

Student: "You can get that by focusing?
I don't know how you do it. You do it by minor reorientations of the head, but it relates to the difference in phase of arrival, the time arrival and the phase, the arrival of the sound of two ears and what this thing in the middle here called the brain does with it. And as I suggested before, you just plug up one ear right here in this room, you'll suddenly discover that the room sounds a lot more reverberant, and aside from the funny sensation it gives you in the ear, you'll have a much less pleasant listening experience here, with this one ear listening.

And a person who wears a hearing aid in one ear, almost anybody you know who has had to go to a hearing aid because of deafness, will tell you that the world has suddenly become the most horrible noisy place that he could imagine. And a lot of them just turn it off. Well to hell with it, I just won't hear anything rather than put up with this horrible cacophony that comes in all the time. Because with a hearing aid, you only have one ear, and you must receive everything [in that one ear], and you have no ability whatever with your brain—having only one ear being stimulated—you have no ability to discriminate, and it becomes much more annoying.

Now I hope, and I think this has happened to most people who have been through this particular course here, that you will become sensitized, and that I have sensitized you, and I may ruin for you some fun that you might otherwise have had in some listening experiences. But if we're going to design spaces for hearing, then we've got to know what the hell to look out for, and try to minimize these things, even though people may not notice them, that if they weren't there would make it better for everybody. I really sincerely believe this.

Student: "In that hall that had the 1.3 second reverb, if you wanted to give it a liveness, would you have to use artificial amplification?"
Yes, it's the only solution. Or, in the case of the Academy of Music in Philadelphia, which is a traditional Italian Opera House style of building. It has great tiers of seats all the way around, and there are boxes along the back of the main floor and of the second level, which are just draped in velour, and everything is carpeted, and velour chairs and gold. And Mr. Louchheim was talking to me on the phone a while back: "well, what could we do to increase the reverberation time and not destroy the sacred acoustics?" And I said, well you're talking out of both sides of your head. We going to change it if we do anything. I said, you could take all those damn velour draperies off the boxes. Oh, well they'd never stand for that. Not in Philadelphia. Very sorry, you have to put up with it the way it is, or we go to electronic reverberation. I'm sure this will happen in time in a good many dead-ish halls.

Now of course in this Audio Lab drivel I read you earlier, the building by instinct and so on, is a lot of hogwash. Building not by instinct, but by very careful eclecticism in its very truest sense. As I mentioned to you earlier, the design of Symphony Hall in Boston was taken directly from the Gewandhaus in Leipzig. Why? Well the Gewandhaus worked, so why rock the boat? We know something that works, so let's copy it. So they copied it. They didn't copy every little thing, ever little egg-and-dart molding, and every piece of statuary, and everything else, but the essence of what was there, the gross dimensions and so on were copied. And maybe it's a little taller, or a little longer or a little wider, but you find that throughout history, the successful halls, the halls that have survived to this day are good halls, and that they all have many similarities and are copied one from another. It isn't a question of science, it's a question of pragmatism, of finding something that works, then we'll have some more of the same please. If I have a recipe that's really suburb for a dinner party, we'll repeat the recipe, and we'll know exactly what's going to happen the next time, because we'll know what the combination of ingredients will give us. It's a recipe, it's a cooking exercise. And the great French cuisine has come down to us, the things that were good have survived, and the things that weren't have passed on.

Well, maybe let's get back to the business in hand here of the multi-purpose auditorium. You have another question?

Student: "Well, just in general that the electronic reverberation, does it really give a full liveness, or does it sound artificial, or tacked on?
If it sounds tacked on or artificial, then it is absolutely unacceptable. It must be undetectable. In cases where it has been used successfully it is undetectable, as something natural, and I can assure that the system at Kresge has either got to have no phoniness about it or we'll never use it, even though we've spent several thousand dollars doing the experiment. And this is true of sound systems, which we're going to begin to talk about as soon as I can get to them."

A sound reinforcement system should not have an artificial sound to it, even though people sometimes feel it sounds better sounding artificial, disembodied from the body of the person who's doing the talking. The multi-purpose auditorium in which we have a stage house, it must always have a stage enclosure for orchestral performances or choral performances. A multi-purpose auditorium, 9 times out of 10, will have a stage house. I'm not going to give a long lecture on stage houses here this morning, but a stage house to be useful must be approximately 2-1/2 times the height of the proscenium opening. I've seen many architects who in the interest of economy will give the owner a stage house which will show as a little bump on the outside of the building, and perhaps, if this is the proscenium opening, let's say the proscenium opening is 24 feet or something of the sort, and this will mean a stage house that's 40, 50, 70 feet or so high.

They usually get to be 70 or 80 feet to the grid up in here, and then you have some more space so people can walk around, and then you have your smoke vents on the top and so on. I've seen architects give an owner a stage house that's maybe 4 or 5 feet higher than the proscenium opening, and you say, well what's that for? Oh, that's for the scenery. Obviously, the man's never been in a theatre. Well, you could hang a few curtain tracks up here for it, and that's of course what they have to do in the little theatre at Kresge, because this is the-floor of the upstairs auditorium, and we can't have another 15 or 20 feet poking up through there, we'll come out through the damn dome, pretty soon, and that would be inexcusable. You can't do anything with this, if you're going to have a stage house, and that's the form of the theatre, then we've got to have a full height thing for handling scenery up and down.

Now you say, well, can't you handle the scenery horizontally on wagons? Well that's one form, but it's only one form of theatre, and if Proscenium Theater is what you're going to do, and if you're going to do classic ballet for opera in classical form; then you've got to have some kind of a space like this to handle the scenery. Now generally the stage house is filled up with junk, hanging junk. It's a storage, warehouse for a lot of old stuff, and sometimes it gets cleaned out once in a while, when another show comes in and needs all the lines, but generally it's filled with all kinds of stuff, and tends to be a fairly dead space.

I'd like to raise this to 30 feet here if you don't mind, change the dimensions, change the scale of the drawing here. What we have to have, if we're going to have an orchestra perform here, is some kind of a ceiling which comes in here and gives us some sort of a live sending end to the auditorium. Now I'm not sure that this is the very best approach acoustically, in fact I know that it is not the very best approach acoustically, but it's the practical approach in a great many auditoria where budget is not unlimited. [You need] an enclosure, [an "orchestra shell"] roughly 30 feet high, at the opening, and going back down towards 25 feet at the back, and the order of 30 feet deep, perhaps 40 feet deep, 30 to 40 and in plan having shape something like this, of course, which is the order of 55 to 60 feet wide at the front, and 30 to 40 feet deep, depending on the size of the performing groups that are to be accommodated.

Now the biggest problem with such an enclosure, there are two problems: one, it must be fairly heavy. The walls of the enclosure cannot be made of normal scenery technique canvas, painted canvas on ordinary wood slats. The walls have got to be fairly heavy, something of the order of 3/8" plywood on up. And when you get something like 3/8" or ½" plywood forming the skin of such an enclosure, you have to have additional framing members to support it, and you'll find that these things get to be very heavy, very bulky things to move around. If you are not going to totally disable this area up in here as a scenery handling facility, which is why it's there in the first place, you will not store the elements of this shell in the stage house at all, you'll get them the hell out. Now getting them the hell out is a problem. We've had a lot of experience with this, with orchestra enclosures, and they do call them shells or "*conch-acoustica*," and a lot of other horrible words, always implying the dreadful form of the Hollywood bowls, which is this ghastly thing.

Never, under any circumstances, anywhere in the world, do something like that for an orchestra shell. It's just the baddiest, bad, bad shape there is. We built these sometimes out of plywood using fairly normal stage handling techniques to put them in and take them out, we have the ceiling in several sections with lighting battens in between, and maybe 3 or 4 sections and then we'll lower these to the floor and put them on a line set to hold them up here, and store them up in here. Well, immediately you do that, if it has any kind of wiggle-waggle which we'd like to have for sound diffusing reasons, these things get very thick, and it'll disable three or four lines for each panel stored. You'll have three of four lines up here that you can no longer use to handle flats of scenery. So that the whole thing just becomes clogged up with a mess up here, which limits very seriously the usefulness of the stage house for its major purpose. But the worst thing is, if you do it out of ordinary plywood, and use ordinary stagecraft handling techniques, it will cost in labor the order of $100 or $200 each time you put it up and take it down.

You say, well, that isn't very much money; no, it isn't very much money, but in the budget of a normal touring orchestra, symphony orchestra, or the ordinary municipal auditorium, that is one hell of a lot of money. And the result is, they just don't use it. It's much simpler not to spend the money, tell the visiting orchestra from Cleveland or Philadelphia, to hell with you, you're being paid to play, get on that stage and saw away, play, play, play. And all the sound goes "*SCHLURP"* and a little glimmer comes out here. This is the analog, as I said before, to the automobile headlamp, with a little filament of gleaming here, and this painted all black. Sure you can see the light. And these poor devils can't hear each other.

You remember the big stink that Leopold Stokowski pulled off in Constitution Hall, that great edifice in Washington? He refused to go on with the concert because the ladies of the American Revolution or whatever the hell they are had a great blue velour drapery on the back wall, and they had nothing overhead, so he said he would not begin the program until that blue velour drapery was withdrawn, so the audience sat there and sat there and sat there, and the orchestra sat on the stage and they waited and waited, and it took about an hour, and finally he cudgeled them into submission, and they withdrew the drapery, and there were all the lovely brick, and, you know, radiators on the back wall. But he was dead right. You cannot perform against a velour drapery.

And we see this so often in high school auditoria: the high school orchestra or band comes on stage, and they pull all the blue velour or the red velour around them, and have all teasers overhead of velour, like having them stand outside and singing into the room through an open window. You just wouldn't do that in your right mind, and yet people do this sort of thing all the time.

There are a number of ways of solving this problem of the stage enclosure, but they end up costing real money. For $20,000, you can do a stage enclosure like this, an orchestra enclosure that will cost you between $100 and $200 to get out of the way each time you use it. It's a cheapie thing, it's made of standard stage-craft techniques, and costs a lot of money to put in and take out but it's relatively cheap in the original investment. On the other hand, you can have something very sophisticated such as we have in Jones Hall in Houston, designed by Professor George Izenour {George Izenour, Professor of Theater Design] at Yale, the mechanics of it, which is the acoustical side, that cost something in the order of, I don't know, $80,000 to $100,000, and which can be removed completely from the stage area in about 20 minutes by 2 men, it's all mechanized, it's all done with winches, and hinged panels, and what happens there is that the ceiling folds up against this wall and the side wall is broken down into 2 sections, and one piece hinges back against the proscenium wall, and this piece hinges back against the back of the thing, and then the whole things rides on a railroad track down underneath here with wheels, and slides back from the back of the stage and is stored back here, and nothing goes back into the stage house itself.

Now these are tricky things, they have to be very carefully designed, and they're easy to louse up, but they are wonderful in as much as—just one second if you don't mind—the big problem is, not only is $100 dollars to put it in, $100 dollars to take it out, but you have a rehearsal this morning, you have an opera this evening, you have tomorrow evening a concert, and you've got two ins and outs of the thing in the course of one single performance. And with this kind of mechanization, you can put it in and take it out; put it in and take it out 2 or 3 times a day if you need to, and accommodate all of these sorts of performances very well.

I will continue with this kind of discussion on Monday.

End of Audio File 23

THE END

Robert Bradford Newman Lectures

7 December 1970

LECTURE 24

Title: "Organs in Concert Halls"

Summary: Newman discusses the fundamentals of how organs work and where they should be placed in auditoriums and concert halls.

Beginning of Audio File 24

I think the answer is that we will not have the third quiz. If any of you would like to have a third quiz because of some ghastly prior performance or having missed a previous quiz or something, I think we would be glad to have one as a makeup, but we've got so much to talk about, and so few remaining class periods to do so. I just don't want to waste one on a quiz. And as I said before, I think the most important thing is the field study, and I'm just very pleased. By and large I'd say 95% of the field studies that I've seen have been very seriously done, and carefully done. I'm just very, very pleased with what I've seen so far, and Field Study #2, I think is due at our last meeting, isn't it? Or, well, just about that time, and I'll simply have to have them pretty soon after that in order to get marks in.

Student: "If we run short on time, can we extend into that last week?"
Well, you know what I mean, if everybody comes in. I don't know when marks are due; that's something I don't set, the department tells me when I have to have them in, and if everybody comes the last day before that with their papers, I'm just going to have ...

Student: "Oh no, I mean of the classes. I mean if we can't fit in…."
Well, let's see how it goes. I'd just as soon not like to schedule any extra sessions, but well, enough of that. There will not be another quiz. We've had our quizzes, and we've had our problem sets, now you have only one more field study that is due.

Last time, as I remember it, we spent a lot of time talking about stage enclosures, movable things on the stage in the theatre, to make for good multipurpose uses. And I had indicated, and I still would like to underscore this, that it is just absolutely mandatory that in a multi-use auditorium, whatever the figuration of the house is, there must be some kind of stage enclosure here, if you're going to have a regular proscenium-type theatre provision. And the orchestra and chorus cannot be expected to perform in the usually draped-hung stage. Now there is the matter in many multi-purpose auditoria, even today, even though costs are continuing to rise on providing an organ, and where shall it be put, and how shall it be handled.

Now the other day, when we were over at Kresge, we looked at the organ, and I commented on a few aspects of it. I'd like to comment on a few more aspects of the organ as it relates to buildings, how we handle them, and where we put them. First of all, the organ is a musical instrument. It's just as much a musical instrument as a piano, or a guitar, or a violin, or anything else, and has no business being put anywhere other than right in the middle of all the other performers. The location in Kresge is because that was the only place left for it. There was no other place it could be put. So there it is—off up on the right hand side where it really is not convenient at all for accompanying people on stage. It's too far away, there's a problem of balance. As far as the audience is concerned, if you're sitting on the side of Kresge where the organ is, you can hear more organ in contrast to the orchestra than if you're sitting on the other side. This just stands to reason.

Now, for the ideal arrangement of an organ: First, let's look at either a concert hall or a church. I would say that Symphony Hall, if we're going to start looking at local examples, the Symphony Hall organ arrangement is absolutely O.K., and it is sort of textbook. You have the organ here, and then you have the performing area in front of it. In Symphony Hall, the console of the organ (and we'll talk in a moment about these things), the console of the organ is on wheels, and can be moved about almost anywhere in the stage area, for various kinds of dos. If it's going to be a recital, the console will be placed in the middle, or perhaps facing to one side. If it's going to be for accompanying a chorus, it will be placed up here somewhere, but the console can be placed in many positions. The organ—the pipes of the organ, and this is the organ—must be placed, however, where it's going to give the same balance of sound to all listeners. In a church, synagogue, any kind of a set-up where you have an organ and a choir, then it always belongs right smack in the middle here, where the organist can see the instrument, see the performers, and often the organist is the choir-master and he has to direct them, and he belongs right here in the middle of this group, and they ought to be just as tightly pulled together as they [the choir] possibly can be.

Let me just say one or two words about the organ, as an instrument, and what its architectural implications are. I'm talking now about a pipe instrument. There are today many electronic organs, some very good ones, and some very bad ones. Some of them are strictly for honky-tonks and some are usable in religious services. Serious organists in general still are not prepared to accept the electronic instrument as a substitute for a pipe instrument (we're talking about a real honest-to-God pipe organ, with pipes).

Now the organ in Kresge, and I may have mentioned this the other day, was designed by the architect working with the organ builder. Bruce Adams at that time was one of the designers on Kresge in the Saarinen office, and Bruce together with Walter Holtcamp, the elder Walter Holtcamp, designed that instrument. They made models, they sent drawings back and forth, and the instrument was designed for that space. It was custom-made for that space. Organs are always custom made. Very, very rarely do you go and buy a Model E or a Model F or something of that sort. You invite the organ builder to your building, or your drafting room, where you're planning a building, and you say we want an instrument for this space. And you may have an organ consultant who will tell you what sort of a tonal quality the instrument ought to have. He'll write up some specifications, and then the instrument will be designed and built for the particular situation. Kind of an old fashioned thing; it's a custom trade thing, and you pay real good money for them. There are a number of good builders in this country, though the fashion at the moment is to go to Europe, of course, for the instruments, and one of the most fashionable is in Holland, Mr. Flentrop. There's Mr. Marcussen in Denmark, and there's some people in Germany, and there's some French organ builders, and it's considered very posh to import an instrument from the other side of the Atlantic, just as we do cars and other things, it's all part of the game. But there are some good American builders, and there are some junky ones.

I'm often asked the question: how large an organ should we have for this space? And the answer is, any size you like. It isn't a matter of quantity of sound, because you can have a single rank of pipes that will give you a magnificent, glorious, full sound in a hall, or in a church. It's a matter of how the instrument is going to be used. Is it going to be a concert instrument? Or is it going to be an accompanying instrument? Is it only to accompany some plain song and some chants or something, or is to do a whole service? What is it for? Because the size of the instrument is determined by its tonal complexity. How many different kinds of tones do you want? What variety of stuff do you want? Is it going to be for professional recitals? For real concert organists to use? It's like how big is an orchestra? An orchestra can be anything from 10 to 100, it just depends on the scale and the variety of things that you want to have, and that you're going to perform.

Now in the organ, as in the orchestra, each rank of pipes or each instrument has a different kind of sound that it makes. And the organ, unlike in the orchestra, each pipe can only sound in one particular way: it either sounds or it doesn't sound. It is not able to be blown louder, or more softly, it must sound exactly in one particular way.

Now just a word about this, because I think it's very important for architects to understand what organs are all about, because one of our friends here in this school, in our faculty, once drew up a small concert hall in a preliminary scheme, in which here's the front end of the concert hall ...... and there was a line of circles across the front drawing here, and this was the outside wall. And I said to him, what's that? And he said, that's the organ, that's the organ. Well, he'd seen the gold pipes at Symphony Hall, and he assumed that that was the organ. Those are what are called show pipes, they're mostly dummies, and have nothing whatever to do with the instrument. They're just there for the symbol of the organ, and behind it is the guts that goes on. Now everything you see in Kresge is working guts, there's no show pipe there at all, but it was laid out to suit that particular space. Now each tone that you get in the organ comes from what's called a rank of pipes. You might as well learn the O.K. words if you're going to talk to the organ trade. A rank of pipes is a whole series of pipes.

For example you might have something fancy like the "*Viol d'Orcheste*." The Viol d'Orcheste, that's a violin-like sound, a string-like sound, and it comes from a rank of pipes. Now the Viol d'Orcheste has pipes that start out 8 feet long, and almost all ranks of pipe start out 8 feet long, and the length of the pipe determines its pitch. So an open 8 foot pipe will be the lowest note, and that will be called the Viol d'Orcheste 8 foot, and you wonder what's the length got to do with the sound? Well, that's the pitch of that particular rank of pipes and the 8 foot pipe will have a diameter of about 2 inches. It's a skinny pipe. On the other hand, you might have an open "*diapason*," 8 foot, and that would also be of the same pitch, and that will be another rank of pipes, and that could easily be 6 inches in diameter or bigger than the 8 foot pipe, and will give a great big full sound.

Now the diapason is the typical sound that people associate with church organs, you know, "Ein feste Burg ist unser Gott," which has to be rendered with full diapason, big, good, solid, heavy stuff, that just shakes the guts and the windows and everything—you know, just magnificent. You could have one rank of open diapasons, and make all the noise you could possibly want from an organ, and have only that one sound that it could make, it would be like having a steam calliope. One kind of a sound and that's it. Well, that's great, if that's all you want. Well, I won't start listing all these things, but each of these sounds is different. The pipes are different, and each rank of pipes has 61 pipes, or five octaves.

How do you get 61 out of 5 octaves? Well, an octave of pipes has 12 notes in it, because you have half a note. You have C, C sharp, D, D sharp, E, F, F Sharp, G, G sharp, A, A sharp, B, C. There's no B Sharp, and what's the other one? E sharp. That's right. But these are the half tones, and you 12 notes in the octave, and they're all equally spaced. It's what's called a well-tempered clavichord, it's a well-tempered scale, and the notes are all spaced just exactly equally in the octave, and made so that they'll sound pretty decent in almost any key. That gets into a whole other subject, and we won't get into it.

It's great fun setting temperament on an octave, and at one time, 20 odd years ago, I was pretty good at that on the organ, as I was an organ tuner. Each of these ranks of pipes contains 61 pipes. Each is a single tonal quality, and each can be drawn with what's called a stop knob, can be drawn on a manual keyboard somewhere and played. Now, this gets very complicated. The organ in Kresge for example has 3 manual keyboards, and one pedal keyboard. And here sits the guy, and he reaches over and plays this one, or this one, or this one, and he plays with his feet on the pedal keyboard. And he can draw for example, *Viol d'Orcheste* 8 foot on the top manual, and he can have *Trompette en Chamade*, or something here in the number 2 manual, and he can have an Open Diapason on this one, and he can have something else down here, and he can just play back and forth, and do all kinds of see-saw business that you might get in a regular orchestra, and he can (makes organ sounds) and then he can clump around with his feet, (makes lower organ sounds), way down the bottom, and well, they usually sound a little better than that, but the idea is, that you have here something very flexible, very flexible, much more flexible than the ordinary piano, in which you-can draw any kind of tonal quality you like on any one of these keyboards, and then play accompaniments and solos and hop up and down and do all sorts of great tricks.

Student: *"Can you mix settings, so that on one keyboard you maybe have three?"*
Yes. You can. I don't know how many ranks there are in Kresge. Does anybody know? I'll guess 40 or 50 at least, ranks of pipes, of different quality, and there are a dozen available on one key board, and another dozen on another keyboard, and another dozen on another key board, and then you can couple them altogether, you can play them all from one keyboard, if you like, and you can couple all these things down at the pedal, and when you play a very bass note, why you can get a whole series of notes along with you. This is all very complicated, but it is a very versatile instrument, and the more expensive it is, and the bigger it is, the more versatile it gets, the more keyboards it has, the more stops on each keyboard, the more couplers, and the more this and the more that you can have, and you just increase the potential of the instrument as a sort of solo musical event.

But the point is that each one of these ranks of pipes sits here on what's called a chest, and here are the pipes, and you know in Kresge, you saw them there, the big long ones at one end, tapering down to little short ones at the other end. And then there'll be another rank of pipes alongside this one. This is in plan, and this is in elevation, if you don't mind a combined drawing; and then there'll be another one, and another one, and they'll sit side by side on these so-called chests. Now in these chests, which are just wooden boxes with little holes in the top for the pipes to sit on, is what we call *wind*. It isn't actually blowing anywhere, but it's air under very slight pressure. Organs are blown at very, very low pressure. 2 inches of water gauge, or 3 inches of water is kind of maximum pressure in good practice today. The mighty Wurtilizer that was used in the theater cinemas back in the '20's, which did come standard; there was a model E and a model F Wurtilizer, which were blown at 12 inches of wind, and every pipe in the thing was made to scream just as loud as it could in that particular tone. It was a strictly for sound, loud sound, that had been maybe 6 ranks of pipes in one of these things, sort of a glorified calliope. And they sit there and accompany all the cowboy scenes and everything—you probably don't remember this, but I'm old enough to remember it, and a marvelous era of the theatre organ.

I guess the last surviving one is in Radio City in New York, the theater instrument. That is the mighty Wurtilizer, and it's all amplified, it's not very direct ... Wurlitzer's the proper name. I talked someday about Socrates (pronounced incorrectly), and somebody wondered whether I really didn't know any better. I'm sorry. The organ is generally heard without amplification. In Radio City Music Hall everything is amplified, so that's the reason it's heard that way.

Now these things take space, they have to have "*Lebensraum*," you have to be able to get up on top and tune the pipes, you have to be able to get underneath and work on the mechanism. These boxes with the wind in them—a small scale or a large scale detail of one particular pipe hole will look like this. Here sits the foot of the pipe down here in this little beveled hole, and these holes for some reason or another are always burned into the wood with a hot iron, and then varnished, so in any proper organ, all the pipe holes will be black, because they must be burned, and not done any other way. Why I don't know, except that's the way it's always been done, and if Grandpa did it that way, then we do it that way today.

And then there's a valve under here that's covered with leather, and this valve is pulled down either by a direct magnet, or by a bellows in here that is collapsed, or by some means or another this valve is pulled down when you mash the key, and the air goes up into the pipe, and the pipe blows. The pipe sounds it particular note, and that's all there is, it's either on or off. Now today, there is a tremendous resurgence to what is called the mechanical action organ, or the "tracker action" organ, tracker or mechanical, in which the action of pulling down this valve is coupled to long series of levers and so on, and to wires, and eventually you get over here to the keys. And when you push down on the key, it pulls down the valve under the pipe. It's just direct mechanical action.

Of course, after a while you get to a point where the size of the instrument gets too large for your fingers to be able to push all these valves away, because they're all being resisted by 2 inches of water pressure, water gauge, which isn't very much- I don't know how many ounces per square inch that is, but it's very little pressure. You can go into one of these and it doesn't do more than compress your ears as if you were taking off in an airplane. It's a very small amount of pressure. But the direct or mechanical action, a tracker instrument, is very much in vogue these days, and all of the real up and coming organists of today will only play on a direct-action instrument. They will not be caught dead playing one—unless they're getting some money for it—that has any other kind of action, electric action, or so called pneumatic action.

Now the Symphony Hall Organ, which lots of good organists will play (Virgil Fox and E. "Power-house" Biggs and other people all go over there and play it), and it has electro-pneumatic action. You can't move the console around, if you're going to have direct mechanical action. The console is fixed, it's there, it's down screwed down in place and you don't move it, because it's got all these little bars and wires and things running back and forth, and it simply cannot be moved around. So there's a limited flexibility in a direct action organ, but according to many players today, they feel they can get a little bit better control over the sound of the instrument from a direct action organ.

Now I am not an organist—I don't know. I do know enough about the generation of organ pipe tones, you know, and you can't just ease the air to it, or let it in suddenly. The pipes either speaks, or doesn't speak, it's absolutely on or off. And any variation in pressure, any variation in anything else, will merely make it speak poorly. If you increase the pressure it will over blow "*OWOOOH"* or "*WAWAWA"* like that, they do wonderful things; or if you just ooze the air to it, I'll just "*WWSSHH*," and when it gets ready to speak, it speaks, and that's it.

So I'm not sure that this isn't partly emotional, the direct action, but nevertheless it's with us. Like any other thing, if it's emotional, it's still is just as real as if it were physical, so I can't knock it. But it is a problem of flexibility; the console is almost forced to be in the right place at least, in front of the instrument and not at some distance. In Atlantic City, in the big Convention Hall, there's one of the world's largest organs there.

Isn't that a great distinction? And I think it's a Wurlitzer or one other of those great big houdi Calliope type things, but it's got more pipes than any other organ in the world, and the organist is seated some 80 feet from the instrument; his console is some 80 feet away, and has to wear headphones in order to hear the instrument in time, because it takes so long for the sound to get over there from 80 feet away that he's already at the next note, so he's constantly in a syncopated *oompaoompahoompa*, so he has headphones on, and there's a mike over there at the organ picking up so he can keep in time at least with what he's doing, and it's quite a dreadful thing to have of that sort.

Forty feet is the maximum you can separate a console from the instrument and be able to play it without headphones. Otherwise the time delay just gets to be too much, and there's no way on earth to speed up the sound, even for an organ, it still goes 1,120 feet a second, exactly that. Well, you get a whole batch of these things, ranks of pipes, divisions of the organ, different manuals, and you'll find, when you get all through that, that the space the instrument will take up. A good big concert instrument, will take up a space roughly the order of ten feet deep and 30 feet wide, and the order to 20 feet high. And if you haven't got that kind of space—this is the multipurpose auditorium, in which you're going to have concert music, which presumes a concert organ—if you haven't got that kind of space for it, then better not fool around with it too much. It's just hardly worth doing, unless it can be done at that scale. Now in a smaller church, or religious edifice, it may well be a smaller thing; you could easily have it only 8 feet deep and 20 feet wide and 20 feet high.

The height is set by the length of the longest pipe of the organ, which is 16 feet. There are always 16 foot pipes in an organ, and this gives you 32 cycles per second [Hz], which is the lowest note on the pedal organ. Now 32 cycles per second may be more of a body shaker than an ear shaker, but just lots of thumpy energy, and also it's very interesting: if you look in a church sometime, the organist is sitting on low C throughout some "*OOOO"* and you have some "*GGRR"* business going down the bottom all the time, you'll see some people begin to squirm. And the problem is that at 32 cycles per second, where you have a 32 foot wavelength, you have standing waves, with a sort of 30 foot pattern, of intensity, and some people will be in a very intense part of the sound, and other people will be just be barely hearing it. And if you're in a very intense part, it can be most uncomfortable, and you begin to look around and think what the hell is going on? My gut is being shaken and I don't understand. This can be quite fun to watch. Sitting in the choir, that's a great place to observe the performance of people in religious services. If you haven't ever done it you should sometime, it's a great experience.

Well in any case, this thing is big, it's difficult to handle, and what in hell are you going to do with it on a stage? What in hell are you going to do with something that's 10 feet deep, and 20 or 30 feet wide, and 20 feet high? Well, there are a number of solutions. The most elegant solution, and one we've just finished doing in the new hall in Milwaukee, is to put it on a lift. Here's the stage at Uihlein Hall in Milwaukee and seats on out here, and the orchestra enclosure at Milwaukee is about 40 feet high, and you say "ooohh you said 30," no, but this is 40, O.K? And then in here you have some extra things, down at 30 feet where god intended that they be, and these are made of *plexiglass*. (Only Rohm and Haas makes plexiglass; and these may be Lucite, I'm not sure.)

But in any case, right back here, at the back part of the stage, is a section of floor, and down here below the floor, sitteth the organ, and then this is on a great hydraulic lift. This was put down in a great concrete tomb here. Water level is about here. And this goes way the hell to Australia practically. It's 28 or so feet high, and then you've got to have another length for the piping for that, for the hydraulic lift. And when they're going to use organ with orchestra, up she comes, and here it sits in all its glory, right here where it belongs, right at the back of this great orchestra enclosure. Sometimes we put them in a pit like this, I've no idea what that costs, I'll don't even want to find out. I'll probably never recommend it again, but we have done it, with the organ installed permanently here at the back of the enclosure and simply have panels which either are <u>in</u> or <u>out</u> depending on whether the instrument is there, but somehow, you've got to get it into this position.

In Salle Pleyel—no, it isn't Salle Pleyel, it' s Palais de Chaillot—in Paris, the organ is on a railroad track, which runs forward, so the pipes are merely rolled forward from the storage way back here in the garage where the organ rolls forward and it's put here. The organ in the Academy of Music in Philadelphia is on 4 or 5 or maybe even 6 wagons, wheeled wagons, and is brought out into place from storage when it's ready to be used. Now the minute you start moving an organ around, like moving a piano around, you may be in for some retuning, after it's put in place, because the tuning of the pipes is accomplished entirely [by hand]. As I pointed out the other day, here's the top of the pipe, then there's a collar on here which is spring-loaded, and you simply take a screw driver, and you knock that up or down to change the length of the pipe, and there's usually an adjustment of a couple of inches on the longer pipes to change the pitch of the pipe, and you just tune it up or down. Now these mechanically-held collars are likely to be shaken a little bit by transportation of the instrument.

I think the air palette [air casters] is going to be the neatest trick yet for moving things like this around, and some of these air palettes that squirt out a sheet of fairly high speed, high velocity air which makes some noise, but you can move things around with tremendous weight and tremendously little effort on a cushion of air, and simply not get into these problems of bumping and jouncing that goes on with ordinary floors.

I might just say one or two other things about the organ. I've talked about the so-called flue pipes, which have the foot here, and the lip, and the pipe is on up here, and the air comes out of here, comes up through the foot of the pipe into this chamber, and goes up here towards this lip, and then it just creates that "*SHUSHHH"* sound, that's all it does, "*SHUSHHH*." And then this resonator here grabs hold of its favorite part of "*SHUSH"* which contains all frequencies and goes "*OOHH"* or whatever else is its favorite mode, and forces this airstream very quickly to behave, and to go "WWOOOHH" you know right in line, it locks it right into its own resonant frequency.

Now the pipes can either be open, or they can be closed. A closed pipe, and some of them at Kresge you'll notice have red felt collars around the snaps here, its red velvet here and you can actually see it sticking out, that's capped by it—that's the top, and the felt is in there to make it airtight, because if the pipe isn't exactly airtight, then it isn't going to resonate properly, and a stopped pipe, or a capped pipe, will have half the frequency of an open pipe.

In other words, an 8 foot open pipe is equal to a 4 foot closed pipe, and you'll get the same pitch out of the rank, but it will have a different tonal quality. A closed pipe will only have an <u>odd</u> series of harmonics. If its fundamental tone is 100 cycles per second [Hz}, you'll have 100, 300, 500,700 and so on as its harmonic sequence, where an open pipe with have 100, 200, 300, 400, 500, 600. So an open pipe has a richer sound, a fuller sound with more harmonics in it, but sometimes we want this other sound and we make them that way.

Student: *"And that's because the 200, 400 and so forth are able to carry out the top whereas… "*

Well, if we have time, this is Physics 1. You remember that the only way you can have a resonance is a quarter wave length in a stop system, one end open, one end closed; and a half wave length in an open system, both ends open. And this is because of pressure of variations, you have a pressure not in the middle of an open pipe, or at the end of a closed pipe, but you can't support pressure against an open end. This is the reason it resonates that way. I suggest you go back to your freshman Physics book, and look this up if you don't remember it, and if we have time towards the end of term, we're going to extend this idea of resonance of organ pipes to resonance of rooms.

Well, I don't want to spend the whole time on pipe organs, but I do want to talk also about reed pipes in the organ, which perhaps give the greatest opportunity for architectural display and ingenuity, as was exercised in Kresge with those lovely copper pipes. The reed pipes actually use a reed in the base of the pipe, and this reed is hooked, well I can draw it, there's a block of lead here, with a wire coming down through it, and there's a piece of brass, and on this, this brass has to come on down here, and then there's a reed. A brass reed on the front of this, and this piece of wire has a roller on it that rides up and down on this reed, and you can adjust the length of the reed from outside. And this reed bats back and forth against this piece of brass, which has a slot cut in it, this would take much too long to draw all of this, but in any case, the reed is here, this is the foot of the pipe then, and the air comes up through here. And then there's a resonator put on the top of this trumpet shaped resonator. And reed pipes can imitate very closely the sounds of the orchestral clarinet, the oboe, the English horn, and we imitate the French horn, the orchestral French horn with a reed pipe. And by God you'd swear somebody was playing a French horn, except that how would you get so many notes? Very, very fine orchestral imitations. You say what the hell are we doing imitating? Well a lot of music has been written for this, and it can make some delightful stuff.

Probably the most sensational reed rank that I know of anywhere is in the Cathedral of St. John the Devine in New York City. On the west wall of the Cathedral is a great rank of trumpets, blown at 100 inches of wind, not 3 inches, but 100 inches, because they are to make a startling sound! It's called "*trompete-en-chamade,*" which is trumpet in the most startling fashion. They are set on the west wall, facing down towards the congregation, none of this up business. Here's the west wall of St. John the Devine, I don't know what it is, 130 feet high or something? Anyhow, back here sits this great flare of trumpets, flared out like this, headed right down towards the congregation. And the organist is about 600 feet away from this rank of pipes. So he plays his stuff, and then it comes back to him a little bit later, and it's used only for great fanfares on big religious festival occasions when they have a whole lot of potentates and clergy, and so on all lined up to come in, there for some kind of a big do. And they "*BLABLABLA"* and, my God, it just cuts everybody right off; it's a dazzling sound, absolutely dazzling. And if you're not expecting it, well it scares the hell out of you, second coming of God, its intended to create that sort of impression. Well, you can do some marvelous things with these instruments, and have an awful lot of fun, particularly *trompete-en-chamade*, which is, strangely enough, a Spanish custom of organ building. Why it got a French name, I don't know, but you find many concert instruments, particularly some of the older ones in Spain and in France with a flare of trumpets across the front, which are designed for this great "*ZZZOOOOO"* kind of a sound that really just cuts right through, and sets your hair tingling, and everything, is magnificent.

Well, maybe enough of this, but in any case, they take space, they've got to be put in a proper place, they cannot be placed up in the attic, or round the corner, or in that goddamn favorite location. You know, every time you do an auditorium you come out with kind of triangular spaces at the front here, this is the stage, and here is the opening, and these spaces are so intriguing for organ, that things that are put in here are organs (unintelligible) and sound. The sound is the sound control for this public address system, and all those are absolutely awful. For God's sake, don't put the organ there, you wouldn't put a lecturer there, you wouldn't put the piano soloist in there, so don't put anything there in the way of a musical instrument. And if you get into a box, such as Saarinen got into over here in Kresge, I don't know, maybe it's just as well we have the organ there, at least we can hear organ recitals. And when we get the reverb going, it's going to be great. But it's an almost useless instrument for accompanying and for working ensemble with orchestra or chorus, just because it's in the wrong place.

And we wanted it in the right place, but this would have meant following the contour for the dome. The dome comes down like this, and here's the back of the stage about here, and the lift here (couldn't move the lift somewhere else), and we would have liked to have had the organ right in here at the back of the stage, which would have meant a little hump like this. And somehow Mr. Saarinen didn't think this would look so hot. I'm sure it wouldn't have either. But it'd be a great place for the organ.

Any questions on that very brief quick trip through the pipe organ industry? There's an awful lot of hokum you'll find if you read much about organs, and there are a number of very good books on organ building, particularly some English books that are very fine, and Professor Fenner Douglas at Oberlin has written a very good book on the French organ. If you're at all interested, you can find a lot to read. But you find an awful lot of lore, as there is about almost anything, about the materials with which you should make the pipes. And as I said the other day, there's been all sorts of research on flutes to show that gold flutes are better than silver flutes, platinum flutes are better than gold flutes, and silver flutes are better than wood flutes. All of which is absolute nonsense. The material of which a pipe is made is quite unimportant, as long as it doesn't vibrate and give. I have done a lot of work on this, and have made organ pipes out of cardboard tubes, out of steel conduit, out of ceramic pipes, out of cardboard and paper, and [out of] copper and tin and lead, and all sorts of materials; and they give exactly the same kind of sound, provided the mouth structure is identical for all of them.

The structure around the mouth is quite important. But the reason pipes are made out of the metals that they are is for ease of manipulation. They have to be "manipulatable" with hands or with hand tools. You've got to be able almost to push the lip in and out with your finger, or even with your thumb, and cut it with a knife if it needs to be a little higher, and to nick the wind way with a knife, and to be able to do these things with just the available tools in your hand, rather than having to machine them, or handle in shop. The result is we use tin and lead, and mixtures of metals that are more of less like solder, that are soft enough to manipulate by hand.

Unfortunately in some old instruments, they begin to look like the camel with the wrinkled knees after a few years, because these soft metals begin to kind to sag a little under their own weight, and you'll find some very old lead pipes, with this kind of a looking corrugation down the side, where it is kind of settled down a little bit, and sometimes they lean over. It's very sad to see these sort of pipes kind of caving in.

Student: "Is it just the base of the pipe that would be soft?"
No, the whole pipe. This metal—you may think this is a terrible waste of time in class—the metal for organ pipes is poured today exactly as it was in the 16th century. You find a table, about like this lecture table, it's made of slate, and on top of the slate is stretched some canvas. And then 2 men strike this end, one on one side and one on the other, and they have a hopper here that's filled with molten metal. Now it's a tin-antimony-lead combination, just like various kinds of solder. And they have a gate, and they can open the gate, and they walk together down this canvas covered slate table, and they have laid out a sheet of molten

metal, which then cools very quickly. And they take the thing off the end to cut off the flow of metal, and then they roll this up. Now, you've got a roll of pipe metal, and they can get the thickness just exactly right, and the quality and the working of the metal comes out just beautifully. This then is a piece of metal that has patterns laid on it, and they cut them out by hand with tin snips, and then they have mandrels and they roll them up into round shapes, and they solder a seam down the back of the pipes.

And if you look at a well-made organ, there is some of the most beautiful solder work you can imagine, because the bead, the joint between the pieces of meta—much enlarged the bead looks exactly like that, and it's just absolutely uniform right down the pipe. It's beautiful to see. Don't start tinkering round with a soldering iron near an organ pipe, because you'll melt it, and you've got to know exactly what you're doing, and these guys who make these things up do. But it's interesting, and if you ever are curious to see it, Aeolian-Skinner, who have moved down to the South Shore some place, still, I think on Saturdays, cast metal, and you can watch these antique old gents with their little box of molten metal here walking down this table, and on the backside of the metal comes the pattern of the cloth, and if you see some pipes made up without the cloth pattern on them, you know that metal wasn't done properly, must be some modern technique slipped in, and the legend is that the tone will suffer.

Student: *"That's the inside of the pipe?"*
Inside of the pipe. Sometimes they show on the outside, but usually it's on the back side. Well, enough of this lore business, because we do have some acoustics to talk about. But you can see how fascinating the whole business of organs is, and for God's sake, don't start talking about placing the pipes on their side or upside down, or some other trick. It just won't work, they're just not made that way. The soft metal would immediately collapse, they have to stand vertically, and they stand by gravity, they have to be lifted out when you have pipe that's got some dirt in it or something, you've got to lift it out and puffpuff and blow it and whack it around a bit, you know, and fiddle with it, and then put it back into the hole, and there it sits by gravity, and get it ready to blow again by the time somebody wants it.

Student: *"They're not supposed to have anything contacting the two…"*
There's no harm in that. Some of the tall ones have to be racked, with some kind of a rack with a little hook in the back of it, and you put a little ear out on the pipe that goes round that hook to hold them, because when they get 8 feet long and only 2 inches in diameter, and made of this soft solder metal, they're likely to fall over, so you hold them up. There's absolutely no harm in holding them up, they're this big. And then you can arrange them in any way you like on the rank. You can have them all coming down like this on top of the chest, or you can say, I don't like that, I would like it to come down uniformly from both ends. OK, you can do that. You can have them C, C sharp, D, D sharp, E, F and so on down the line like this. Or if it comes down lower than this, you can have them like that. Or you can have them like C, C sharp, some here, and then some here, and cross them like this, and higher ranks down in front of these. You can do all sorts of wonderful things with them, just as long as you keep them more or less together. The chest would be about 8 feet long, and you can do just anything you want. Now do remember, when you get tricky with these things, that somebody… there's that 16 foot sound—feel it; it's like something downstairs that's running the bomb.

Remember that somebody has to tune this instrument, and if you get too tricky with where the pipes are, it takes a long time to find out which pipe is sounding, and you go "BONK, BOINK, BOINK," you can always tell by putting your hand on top, that makes it stop. But it's nice to have some sort of order, you know, C, C sharp, D, D sharp, E, and so on, you have them all in a row, just for the convenience of tuning. And organ tuners are always drunks, falling like piano tuners. They're usually soused, so you have to make it fairly simple (laughter). I don't know why this is. I was one of the 2 non-drunken organ tuners I knew at the time; I didn't belong to the union.

The other thing I want to say just a word about is the business of which you will no doubt read much, and have perhaps seen—another degree of flexibility that we sometimes put into the multi-purpose auditorium, namely, the moveable ceiling.

Now the moveable ceiling to change the physical appearance and the acoustical performance of the space has much appeal, although I'm not sure that we're going to see very many more of them, because of their considerable cost, and because in most cases when we have a moveable ceiling to change the size of the hall, we find that it doesn't get used. It’s like those curtains I was talking about in Philharmonic Hall [loud noise from saw downstairs], where nobody bothered ever [loud ringing; it's some kind of saw downstairs, that’s the extractor for it there.] Where was I at? The Jones Hall in Houston is one of our more successful moveable ceiling jobs. There are 2 balconies, extended side balcony here, this one does not extend, and we have a ceiling of I don't know how many panels. They are all six-foot hexagons, a whole series of six-foot hexagons, pyramidal, downwards. And this is a six foot dimension, and these nest. (Well, I guess we'll have to continue with this next time.) These all mesh together, and there are little spaces in between them. And the ceiling can be up like this or it can be down like this, and we can cut off the back part of this seating, and the back part of this seating, and we can change the seating of the hall from 3,000 down to 1,700, all by mechanical means of dropping these panels down in great arrays.

Now it takes about 20 minutes for this ceiling to change. It's very slow motion, almost like watching the minute hand on a clock, you can see it move, but it's a very slow operation. Well the problem is that the box office, which controls where the ceiling is set, will sell 3,000 seats for anything if they possibly can, whether it is appropriate or not, and the result is, that because this is the only decent auditorium in Houston, they sell 3,000 seats for almost anything, even the Juilliard Quartet, and they're sort of lost. We intended for them to be in 1,700 seat configuration.

Well, I'll take up with Jones Hall on Wednesday.

End of Audio File 24

THE END

Robert Bradford Newman Lectures

9 December 1970

LECTURE 25

Title: "Enormous Auditoriums"

Summary: Newman lectures on dealing with the acoustics of large auditoriums and arenas.

Beginning of Audio File 25

(Pre-class chatter)

Yesterday I spent with an architect from Asheville, North Carolina, and he's designing a 7,000 seat auditorium for what seems to me to be a perfectly dreadful institution, Bob Jones University, I don't know if any of you know it. Oh God. "Oh God" is right. I think Mr. Jones thinks that he is, and this 7,000 seat auditorium….you know I told him, you and I are both just whores, we'll do anything for money for anybody who comes along. But I feel kind of bad about this one, thinking about these poor 7,000 students who are being forced daily to go to Chapel.

Student: "Give them bad acoustics so they don't have to hear it."

Well maybe so. This is always a moral question. Should you or shouldn't you do good acoustics? The very first job we ever had of any significance was the United Nations Headquarters in New York, and even there we were wondering whether we should or shouldn't do a good job, because maybe non-communication would have resulted in better international relations, I don't know.

And another project that I did, that I was sort of sorry about afterwards, when I didn't know what was going to happen, was in Havana, *The Palacia de Deportes*, which was the big sports palace that was finished just before the revolution—not for Mr. Castro, this was done for Mr. Batista and his crowd—and right after Castro took over, and they had a lot of political prisoners and trials and so on, these were held in the big sports palace, and they could hear very well. Sometimes you wonder whether you should or shouldn't do such things.

Anyway, this was interesting to me, this Bob Jones University proposal for a 7,000 seat auditorium. The architect had come up with a fairly conventional sort of arrangement, and sort of a- (…My God, someone eats this chalk here every day….) a sort of a big compass, a wide plan with balcony extending back like so. There's nothing very new or original about it, but the interesting thing to me was that, in going to a 7,000 seat auditorium, he was still thinking as if it were about 1,000 seats.

And he had a stage platform down here that was more than 100 feet wide. And he was going to put orchestra and organ and piano on here. And you only had a concert grand piano, drawn here, and it looked about like this, you know, and I said: what the hell do you think, how big the is piano? Well, in his scale it was 20 feet. He'd forgotten about the scale at which he was drawing this thing, and he had a section through it, and this is about 65 feet high. It just comes out that way, you know, if you get that many people in and seat them and have them all see and everything. And you have some kind of a ceiling like this up here, and then you have the preacher standing here, and the choir and so on, and everything is way off. It's about twice as big as it ought to be, twice as high as it ought to be, just because he had never dealt around with a 7,000 seat hall. And I made the point very clearly: that even though this is 7,000 seats or a million seats or ten seats, or how many ever many seats it has, we've got to have a ceiling at the order of 30 feet, and so we came to terms on this.

Well, it'll all work out, and I'm sure it'll be a good place. And in the course of this, I got out some drawings and photographs of a job that I did a good 20 years ago, and I'd completely forgotten about it. And it's sort of interesting, because it relates to this business of adapting an existing space to be good acoustically, and of recognizing the need for this sort of 30 foot height of something happening over the performing area.

In Independence, Missouri, Harry Truman's home town, is a large world headquarters of the Reorganized Church of Jesus Christ of Latter Day Saints. Now the Reorganized Church of Jesus Christ of Latter Day Saints is the group from which the Utah Mormons split and went to Utah, and did well. And the people in Independence never ceased to grouse and grumble about how well the Utah Mormons had done. But in any case, they stayed back in Independence, and they did put up there in "latter" years (well after the Saints who went to Utah put up their monster, that dreadful building, that Tabernacle in Salt Lake City, which has the world's <u>worst</u> acoustics, not perfect acoustics, as the tourists are told, but the world's <u>worst</u> acoustics). These guys in Independence put up a kind of pale imitation, but quite large. It also seats 7,000 seats, and I was talking about this yesterday afternoon, so I had my secretary dig out the drawings. And it's a great big oval, like so, and there's a balcony that runs all the way around this thing, and at this end, they have a very large pipe organ down here, and then they have a great section which comes down in here for 300 seats for the choir, descending down into the room. I'll show you how this goes in a minute, and then this ends up in a platform at the front here for preaching, and then the seats go all the way around here, and there are 7,000 people here.

Now obviously these balconies overhang differently and so on, I'm not being accurate. And we were called in by the architect. Actually the consulting architect on this job was Joe Murphy of St. Louis, who's a very good architect, and I don't know how he got dragged in with the Latter Day Saints because he's a devout Roman Catholic, and I don't know how I got dragged in either. But anyhow, we were ministering to these folks, and they wanted to fix this place up. They were buying a new organ, and they had a choir here and they had a rostrum, but the building had never been finished and they couldn't hear, and they had the most incredible array of drug store loudspeakers all over the place. You know, the round boxes. I can describe them a bit more in plan and elevation; you know a few things like this with a G clef in the middle there.

OK, they had -them all over the place. Just an incredible situation. Well, what to do. I went out there and visited the Bishops of the Church, and one of them was a fellow named Israel Smith, and he was a direct descendent of Joseph Smith, one of the founders of the Church. And he was a very reasonable old gent and there were a couple of others that were very reasonable. And I said to them: look, here's the shape of this place, here's the kind of thing in the middle, and then a dome which came down like this with a sort of watermelon motif, balcony, so you know, and then here a platform and then you go on up here and leave the balcony here and then the organ's in here, and this is the choir. Maybe this roof comes out over the organ, I don't remember. It doesn't matter. I said: look, from here to there is of the order of 50 to 60 feet, we're going to have to have a ceiling in here somewhere. "Oh, we can't change the appearance of the place." And I said well, did God tell Joseph Smith how to look? And the answer, they agreed, was that probably God didn't. But it had looked this way for some years, and the people felt rather strongly that it should stay the way it was. So I said: well, I might as well go back to Boston, because I can't help you, you're already dead. Here's the balcony seats coming all round here, and then, I don't know, this comes down like this.

Well to make a long story short, we finally prevailed upon them to use good sense, and we put in a hung ceiling, which is just below eye level for these people sitting in the balcony, consisting of a series of panels, rather large panels, which go uphill like this. It's not an upward canopy, it's a downward one. Each of these big panels is plaster, and oh, they're 8 feet square, sort of a slightly rounded square. And in them are some down lights for lighting this thing. And up here over the top we hung the loudspeaker system exactly where God intended that it should be, right in the middle above the speaking position. (We're going to talk about this quite a lot here, today and ensuing days.) And the line-of-sight is such that for anyone sitting on the main floor, you certainly do look up at this thing, and from the balconies you look sort of across at it. It isn't doing you any good but it isn't hurting you, and the organ pipes simply go up behind it.

This was something like at Symphony Hall, when we put up our temporary rig of panels, everybody thought, oh my God some of the organ's been cut in two, like this. Well isn't that a pity; so what? Yes, they're much taller than we can tolerate for an enclosure of this sort, especially when the organist is way up here at the top, but this thing sort of kept a constant 30 foot height above the floor where the performers are, and it's only in that area of the room that we did it. It's been very, very successful; it really works; and they're tickled to death with it; and it even looks good.

And it keeps the sound from going up to the dome, directly to be focused down. It gives these people an immediate kind of reinforcement that they need, and is just great. One thing in plan…. again, I encouraged this, and I always encourage this; this is a textbook installation, with the organ here, the choir here, and the organist here. Now in this case, the organist gets to be about 35 to 40 feet away from the instrument to play. But that's the maximum distance that he can do that, if he is to perform on the instrument and not have this problem of syncopation that I mentioned the other day, which is: when he hits the key, the note doesn't come for a while, and he goes on to the next key before the next note "*UUMBUMBUMBUMBUM*" and that business, would just drive you up the wall. But with this sort of thing, everyone under a canopy together, the organ there, the choir, the organist can hear them. Absolute magnificent situation for a musical performance. If I racked my brain, I could think of 100 other examples, all of which would tell you the same story, and there's no need to do that, but it is absolutely essential for these performing situations, so our friends at Bob Jones are going to have some kind of business in here, which will give them this reinforcement.

They also, in preliminaries, have located the organ to one side, a la Kresge, the organist way over here, we're going to have a piano over here, and everything was getting about 80 or 90 feet apart. Again the scale of the thing just got all out of kilter, and the whole sending end has got to be rethought. The sending end of a room has certain dimensional requirements that have to be met in any size space.

One very safe rule of thumb is that all of the performers, and all of the instruments and everything, should be contained within a circular area no greater than about 60 feet in diameter. If you get performers more than about 60 feet apart, you've 60 milliseconds of delay between the two sides of the group and you simply cannot get everybody performing together. Now you say, well how on earth can a congregation sing a hymn together in a large assembly of people? Well, they do sing together, but if you really check, everybody isn't together, you're together with your neighbors, and mutually supporting each other, but if you really did some microphone pickups, you'd find that everybody isn't precisely together in a very large group like that because the organ sound or whatever is accompanying them doesn't reach the back people until after it reaches the front people, and it's kind of a wave of sound that is coordinated in local zones, and never seems to bother us very much. Well, maybe enough on this business.

Yes?

Student: "Oh I was just looking in the newest PA [Progressive Architecture Magazine] and it talks about (unintelligible) and it has a concave enclosure for recital hall and has a concave enclosure around the small performing area back, sort of back…."
I can't believe it, I'm sure you're telling me the truth. It's in the latest P.A.?

Student: "There's been a lot of stuff on Eisenhower Theater recently. But it looked good with a piano center stage."
I see. Oh, my goodness, somebody looked in a book somewhere 20 years ago or something, and something could have happened. That could only be a disaster. Guaranteed.

Student: "And it said they had a wooden sound reflector stuck in a line around back."
But it's semi-circular in plan? Well, it can happen, it can happen in 1970, and it will happen in 1971, and all I can do is encourage all of you not to let it happen in any work you do or can influence.

Yes Ma'am?

Student: "So the performing end of a hall actually being set on a circular…."
No, ma'am, I didn't say that. Now let me tell you what I said. I said a circle…. I said that if you're going to have an organ, an organist, a piano, a choir, an orchestra and so on, that all of these people need to be contained in an area not more than 60 feet across. Please don't anybody go away from this class ever thinking I advocated any kind of circular or concave geometry, because it is the work of the devil. It's immoral, wrong, and will cause nothing but disaster. And it's the business of the thing like this behind us in the performing area. If I teach right, it is just incredible in this day and age that anyone would do this.

What happens, of course, is exactly what happens to your automobile headlamp where you have the high and low beam, you know, that's the way it works. You put the filament at the focal point, and then you raise the filament and then that changes the direction of the beam. Now here, if you have…. if this is center of curvature arid if you have a performer here, it's going to send out a very plane wave. A performer here, and you get everything back, and performers in the middle will send out varying degrees of focusing to varying parts across the hall, and you'll hear tremendous concentrations of energy from certain instruments in certain seats. This is just plain physics that tells us this. You can draw the optical ray diagrams, and if 'Joe Blutz' sits here and plays some magnificent bassoon, and you really like his playing; you'll find that he's out here somewhere on the other side of the hall, it always crosses the hall, where he'll come in like a ton of bricks. And the rest of the thing will merely be like an *obligato*. And then 'Schmalz' here with his fiddle will be heard fiddling over here somewhere. I mean it's just inevitable.

Student: "It's in Trinity Church where the whole altar area is a semicircle and it loses the choir, which was singing in another room facing away from the audience and the sound never reached them… the full sound never reached the audience."
Let's see, the choir singing in that apse?

Student: "Yes, but they sing facing one side, they don't face the congregation and yet it sounds like (unintelligible) and it's not always obvious how on-stage communication is difficult to people who don't know much about music like myself, but it was extremely obvious in there that they were having trouble listening to each area of the choir."

I think that this business of communication, let's call it on-stage communication, whether it's on a stage, or in a choir in a church, or a synagogue, or wherever it is, is probably the toughest problem that we have. And the thing is that most of these people who sing in choirs are amateurs, singing for the love of God or something, or the choir director, or some other purpose, and they are not experienced people and they need this mutual support of other people to give a good performance. How often we see the architect taking over this matter and deciding how it's going to be arranged?

Now, e.g., Trinity Church in Concord, Massachusetts. I don't know how many of you know that church, but it's an Anderson, Beckwith and Haible [Anderson, Beckwith and Haible, Architects] cum Belluschi [Pietro Belluschi, Architect] church, and Kepisch [Georgi Kepisch, artist] did a window, a stained glass window, in the east end, which is as magnificent a piece of stained glass as done in Chartres, beautiful glass. And the organ is an Aeolian-Skinner instrument that was bought new and had to be put in the church, and the choir. It's quite textbook: here is the organ, and the choir is seated in 2· rows here and the organist is here.

Now the problem is that the choir is so spread out here in two rows, that's not the way you arrange a choir. You arrange a choir in a square, and if I any use the word circle again without your inferring circular geometry, in a circle if you like, as tightly together as you can possibly pack them. Now I wanted some kind of a little insertion: there's the organ, here's the pipes here, here's the wall and then here's the choir standing down here on two rows, but here across. I wanted to get some kind of a little hoosy here or something that would give a little bit of kickback to them, so they could sort of hear each other, because the ceiling over their heads is up at 40 or 50 feet; it's a very high ceiling with a beautiful stained glass window up above the organ here, and finally up above is the roof. It's a very nice composition.

Well, we've tried. We experimented with pieces of plywood, I've gone up there many times to choir rehearsal and we hold up pieces of plywood over them and "*OOOH"* that is great, and they all get a big charge out of it, but then we say, how are we going to do this architecturally? And, of course, it louses things up, and we're just permanent victims of the design, because the architect said I don't want to fiddle around with any kind of interruption on this, because in elevation, the Kepisch window, does it come down like this, sort of, yes. I think it does, and the roof comes on down like this, and then this is all done in a vertical wood strip, with the organ behind this part of it, but you don't see the organ at all, and strips go down right to the floor, and he didn't want any interruptions there. What happens is that the choir has a neat sort of a maneuver: they all stand up when they're going to sing the anthem, and they then all shift to one side. You see this great shifting, and they all move over just as close as they can stand, and they all shove into the middle, and try to get close together so they can hear each other. So it isn't just circular apses that give trouble (well, they'll give even exaggerated trouble, you can be sure that the circular aspect will always cause a lot more trouble than rectangular geometry).

One very funny thing, I can't resist ceiling you some of these silly things that happen in life. We were attending a service here one morning, and the organ had what's called a "*cipher*." A cipher on an organ is when the organ just goes "*OOOOOO"* and doesn't stop because something is clogged up somewhere and the valve is open, and there's wind in the chest, and the wind runneth out and bloweth the pipe, and the pipe continueth to bloweth until someone stops it. So this was right as the end of a hymn or something, I think the sermon, that's right, the sermon was about to begin, and the organist turned the thing off, and the pipe went "*WOOOOOOO…"* and stopped. Some member of the choir was expert on finding such things, and he checked with the organist which note it was, so he went out the side door here to go fix this pipe during the sermon.

And this is the funny part; he turned on the lights in the organ chamber. Now the organ chamber has just an insect screen in front of it, just regular window screening, which as long as the lights aren't on back there gives one complete obscurity. But you turn on the lights, and the whole thing is revealed. Well the organ is quite handsome, but the funny thing was to see this man in his white robe climbing around up in here, all lighted, and this great scene going on. Nobody paid a bit of attention to the preacher; it was a marvelous little act, and he went prancing around, and he found the pipe, and took it out, and came out and turned out·the lights, and came back and sat down. And at this point people began to hear the sermon. Very, very funny.

Remember that about any kind of screens you do, that the balance of light is extremely important as to whether you see through or don't see through.

Student: "Have you had any experience with geodesic domes or any of these spherical…."
Yes, they are all disasters, for any purpose but storing grain, or lumber perhaps.

Now let me be serious. Out in Honolulu, the Kaiser people [Kaiser Aluminum Corporation] put up a dome in the Hawaiian Village (what's it called, there's a Hilton Hotel there now?). Anyhow, Mr. Kaiser, suggested to his engineers that they probably ought to get some advice on acoustics in this dome they were about to put up. They were going to put a Bucky Fuller aluminum dome, since it was Kaiser. So I was asked, would I go to Oakland, to California, to their headquarters for a day, from Boston, and consult with them and tell them what to do about this thing. And I said certainly. There again, for money, I do all sorts of things.

So I hopped on an airplane and went to San Francisco, Oakland, and went to their office and spent a day, and I said, you've got to have fuzz. That was the essence of what I said: You've got to have fuzz. You can't have this great big aluminum dome, because it's going to be used as an auditorium.

Now I said, first of all, let's forget about any performances during rain, because it's just going to be so noisy you won't be able to hear anything. And then we worked out a pattern, the thing had a kind of an interesting kind of six-sided double star or something, I don't remember, but it was a series of slightly bent aluminum framing members, and we worked out we could cover about half of the dome with areas of fiber glass, and I suppose about half the aluminum, just alternating areas of fiberglass with the bare aluminum, and I've told you, when you spot treatments like that, with hard/soft/hard/soft, it's almost as good as doing the whole thing soft, not quite, but almost. At least a very good gesture towards acoustics.

Well, Mr. Kaiser wouldn't buy that solution, because it covered up the aluminum. O.K. if you're not going to cover up the aluminum, you'll have the consequences. And they have the consequences. They've got a lousy dome, with dreadful focusing in it, absolutely useless during a rainstorm, and it has had almost no successful use at all. It's had no successful use.

Any kind of curved geometry, whether it gives you the kind of flutter that I described to you that we had with the Ford Motor Company or the kind of flutter that you heard over at Kresge, which occurs between a very flat dome and a floor, or whether it's more of hemispherical thing, such as a geodesic dome, you're always going to have it be very difficult.

Student: "What about the opposite of that- a convex surface?"
Oh, magnificent, just a great scattering job. Now there is one geodesic dome that works: Joe Murphy's *Climatron* as he called it, or something. It's a green house, great greenhouse in the Botanical Gardens at

St. Louis. It's a Plexiglas dome, it's filled with plants, you're just walking round looking at plants, you're not talking to people, particularly, or just to one person there, no lectures, no concerts, and it's just filled up with plants, and it really is quite successful. And the circular geometry, although you can find it if you look for it, does not bother people: it is very successful building.

But any time you do a Planetarium for example, or any such place as that, you have to make the dome of out of very finely perforated metal, and behind that you have lots of fiber glass and fuzz to soak it up, make it absolutely dead. And even in plan sometimes in Planetariums, they don't bother with treating the walls, the cylindrical walls below the skyline, you know, all around, and that can cause all sort of freakish conditions.

Student: (unintelligible)
Well, as in Kresge, by hanging in other things.

Student: "Can you just absorb all the sound to avoid focusing?"
Well, of course if you solve it that way, then you're going to have to resort to amplification of everything, and it's a different kind of an animal. I personally am not against amplification, and I'm not leaving it to the last because I think it's the least important, because it's a very important part or this bag of tricks we have, but I personally feel that we ought to do everything we possibly can with natural sound first.

Now I guess I haven't told you this one, but Eero Saarinan called me one day and asked about a dome that he wanted to put up at Stevens College in Missouri, for a chapel. And he said, I want it like an igloo, a hemisphere, a full hemisphere, and he said: I don't want any of your clouds this time, see? And I said OK. And he said, I'll give you all the sound absorbing material you want, you can spray on 4 inches of asbestos on it if you want, on the inside of this dome. And I said: Eero, you said this was a chapel, not a boudoir, didn't you? And he said, yeah , what are you talking about? I said well, you'll solve the circular problem, but you'll make it so dead, it'll never be a chapel. Whether you introduce artificial reverberation, or what, nobody will ever feel he's in a reverberant space.

Now this is my hang-up on chapels, I think they ought to be reverberant, and if people ask me what to do about a chapel, I'll make them make it reverberant, whether they want it reverberant or not. OK you say, you arbitrary bastard; I am, very arbitrary, and very much for imposing the way I think about things on other people, because I'm right, but you'll see. But what we did do for Eero—any of you know the Kings College Chapel?—he wanted this, and I said No, we'll do this.

First approximation to a dome, and in plan it's a square, and has a pyramidal roof. And a pyramidal roof has an egg crate, not an egg crate, I mean a waffle slab, and it's all hard as nails, it's concrete, exposed concrete; the walls are brick, and the place really sounds great, they've got an organ in there, music sounds wonderful, and it's a very nice chapel. It's not a dome, it's a square plan with a pyramidal roof. He gets the same volume he was after, the same height, but he doesn't get the pure circle, and it's an infinitely more successful chapel than we ever could have done in the dome. Even hanging things in, it's difficult to get rid of all the effects of curved geometry.

Student: "Why the waffles?"
The waffles were structural and acoustical. I wanted them for sound diffusion, for scattering sound energy. And any kind [of diffusion] in a room you can introduce bumps and wiggles for any reason whatever. I

mean, even such things as this engaged column, and the recess of the windows and back again, all of these things, all this bumpiness and so on helps in room, scattering the sound more uniformly.

Because even with flat geometry, you're going to have some kind of unique path between source and receiver—for every source position and every receiver position—and if we diffuse it with coffers of whatnot, we improve the scattering of the energy so that it isn't all in one plane. We don't get a glossy reflection, we get a diffused one. I think I've talked enough about diffusion, but diffusion as confused with absorption, and we had that question on the quiz. There are still many people in the world, including Pier Luigi Nervi, who believe that diffusion is the same thing as absorption. There's just a lot of confusion about this, so keep· the two separated in your minds. The reason I never get to my notes that I'm going to talk about is that I get off on these stories about people fixing organs and so on in churches.

Are there any questions that anybody has about this music performance because I don't want to belabor it forever. It's a very important thing. The wall behind the performers? Yes, the wall behind the performers should be hard. Now there are occasions when you might want to make it soft. Having said yes, it should be hard, I'll turn around. For example, I described to you to stage at Salem College in the recital hall where we had the persistent flutter. There was a Flintrop organ here, and there's some pockets back here, and each side, this is the plan, this is the stage, and we have some heavy draperies. Sometimes we draw these draperies out like this. And that is when the stage is being used for recitals of instruments where too much reverberation is not desirable. For example a string quartet, a flute soloist, a vocalist, a pianist—many instruments require less reverberation that you want for the organ or for full orchestra, and on those occasions we might well use a drapery to give us control of the reverberant environment. And in that case you'd probably have some additional screens here surrounding the small performing group, to give us some local reflection. And this would merely become part of the room, not the performing area.

But to have this curtain out, and more especially to have the full drapery across here and have an orchestra here would be unforgivable, absolutely unforgivable. Does that answer the question?

Student: "When you were amplifying for reverberation, let's say a choir or something, or an orchestra whatever, isn't there tremendous difficulty, I mean it's one thing to do an organ, where you can design, but is it possible to do an orchestra well?"
Yes, it is possible, it has been done, and we're trying to do it right now in Kresge.

Student: "That'll be for orchestra?"
Yes, as well as for organ.

Let me, let me take one other question. O.K. then let me move on, and perhaps we'll get back to this. Just to say a word about large-scale spaces like arenas and coliseums. They're very simple to talk about because there's just one solution to the arena or the coliseum, and that's fuzz. Every square inch of ceiling and wall surface that is available in a large, you know, 5,000, 10,000, 20,000, 40,000, 50,000 seat enclosed space, all the way from the Harris County sports stadium, alias Astrodome, on down to just very ordinary size spaces, must be made as dead as you can possible make them, as much like outdoors as you can possibly make them, because all the surfaces are so far away that they cannot be of any help in giving us useful reinforcement. So we say, throw away the room, and make it as dead as we possibly can, and then resort to amplification.

Now very often—this is a special requirement, very often today—we find these large buildings being put up, and we're designing one right now for another frightful Oral Roberts University - I'm sorry, I work for a living, I don't ask your approval, but anyhow they're putting up a "*gymatorium"* or something or other, which is going to have one quadrant devoted to cultural activities (when it's not being used for basketball and other such purposes), they'll use one quadrant for concerts and other such events.

Now in this particular place, everything is going to be amplified. We are going to have an orchestra enclosure for symphonic performances, but an awful lot of the stuff is already pre-recorded, and apparently done in Hollywood, and this is presented over the sound system. But one requirement that comes up is that the ventilating system that's customarily used, the heating system, or ventilating system for these large sports palaces, is generally pretty noisy. It doesn't have to be quiet, because all you've got to be able to do is hear the announcements over the crowd noise, which overrides the ventilating system anyhow, so what the hell if it is NC-50 or -60 or -70. You know, telephoning would be impossible there, this great roaring goes on, and it just adds to the general feeling that something's happening, and maybe enhances the pleasure of the spectators, I don't know.

[But] the ventilating system in a large arena in which you're going to do any kind of cultural events has to be a hell of a lot quieter than normal, and it will cost some money to get it that way. Usually we require that the air system, not the unit air handlers hung from the roof, as is so often the case. A lot of these places are heated with gas-fired furnaces, which are hung right out in the middle of the space. There will be four of these monsters, and the blowers and everything for the air handling unit and everything, is all in one package. And all they do is put a chimney through the roof, and bring in the gas, and start blowing the air, and you've got heat and noise. My God.

And generally we require that these things not be used, and that the air be ducted into the space from central fan locations through long lined ducts, and this costs some extra money. I wouldn't waste the money doing it except in a case where they're going to try to use the place for other purposes than sports events, and they very often do. It means, though, that we must have sound absorbing finishes. We cannot have exposed concrete. We cannot have exposed steel deck, or wood deck, or any other kind of hard sound reflecting material; we must have soft stuff. We quite often today, as in the big Sports Building at University of Illinois in Champagne-Urbana, we used Tectum (I believe it was Tectum, it may have been Porex, I don't know) as the form work for the concrete dome. And these things do turn out to be domes more often than not, simply for structural reasons, and I say, more power to you, go ahead and use the dome, because we're going to try to get rid of it anyhow acoustically, and if we can make it absorptive enough, we don't give a damn what shape it has.

Now the dome at Illinois happened to be a folded plate approach to a dome so it went zigzagzigzag all around. And we used these wood-wool slabs 2-inch thick, or three inch thick , wood wool slabs, or Tectum, Porex, Insulrok, Beraclete, Durasol, there are all kinds of names for this stuff. It's like excelsior bonded together with 4 foot cement in a matrix that makes a very fine sound absorbing material, makes an excellent heat insulator, makes good form work for concrete. You just put it up and leave it there. Pour·the concrete on top of it, and have a few hooks so it doesn't' fall off on the people, because from 100 feet this could be a disaster if the stuff fell down. So you end up with a sound absorbing ceiling.

In the Astrodome in Houston, you remember the fiasco where was lighting for a change and they had to have a one-third perforation of the roof for daylight in order to grow grass; this was before the discovery of Astroturf, which is plastic. They had to grow grass, and they had been advised by the grass consultants that 33-1/3% open area in the roof would do it, so they put Lucite bubbles on the one-third of the roof, and they had the remaining two-thirds to put our fuzz on. Well, it was just not nearly as much fuzz as I would liked to have had, but I didn't have much choice. And then, of course, it turned out that the light was so terrible because the visual contrast of bright to dark, bright/dark, you couldn't see a baseball going over, you couldn't see anything, and so they had to black it all out anyhow, and use artificial light and resort to plastic grass. But over and over again, every time we've seen one of these places that was not adequately treated, it's been a disastrous event until it did get a sound absorbing treatment in. And then we resort entirely to sound amplification systems, which I would like to talk about.

Does anyone have any reactions about arenas? They're not very often done, but all I can say is just make them real dead.

Student: "Making them real dead and making them as close as possible to the natural outdoors. Is it asking too much to think that you could design something, which had the acoustics of say a Greek theatre, which were supposed to be pretty good."
Well, the Greek theatre is outdoors, that what we're trying to approach.

Student: "Yeah, but is there some sort of geometry or technique so that this can be achieved, in designing an indoor space?"
Well, of course, most indoor arenas, sports arena, have as a model, the Greek theatres with steeply sloped seating and arranged as close as possible to each other?

Student: "Is that the only secret of the Greek theatre?"
The Greek Theatre has two secrets: one is no background noise, two is steep seating, with everyone as close as possible to the performers, and loud speaking performers. That's the only trick there is. And of course in the big arena, in the coliseum, in the big Sports Palace, we try to duplicate just exactly that, and when you must hear something, then you must have no background noise.

Student: "You know Greek arenas are also based on 180 degrees approximately. They could use an arena for anything other than sports events. Some other performances at the Boston Gardens, they have the occasional rock concert every so often."
Do they try to seat the whole place?

Student" "No, they try to seat- Oh God you can't even see the stage from right behind the performer. I was actually at one in Rhode Island that had worse acoustics than the Boston Arena. And the seats that I bought were behind the performing group. (unintelligible) If you want to know about the acoustics of rock concerts, they have a new thing when they're in a big theatre, you know, a 360 degree theatre, they put the group on a revolving stage, which means you get one fifth of the music as it comes around."
Don't they have amplification for everybody?

Student: "No."
Oh. So you hear the music as it comes by. It's like the merry-go-round bar at the Copley. That's nice and quiet piano music.

Student: "Well this is amplified in one direction, as it goes by you, you sort of hear a whine as it goes round and you wait for the next one, and you hope you get it back again at the downbeat. Shameful.

You're right, the Greeks didn't attempt to do more than 180 degrees, some of them a little bit more, but they recognized the directionality of the sources, which were frontal. And one of my colleagues has just returned from Berlin, and he attended a concert in the Philharmonie, and he says it's absolutely unbelievable the way an orchestra sounds from behind. Terrible. It's just unbelievable. And I haven't listened to it there, but everybody tells me the French horns are very loud, and so, on. You know the piano doesn't come through at all, and vocalists and so on. We just can't get away from these fundamental things.

If you're going to put on a cultural event, and I'll put a rock concert in that category, you just can't perform to more than 180 degrees, you're right. Now the thing I was talking about the other day, about movable ceilings and so on in halls; and I commented about that for Jones Hall in Houston. The movable ceiling has not been used very much, simply because of the greed and avarice of the box office. Well, they've got to be greedy, they've got to run the place, and finance it, and if they can sell 3,000 seats to a performance, they'll sell them, whether it's a 1,200 seat performance or not. And if the Boston Garden can fill the place with people, they're going to sell all the seats, whether they can expect to hear or not.

Of course the hearing part can be solved with an adequate sound system, and the Boston Garden has an incredible sound system.

Student: (unintelligible)
Well the Boston Garden is a pretty horrible place; yup. We did set up a sound system there for Winston Churchill, back in 1950. MIT put on a great mid-century convocation, and Winston Churchill was here, and a lot of distinguished people of the time, and they had a big do over in the Boston Garden. And we rigged the sound system for that occasion, an Altec-Lansing sound system, which sounded magnificent. And at that time, we tried to persuade the Manager of the Garden: Hey, you, hear what a good sound system can sound like? Why don't you get a decent sound system? We'll do one for you?

Ah, costs money! And then the funny thing was that right before Churchill was to speak, the system starting going "*HHHUUMMM"* which is what is called feedback, and when that happens you're supposed to turn the gain down so the thing stops feeding from the loudspeaker to the microphone to the loudspeaker to the microphone to the loudspeaker "*OOOOOH,"* like that. Leo Beranek was there kind of in charge of things, and I saw him start running to grab the throat of the idiot guy on the controls; why the hell don't you turn down the volume, and he was turning it down and doing everything he could, and nothing was happening. And they found out in a minute that it was a steam engine outside, letting off steam, blowing his whistle, having a great time "*WWOOO*." So they sent word to the yard to have him stopped, but that again doesn't have much to do with the temptation to say: let's just build bigger halls. I mean, what the hell, we're getting more people in the world, and there are going to be twice as many people in the world in the next two decades, and 3,000-seats auditoria have got to become 6,000-seat auditoria and so on. It's not going to solve any problems, and I think the 7,000 seat solution is a great big monster of a thing; it's not going to be a terribly good space. It'll be great for huge presentations of Aida with elephants and so on, big scale, you know. OK and a compulsory chapel, you can cram them all in there and make them sit there and listen for an hour, and take attendance, that'll get them. But it's not going to be a great place acoustically, even with amplification.

Student: "Because that clunking wall is so far away, is it going to make a difference; like will all the sound be absorbed before it gets there?"
Oh, you have to have fuzz here like mad, I'm thinking of about a foot of fuzz, real deep stuff. Yes?

Student: "When you did the sound system for Boston Gardens, did you put any fuzz on the ceilings?"

No, we didn't do that; this was strictly a one shot deal. The house was full of people, and we did the sound system, very carefully directed down towards the audience, so we didn't involve the room very much. I'm anticipating a lot of things I want to tell you here in the next lecture [about sound systems]. Well this had a noisy fan system too. We had that turned off too during the Churchill convocation, so there was no air moving, just sit there. Well, I promise to begin sound systems next time.

End of Audio File 25

THE END

Robert Bradford Newman Lectures

11 December 1970

LECTURE 26

Title: "Intro to Amplification Systems"

Summary: Newman introduces concepts relating to use and placement of microphones.

Beginning of Audio File 26

….just as roofs don't have holes in them if you want to keep the water out [and make buildings] watertight to keep the water out, there are certain things you simply have to recognize about these [sound] systems. I don't want to go into any tremendous detail about the mechanics of these things, but I would like to talk just a little bit each of these three elements. And there is, by the way, a 3-page section in the Time Savers Standards Reprint that summarizes a lot of this, and you might want to refresh your memory on it later on by looking at that.

Now microphones are usually pretty small gadgets. You are mostly too young to remember the days when the radio stations' microphone was a great big thing with a circle like this with a stand, and some springs, and a thing sitting in the middle like this—that's almost full scale. This microphone, this was a ring, and these were springs here to keep it from getting wonked; and even back in the 20's, when these things were in vogue, they discovered that you don't thump on a microphone, otherwise you hear thumping sounds coming out of it. How many Broadway theatres have ever come to grips with that problem, even the Colonial Theatre in Boston, which has a dreadful sound system, has the microphones attached rigidly to the stage and when you "*BANGBANG"* on the stage like this, you heard "*BOOMBOOMBOOM"* coming out of the microphones.

You know the rules haven't changed. You put resilient mounts underneath things that you don't want to have struck. This kind of an instrument was what was called a <u>carbon microphone</u>, and a carbon microphone is never used in anything except the telephone; the handset in your telephone has a carbon microphone in it. Now for ordinary telephone communication purposes, this is quite adequate. We don't ask for high fidelity, we ask for recognizability of voice, and perhaps a few such things as that, but we don't really ask for broadcast quality, don't ask for very super-duper high quality from our telephone. The carbon microphone has the advantage that it puts out about 10 to 20 decibels more output that any other kind of microphone. It's a very high output device, so that you can do with one less stage of amplification in the telephone system, and this is worth real money, and I'm sure that we will always have carbon microphones in our telephone systems. Now there are many situations though where we use carbon microphones where we shouldn't. Some aircraft have carbon microphones in the PA system—public address systems—and you can always tell in an airplane whether the stewardess or the pilot is using a carbon microphone or a good microphone simply because of the dreadful quality that you get when you present carbon microphone pickup over a high quality loudspeaker system. It just comes across as a very crummy quality sound.

Many times in airports the telephone handset is used to make announcements over the PA system. The fellow at the counter, at Eastern Airlines or American or whatever it is, dials "7" or some other number on his telephone and that puts him into the PA system, and then he always blows on it, spits at it a little bit, thumps it on the table, and "*AWAWAWAWAWA,"* it just comes across with this dreadful quality. And if you possibly can, [you should] discourage the use of telephone handsets as source instruments for airport announcing systems. One can—for for an·extra $20 or so—get a high quality microphone that goes into the normal telephone handset, and has a transistorized stage of amplification right there in the same package, so that it looks and acts exactly like a normal telephone handset, but has a good quality dynamic microphone. Most airport operators are loathe to spend one cent, much less $20 on anything that isn't absolutely essential to the operation of the building, so you find carbon instruments used in many airport announcing systems. High quality systems never use such a device.

The really good microphones that we use today are the dynamic microphone. Some of you probably know all this anyhow, but we'll just review it for a minute: dynamic microphone. We sometimes use the ribbon microphone, and quite often today we use the condenser microphone. Now there's another cheapie type that we don't use at all in good stuff, it's the so-called crystal microphone, and carbon never. Crystal microphones are the kind you can get for $15, you know in a chrome-plated [bracket], for groups to use. If you really are limited with your budget, you buy a crystal microphone. It'll make noise, it'll make sound, and sometimes if it's just screaming and yelling you want to do, it doesn't matter, and it has a good high output. Never leave a crystal microphone in the trunk of a car, because when you get back after a summer day of the sun shining on the trunk, you'll find a drizzle out of your crystal microphone, and that's the crystal, melted like ice.

So, but we draw the line here. This is junk, cheap, and these are the goods down here. And these two are more expensive and better, not because they're more expensive but because they are more carefully made. The condenser microphone is probably the ultimate in microphones. It has many problems associated with it, but one of the things about a condenser microphone is that it can be very, very small. We have condenser microphones that are only a quarter of an inch in diameter, very, very skinny. We use them in working models, studying auditorium designs in model form. And when we need a very, very small microphone, ¼" is as small as a microphone can be. The Altec people, and a number of other people make what they call the lipstick microphone, which is exactly the size of a woman's lipstick, a small ½" diameter, 2" long microphone. And these have been developed, of course, because of the demands of T.V., and to get something small that doesn't look like a great big monster that we used to have, but small and inconspicuous.

And condenser microphones have one tremendous virtue over any other kind, and that is that they are absolutely smooth in their response. If I draw a response curve of a condenser microphone, the frequency output as a function of input will be absolutely flat, it looks like this, perhaps out to 10,000 cycles per second [Hz], and then falls off, but there are no peaks and dips in it. It's a much more perfect device than our ears are, for example, or anything, but it simply doesn't add or subtract anything from its pickup. It's a beautifully smooth gadget. A condenser microphone consists of a very fine, a very thin stainless steel diaphragm, sort of like aluminum foil, stainless steel foil stretched over a whole piece, then these two are connected with voltage and so on to give us a [transducer] when the sound strikes this diaphragm, it moves it in and out, and changes the capacitance of this condenser, by changing the spacing between the two plates. And this is picked up as a change in voltage out on the line and this is fed to an amplifier.

Now you have to have with every condenser microphone a preamplifier right at the microphone—you can't go 100 feet before you come to a need for amplification, so this is another problem with it. You have to have a little local preamplifier practically in the microphone case itself, and then you go out with the wires to your system. But they tend to be quite expensive, $200 to $300 apiece, very high quality [sound], and you can't ever touch this diaphragm with anything or you'll ruin it, so it's always protected. You don't even blow the dust off it. And in damp weather, it tends you get some conduction around the dielectric that separates these two plates, and then you get noise from moisture in the system, so they have to be kept dry--keep them in desiccators. And there are all sorts of problems, but they are super-duper, wonderful microphones when they are working well. They are not for the high school auditorium-type use, where kids are going to bump them around and drop them and so on. Probably these are the best for that kind of thing, or perhaps a dynamic microphone.

Now a dynamic microphone works exactly like a loudspeaker in reverse. In fact, you can use a loudspeaker as a microphone, because it is an electro-acoustic transducer, and if you push on the loudspeaker it will generate a voltage, and if you turned it around and hooked into the other end of the amplifier you would have a microphone. Most intercom systems that are used in theatres, in office buildings, in houses and so on use the loudspeaker as a microphone; you simply switch it back and forth and use it both ways.

Now how does it work? Let's look at the loudspeaker because the dynamic microphone is just a special case of this. Question or are you just stretching? OK; that's perfectly all right.

We have here a magnet. I'm going to draw this in bigger scale. This is the North Pole and this is the South Pole. This magnet is a funny magnet because it's an angular magnet. It's a ring in plan, it's a circle, and you've got a slot in the middle, this is the North Pole, this is the South Pole. This is a permanent magnet, and it can be made out of a variety of metals, aluminum, nickel, cobalt, alloys of all sorts, and we've no need to go into that. You can tell a little bit about the quality of a loudspeaker and its efficiency and everything else by how much it weighs. If it's very light weight, it's probably got a pretty poor magnet on it, and isn't very efficient, and isn't very good.

The heavier loudspeakers, the more expensive ones have better magnets and are generally better. Now in this magnetic field, because we have supports running across here, we have a little bobbin of wire. Now you all know what a bobbin is: a bobbin is a little cylinder of paper, with wires wound round and round and round it, just like a bobbin in a sewing machine. It's a little disc or little paper cylinder with very fine wires around it, round and round and round. And these come out here, so here's our little bobbin, and this is called the voice coil. Attached to the voice coil is a radiating surface called the cone, and in most ordinary loudspeakers, this cone is made of *papier mache* in various and sundry forms. It's a felted paper fiber that is collected in water on a form that is shaped like a cone, a screen form—you just go swuuush and you've stuck a lot of fibers onto it, and it's just like felt, regular *papier mache* technique. Some cones are made of Bakelite, some cones are made of metal, there are all sorts of special things, but in general the cone is a special cone of some sort. And at the edge there is a springy resilient suspension, and then this is tied back to some kind of a framework that holds the whole thing in place and connects to the magnet.

Now what happens? We have a pair of wires corning out of the end of this bobbin, and we'll bring them out to the front in a moment, it doesn't matter. Here's our bobbin of wires, round and round and round, and we take a couple of wires off this. Now, when we pass a current through this bobbin of wire, a current from the amplifier, this current is exactly the same kind of current that went into the front of the amplifier, except it's now bigger, because the amplifier is feeding in electric energy from the mains, from the electric mains—that's where the power comes from—and sends up this larger signal, that voltage or current goes into this coil, and the coil is in the magnetic field.

Now you remember from Physics 1, or whatever number you called it, when you have a current carrying a conductor in a magnetic field, it experiences a sideways force. This is how motors work, nothing in the world but an electric motor, and you can apply the right-hand rule and figure out which way the lines are going, and which way the thing is going to move, and so on. This is alternating so it goes back and forth, so your right hand will get tired pretty quickly following it, but in any case the current goes in here, and because we have a strong magnetic field the bobbin gets pushed to one side pushed and back, back, back, and moves the cone with it and we have sound, just as simple as that. The sound is radiated by the loudspeaker because the cone is being moved in and out by the force applied from this voice coil, which is an electric wire in a magnetic field, which has been fed a signal which resembles exactly the signal that came to the microphone that went into the amplifier, that came out of the amplifier, that went to the voice coil, and moves the cone. And that's the way it works.

Now if I reverse the procedure, and I say, let this be a dynamic microphone, and I put sound onto the cone, I thus move the cone because sound does represent motion, to-and-fro motion of the molecules in the air. I move the cone in and out. And I force this voice coil in and out of the magnetic field, and I've got an electric generator, and I generate an electromotive force in the wire by moving the wire in and out of the magnetic field, and then that comes out here, as a little voltage which I can then feed into the amplifier, and on down the line into another loudspeaker. Dynamic microphones (as opposed to loudspeakers, which are generally sizeable things), dynamic microphones generally aren't more than a couple of inches in diameter. They don't have to radiate efficiently, low frequencies, and we can compensate for their lack of sensitivity to low frequencies (because of their small size) in other ways in the circuitry. But a loudspeaker in order to radiate low frequencies—well, it has to be fairly big, and you know perfectly well that out of a small portable table radio or little pocket radio you don't get a great deal of low frequency sound. You certainly don't get any big "*WOOMPWOOMPWOOMP*," it doesn't shake your gut, and that's simply because the thing is small, and is incapable of exciting long wave length sounds.

Student: "Can you can resonate little speakers off together and get a big sound?"
OK, it works, it's not a theory, it works. There are all sorts of tricks in the hi-fi game of getting low frequency sound out of smaller things, but you always pay a price for that, usually in much lower efficiency of operation. I'm talking now about straight radiators. Yes?

Student: "The name of the game is equalization; in order to get the same phase out of a loudspeaker or bunches of them, you need a whole bunch of equalization."
Yes, and filtering. You can get great excursions of a small thing at low frequency, which will carry a lot of energy, though it may have a lot of distortion with it—you filter that out, you get rid of it. I mean, take the AR 3A loudspeaker, just for instance. There are lots of them, but you need to drive that with 40 watts or so to get the full *oomph*, and if you put 40 watts into an ordinary straight radiator loudspeaker, you probably would rupture it, you'd certainly rupture your ears. It's just orders of magnitude less efficient, that's all.

Let's just stick to this, because in the big professional systems, in systems for airports and systems for auditoria, we never use hi-fi equipment. It's a whole different game. We always use direct radiating efficient loudspeakers, otherwise we can't afford to run them. We'd have to have several diesel engines running down in the basement generating power to run our amplifiers. We do it with much more efficiency. Now the loudspeakers, as I say, are architecturally the most difficult thing to accommodate, and they are probably the most important element in the system. The amplifier is not nearly as important an element that has to be of super-duper quality as is the loudspeaker and the microphone. You can take the crummiest little transistor pocket radio, and you can get the leads out of the loudspeaker and put it into a big high efficiency theatre loudspeaker behind the screens in a movie house, with great big monsters that are 8 foot cubes, and you get the most gorgeous sound out of this little squawker box. It can just slay you, what's coming out, the signal is perfectly good, there is plenty of power to drive this big efficient loudspeaker and all of sudden you hear this glorious sound with highs and lows and gut-shaking and everything out of this little tiny squawk box. A nice experiment to do.

The loudspeaker in any system—whether it be home hi-fi or a sound amplification system in a public building—the loudspeaker is probably the most important thing to have properly done. Amplifiers of course vary in quality. There are very good ones, very reliable ones and there are punk ones that just don't last very long. And microphones, as I've said, vary in cost and in durability, just depending on what you are going to do to select the microphone that you need.

Now, it's very important to realize when talking about sound amplification that we realize that the microphone has only got one ear. The other day I asked if we plug up one ear (and let's all plug up one ear if you don't mind looking like asses) and notice the difference of the sound in this room that you are getting: a very funny kind of reverberant sound. Now that's what a microphone hears, and if you have a microphone where you are, that is exactly what it will pick up and would amplify. And you would say, well, that is unacceptable in quality what you hear with <u>one</u> ear stopped up and that's right, it is unacceptable in quality as compared with <u>two</u> ears, because with two ears you are sensing direction, you are getting rid of unwanted reverberant energy, you are doing a great deal of discriminatory listening in your brain—that's what it's there for, amongst other things, is to help us hear with binaural hearing.

A microphone, in order to pick up any kind of performance has to be fairly close to the performer. We did a new sound system in Pittsburgh in the Orange Peel Dome Stadium several years ago. They had there a very crummy system that they had put in by Stromberg Carlson. They went to a contractor—this is like I want to build a house and I go to a contractor and he puts up a house—I just want a house, I don't give a damn what it looks like, just put me up a house Mr. Contractor, and he does so. He sends me a bill and I move in. And so they said to Stromberg Carlson, put us in some sound, and of course Stromberg Carlson put in some sound. Stromberg Carlson doesn't make anything fit to use in a decent building. But they put it in and so it didn't work, and finally we put in a good system for them, had RCA do it, and the first event that came along was some sort of a jazz concert and it was very successful and the press was most favorable about the new sound system, just marvelous. Jazz musicians, like any others, are accustomed to using amplification; they know how to use it, they know that if you're going to sing you're going to have the microphone right up here in front of you, and they know you're going to sing right through it just short of spitting in it, and you're not going to insist that the microphone be twenty feet away and where nobody can see it and then you just pretend that you're not being amplified. It's part of the art of amplification if you use it, and if you use it well, it can serve you well.

The next thing that came along was the Civic Light Opera and the jackass in charge of that came from Germany and, of course, in Germany everything is known about everything, it's all done right there and he says: “We don't use amplification in Germany, I won't use it.” Well OK, don't; see if we care. If you won't be heard; that's alright, go ahead, just pantomime light opera. The customers don't want that, but this jackass insisted on trying to use the microphones twenty feet away from the performers. Now the stage in this particular setup is an enormous stage, and in order to change scenery they simply turn out the lights and everybody comes out in black tights carrying the changes of scenery, and they have big set pieces and so on, and so they can't have any microphones hanging overhead because they get bashed by the scenery changes. He said, well, couldn't you change the scenery in some other way, and we said, oh no, this is the way we do it. OK. Well, there was a tremendous brouhaha in the press about the disaster of the sound system. Now the press has just got through saying what a marvelous sound system we have, and how wonderful it is to have this clear articulate sound of the jazz concert; oh, it's great, isn't it nice we have the new sound system. Then the Civic Light Opera comes along and totally misuses it, backs the car over the cliff, the car is no good it went over the cliff… sorry, never mind what it will do from 0 to 60 .... disaster! Fake quacks, the acoustics people don't know what they are doing.

You know, I tell you, this is a rough game to be in when people insist on backing their cars over the cliff and they blame you for this lousy car. Well, we operated on this joker some; I don't think he was ever convinced but he did have to admit after a while that the microphones would have to be within 6 or 7 feet of the performers if we were going to get any kind of decent pickup. Now 6 or 7 feet is not mouthing the microphone or spitting on it, but it is something that is very common and requires a great deal of care and setup for a play, opera, or anything else you are going to amplify; a great deal of care in locating microphones so that performers are never more than 6 or 7 feet away when they must say something.

Student: *"Aren't there large microphones in TV studios?"*
Well, that of course is a very special kind of thing and you can operate at great distances with those microphones. I'm talking now about something that doesn't require that you just stand here where it says X if you are going to talk. We can do that from 50 feet away, not with super quality, but it can be done. I'll talk about those a little later; they are very, very special.

Student: *"In that arena, did they actually expect to hear something when they opened up the roof? I mean that is why they made a moveable roof, it was for the opera."*
I don't think anybody ever thought about that.

Student: *"It's right under the flight path of the airport, it's just unbelievable."*
The first act in the summer is usually with the roof closed because it's too light outside.

Student: *"It's too expensive to open or something?"*
Well, I've seen them open it at intermission and you were comfortable and cool and you didn't hear all this jazz and then they open it up so you can enjoy the outdoors and you know it's a hot night and the damned airplanes are going over, the city traffic, and you really wish they would close it up again. Outdoor performances are great if you have a quiet site. They can be just ridiculous otherwise. Well.

Student: *"Ever try transmitting the mike without a wire?"*
Oh yes, wireless microphones, of course, can be used and we've just designed a new sound system, it's just being installed now, in the Senate in Washington. And one of the things one of the Senators thought of, or several of them thought of, is that they should all have wireless microphones. Well, if you start using wireless microphones for 100 Senators you have to have 100 radio channels and there aren't that many available in the bands that this kind of equipment uses, and it would have cost the taxpayers a tidy sum of money so we…

Student: *"That's one of those jobs where you have to decide whether you want to do a good job or not."*
Yes, well we decided to do a good job, I think we'd better; we can't take the chance or afford to do a bad one.

Student: "Put them all on the same channel!"
They're going to have wires, they are going to have a 15 foot retractable cord, an umbilical cord with a 15 foot reel that they can get up and pace around within a 15 foot radius..

Well, we always get off from what I was talking about. The point I was trying to make about microphones is that, in order to work well, they cannot be placed arbitrarily, just any place, they have to be pretty close to where the performance is going to happen.

Several years ago, some of you may remember, along the Charles River, the MDC [Metropolitan District Commission] summer festival thing that Carl Koch [Carl Koch, Architect] did (with the inflated nylon roof and a circular metal frame that held it up, up the river on Soldiers Field Road where the Institute of Contemporary Art is now), kind of a lump of ground there, the whole thing burned down a while back. But in any case, they operated one summer with various and sundry kinds of drug store sound systems, none of which worked. And then we were asked to design a system for them, which we did, and then they put in about a $10,000 or $12,000 amplification system, which was very, very good. But one of the things that we said to this producer there is: if you are going to have sound amplification, the microphones have got to be there near the actors. "I don't want to see any microphones, I don't want to see any microphones at all.," And I said, this, my friend, is exactly like saying I don't like those wings on the airplane, take them off, but fly them anyhow. It doesn't happen. And if we are going to have amplification, we are going to have microphones, amplifiers, and loudspeakers. They are all going to be there.

And what we did at that theater (and he finally had to give in because he had to admit it wouldn't work otherwise) was: if this is the stage, the performing area—it was a thrust staged theater, was to put a grid of 10 condenser microphones suspended from overhead, here, one, two, three, four, five, six, seven, eight, nine, ten. Ten feet on centers and ten feet above the floor, hanging down. Here's the-floor, here's an actor that's just 6 feet or so, and at 10 feet there is a microphone. Every 10 feet there is a microphone and always an actor must speak in this area. This is the acting area, he is always within 6 or 7 feet of a microphone.

Now we don't keep all the microphones on at the same time in a setup like this because actors have a way once they finish saying their lines, standing around back there with the spear carriers, and they say all kinds of four letter vulgarities. And if the microphones are on, they get picked up. Wireless microphones—some very interesting things have happened when actors have walked off stage and have been still connected with the wireless microphone and they have made some comments that never, never, should have reached the ears of the audience. There have been some disasters of that sort.

Now what do you do. Well, we did a little bit of human engineering. We said no technician or any other person is going to be able to learn that this is #1, #2,# 3, #4, #5, #6, #7, #8, #9, #10 and have a series of knobs marked, 1,2,3,4,5,6,7,8,9,10. Instead of that, we gave them a control panel that was in plan exactly like the stage and like the microphones. So you have a control panel exactly like this, with its knobs here for each of the microphones and all he's got to do is see where the actor is and run that one up louder and run the others down. Perfectly intuitive way to run things.

Many times you can make life an awful lot simpler if you just think about how the guy is going to do it, how is he going to know it the most easy way, what's the easiest way for him to do that, how would I like to do it, if I were in his place, and what would I do if I had to memorize that the third mike back there is #4. I would never know that, but if it's just the microphone that's there, right here, where he's there, then that's a cinch to do; and it did work very, very well, an extremely successful thing. But the microphones were all just hanging there at 10 feet above the stage and you couldn't have a bunch of guys coming out when the lights were turned off, in black tights, changing scenery and bashing these things. They had to recognize that 10 foot is the ceiling.

Student: *"Was the sound continually adjusted to the performers?"*
That's right - just as you continually adjust a car when it's going down the road. You know, you sit there and you drive, you steer, you accelerate, you brake, you clutch, you shift gears, it's exactly the same kind of thing—you've got to have a chauffeur. These things are not automatic. You don't turn them on and set the dial at 7. Most churches have these systems where the janitor comes in on Sunday morning, he turns on the sound and sets it, at 7:00 AM, and then it runs that way all morning. Just a horrible sort of thing.

Well, microphones many times are placed in footlights in front of stages and when they are placed in footlights the sophisticated installation puts them in rubber bands, in a sling of rubber bands so that when you thump on the stage like that you don't hear "*BOOOMP, BOOOMP"* in the microphone.

Microphones pick up only airborne sounds to get rid of the structure borne component of stage vibration. There just are oodles of ways that these things can be handled but they must be handled well, and they must be close to the performers, I cannot over emphasize that. And that's going to be one of the hang-ups I'm sure in the use of the new reverberation system at Kresge Auditorium—is that microphone locations are very critical and they have to be quite close to the performers and you may even have to have microphones on stands in amongst the orchestra and I'm sure this is going to be troublesome. We may have to hang them overhead where people will almost touch them but they've got to get within a very few feet.

Well, we'll talk about loudspeakers on Monday. Any more Field Studies No. 1? I'd like to get those wound up.

End of Audio File 26

THE END

Robert Bradford Newman Lectures

14 December 1970
LECTURE 27

Title: "Placement of Speaker Arrays"

Summary: Newman discusses the methods of sound amplification and the placement of various speakers in auditoria.

Beginning of Audio File 27

[This is the last] week of classes I believe. And I'm going to try to wind up everything that I want to talk about here in the next three hours: today, Wednesday, and Friday. And today, hopefully, wind up most of what we're going to say about sound reinforcement systems. They are terribly important to us in buildings for good hearing. I've just been hearing a tale of woe of a movie that was presented in Kresge Friday and Saturday? What is it? "2001?" Well, in any case, the sound system was pretty primitive and the usually sort of jack-assery, if I can call it that, that goes on at these productions. Apparently they wanted <u>stereo</u> sound and Kresge is equipped with only <u>single</u> channel sound for movies. So they got in some hi-fi type loudspeakers which were put on the stage and then, of course, they blew right away. Because when you try to make enough sound for an auditorium like Kresge with a hi-fi type loudspeaker that is designed for an ordinary living room, you're quite likely to blow its cones. So then you don't have any sound and you end up with…

Student: (unintelligible)
Oh, the amplifier blew?

Student: (unintelligible)
What kind of speakers are they?

Student: "They're Bose. They're rated for 200W a speaker."
I see. OK well, my information was a little bit off, yes?

Student: (unintelligible)
I see; OK. Well, it's what happens when you start diddling with temporary stuff. This is all I'm trying to get at. And I'd take good old Altec Lansing A-7 any day to anybody's high fidelity loudspeakers.

Student: (unintelligible)
Oh, that's great. Well, there are all sorts of things that can happen and every time you start rigging stuff up temporary, throwing in temporary stuff, you get into fantastic problems. You can't even predict what they are likely to be.

Student: "You said that Kresge wasn't designed for stereo; is that the configuration of the room, or the speakers?"
No, the speakers, it's a single-channel system. I want to say a word or two about stereo reproduction in large rooms because it's a very different animal from what you have in small rooms. When used for sound systems, it's very, very difficult to manage. But let's talk a little bit more about components and about how we put them together to make systems. We talked the other day about the three elements of the system: the microphone, the amplifier, and the loudspeakers. And I had drawn a picture of the cone and voice coil of a loudspeaker—a dynamic loudspeaker, to illustrate how this thing works with a magnetic field and the

current-carrying coil being moved back and forth in the magnetic field. When the current is sent through it, alternating current, this results in the motion of the cone, which gives us sound out of the loudspeaker.

And as I pointed out to you, you can use the loudspeaker in the reverse as a microphone as well. Now we come to the problem of baffling or enclosures of horns, or what have you for loudspeakers. Why do we need them anyhow? If we put in a perfectly decent voltage here, an alternating voltage which corresponds to the signal that's coming in, putting that on to the voice coil of the loudspeaker, then the loudspeaker moves in and out. Why do we need anything else?

Well, first of all you have probably all had an experience of listening to a bare loudspeaker without any kind of a baffle or enclosure. And you probably noticed that it's making a pretty tinny-sounding thing. No matter whether it's a 12" or 15" or 8" [diameter cone] or whatever it is. If it doesn't have any kind of an enclosure, it's very tinny sounding and the same loudspeaker put in some kind of a baffle can [make it] sound a lot better.

Why is this? It's very simple to explain it. When we have a loudspeaker cone mounted with its voice coil and magnetic field and so on here, the voice coil moves in and out, and with it, the loudspeaker moves in and out, and sends out compressions. And when it pulls back, it makes a rarefaction; and a compression and a rarefaction. Now at the same time the front side of the loudspeaker is moving forward, what's happening to the backside? It's coming along with it, isn't it, and this thing isn't doubled; it's single. So when this side creates a compression, this side creates a rarefaction—we're pulling away. We're reducing the pressure. The result is that the back-side radiation from loudspeaker and the front-side radiation from a loudspeaker (especially at low frequencies where the wave lengths are quite long) cancel each other. And as you're sitting there, it's pushing and pulling itself at the same time. And the result is no sound comes out at low frequencies and it sounds tinny; it doesn't sound very good; it doesn't have any low frequencies in it.

In order to get the low frequencies in it, what we have to do is to keep the backside radiation from getting out the front side and joining this material. And all we have to do is put up a board of some sort which we call a baffle. And the baffle, which is some kind of a large board with a round hole in the middle of it for the loudspeaker, is merely something that keeps this backside radiation from joining the front side radiation and cancelling. That's all in the world it does. Now, you hear about "infinite baffles" and you hear about "enclosures" of various sorts. An infinite baffle is the very large surface which goes off to infinity and prevents anything at all from coming around and joining the front side. Now a very nice way to achieve an infinite baffle is to put it in a box because a box tends to be that sort of a thing. It will not let the stuff come around front, and so we often have an enclosure, a box of some sort around the loudspeaker which prevents the backside radiation from cancelling out the front side radiation.

Now if you're in the jukebox business (and some people are in the jukebox business—somebody makes these things, evidently loves them), what you want out of a jukebox is lots of "*THUMP*." At least that's my interpretation and that seems to be the manufacturer's interpretation. You want a lot of good "*THUMPY"* stuff. Lots of bass. If you listen carefully to most jukeboxes, you will discover that all of the base has the same pitch. It's "*WHOMPWHOMPWHOMPWHOMPWHOMP*" or some other tone and all exactly the same pitch. And no matter what the old bass fiddler is doing on the original recording, it all comes out "*WHOMPWHOMPWHOMPWHOMPWHOMP*," but lots of "*WHOMPS*." Now what you do in a jukebox is to find the lowest natural resonance of your loudspeaker—say 40 cycles per second [Hz] will be the lowest resonance because it has a dynamic system stiffness. And with a spring in it, and so on and therefore it will have a resonant frequency.

Say 40 cps [Hz] is the resonant frequency of this loudspeaker. Then you will design this box to resonate at 40 cps so that it has this room at a resonant frequency at 40 cps [Hz]. And every time you get anywhere near 40 cycles per second for this speaker, the whole system just (screeching sound) it just goes "*WHOMP"* and gives you lots and lots of sound out in resonance. So you combine the resonance of this with the resonance of this—I think both of these resonators are at about the same point—and anything from 30 [Hz] to 50 [Hz] will come out sounding like 40 [Hz]. And so and the whole system will just resonate and put out the most gorgeous amount of energy. And the frequency response of the average jukebox looks about like this: here's 40 cycles per second and then it's like that. I think that's a 1,000 [Hz] or maybe 2,000 [Hz], it will be down 30 dB by the time we get out there. That strictly gets rid of all the record scratch and you can play the record for 10 years and it'll sound exactly the same. And lots of boom and whack at the bottom, and that's a jukebox! Now that's sort of an anti-good design principle.

On the other hand, I think that's just great for its purpose. It does give you lots of "*THUMP*." In legitimate design for home listening and other such purposes (and I'm not talking now about any of the very sophisticated loudspeaker systems in which distortion is used and filtered and the great output from small volume is achieved and so on). I'm talking about the ordinary everyday direct radiator cone loudspeaker in a box. This is by far the most efficient and the least expensive form of sound reproducing device—perhaps not having quite the super-duper overall characteristics and some of the more sophisticated ones. What you do is to design the box to have a resonant frequency significantly lower than that of the loudspeaker itself so that you don't do this double resonance business. You don't excite the box and the cone at the same time. And you might design this to have—oh, but this is a 40 cycle per second resonance, this will be a 30 cycle per second resonance.

Now what this means in actuality is that you have an 8" loudspeaker here. This is an 8" cone; its resonance will be such that a box having a volume of about 2 cubic feet has a resonance lower than that of the cone. So for an 8" loudspeaker you'd use about a 2 cubic foot minimum size box, and for a 12" loudspeaker is something in the order of 4 cubic feet, plus or minus—I just don't remember exactly. But it might even be 5 or 6 cubic feet, but it's of that order of magnitude. The shape of the box isn't at all important; it can be fitted into anywhere and there's no reason at why it has to be as small as this. This is merely the minimum volume that it can have so the resonance will not get into the resonance range of the speaker.

Student: "Where did you find this information? If I wanted to build a speaker box, say something like this, what type of book or journal would I use? They wouldn't have it in Time Saver Standards, would they?
No, I don't think it's in Time Saver. I really don't know. Do you know?

Student: "To my knowledge there is no good book on design of loudspeaker enclosures, other than, well AR recommends Leo Beranek's book because it's all they carry. Most of the books that I've seen are written about 1950-55 describe loudspeakers…."
Well, I can tell you in a nutshell all there is to it. The box for a loudspeaker: if you want to build one for home listening purposes, it should be made out of reasonably thick plywood, like ¾ inch. That's kind of what you ought to use so it doesn't rattle. It ought to be made airtight, that is, put together with glue and screws so it isn't going to rattle and jump around. You generally drill 1/4" holes somewhere in the box so that you get pressure equalization with atmospheric pressure changes so that you don't it get under

pressure changes, and so this doesn't act like a barometer and start moving against the (unintelligible). So you have a little bit of a leak just for pressure relief.

The box should have a minimum volume of the order of magnitude of what I've indicated here for the given loudspeaker size and it can be anything from a cube to a pretty flat thing. And you could even make a sphere if you got very ambitious and wanted to make spherical plywood or something. You line it with fuzz. You put in here old carpet scraps, T-shirts, anything you can find in the way of fuzz or carpet or fiber glass. If you really want to do it up very sophisticatedly, you'll go out and buy yourself some very fine fiber, fiber glass that won't shred and so on. And you put in here an inch to two inches of fuzz behind the box and put your loudspeaker in it and don't start fiddling around with a lot of bass reflex ports.

Now you will find in some Popular Mechanics type articles (at least I've seen them in past years, though this may be just indicating my age), great fashion for what's called a bass reflex opening. You cut a hole here and the purpose of this hole in the front of the loudspeaker is that some of the energy from the backside of the loudspeaker is allowed to come around through a greater path and join that which comes out the front in phase, at the certain low frequency. And what this does is to take an otherwise perhaps kind of drooping characteristic of the loudspeaker function of frequency, and it gives it one more little kick down here and it sends downwards the low frequency response of the loudspeaker output.

Now this is fine if you have the loudspeaker box in hand at a laboratory in which to fool around and adjust this hole, its size and its positions specifically to do this job.

I think unless you have such facilities—and very few of us do—it's much better to use a tight box. Now this is a private prejudice of mine. [If you have] some furniture around a good solid tight box with one little leak in it for air, then stick something on the front here so that if you have children around they won't poke pencils through the cones. I've had several ruined that way, and if kids can get into it they will. I've even devised, for a boys' school, a loudspeaker grill consisting of three layers of perforated metal offset one from the other so they couldn't get paper clips and puncture the loudspeakers. If you have very finely perforated metal, you offset three layers so you can't even get through diagonally. You can make things even school-boy proof if you work at it. Well, enough perhaps of that, but the…. question?

Student: "Just one thing, what if your speaker resonates at a frequency and the whole enclosure resonates a certain frequency?"
Well then you need a bigger enclosure.

Student: "Well is there any way to dampen it?"
No, don't start fooling around with the speaker, you'll really louse it up. There are ways, but again it's the sort of thing you can't just do by getting some Sears and Roebuck gunk and start slapping it on. You've got to know what you're doing. The main point, however, here—and I haven't even begun to talk about frequency coverage, because the basic loudspeaker like this is about an 8" [diameter] very high quality loudspeaker like an Altec 755 or something of that sort—can put out some pretty decent sound, high and low frequencies.

But if you get a larger speaker, a 12" speaker, it's quite likely that it won't put out much high frequency stuff, and you have to add another loudspeaker to the system called a "tweeter." So you have <u>woofers</u> and <u>tweeters</u>. And the tweeters "tweet," and the woofers "woof." It is descriptive terminology and we might just as well use it because it's as good as anything else. The low frequency loudspeakers are big ones; they have big enclosures and they are called woofers, and the high frequency loudspeakers put out "*PSSST*, *PSSST*," top-end perspective and they are likely to be small physically. We will talk a little bit more about them in just a minute.

Now once we get to this point, we have arrived at the maximum output that this kind of a loudspeaker could have by direct radiation to the room. We use this kind of loudspeaker in all sorts of distributed loudspeaker systems for when we have loudspeakers overhead in a room. We use it for monitoring for listening and so on. But when we get ready to put out some real high-level sound in motion picture theatre or in a sound system in a large auditorium, we cannot anymore deal simply with direct radiator loudspeakers. We have to attach a horn to the front of the loudspeaker to make it a more efficient radiator of low frequency sound. This has to do with the wave-length size. This thing is say 12" or 15", if it's a real big woofer, and we really would like it to go down to 50 or 60 cycles per second [Hz], maybe 40 Hz or so where we have very long wave lengths, 20 feet or more wave lengths. And we simply cannot radiate a 20 foot wave length very efficiently from a 1 foot source.

So what we do is enlarge the source by putting on a horn and the horn is merely something that increases the radiating area. That's precisely what it does, and it acts sort of a transformer—an impedance transformer in the acoustic impedance sense in matching this loudspeaker more efficiently to the air. And that makes it able to move more air in and out at the very low frequencies and that of course results in your hearing more. A horn is attached to a loudspeaker merely to make it more efficient as a radiator.

Now, you say: well, I've never seen any great big long horn sitting out in front of loudspeakers. No, because what we do is to <u>fold</u> them around, and a horn merely has to expand into an area so you can bend it back on itself, just as the *tuba mirabilis* in the orchestra goes around and around instead of going straight out. You'd have to have several bearers coming in with the tuba player if this were straight out. You know tuba carriers would come along with him. We don't do that; we simply fold these things back and forth on themselves. And you find, for example, the Altec Lansing theatre-type loudspeaker will have a horn (well, it's a direct horn) which is probably 3 feet long maybe (the whole box is about 3 feet) and then we take some more stuff out of the back and we fold it around underneath and behind and bring it out some extra ports. And we do a very carefully engineered job of giving us this little bit of a boost at the bottom end here with the reflex opening, and we can carry the sound down, a really efficient output, down to 40 or 50 cycles. which is what you need if you are to really reproduce the bottom end of the musical spectrum. And, of course, you need it if you're going to do movies and have battle scenes and thunder and lightning and thundering horses and all this kind of jazz if you are really going to get the people involved in the sound of things. You've got to put out lots of soup at the bottom end. So a horn on a loudspeaker is something that we use only when we're really after very high efficiency, high output in a big audience kind of a situation.

But it is not something that most of us use in our residential application. There are many horns but one of the more popular ones that was being built, back in the 40's anyhow, was the so called Klipschorn in which the corner of the room was used as the horn itself, and the loudspeaker was faced back into the corner in a labyrinthine enclosure, and the corner of the room became a horn. This also assisted mightily in the audibility of the low frequencies to whatever neighbors happen to share that corner wall with the horn.

A number of you in your field studies have written about things you've done to keep your neighbors from hearing your hi-fi and things you presented to your neighbors to help you from hearing theirs. This is a very neighborly sort of thing to do. About as big a unit as one ever sees in a private residence in sound reproduction systems would be an Altec Lansing A-7 which is sort of a 3 foot cube affair takes up quite a lot of house room and does indeed have direct radiator loudspeakers with a horn of this sort. Now at the high end of the spectrum, we find that the loudspeakers almost all get to be very directional. That is to say they like to put the sound out right straight in front. I was walking around in an office building—this happens to be in Australia but it could happen here just as well—in which a loudspeaker system had been installed for background noise purposes. Just to go "*SHSHSHSHSHSHS*" all the time to increase privacy, answering that part of the formula and I've described several of these to you. The particular loudspeakers they all use in this place, though, had a very strong directional characteristic straight down below the speaker above about 5,000 or 6,000 cycles per second [Hz].

And the result was that as you walked along you'd hear this kind of general "*SHSHSHSSHSH"* like that. And every time you got under of these things, you'd go (*whistling noise*) right on top of you, you know. Really zinging down at you, but it just was about a foot [area], and you were acutely aware then not of the nice general continuum of "sh" sort of noise but (whistling noise) every time you walked along under one of these things. A very, very poor choice of a loudspeaker.

Well, I checked up and found out that they were extremely cheap and they'd gotten them for $1 apiece from Japan or someplace, and they were worth just about that. A really good loudspeaker, direct radiator, 8" type will cost $20 or more. They are reasonably expensive, though not out of the question and can have excellent dispersion characteristics. Now when we go back to these large boxes that we have, the big loudspeakers for big halls, we divide the energy that we feed to the loudspeaker with a so-called *dividing network.* And we feed everything below about 300 cycles per second [Hz] to the low frequency woofer loudspeakers, and everything above 300 cycles (which is called the crossover frequency) to the tweeters.

Now tweeters in these large systems are always horns also, and they are horned for directional characteristic reasons. The usual tweeter will have (these are shown in that Time Saver Standards section; there are pictures of a lot of these things). A tweeter will have a so-called driver which has a cone, a loudspeaker (usually it's Bakelite); its voice coil is equal in diameter to the cone size. It's a very small cone to permit lots of motion at high frequencies. And this has been coupled onto a throat of some sort and you have a very long horn, which looks sort of like this. And it will be divided into a number of segments, each of which will send out a beam of sound about 20 degrees tall and wide to a different sector of the audience. Because one of the things we have do for the loudspeaker system is to give uniform coverage. We don't want anybody getting only the "*pst*" part and other people not getting that because you need it <u>all</u> for articulation. The parts of these things, as you see in the reprints, have a number of openings like this. Each of these is one of these cells. Yes, Ma'am.

Student: *(unintelligible)*
It's homogenous all right but if it gets into a horn like this, just a straight horn, it'll find itself getting beamed again. And what we have to do is to prevent any addictive or subtractive efforts of the total air stream acting as one, and break it up into separate ones. And in these separate compartments, what happens here doesn't influence what happens here. But if they are all together, they would. So we get a better sort of a distribution [by having separate cells].

Now there are various and sundry ways of doing this. This is one way—the so called <u>multi-cell</u> horn. This thing is about 3 feet long, is the order of 16 to 18 inches high at the front end. These horns are very heavy, and they are made of metal filled with puttying compound, the tar-ry stuff that you use for puttying transformers.

So they are very dead, very non-resonant and very heavy. They are not easy things to flip around. But when you are laying out a loudspeaker system in a hall—let me just show you the sort of thing you do. Say we had an auditorium with that much ceiling, and say a balcony, and here is our proscenium opening and first of all we have selected the only location for a loudspeaker system in a large hall, mainly right smack above the center of the proscenium. It cannot go to the full size of the proscenium (even for Philip Johnson) and work. You can put them there, but it doesn't work; that's the only problem. So we have a loudspeaker system, we've found the location where it's up, up here 30 feet maximum height at this point and here is our loudspeaker system. Now we probably will design it with some tweeters here. We design one set of tweeters that covers perhaps the front half of the room. And we'll have another set of tweeters here, another set of horns that will perhaps cover the back part of the room. And this tweeter will be operated at a slightly higher level [volume] than this tweeter because this is closer to these people and these people being father away get a little bit more soup. And so we can achieve remarkable uniformity of coverage in an auditorium by tailoring these horns to give just the right coverage pattern.

In fact, in our office when we design the sound system, we have a little light machine. We make a model at ¼ inch to the foot or something, sort cardboard model, in a dark room. And then you have a little flashlight bulb kind of a thing and little templates that give us the coverage patterns for various kinds of loudspeakers. And we actually aim the template and aim the whole machine to give us coverage of certain areas, and draw it out. And so we know what kind of a loudspeaker will give us that coverage. And then we go to the next one and we cover the whole room that way.

And we find out that we can design a whole array of these horns in a sort of a fan arrangement vertically and horizontally and get uniform coverage. And when you do this carefully and install it carefully, you actually will find variations in the higher frequency of less than 3 or 4 dB throughout the seating area. This is very, very fine and very, very uniform. So we place our high frequency units very carefully to give us precisely the coverage we want, and then we stick a woofer up on top and just let it woof, generally, sort of facing it toward the audience. But there's no problem at all in getting very uniform coverage from the low frequency loudspeaker. You don't have to have but one for the whole room, whereas above 300 or 400 cycles per second [Hz], with the tweeters, we have to have very careful orientation to give us just the right kind of coverage.

So every sound reinforcement system in a large hall has to be designed for that space. One interesting way of checking a sound system coverage, if you really want to, is to do it optically—if the thing is way off and you can't figure out what's wrong. You take the driver off the back of this thing and shine a flashlight down the throat. And then you sit out there in the house and every seat in the house should be able to see the flashlight at some point as it's oriented around through one of these horns. And you can very quickly line things up with a flashlight if there's anything wrong with the basic orientation. Contractors get pretty good at placing these things and orienting them, but they really have to be done very, very carefully if you are going to get the kind of room quality coverage you want.

This is a big thing. I've said this about a dozen times. It's the order of 4 feet in this direction and maybe 8 feet to 9 feet high and as wide. It's a big chunk of stuff and it has to be right up there in the middle, in the front of the hall above the proscenium opening. Yes?

Student: “You’ve been talking about having it in the middle all semester, but I’ve been trying to explain this to someone over the weekend and I have no idea why.”
O.K. Maybe I haven't ever told you. Let me see if I can explain this.

Student: “This has to do with why everything is in the middle, which is fine for sound reinforcement for whatever the hall is used for. But what about a movie theater where sound…”
O.K. That's a different matter. I'm talking now about sound reinforcement of live stuff. This is a very poor place to have the loudspeaker for movie sounds anyhow unless this is a very incidental use of it. The loudspeakers for movie sounds should always be behind the screens for maximum realism.

Now to answer your question: why in the middle? This has to do with realism. Each of us with our two ears, I think I have said this, have very strong sense of localization, laterally, left and right. Not up and down, unless you pop your head sideways and then you'll hear up and down. But it's in the lateral plane that goes in between our ears, which for most of us it's horizontal. And you and I and everybody else has this facility for saying the sound is there, there or there. Even blindfolded, you can tell where it is. Now if I'm going to amplify sound, the sound should appear to come from the source.

It's a live source, I'm talking about now. And this is why I say if you have movie sounds, the sound ought to come from behind the screen where the picture is at. This portrays realism. Now if I were going to amplify my voice in this room and wanted to give you no sense whatever of amplified sound, I would put the loudspeaker up here in the middle; and you say O.K., why? Well, it’s so the loudspeaker sounds will appear to come from me because it's neither left of me nor right of me. Then you say, well, but you are going to move around and are you going to move the loudspeaker with you? Well, that's silly, of course. No, we don't move the loudspeaker around, but if you've checked on me or anyone else in a room like this, the greatest probability' is that he performs in the middle of the stage. You'll find exactly this happening; most of the talking is near the middle of the stage. Now, a little bit off to the left or right doesn't matter.

Now what's so horrible—we heard a minute ago about the phasing of these loudspeakers over at Kresge—what’s so horrible is to have…. Let's presume the phasing is proper, loudspeakers on either side of the proscenium. Then you sit out here, here is the performer and there's a source over there and a source over here. And there's no realism whatever to it. It doesn't seem at all to be coming from him, it seems to be coming from the two sides. Now you will read garbage (absolute trash in articles and so on!) that tell you that there's a real center and that you don't hear from the two side. That's just not so. You do, and all you've got to do, if you are sitting along the middle of the hall, is to wiggle your head back and forth and you can make the source jump from one side to the other. And this is great sport if it's a dull performance. Or if you're outdoors, what’s really horrible is to be outdoors at some kind of a presentation.

I remember the dedication of the General Motors Technical Center in which they had great big battleship bullet proof, waterproof squawkers “*YAKYAKAYK”* that kind of quality, grade “C,” that they were bullet proof and weatherproof, that's very important. And they were mounted outside 200 feet apart. And then we all sat in open grandstands and all the big muckety-mucks were down in the front here in the middle, and there was quite a breeze. And as the breeze went back and forth and it carried the sound from one side to the other like a regular ballet. It was great fun to hear the voices shift from left to right and you got saying: I don't remember anything ever said. It was so fascinating just to hear the voices jump and I just paid attention to the acoustics. But does that help you to see what the reasons are.

Student: “What about hi-fi stereo systems, is that because the stereo track…”
Now a stereo is an entirely different matter. In a hi-fi stereo, if you send the same signal to both loudspeakers (not the split signals such as you get regular stereo sound), you will not get anything like the effect that you get when you feed different kinds of signals to the two speakers which gives you this sense of being surrounded and simulating, somewhat the way real sound comes to you in rooms.

Student: “When you have two speakers, don’t you get the nodal points and reinforcement?”
Yes, you do; you get cancellations and reinforcement just as we experienced here in this room with standing waves. And this is another argument against the split system. But the main thing is that it gives us realism, and the only way we can get realism, really real realism, is this central loudspeaker. Now, there are plenty of cases (and we're designing loudspeaker systems all the time) that don't use central loudspeaker locations simply because you can't have it. For example, we are doing one right now in the Duke University Chapel. It's a rather handsome bogus Gothic building, rather well done, and it has a loudspeaker hanging up in the middle of the crossing in this big Gothic kind of space. Well, even I wouldn't want to propose it, even to an acoustics man; I would think that would be rather desecrating to the place, and so we are resorting to other means. But we're going to give them grade A sound anyhow, because I feel people come to expect it.

Well, this business of the central overhead location has been a hang-up for many, many designers of auditoria some of whom, like Philip Johnson, simply say: I won't have it. Because it happens that Philip, in the State theatre in New York, had a proscenium which was some 40 odd feet high, and he said he could not have anything like that desecrating the gorgeous proscenium. Now he doesn't use it; it's just a curtain, an opening, it's a thing, it's a harkening back to the classical opera house. You say, why didn't they have them in the classical opera houses, the Italian opera houses? Because they were little opera houses, they were 1,200 seats and smaller, and you don't use amplification in that kind of a situation. It's when we go to these enlargements that we make today, seating 3,000 and 4,000 people, that we really have to resort to something other to get the human sounds loud enough for people to hear, because people are the same size. And just because you put them in a 4,000 seat hall, they (i.e.,, the performers) don't suddenly put out 4 or 5 times as many watts or as much sound.

Student: “Should a speaker system utilize those reflecting panels, or should they….”
No, a loudspeaker system never utilizes any reflection. We do it entirely by one zing.

Student: “OK, so you put them above…”.”
No, you can't have them above because then that will cut off line-of-sight. So what you have to do if you have some panels, is you can have the low frequency loudspeaker above (because that's a 3’ and 4’ and 10’ wave lengths and that stuff will bomb right out of anywhere). Put it in a closet back there with [stuff all around]. But it really ought to be right next to these, it helps a lot in realism. And they can be above the panels. But these things [the high frequency horns] have to hang down below and they cannot be masked with anything that cuts off high frequency sound. Anything much more dense than the fingers in my hand here, is too dense for a screen for these things.

There is a screen around the loudspeakers that hang in the middle of the TWA Terminal at Idlewild Airport, New York [now JFK Airport]. It’s a screen made of ½” steel bars bent, it’s a cluster of horns, it’s a completely circular cluster and these things come up sort of like a fruit basket of ½” steel bars, a couple of inches apart. But it's a wide open thing because we don't impede in any way the transmission of sound from this. Many, many installations today would simply paint these things black and let them hang up there and you can see them. They don’t look so bad; in fact, they look quite good. We've got quite accustomed to seeing lighting instruments.

I think it’s time we perhaps got used to the idea that maybe a sound instrument is legal and valid and not an immoral thing to show in the hall. But they do take space, they are big and you can't just hope to hell it will go away and why doesn't somebody invent a little one? I don't know when it's going to happen. The amount of power that it would take to drive a small loudspeaker unit that would be like the home hi-fi things would be made out of stainless steel and be quite able to handle a megawatt or two of power. The power to drive these things would just be fantastic and we'd find that we must resort to these rather efficient direct radiant type units.

These units are used not only in large auditoria like this. They are behind every motion picture screen in the land; you go behind the motion picture screen in any first class movie house you'll find loudspeakers exactly like this, and we use the same equipment in the sound amplification. We use them in arenas, in sports buildings, and all sorts of situations where we have to cover a large crowd of people with a lot of sound.

Now once in a while we get into the situation where we have a deep under-balcony. One of the first times we ever did this was remodeling the Reynolds High School Auditorium in Winston-Salem, North Carolina. Maybe some of you know that building. It was put up by the Reynolds Tobacco money and done in the 30's, the early thirties, at which time acoustical materials had begun to come into their own. And you'll find great quantities of sound absorbing materials were used in all sorts of places to line things like the Duke University Chapel, which is lined entirely in an artificial sound absorbing stone. And right at this minute we've got that whole place scaffolded and we are filling it all up [filling in the pores of the artificial stone] with real gunky paint to stuff all the holes so that it will begin to behave like limestone and we can make it sound like a cathedral rather than a boudoir.

Now this Reynolds Auditorium had been treated with a stretch cloth in panels, stretched cloth over mineral wool, and it looked exactly like plaster. It was the best damn fake plaster I've ever seen and it just soaked up sound like mad, the whole ceiling. That room didn't have any kind of acoustical characteristics. It just was dead and had no characteristics at all. So we got rid of all that plaster on the ceiling. But they had something that they couldn't get rid of, mainly a very deep under balcony. And these poor souls back here just get a little bit of original sound from here, but they are out of line-of-sight for the loudspeaker system and they had to struggle for years with loudspeaker systems that were too wide so they could squirt sound back underneath here. You know, just send some back there like with a hose. But we said that won't work. We'll have to put it up here. Then what we will we do? What we do then is to resort to a trick, we fooled these people. We give them loudspeakers. We had two lines of loudspeakers, direct radiator cones, mounted in the ceiling. But now if we just hook these on the beams and what this guy gets is “*KLUNK, KLUNK*,” then “*KLUNK*,” and then “*KLUNK*,” maybe “*KLUNK”* and then maybe the original sound which sounded like an echo of itself.

So it's all ass backwards. It's just a terrible thing. So we <u>delay</u> the sound. We put in time delay and we don't let anything come out of this loudspeaker [under the balcony] until the original sound (and what little of that there is), comes from here, and has reached this side. And all of sudden, right after this comes by, "*BLIIIIIP,"* down comes the signal from here, and then the sound goes on back here, and "*BLIIIIP"* down it comes from here. Now these delays will be of the order of milliseconds. But a time delay of this sort is accomplished with a tape loop that runs around and round and round, and we simply record and play back the continuously.

One time we did a time delay system in a Bunny Club [Playboy Club]. We do sound systems for all sorts of places, and this is the Bunny Club near Madison on Lake Geneva, Wisconsin. This is a very posh bunny club. They had an interesting problem. They had a rather low ceiling space, and here is the band up here performing away and there's about an eight foot ceiling, you know. And we were way back here, and here sit all the customers in some little raised sections and so on but we won't worry about that. But there were people all through here, and the band itself made quite a lot racket. And it was desired not to have the usual 'Grade "C" sound in which you have loudspeakers all over the ceiling putting out sound from the front and you hear this one first and then this one and then finally there's this echo, which is the band.

They wanted something more sophisticated, and so we said well, what you need is time-delay and a tape loop. Well, we don't have nobody around here to tend no tape loops, man. What can we do that is all the more automatic? So we gave him a pipe; a pipe is another solution. We'll literally take a 2" conduit, regular electrical conduit. And you pick up the sounds in here and you blast it out of a loudspeaker here from the immediate foreground and then you take some of this energy and you feed it into the loudspeaker and into the pipe. And you've got your pipe back here in the back of the room over the ceiling, and then you pick it up over the microphone here and send to another amplifier and into this loudspeaker. Why, not, I mean just carry it overhead through the pipe.

Now there are a lot of tricks to this. It will kind of come out kind of pipe-y sounding (laughter) And there has to be a long skinny fiber glass termination in here so you don't get any whoomp, whomp reflections and echoes from the end of the pipe; you just hold it all there if you can, swallow it up in fuzz. And then you have to compensate for the frequency characteristics of the pipe, but you can have a pipe that's exactly the same length as your house and you can feed out at any point here in pick-ups with amplifiers. And that's exactly what we did. Now this is always there working, you don't have to rewind tapes or tend to any machinery; just turn on the system and set it at seven and off we go for the evening show.

Student: "But the sound is still traveling at the same speed as the sound in the room so…"
Yeah, that's the idea. We want this sound to come out of this loudspeaker, not instantly as it would if we hooked the loudspeaker into the microphone system. Then it would come out here first and then you'd get the other stuff. Wait, you have a microphone here and then we feed into another amplifier a loudspeaker. You'll say, gee, that's a lot of equipment, isn't it? Yeah, yeah, but you know this isn't a charitable undertaking Bunny Club. What they wanted was something rugged and that one of the bunnies could set it at 7 in the evening, and then nobody would have to fool around with it. You can't have a man here running this thing all the time, just let it be automatic. Well, it worked beautifully.

Student: "If it is continuous loop, why does it have to be rewound?"
No, you have to replace it quite often, they wear out. They run at rather high speed. Sometimes it's 90 inches instead of 15. They really zoom around. And once in a while somebody does a bad splice, so the customers here under the balcony you get "*WHOOMP, WHOOMP, WHOOMP, WHOOMP, WHOOMP, WHOOMP*," in addition to the program. You have to do very beautiful splices that are non-whoopers, and it's tricky. Telefunken used to make a very fine rotating magnetic disc that the heads didn't quite touch and

it lasted a very long time and had no splice problem. But they never sold very many so they quit making them. Now nobody makes proper discs. This was in the 50's that they were making it. Phillips makes a very good tape unit. There's an outfit in this country that makes a very lousy tape unit and we keep working on this. Now, there are now some very sophisticated computer arrangements that I think will accomplish this but at present we can do time delay with a tape loop delayed machine for about $2,000 and the more sophisticated computerized gizmo must run around $10,000. And this difference between $2,000 and $10,000 is this bit of a stumbling block for a lot of people, and so we haven't used any yet.

Anymore field studies I'll be glad to have them and we'll proceed and try to finish this up on Wednesday.

End of Audio File 27

THE END

Robert Bradford Newman Lectures

16 December 1970
LECTURE 28

Title: "Loudspeaker Placement"

Summary: In this lecture, Newman talks about the placement of loudspeakers and discusses some examples from his experience.

Beginning of Audio File 28

Grade sheets have to be turned in and I have to turn them in on Tuesday morning of next week. So we haven't much leeway; I'll really have to have your field studies on schedule on Friday. Certainly in an extreme emergency, if you can get them to me Monday, but I will not be down here at the Institute Monday so you will have to get them to my office. It will be just a lot easier if you'll write up something and get it in on Friday.

Now if you are unable…. I mean, the field studies as I've been saying all through the term are the most important part of your turned in work and if they aren't in, I'll simply have to give an incomplete and then turn in the grade when the field study comes in. I have really no options but to do that. Some of you asked about Quiz 3 which I said will be an optional quiz, if any of you want to take it. We have decided that at the end of class on Friday, which will be our last class, I will hand out to anyone who wants it, a one-hour quiz which he can take off to his room or studio space and do some time on Friday and turn it in to Terry during the day. We'll work out the turn in place. Anyone who wants to do that is welcome to do so. It obviously can be on anything that we have done during the term.

Also, I think you know me well enough to know that I'm not going to get out a lot of little tiddley-winks problems on transmission loss. We've done that. So it will be a non-tiddley-winks one hour quiz. One other thing, a number of people have asked about the course that follows this one. It is listed in the catalogue and will be given in the spring term. It's called: Special Problems in Acoustics; 4.431 I believe is the number. We generally try to keep the class down to 10 or a dozen at most because it is a seminar type course, and we will do a lot of acoustic measurements, learning to use instruments and make measurements and sort of sharpen up some of the things that we've talked about here in this class in a more general way. Any of you who are seriously interested in following through with more detailed work in any particular area we work in—almost anything anybody wants to work at –certainly may sign up for that. I think a few of you have signed up for the Environmental Controls course that John Reynolds is offering in January, and I'm going to do one day of that course just before I leave for Singapore.

Student: "Is that a vacation or a job?"
A job, man. (laughter) You think I'm made of money. (laughter) But during that day, I will have to be as clever as a tight-rope walker to avoid going over things that we've already done here. Some of the people have had the course before, and some of them are virgins, who have had none of this, and so it's going to be difficult but I'll try to do something interesting. And for part of that we will go out and spend the afternoon in our labs and do some demonstrations and things that you haven't been able to do here. So you suit yourselves. If any of you are interested in 4,431, well, talk to me about it and sign up and we'll begin meeting in February. When do classes start in February, does anybody know? The 3rd is registration. I think that's the day I'm lecturing at Utah.

Student: *"On your way back from Singapore? Mmmmhum…After a stopover in Honolulu? Guam?"*
Oh, no, I'm not getting back until the 9th, Salt Lake City on the 9th. Well, we'll begin classes when I get back, the hell with it.

Yes?

Student: *"Are there any anechoic chambers on campus?"*
There is an anechoic chamber in what was formally the acoustics lab. It's at the corner of Vassar and Main Streets, right across from the garage, the parking garage there at the driveway entering the Institute. And it's in an old building that looks like it was a garage once upon a time. And there is an anechoic chamber in there. Now I'm not sure who's doing what with it at the moment, but there is one there.

Student: *"[Is there one at your office?]"*
We have one at our office and I'm going to take the John Reynolds' crowd in and decompress them, make them very uncomfortable.

Student: *"[Any others?]*
There's a couple of others over in the bio-physics lab that they use for running tests."
Oh, that's right, there are. I had forgotten about those. They've been buried over there for so many years; that's in Building 20, isn't it, some of that complex there.

Student: *"Aren't there some in the psychoacoustics program?"*
That's right, the "cat's ears" lab. And there is an anechoic chamber at Harvard which is about to be dismantled, unfortunately. Acoustics is a funny kind of field; it's not at all popular anywhere. And Harvard is kind of giving up acoustics because the professor, Professor Frederick Hunt, having taught acoustics for years in the physics department, is retiring. And nobody else gives a damn. Hunt is responsible for the whole gang of loudspeaker geniuses that have turned out the AR speakers and all that kind of jazz, and for years and years they did research on loudspeakers and so on. They are at Harvard and had a very large anechoic chamber. Actually, the anechoic chamber was built during World War II, in 1943. They are going to tear it down.

It's a 40 foot cube of one foot concrete lined with 4 foot wedges of fiberglass all over. Stalactites, stalagmites and whatever the things that stick out from the side like stalactites might be. We don't have them in nature. And it's a very fine anechoic chamber but there is no use for it and they want the space for something else, and it's a funny building because it's a 40 foot concrete cube and it was intended originally to be in the corner of another building. It would have been built extending the Gordon McKay Laboratory along Oxford St. It's on Oxford St. right across from the Peabody Museum, just beyond Pearce. And it's this funny looking concrete cube with a silly little pitched roof on it.—a temporary pitched roof that was put on in 1943, tar paper and so with little wood gables and that was to be taken off and then the concrete would be part of the rest of the building.

Things change, and they are going to knock it down. Anechoic chambers are very interesting to go into, just for the feel of them. But we'll certainly do that one and the one that we have at our lab. It's a very small one but gives you certainly all the effect.

Let me just repeat for those of you who have come in late. Friday after at the end of class we'll hand out quiz 3 for any people who want to take it. It's an optional quiz and you can take it away and take it wherever you like, when you like. And I have to have all of the field studies in this week because we have to turn the grades in on Tuesday morning. We haven't any option but to give incompletes if they're not. Excuse all the dishwashing but it's part of the game, I guess. I'd like to sort of wind up about sound systems today so Friday we can have a general wind-up. Before I do this, are there any areas of acoustics that I haven't touched upon that some of you are interested in. This has been somewhat abbreviated term. I've had to skip over a few things.

Student: "Are you going to talk about stereo sound systems?"
I will talk about stereo sound systems, I'll try to do that today as part of sound systems. Yes?

Student: "How do you measure reverberation time in a hall?"
How to measure reverberation time in a hall? Let me put that down to discuss on Friday. It's a difficult operation but one that certainly you can do if you just have instruments to do it. But I'll tell you about that, let's see, I'll just make a note here, RT [reverberation time] measurements.

Also I'd like to talk a little bit on Friday about models and the usefulness of models in acoustical studies, acoustical models. Anything else, yes?

Student: "The formulas that you gave us, how accurate are they?"
All of the formulas that I gave you are extremely accurate if, if, if, if…. O.K. In other words, if you know the absorption coefficients very accurately for materials in a room and if the room has a fairly uniform distribution of absorption throughout its perimeter, then $T = .05V/A$; it's very precise. If you don't, then it's precise only to the limit that you know other things about the room, the volume precisely, the absorption coefficients of material. Now in actual practice, if you can calculate the reverberation time of the room to within 10%, you feel you've done very well, very lucky. If you can predict the transmission of sound between rooms within 3 dB, you can consider yourself very lucky. Because again, we simply don't know our constants well enough—the formula, there's nothing wrong with the formula. It's our knowledge of the physical facts of the situation that limit the accuracy. Acoustics is not a precise area of activity; we're happy to be within 10%, we are happy to be within 3 dB, and 3 dB you know is a two to one power ratio. So if we get within 2 to 1 of the right answer we are just elated. Now, there are things that one can do such as the calibration of microphones and detailed precise laboratory measurements that can be done with great precision, to within 1/10 dB or so. But ordinary building acoustics is not that precise. The formulas are good; we just don't know all the numbers to stick into them. Does that answer your question?

Well, let's see if we can't wind up with loudspeakers and then we'll have a general hash of stuff on Friday. I talked about time-delay—the use of time-delay in loudspeaker systems—the other day. Time-delay we sometimes use even when we are going to do a sort of a central system or a modified central system without distributed loudspeakers.

I described to you the other day the microphone arrangement that we used in the tent theatre on the Charles River several years ago, the Carl Koch inflated-nylon-lens sort of tent theatre. I described the microphone array in which we had the ten microphones, remember, suspended above the stage in two rows 10 feet apart, 10 feet high. Here's the stage and here's the audience all around here, 2,000 people in a tent with lots of background noise from aircraft, from traffic, from motorboats, from everything around. It's in the city and it has all those problems.

And back here sitting in the middle of the house—and this is a very important point: taking up six prime seats—is the control console with a guy who's being paid to sit there and run this thing. He's not a paying customer, he's being paid, and he's using up six good sellable seats. And he's right here in the middle of the audience where he has to be if he's going to run this show. You could, conceivably, drive an automobile lying on the floor in the backseat with dutiful numbers of interconnections and mirrors and things and it probably could be done. It's a hell of a lot easier if you sit in the front seat and look out the window, and it's exactly the same idea with running a sound system. The guy who's running a sound system should hear the sound that he is running. He ought to be in the audience in the coverage pattern of the loudspeakers and in a position where he could see what's happening and hear what's happening. So he has this little dummy console in front of him with 10 knobs on it just like these; I described that the other day.

Now then, what do we do for a loudspeaker position? There is no such thing as a proscenium in a tent theatre because everything is hung up here on wires, and we had a few wired cables running across here with lighting instruments and so on mounted on them and a few cables running back here. And so we said: let's take advantage of the cables that we've got, the points where can hang loudspeakers and do a slightly different kind of a system. This is the one we cooked up for this occasion and it worked, worked beautifully. We had five sets of column loudspeakers (now I'll describe a column loudspeaker to you in a minute). A column loudspeaker is a loudspeaker which has a whole raft of loudspeakers hooked up in a vertical array. I'm sure you've seen them: this is the section through it and so on and in elevation it looks like this. These are direct radiator cone loudspeakers, all stacked up in stacks.

Now what's the advantage of a column loudspeaker? A column loudspeaker, because all these loudspeakers operate in phase, has the property of being in phase only directly in front of the loudspeaker and at all angles <u>off</u> from directly in front, you get phase cancellation. Because if you stand off here and look at this loudspeaker, this sound comes in first, this one next, this one next, this one next, this one next and they are all out of phase and they tend to cancel each other out. But right smack in front of the unit they all go together, "*WHOMP, WHOMP, WHOMP, WHOMP"* and they add up. And the result is that a column loudspeaker sends out a very strong beam of sound directly out of the middle across the axis of the speaker.

I have seen architects who didn't like the look of a vertical column loudspeaker, turn the thing sideways in auditorium, and put it across the proscenium opening. Now what does that do? That sends a "zing" of sound right down the middle of the room and nobody else gets anything. But architecturally, it's easier to solve than standing the damn thing up, which would lay out a flat disc of sound across the audience. The latter is a very desirable kind of thing to do. If you want to conserve your energy, then don't waste it in the sky or in the ground; instead, direct it right at the ears of the people, and you use a column loudspeaker and it puts out a flat disc across the vertical axis. Remember that it's a flat disc of sound by virtue of the fact that the speakers are omni-directional and in the horizontal position it's a random business, but in the vertical position they add up in phase only right in front. Now you see column loudspeakers used in all kinds of asinine situations (that means jack-ass-like) situations. They are used to cure anything just as aspirin is good for anything, just take an aspirin and you'll get well.

And a column loudspeaker is kind of an “aspirin cure” that every local punk hi-fi dealer in Nebraska or anyplace else will have some of, and will gladly rent to you for your event and a column loudspeaker is just bound to be good. Well, they are good in some cases but they are not magic. In any case, we had five specially designed column loudspeakers, there, there, there, there. And, of course, again the director said I don't like the looks of those things. We said if you want sound you are going to have them, buddy, and so O.K.

Now you say: well that's kind of a kooky arrangement, wouldn't you get into trouble when you are seated between these. You talked the other day about the problems of phasing of two loudspeakers at each side of the proscenium. Yes, you might get in trouble. But we decided to be just a little bit more sophisticated this time and so we put these loudspeakers on a time-delay and the thing that happens is this. Here stands the actor talking out in this direction. And you sit back here somewhere and the first thing we let arrive at your ears is the sound of the actor's voice. He comes out here (bing) and then within about 30 milliseconds, (we let it wait awhile), 30 milliseconds later we then present you with an amplified signal from several loudspeakers. The first sound that you get always gives you the cue as to where is the source. That tells you the direction. Your ears localize on that even if it's just a little smidgen of sound, you'll still localize on the actor himself. Then the time-delay stuff comes out and merely adds to the loudness. It's a 30 millisecond delay like a reflection from a ceiling, exactly as in a room. It behaves exactly the same way, there's nothing very magic in that. Well, the result was absolutely incredible, I must say the only way you could tell that sound system was on was to turn it off. Then you couldn't hear anymore.

Now we had a master gain control here so that when airplanes came over the guy didn't have to start fiddling with all the mikes that were on; he just ran the master gain control up and just rode up over the airplane noise and then down again as the airplane went away. And when the airplane was flying over, you could begin to hear that it was a sound system operating, but in normal just traffic going by and boats bumping up and down the river and so on, you couldn't even tell the sound system was operating. Had we not had time-delay in the system, you would have been acutely aware of sound system operation. It's a very useful device to use once in awhile even though it costs money.

A time-delay system, at present—as I said the other day—adds about $2,500 to $3,000 to the cost of a sound system. This sound system with microphones, high quality condenser microphones, specially built column loudspeakers, time-delay controls—everything—costs about $11,000 and today it would probably be $15,000 or $20,000. But good sound systems are not cheap. On the other hand, they are small in comparison with other costs of performing arts facilities of this sort. The ordinary distributed loudspeaker system, the kind of cheapy system that we might use if we simply couldn't afford to have a really first class central system, we would probably not use time-delay. Now where do we use distributed systems rather than central systems?

We use them whenever the geometry doesn't permit the use of a central system; for example, in the usual church basement, which I've drawn before. This is a section of the church basement “Type A,” seen throughout the world. It has an 8 foot high ceiling and is generally 100 feet long and 60 feet wide or whatever size you happen to have. And they are going to have plays and church suppers, those horrible things, and other events. And there is always a speaker afterwards and the dishes are washed back here creating a huge amount of noise. And these people are not going to get very much anyhow, but these up here will often get something and usually the ceiling is covered with acoustic tile. This controls the noise of the little ones when they are using it for Sunday School purposes. And very often we put in loudspeaker systems in rooms like this.

Now it's absolutely hopeless to try to do this from a central system up here. First of all, you would have to blast a real Lucas-type beam out of this thing right down the house to get back to these people [at the rear]; and it would just blast the hell out of these people in the front. In general, we try to keep the “throw ratio” no greater than about 3 to 1 for a loudspeaker central cluster. In other words, if we can get up about 30 feet, we can zing back about 100 feet, and that's about as far as we should try to do from a 30 foot high location. And this is simply because the ratio gets to be so great for distances that we have to blast the front people in order to get to the back of the room. So in order to do this, we put in a distributed system of loudspeakers and a good rule of thumb to remember (this isn't precise but it's pretty good and certainly much better than just guessing) is that the on-center spacing of the loudspeakers ought to be about equal to the ceiling height. If this be H, then this should be approximately H. If this is an 8 foot ceiling, then you have loudspeakers on about 8 foot centers.

Now if you say, oh, my ceiling pattern works out better with 9 foot on centers, or 7 foot on centers, go ahead. But don't make them 16 foot on centers and expect not to have a lot of pretty dead areas in-between. If this is an airport terminal, if this is one of the fingers (you know, corridors going out towards the loading dock), how many times have you heard these cartoons of loudspeakers that appear in most airports. Cartoons of loudspeaker systems in which there is a little squawk-box loudspeaker sitting in an aluminum case with perforated metal on both sides facing in one direction and counting on the fact that the backside also radiates and these occur about every 40 feet down a reverberant tube. And what you get is (*roaring sound*) (laughter) You can't even tell what language they're speaking.

We’re about do some work at the new airport in Caracas and I wrote them, in our proposal, that in the present airport I could not understand the announcements—in either Spanish or English. The point is it doesn't matter what language you're speaking; the system has got to be good. Now this kind of an arrangement is hopeless: it's economical; it's cheap; and it’s no good, all combined in one. You must have loudspeakers overhead and they must be on centers no greater than the ceiling height if you're going to get uniform distribution. It's exactly like down-lighting; you just think about it as an analogue to down-lighting.

Student: “When you’re in the middle, you’re getting stuff that’s reflected around so much that it’s all muddled?”
Yes, if you're walking along here, and this thing is squawking at you, and here is another one down here and it’s squawking at you. You are just hopeless. And if it's reverberant—even if it's not reverberant, it's hopeless—but it's even more hopeless if the space is reverberant. You must get sound in a good distributed system only from one loudspeaker. Just one loudspeaker at a time.

Student: (inaudible)
Yes. It's important in any space in which speech articulation has to be good. It ought to be “dead” [short reverberation time]. Eero Saarinen resisted, fought and bled and fought and argued right up to the last minute on the TWA Terminal at JFK Airport: “Do we have to spray all our lovely concrete with asbestos? Must we? Couldn't we maybe this time just have a special exemption from God and we wouldn't have to have it? Cut out all this physics foolishness and physical laws and just let's not have it because concrete is so beautiful?”

Must we cover it up with sprayed asbestos? The answer is yes. Now it was much more critical in the TWA Terminal because we couldn't find places to put the distributed loudspeakers and we had to hang in a central cluster. (I mentioned the other day it is above the little bridge in the middle of the space.) All announcements come from that central cluster and if that space had been reverberant—with a concrete floor, concrete ceiling and terrazzo floor or tile floor or whatever it is, and with glass walls—it would have been an absolutely hopeless mess. It just simply wouldn't work. Now, if the space is highly reverberant for some reason, a distributed system of loudspeakers is much more likely to be successful than a big central squawker.

Student: "That's essentially because you don't have to operate it at as high a level?"
You don't stir up the room. That's right. You don't engage the room's reverberation. Dulles Airport has one of the best sound systems of any airport in this country; it is fantastically good. It's unfortunate that more of us don't have a chance to hear it because Dulles doesn't get used very much. But in addition to having a very large number of small loudspeakers, sort of a personal kind of a sound system for each person almost, it has an automatic volume control on the system that is governed by a microphone out in the public space that tells the system how loud the ambient noise is and how loud should the system be in order to override it; and so the volume is changed up and down depending on the ambient noise in the waiting room.

Student: "Is that what you call the gain system?"
It's an automatic gain adjustment system. Yes, it's a very, very good and expensive and sophisticated sort of thing.

The main problem with distributed systems that we find—the unsophisticated type and I'm sure you've seen this—is the kind where you put loudspeakers along the wall of the room facing across the room, crossfire type. I've seen them in churches, particularly the old Victorian square churches where you line people up on the diagonal church, you know. And they'll have a loudspeaker in the back corner, and that corner, in that corner and this corner. Four of them in each corner and that's all. And they all speak simultaneously. And it's just incredible how you can improve speech articulation in a church like that with cutter pliers. (laughter) I've used them. That's the end of it.

I went one time, I was in New York, they were having a choir problem, I think it was the Madison Avenue Presbyterian Church. I can't remember exactly what breed of cats they were, but it was one of those big, old Victorian barn type churches with a great gallery all around the three sides, and a kind of a flat floor and deep under balcony spaces. And then the preacher stood in the middle up front (a fellow named Bonner was the preacher then). They had a choir problem, Robert Baker was the organist and the choir stretched out in two rows about 60 feet wide, and the end guys couldn't hear what was going on at the other end. And you know—a big surprise!

I said: well, let's bunch them together and that was the consultation, bunch them together and then we worked out how we would carry on with this bunch. But if you get them in four rows instead of two rows, and then they'll be only 30 feet [apart] instead of 60 feet, and then they can hear each other. And then I said to the minister—I was looking around and I saw, this time they weren't walnut boxes but they were white boxes; they were painted white, and you just won't believe this. Here is the plan of the balcony and here is the rostrum and there were columns supporting this balcony here and there, cast iron Corinthian capitals. And the loudspeakers were on these columns facing both ways, you know. They were in section like this and they were painted white. And there were none up here in the balcony. These were <u>under</u> the balcony. I should have thought of this. So I said to the preacher, I see you have a sound system. Yes, he says. I don't really need it, but the visiting ministers are terrified by this place and they need the support of the sound system. I said, well, could I hear it? Oh, of course.

So he got the janitor and the janitor turned it on and set it at guess what? Seven. Absolutely, this is a universal rule, the dials are on here from 0 to 10 and here is "5" and "6" and "7;" "7" is where they always set the dial. You wouldn't want it on full because that might blast them out, and if it is on "5" you are getting only half of what you should get, a half of whatever it is, I don't know. But anyhow "7" feels like the right place to put it. "7" to "8" is where they are always set. So the janitor turned it on and set it at "7" and the minister said, well, that's where we always have it on Sunday morning. And so he stood up here and began to sort of preach a little sermon to me and I walked around, strolled around, and I got up here in the balcony and what you heard in the balcony was absolutely incredible. Nothing but backwash from this stuff coming up from underneath. Kind of a basement sound—just awful.

Then I said, well sir, would you mind walking around and let me preach to you. Oh, he would be delighted. And I knew that it was a very amateur-type system because I saw that the microphone had an on-off switch. If you see an on-off switch on the microphone, you know that it's a real drug-store installation; no relation whatever to a proprietary system. So I had a newspaper there and I began to read to him something out of the newspaper and he wandered around. And then I just clicked it off because I had the on-off switch right here. And he stood still where he was and said: what happened? All of a sudden your voice seems to be coming from you. I said it is. (laughter) Isn't it better? Oh, much better. What did you do? I said I cut the damn thing off. (laughter)

It turned out that somebody in that congregation worked for Muzak and, therefore, knew about sound. Muzak, you know, is soothing, tasteless, soundless music. Lawrence Anderson [Dean of the M.I.T. School of Architecture] once observed, I remember--back when I was in architecture school here—he asked if any of us had looked at a program for Muzak. They usually hand out the program in reference to what was going to be played between 11:00 and 12:00, and 12:00 and 1:00. He said have you ever looked at one these programs and did you ever recognize any of the names of the composers? The answer was no; it was strictly hacks that crank out this stuff for the Muzak trade. Well, anyhow, Muzak had done this system and had donated it, $500 worth. Imagine that: $500 for a sound system for a Madison Avenue church in New York City. Well, maybe they could do it for $5,000 decently, but they didn't even need a sound system. This is the point and so often in lecture halls, in auditoria, in churches, synagogues, all sorts of places—we find people using sound systems when they just plain don't need them.

Student: *"What about the case in a huge church which has a high reverberation time?"*
Then you have to resort to a distributed system of some sort. Now let me tell you two or three of such cases. Let me first begin with a very beautiful building, The North Shore Congregation Israel, North of Chicago in the town of Glen Cove, in which Yamasaki [Minuro Yamasaki, Architect] did. It's one of the handsomest spaces I've ever been in, I spent a whole day there one time at a conference less than a year ago, and it's a perfectly beautiful building and it looks out through windows at the lake and the woods, and it's just lovely.

Well, question: where to put the sound system, because it is a quite reverberant building? We wanted it reverberant because they have a very good music program and they wanted to have concerts there and yet they have a very good rabbi who wants to be heard. He works on his sermon; I don't blame him for wanting people to hear it, so here is the set up: a great big space, balcony at the back and the organ and the choir are in the rear of this particular sanctuary, which is a perfectly good place to put them. It's not so good for a concert organist because people can't watch his fancy footwork, but you can hear perfectly well and that's the main thing.

Up front here was the platform with the cantor on one side and the rabbi on the other, steps coming up here and the ark was back here. Now this was done in a very handsome sort of Calla Lily sculpture of plaster and then the ark itself was done in gold leaf on wood with doors opening up at the bottom (and I can't draw exactly how it looks; it's something of this general shape).

The whole thing is very sinuous and then the doors are here, and this is all covered in gold leafing and this is contained in the great plaster Calla Lily sort of thing that kind of wraps around partly. It's much better looking than I'm describing. It's quite beautiful. And in any case, we said to Yamasaki (and he checked with the authorities there to see that we weren't desecrating anything because you run into this when we start talking about putting loudspeakers in the Catholic church; people get a little jittery about the liturgical propriety of this, but apparently there is nothing liturgically improper in our suggestion): Why don't we perforate this part and put the loudspeakers in here?

So they are in there, and this perforated gold leaf covered material here in front of this and it reads, if you know it's there, you can see that there is something a little different in this band but here are the loudspeakers of this place, sitting right up here in the top of the ark, and they cover the whole house. Now we have a bit of a problem since the loudspeakers are behind the microphone position and we are asking for greater potential of feedback. Feedback in a loudspeaker system is when the sound from the loudspeaker comes to the microphone, is fed to the amplifier, is fed back to the loudspeaker, is fed to the microphone, is fed to the amplifier, is fed to the loudspeaker and pretty soon the system goes "*WHEEEEEEEEEEE"* or some other such sound as that, and that is oscillation just feeding itself back, round and round and round. But with careful orientation of these loudspeakers, with careful equalization of the system, with a very good sharp hand on the knife, this operation can be very successful.

And indeed, microphones are here. Here, the sound comes from here, and covers the entire congregation from one central position. Now this space is moderately reverberant; I'd say it's up close to two seconds. We find that two seconds is about as reverberant a space as one can have and expect a central system to work. If the space has a reverberation time of much more than two seconds, then a central system, which isn't all that directive—I mean it really isn't like a flashlight, it just generally directs the sound energy towards the congregation—if it's up to four or five seconds, you'll find an amplification simply deteriorates the quality of speech sounds and we must resort then to some other kind of system. Generally, it's a distributed system; with or without time delay; with time delay it's better than it is without.

There are several approaches, I think I've already described to you the one that was originally used in St. Paul's in London in which the columns of the cathedral church go down a line like this—great big fat columns down this set of rows and down here, and here is the pulpit and then the aisle and all that jazz up there and column loudspeakers are placed along each of these structural columns on both sides. If you go into St. Paul's, you'll see them. You'll see column loudspeakers in almost all of the large churches in Europe today placed along the structural columns. The two words "column" have nothing to do with each other; they just happened to be the same descriptor. These loudspeakers are placed here laying out a flat disc of sound. We like the column because of its directional characteristic; it doesn't engage the whole space. The reverberation time, RT, is approximately 8 seconds in St. Paul's. It's exactly the same reverberation time as the 77 Mass. Ave. [at M.I.T.] entrance has up here when no people are in it. If you want to hear what St. Paul's sounds like, just go out there and do yourself a Gregorian chant. Great fun.

Student: "How high is the horizontal band?"
Well, here is a structural column, and here sits the congregation, and here stands the column at a slight angle, and it would sort of have that kind of characteristic. It's quite narrow, really, but it can shoot out, oh by the time you get out to 50 feet the pattern may be 6 feet high, you know something like that. It isn't all that very knife sharp, but it's quite confining, and certainly keeps it out of the top space.

Now then these, in turn, are like our Bunny Club installation. They are fed from separate amplifiers with time delay. Each microphone here goes out and then this goes to an amplifier and this goes to an amplifier and this goes to an amplifier, and all these are fed from a tape loop on which a microphone sound has been recorded, and the tape loop is going this way. And then you pick up and send it to this one, you pick up and send it to this one as the sound comes by: a continuous tape loop time delay. And again, we allow the original sound to arrive at the ears of the listener, and then present him with an amplified signal, and the result is absolutely incredible, and the only way you can tell that sound system is on is to go right up next to one of the loudspeakers and put your ear up to it, and you can hear it talking. Otherwise you sit down there and you just don't know that the thing is running, which, of course, is the ideal we all strive towards in sound systems, "unrecognizability" of the operation. We're doing exactly the same thing right now in the Duke University Chapel down in Durham, where we're hardening up all the surfaces to make it much more reverberant, and we'll put in a new sound system of this sort.

Now another approach (excuse me just a second), another approach is to use what we call a <u>pew-back</u> system. This is sometimes done in areas where we simply can't get column speakers or we can't get speakers in the bottoms of chandeliers (which is another way to do it, distribute them that way)—put loudspeakers in the back of every pew, in between all the people. You have one for every two people, and you mount it in the hymn book rack. We're doing a system for the Senate right now that's being installed, in which every senator has a loudspeaker at his desk, a distributed system. It will be done without time delay. We quite often do them, operating at very low level without time delay; at least, I think it doesn't have time delay; I'm not sure.

Yes?

Student: "If that is a 2 second reverberant time, won't that sometimes tend to muddle it?"
This is 8 seconds – no – this is 2 seconds. Yes, but it still is very good, very intelligible. This is not a lecture hall. It's a place for congregational worship, and if people are going to sing hymns and say prayers and so on together, they've got to have a big reverberant sense or nobody will participate. None of us likes to be conspicuous in these situations and feel that he's performing all alone, that he's the only bad one there that has to go through all these confessions and so on. Everybody else is just as bad and you might just as well admit it. And so a nice good healthy reverberation time adds to that effect. So 2 seconds we find we can work in.

Now, pew back systems….Yes?

Student: “Do you find that there’s any way to make the quality of reverberation…I’m just wondering whether this has been your experience that the quality of reverberation in a large space with more absorption is different from a small space with no absorption.”
It certainly is very different, a very good observation. We're often asked, couldn't we have our rehearsal room sound exactly like the hall? And the answer is no. No matter what the reverberation time is in the rehearsal room, no matter what the reverberation time is in the hall, even if they were the same, they'll sound different, because there is a difference in the spacing and the time of arrival of the signals. And I can't tell you any more than qualitatively, and I could tell you quantitatively by showing you a lot of pictures of reverberation patterns because they are a series of spikes, it's not a continuous thing, it’s a series of reflections that comes from all around, but the spacing is wider in a bigger space and that sounds different to us. It's much less pleasant in a small room than it is in a large room, the same amount of reverberation. You’d find 2 seconds intolerable in this room, where it's very tolerable in this space. Now partly because we never stir up this space to quite the level that we do a smaller space, this big one, and while the reverberation time may be the same, we don't hear quite as long a tail. Usually, we don't hear all sixty decibels of decay in a large room. There are many reasons why it's different.

Student: (inaudible)
Well, take the chapel over here. I think that's about as small a room you would really enjoy a longer reverberation time. And that's quite enjoyable there for music and that sort of thing. But you get down to a room the size of this one which is, well, this is maybe half the size of the chapel, isn't it? Or maybe even more than that. But take a room a third of this size, and have it all hard and reverberant, and the trouble is (another problem which I haven't had time to discuss, and maybe we'll get to next time), is the fact that in smaller rooms we have resonances of the room, which begin to exaggerate certain tones. And these are up in the audible range in the very small room, whereas in the very large room they are very low frequency, and we never hear them, so this tends to color what we hear, and add on top of the simple reverberation time. But there are occasions when you do want a very small reverberant room for certain kinds of effects.

Well, the point here about these distributed systems is that they can be done with any degree of sophistication that you want, using time delay, using lots of loudspeakers, and they can come out sounding perfectly magnificent. The House of Commons in London has a distributed system, in which the loudspeakers are mounted right behind the ears of all the members, behind the upholstery, and it's quite an invisible thing, and very elegantly done, and it works beautifully. A distributed system will not work beautifully if you don't have enough units, if you're operating at high level, or anything of that sort. That's why we call them “low level distributed loudspeaker systems.” But you've got to have the instruments there, just as if you're going to get light into a space, you've got to have the instruments for light. And a time delay is something I would say is a degree of sophistication to be used only in very expensive systems in which you have the opportunity of having maintenance and operation all the time. The janitor cannot keep up with it, it's just one of those things.

At Christ Church in the Common here in Cambridge, there is a reverberation system for the organ. I think I may have mentioned this to you, with loudspeakers running along both sides of the room facing out, but it’s a different animal from a loudspeaker system for speech amplification, because it's not that; it only reverberates the organ. And there was a tape machine down in the basement. This was the first one of these that was done in this country (we did it experimentally about 20 years ago), and there's a tape machine down in the basement that runs continuously, not on a loop, but with continuous tape feed, and it has to be rewound every Sunday. And the organist tends to this, and once in a while forgets and runs out of reverberation about the middle of the service. But you've got to have somebody willing to handle these things to make them work. Well we'll try to wind things up on Friday.

All field studies welcome.

End of Audio File 28

THE END

Robert Bradford Newman Lectures

18 December 1970
LECTURE 29

Title: "Reverberation Time and Models"

Summary: In this lecture, Newman talks about measuring reverberation time and discusses the use of scale models in acoustics.

Part A: Beginning of Audio File 29A

I have made Quiz No. 3 optional, and any of you who would like to take it may collect one from me at the end of the hour and take it somewhere and at your leisure spend an hour on it. It's not too long from now and turn the papers in to Terry and make arrangements with him about collecting it. I think you may even learn something doing this.

There is a new book that has just come out that I recommend it to you for reading. It's called the "World of Sound." It's published by A. S. Barnes and Company. It's by Vernon Alvers who is a professor at Penn State. It's quite a nice book. It's not terribly long and it's written for the layman to read. Some of it may sound even a little bit naive but it has a lot of stuff on hearing and speech and microphones and how they work, and diagrams and sound measurement and analysis. It's quite nice reading, I recommend it to you.

The field studies, as I said the other day, I'll simply have to have by Monday at the very latest, and if you are unable to turn them in today to me here, then I will have to ask you to fetch them to my office, which is in the west part of Cambridge, because I have to turn them in Tuesday morning.

This being our last meeting, I am going to try very quickly to summarize the number of matters and discuss two or three new ideas as well. And I realize now having gone through this abbreviated term that next year, if we have the same arrangement, I will have to spend a lot less time recounting episodes and a lot more on attending to business because there have been too many things I haven't talked about this term. If you want me to continue with episodes I can. Changing me is pretty much impossible at this point of my life.

We've talked a lot about sound amplification and maybe I've made the point. Let me just make the point again. Sound amplification is great stuff, it's very useful, it's a very wonderful way to make it possible for people to hear in situations in which natural sounds just won't work because the place is just too noisy or too big, or something of the sort. But it just doesn't cure everything. Now the typical argument is this (and for God's sake, knock this down fast, and maybe this is something that the wave crest has passed, but I think it will happen a few more times anyhow): A municipality decides it's going to put up a new civic auditorium for purposes of civic pride, competition with neighboring cities, and so on, and they have gotten a promise from the Metropolitan Opera Company that they will come to this town if they have a hall that will seat 4,500 people. So that is the criterion on which the new hall is to be built: 4,500 seats for the annual appearance of the Metropolitan Opera Company.

Now the rest of the year this thing is going to be a real monster, a real dog, and the designers will say to the City Fathers: well, you must build it that big because otherwise the Met won't come to our town and gee, that's tough, but the little theater group will use it, the local symphony and chamber players and so on, and well, we won't attract 4,000 people to the local chamber players, will we? No, we will probably attract only 500, but you know they can distribute themselves throughout the house like molecules in the perfect gas and have a nice non-intimate kind of feeling. But the local players who want to use it: well how are they going to be heard well? They will use amplification, I've heard it said. Baloney; it just won't work. The amplification of drama—the pick-up of people moving around doing things—is possible but very difficult, and certainly is not for the local amateur theatrical group. The cost of doing it is so great and the sophistication with which it has to be done is so great that it will just be a thorough folly.

Student: "I was wondering how large (inaudible) … if it's incredibly difficult to amplify drama, can you have drama outside without amplifying?"
No, unless you have a very small group of people or a very, very quiet situation.

Now at Wellesley, I don't know whether they still do it or not, they have the Theater on the Green there. There used to be a theater outside at Wellesley and I guess they seated 400 or 500 people in kind of an amphitheater way over behind a lot of buildings, with no traffic nearby. It was quiet and it worked beautifully. When I say drama is incredibly difficult to amplify, it isn't incredibly difficult, it's just difficult and is usually done very badly. It can be done but it's a matter of having mikes near the performers all the time—the sort of thing I described on the Charles River Playhouse thing. That's ten years ago, with $10,000 worth of stuff.

Student: "Isn't it a very old-fashioned idea to try to perform drama in the same room that you're doing something like concerts?"
Why sure, it is very old-fashioned and stupid but it still is done. Intimate drama is intimate drama. It's for a small situation, a few hundred people in which you can see, hear—you know you get more than about 80 feet away from a performance and you can't even see anything but gross gestures. You can't see little twinkles of the eye or grimaces of the face, you lose all that and it becomes a sort of tableau. Well the point is there is a proper size for any kind of performance. There are situations, outdoors or indoors, where things are so noisy or you have too many people around or something, that you have to resort to amplification. Use it, but do it properly because it's very easy to do it very badly.

Another matter I just noted down here that is running through my head is about things you should have under control. I don't know whether I've said enough about the background noise criteria for performing arts facilities. This is probably pretty well outlined here in the Time Savers Standard, but I'm not sure it's strongly enough underscored. There are, on page 616, some so-called Noise Criteria curves, these so-called NC curves. And today, even more than ten years ago, we would advocate in any kind of concert hall or theater or any performing arts facility, that you aim for a background noise spectrum of NC-15, Noise Criterion 15, now that's below the NC-20 here on this chart and I think it's very, very important to head for an NC-15 in any kind of a theater.

I think I've mentioned this before, but I just want to underscore it. It can be achieved, though it is not easy to achieve. And when you get to delivering air, if it's an air-conditioned space, get to delivering air to such a space, it cannot be delivered in the usual way at the usual velocity that works in an office building. It's a different kind of problem and it has to be done with great sophistication and possibly even with some different approach to the problem than the conventional one. It's doable and we've done a number of halls in which this is the case. And it's just marvelous to go into such a place and not be able to tell that the air conditioning is running. It isn't drafty, it doesn't make any noise, and every little nuance of the performance is clearly audible and nothing is masked. So I would say again, and again, and again: the achievement of a silent background is probably the most important thing you can do in designing an auditorium, next to not using acoustic tile or acoustic plaster all over the ceiling; or doing a dome, those are no-nos too, but an absolutely silent background is just dreadfully important.

Now the other day, one of you asked about how we go about making measurements of reverberation and I would like to couple this with a brief discussion on the use of models in acoustic study. What use are models, do we use them, or don't we use them, and what do they tell us? First of all, how do we measure reverberation time? Now please remember that I told you again and again, don't go into a hall, go "HOOT" and listen to the sound, watch your stop watch and say "ah! that was 1-1/2 seconds, therefore, the reverberation time of this hall is 1-1/2 seconds;" that just probably is not true. Remember reverberation time is defined as the time when you take the "*EEEEEE*" to die down to some level here 60 decibels below the initial level. You must hear all 60 decibels of the decay if you are going to hear the true reverberation time in the room.

If you have an ambient background noise which is here, say….suppose this is 10 decibels above or 50 decibels down from the initial level, then you will hear only 5/6ths of the reverberation time. Now this is a logarithmic scale so you can take direct proportion because this is going to be a straight line function on a logarithmic scale. And if you measure here a time or observe time of say 1.5 seconds that is 5/6ths of the true reverberation time, let's make it 1.8 so I can figure it out a little easier. 6 goes into this 3 and therefore, 6/6ths, wait a minute. 1.8 is to RT as 5 is to 6. What am I doing wrong? OK that's what I was thinking ... that's right.

Student: *(inaudible)*
Sure it is for this particular noise, but what if somebody really went "*WHAAAAAAAAA*" then you'll hear it, but what it is, is the characteristic of rate of decay for sound, it's the reverberant character of the space.

All right, now how do we measure it? It used to be that we thought we had to use a small yacht race starting cannon for the source of noise. And in Kresge—I remember when Kresge opened—we had a special meeting over there for the local institute of electrical engineers and I spoke to them awhile about Kresge, and then we said: now everybody, we're going to shoot the cannon and measure the reverberation time in here, in the occupied hall. So this little cannon, you know they're real cute little cannons, about so big; and we put a twelve gauge blank shell in there (there's no ballistics up front) and some newspaper stuffed in and then you pull this thing and it goes "*WOOMPH"* and it makes a hell of a racket, lot of smoke, and plaster dust always comes down on the audience, and everybody is like this, you know, startled. But you record this sound on a piece of magnetic tape; you have the microphone planted out in the house somewhere and you record this signal and you record this great boom which will rise up like this and then decay.

Now we found out that you don't have to do that. We started using 22 gauge blank pistol shots for measuring reverberation time. This causes all sorts of trouble carrying around pistols and so on. So we found out pretty soon that there was something very simple that can be used, and that is a balloon. And today we use balloons when we go on a field trip to measure reverberation time. And you take along a dozen or so balloons and they are fairly standard balloons. We blow them up to about two foot in diameter and then just pop them and the make a perfectly magnificent noise.

Now we use noise of that sort simply because it has no tonal characteristic; it is a white noise. In other words, it has all frequencies in it. It doesn't go "*BEEEEP*" or anything like that. It just is a big bang with everything in it.

Now we are interested in measuring the reverberation time of the room not only as kind of an overall thing (because there isn't any such thing as an overall reverberation time). We are interested in measuring at a number of different frequencies, and we have to have all these frequencies present in our noise if we are going to measure the reverberation time. We find that we get by far the smoothest and best decay in a room for this sort of thing from an impulsive source like a balloon, or a cannon, or a pistol shot.

Now sometimes we'll take terminal chords of orchestral music or of organ music, and the orchestra will be up to some grand and huge fortissimo and all of a sudden the conductor will stop them and we will record that stop and we will get this kind of a pattern. But this thing with a lot of tones in it, it tends to excite certain normal modes or natural frequencies in the room, and you get a much more jagged kind of decay and you have to do more guessing about what is the average slope of that curve. I just did a lot of reverberation measurements down at (inaudible) and we used the organ; the organist just sat there and kind of went "*GRAAAAAAAAAAA*" and he sat on a whole batch of keys and it made a huge grand sound and then stopped, and we recorded that. And I also burst balloons and my balloon data are much, much better than this great big old organ.

Student: "How did you get a tape recorder?"
We use, in this sort of work, a very high quality Swiss tape recorder, battery operated, the Koedelsky. Koedelsky is the name of the guy who developed it. I think it's $1,500 now. We feed that from a condenser microphone on the Danish Bruel & Kjaer sound level meter that you saw here, this thing that sort of looks like a space ship and we have to calibrate everything very carefully. To start with, we put a tone acoustic calibrator on the sound level meter and we set our gauge. We record that, and we know exactly how many decibels that was, and then we don't actually record 60 decibels of range—it's very difficult to get that much, we're very lucky if we get 45—and we simply extrapolate, just as I suggested here. This is the reality of life and one has to be very careful with an impulsive source of this sort not to overload the system because the dynamics of the meter on the scale are such that it will not rise up to full level that the bang gives us, so we allow ourselves about 10 decibels of leeway at the top of the thing when we are setting up. But we almost always record the balloon burst on the magnetic tape because then we can take that magnetic tape and play it through many, many times and break it down into particular pieces, octave bands.

Now let me just say how we do that, and then I want to talk about another kind of gadget that is now available and it is a lot more fun to use and maybe even more useful. When we have the magnetic tape of the balloon burst, we look at the tapes, if we look at the recording of the balloon burst, and this carries over to the model story. What we find is "*BANG, BANG, BANG, BANG, BANG, BANG, BANG*" like that; if we look at the picture on the oscilloscope of the balloon burst we find that the decay is not a smooth thing like this, but it is a whole series of spikes, the envelope of which begins to give us this sort of thing. We look at that and we say, aha, well that looks good, maybe there is a gap in here where there aren't things and maybe there's a couple of little spikes down here and we get to be a little suspicious about how this hall is going to sound if we see too many little gaps in the time of arrival of signals from the room to the listener.

But we take this tape, and we play it into what's called a high speed level recorder device which gives us a read-out on a tracer that actually scratches the wax off the surface of the paper and gives us a black line. Black paper with a white wax on the surface and you scratch that with a stylus, and we put the output of the tape, here's the tape, we put the output of that into an amplifier, into the graphic level recorder, and in here also we have this amplifier, plus octave, third-octave filters. And then what we do is start at the bottom and set on an octave band, and say that it has a center frequency of 125 cycles per second [Hz], and we'll filter this recorded signal through the octave filter, and then record a tracer of this sort for 125 cps and then we'll do it again for 250 [cps], and we'll do it again for 500 cps, and we'll do it again for 1,000 cps, and so on up the line. And when we get through we get a plot. We plot it out on a piece of graph paper and we'll get some kind of picture like this of reverberation time in seconds as a function of frequency (125 cps, 250 cps, and so on). And whenever we give the reverberation time of a hall, we always give it in terms of its frequency dependency because there is no such thing as just the reverberation time of a hall. When somebody says the reverberation time of this hall is 1.3 seconds, what does it mean? You must say at middle frequencies, at high frequencies, at low frequencies…., because it's going to be some function of this sort. It's never flat, at least I don't know of any room with flat reverberation time; it's almost always higher at the low frequencies than it is at the higher ones. This might be two seconds, this might be down to one second with all these places in between. So it's a process of recording some information in the hall with a loud source of noise, taking that information back to a lab, and reducing the data in this fashion.

Now this is something that no architect that I know of, and certainly no architect in his right mind, would buy all the equipment and develop the skills to go through this; it just isn't worth it. You might be interested one or two times in your whole professional career in actually measuring a reverberation time and knowing it precisely. It's the sort of thing that people like us, who are in this game of acoustics, have to be set up to do and have to make the investment in the equipment. It's a very expensive and time-consuming sort of business.

Now one of my colleagues invented a very nice little gadget, it's called a "reverberation meter," and this is made by the General Radio Company out here in West Concord or Maynard (I'm not sure which they're in). This has a little oscilloscope screen on the base of the thing, it's a display. You go in a hall and you go '*bang*!' and the little oscilloscope....I'm going to exaggerate it and you'll see this line like this coming across here and then on top of that you can display a straight line, and this straight line, the slope of this straight line, can be varied with a knob over here calibrated in seconds. And what you do is go *bang*, and then this is a long-retention screen, and you match the slope of the decay that you see with…. I mean it's really a whole series of things which you can see the envelope on the top of it. Then you match that slope with the best match of the straight line which is displayed, and which you control by turning this knob to 2 seconds, 1.9, 1.8, 1.7 and so on; and when you get the slope matched to the display from the signal in the room, then you've got the reverberation time and you read it off here in seconds.

Student: *(inaudible)*
Again, you should have filters and so on in connection with this because if you just get the whole bang, you'll just get a kind of general number somewhere in the middle of the thing, but that has also to be filtered. And again, you have to have high quality microphones, filters and all the rest. But it is a direct-reading display device. Very, very, cute. I don't know what that costs. In the order of thousand dollars. Most of these things are at least a thousand; you'd be suspicious if they were much less than that. Obviously, I wouldn't suggest you go and get one, though it's a lot of fun to play with. If you like expensive toys, why

that's a good one to have. You can do all sorts of things with it. Now I don't want to dwell on this too much because it is a rather academic discussion.

Student: "If you are in an auditorium, can you bring all this stuff down there and have a data line back to your office?"
Well you might, but the trouble is you don't trust any lines. For example, you can never take data from the air, from a broadcast of a symphony or anything like that, because they're always using compression--they compress the signals and you don't get the full dynamic range that's in the hall because the lines in your circuitry and everything else won't take it. There is compression in almost all recording and broadcasting, and we don't want compression, we want the full thing; and the quality of telephone lines are such that we wouldn't trust them.

You've got to have your microphone and preamplifier there anyhow, and the tape recorder only weighs about 50 pounds so you take that along and (inaudible) You don't trust anybody else's equipment; you learn after a while that it is absolutely perfect or it's worthless. I just thought you'd be interested since somebody had asked about it, how do we do it. And it isn't simple, it's complicated; we almost never make a direct measurement of reverberation with the level recorder actually present in the hall because that is an awful lot of equipment; it's much too delicate, and just can't be carried around.

The other thing that I wanted to talk about a little bit is what have we learned from these balloon bursts and what have we learned from models? Now you will read in literature from time to time about people who have done models for auditoria. Right at the present moment, for example, in Sydney, there is a tenth-scale model of the large hall and of the small hall in the Sydney Opera House, at least it was there almost two years ago when I was there. I assume it will still be there this year. It's in Technicolor which is pretty jazzy. In Munich back about 10 to 15 years ago, there was a fellow named Spandoff. He did a tenth-scale model of the new Munich Opera House or the remodel of the opera house, and it too was done in Technicolor, by that I mean: full rendition of all the colors and it looked just like the hall.

It's a real nice model and a tenth-scale model is a biggie! We had a tenth-scale model in our lab of the Houston Jessie Jones Hall and it's a big thing. It's a 3,000 seat hall, at one-tenth full size. By the time you get it up off the floor 3 feet, the top of the thing is up to 12 feet and it is 15 to 18 feet long. It's big, a great big thing and it costs about $8,000 just to build the thing and do the test. Now Spandoff and somewhat later Jorden in Copenhagen, the consultant on the Sydney Opera House, did a lot of what we call Mickey Mouse Music in these things. They got a recording, actually it's an Austrian recording which was made outside in a hay field. This sounds awfully funny….

End of Part A: Audio File 29A
Beginning of Part B: Audio File 29B

[It is] pretty absorptive, so you don't get any ground reflections, so these good Austrians got out there and it's just the deadest sounding music you can imagine. It has absolutely no life and everything is just "*BLUMP, BLUMP, BLUMP, BLUMP"* chopped up. OK.

They take these Austrians playing in the hay field, this record, and since then another record has been made in the Building Research Station near London in Watsford, and they had a bunch of musicians performing in an anechoic chamber, which is the same idea. You get this totally dead music to start with.

Then Spandoff's trick was to feed this into a tape recorder running at 1/10 speed or ten times (I don't care, anyhow you speed it up for presentation in the model at 10 times normal speed), and that's the Fifth Symphony of Beethoven, you know, over quickly in one-tenth normal time and at 10 times the frequency. Everything is up 10-fold because we have scaled our models down 10-fold and therefore we want to get the behavior of the sound waves with respect to surfaces and shapes in the room that will correspond to what happens in the real room.

Do you get the picture? Remember we talked about reflectance of surfaces as a function of the wavelength of sound that strikes them, so we have got to scale our room down and scale our sound frequencies up. Well Spandoff did an incredible amount of work and he had a little dummy head, one-tenth size, and two little microphones in the ears and he did binaural recordings in this hall, and he had a little loudspeaker up here on the platform and he said when he got through: "that's what the finished hall is going to sound like."

Because you record this, what the dummy head hears with two ears, and then you play it back at one-tenth speed and presumably you get "*BAHBAHBAHBAH"* just like the real hall is going to be. Now this ain't so.

It makes awfully good public relations, the Technicolor models are "oooed" and "ahhed" over by everybody who sees them—isn't that cute; cute little chairs, and they are very cute, and but that's not what the hall is going to sound like. Why? Well, first of all an orchestra cannot be simulated by a loudspeaker on stage. At best, if it were perfect, it could tell you what recorded music played in the hall from a loudspeaker on stage might sound like in the finished hall. But we really can't scale things acoustically. How are you going to make one-tenth scale plaster, for example; you can make it a tenth of the thickness but the molecular size of things is still the same. Wood can't be scaled down. Nothing can be scaled down. And today we have abandoned Mickey Mouse Music and even Jorden in Denmark has abandoned Mickey Mouse music, and Spandoff is dead. So the whole thing is past.

We found out very early in the game that all we can possibly learn from models is to examine this sort of behavior—the pattern of reflections that are received at a given point in a hall—and compare these to the pattern of reflections that we get in full scale halls. Now this we can do. So what we do with the model today is to assume that everything is either <u>reflective</u> or <u>absorptive</u>. We make them out of….we actually do them now at 24th full scale which is half-inch to the foot. Now then, a model for Symphony Hall in Boston, we have one that we keep in the lab to standardize things, is about this big here, so high, and its roof comes off and so on. And we keep this one because it's very handy once in awhile to make a measurement in the model and run over to Symphony Hall and check it out in the real place. And as long as we've got it right here in Boston, we might just as well use it, so we have the Symphony Hall Model for the purposes of standardizing and comparing. In the model, what we do, we have seats that look like people in seats. They're in rows, they're made actually out of this "ozite," indoor-outdoor carpet (I hate to use the word carpet, they call it carpet, it's kind of a felt junk) and but it's just right for models of people in seats at one-twenty-fourth the full scale. And we have little rows of people and they're red, because that was the color of the stuff we got; and everything else is white or grey or whatever color it comes out to be. And we use either cardboard or plywood or this model Styrofoam core paper, yes, whatever is handy. That's hard enough, that's 24 times the frequency.

Now, what we are going to do, you see, is to look at this model—now balloons are hard to get that small, so instead of that (and it's a nuisance to have to blow them up all the time), so instead of that we use a spark gap, *bang*, from the spark gap. And we have a little spark gap with a screen around it so you won't get a jolt out of it, and we set that—here's the hall and the model and we set the spark gap right here with a little screen around it. And then back here in some seat or other, some typical place in the hall, we'll have a microphone, and this microphone is a very small miniaturized, I think quarter inch is about as small as you can get our microphones, we actually sometimes use a probe.

But we generally put in a quarter-inch microphone, a little condenser microphone, attach it to the proper preamplifier and so on, and send it out here to an amplifier and to an oscilloscope screen here. Now this particular oscilloscope that we use is equipped with a Polaroid camera so that you can view it through a mirror at 45° and have the camera straight on, and when you get something you want you take your camera and you get a picture right away, which is like any Polaroid camera available in a minute or so for you to look at. This screen here is a long retention screen so that the picture stays on it for awhile after you've done the bang; you see a whole series of little things come up and then you take pictures.

Now the screen is calibrated in the grid, and these are 5 decibel steps and in this direction these represent milliseconds and in the 1/24th scale model these will be a 24th of the time that we will have in real life. And we have a spike here, and spike and spike and spike and so on. And now, looking at this picture, we can see the magnitude and time of arrival of signals at a given seat in the house. We can filter this at the appropriate frequency if we want to (and we generally do), and then we can compare this picture that we get in the model, with the pictures that we get in the real place bursting balloons. Now you say, well how do you know what's good? Well you go to a good hall to start with. Well, how do you know that? Well everybody says it's good, and everybody isn't wrong. Symphony Hall, I've knocked it a couple of times, it's got some lousy seats, but by and large it's a damned good hall, and everybody thinks so and has for about 70 years, so let's not start pretending that it isn't. We go to Symphony Hall, we go to other places that are good, and we burst balloons and we make lots of these pictures, and we know what they look like and we begin to get a feeling for what is the important thing, what kind of pattern is important.

Is it important that there not be anything popping up out here? Does that matter, or doesn't it matter? Does that ever happen in a good hall, and how long delayed is it and so on? Now as a result of all this, we've been able to predict with these false pictures, predict from a model, the articulation that you're going to get in a finished hall, or you can predict in a finished hall the articulation that you're going to get. Now articulation, actually it's called Articulation Index, and we haven't had time to discuss it—if the articulation index is 1, you have perfect speech articulation. In this room, the articulation index is very nearly one. You have no difficulty, I think, in hearing me or in making out any of the words I say. There's no reverberant confusion, and if the background noise is low enough you have perfect articulation. If the articulation index is only .5, this means that you'll hear only half of the words spoken correctly, words spoken out of context. For example, I say now write down "CAT," and if you put down "BAT" instead of "CAT," you didn't hear it properly. But you don't know what I was going to say, because I say now write down something.

If I say the cat chased the mouse, then you know it was "cat," even though it sounded like "bat," because bats don't chase mice, and you know that. And it wasn't lice or louse, it was mouse that the cat was chasing. The cat chased the mouse, and it might have sounded like louse, but you write down mouse because you know. The sentence in which a word is carried gives you a lot of meaning, and you can understand things in difficult situations just by putting things together, and using the old brain up here. But we can predict, on the basis of these patterns and what we've learned about them in doing a lot of real tests in halls, we can predict the quality of speech articulation that you're going to have in the finished hall.

We are not yet refined enough in our techniques to predict exactly what music is going to sound like. We can tell, though, whether the pattern of reflections is a good one or likely to produce good results. You can't tell exactly what is going to happen. But this technique has helped us a great deal today when we design a new hall. It hasn't got any kind of a consulting budget, and we are not a non-profit organization, so we have to have these things paid for somehow. But if we can possibly afford it, we will build a model today at 24th full scale of almost any new hall we're going to do, and do it during the design stages, and monkey around with diffusing surfaces, monkey around with angles of reflection, worry about the rear wall (e.g., is it really a problem or not?), and we can see all these things and we can change them, and watch what happens, as we make changes in the model by just banging a little spark back and forth, and change something you know, you can just watch it. It's a very, very useful analytic tool in the design stage. I think that it probably is about, well not as far as we can go, one should never say that, but I'm quite sure that at least in the foreseeable future, the Mickey Mouse music approach is not going to be one that has much validity. So we simply scale the general form of things, and say "reflect/not reflect" and let it go at that. It's about all we can do.

Student: "Do you use a light source in the model?"
Yes, and we often do that to analyze focusing problems and so on. We coat the surfaces with this silver mylar film, and then use a bright flashlight bulb or something, and look at the [reflection] patterns. Now optical models however only tell you about specular reflection. They don't give you the wave interaction, which is the important thing in this kind of a picture. Also, as you see in all the classical books on acoustics, the spark photographs that you can get in a section of a model, you can watch the waves go out, and see how waves interact with each other, watch them travel, and disperse or concentrate. You can do the same thing in a ripple tank. You can take a tank of water, a very shallow basin of water, and do a cut-out model of your auditorium, and then "*BOINK"* on the water and the wave goes out and comes back and flows all around. It's quite wonderful to watch. And it's very instructive to see how waves behave in a room, but it really doesn't tell you anything about what the hall is going to sound like. It's an instructional tool rather than a working one.

Any other questions or comments on that?

Student: "Were you able to locate in the Symphony Hall model the same problems—you said there are bad seats?"
Yes, and you can see the gaps, you can see—sitting down in the front here—that you get some initial stuff, and it's quite a while before anything else gets there, so you have a lot of (inaudible) stuff here, and nothing till out in here, and there's a big gap in here, which is not good.

Student: "Do you think you might be able to take some of us to Kresge on Monday [to hear the artificial reverberation system]?"
Um, it's not quite ready. I'll be very happy to do it, I just don't quite know how to handle the logistics of getting hold of everybody. Maybe if I post a notice or something, where would be a good place to post it? As soon as it's ready, I'd like to take you all over, and have it "on/off" and do a little listening; it's a nice experience.

Where is a—outside the elevator? All right, well as soon as it's ready I will do so. It will probably be after Christmas, or after the New Year when you're all back.

Are there any other questions? There are millions of things that we haven't talked about, but if anything is bothering you, is anything, does anybody disagree heartily with anything I've said – I just love a good argument, because I believe it all.

Student: "I'd like to know something about bugging devices."
Bugging devices? Well, there are, of course, many very sophisticated ways of bugging, and it's almost impossible to make a bug-proof space. We did a room for the State Department that was supposed to be bug-proof for installation in consulates and embassies around the world. But here's the trouble, whenever I'm talking in this room now, and if somebody wanted to know what I'm saying, if he's real clever, he could devise an optical device, a laser beam on that window from across the way and he could hear me, by the fact that that window pane is moving in and out, ever so little, but it is moving. And by God, you get some real sensitive sophisticated optics going on this stuff, and it's almost impossible to make things really bug-proof. Bugging is largely a matter of, well, of course, planting microphones, that's kind of crude. But there are gadgets, you can fit a microphone and transmitter, all transistorized into a thing the size of a ball-point pen, and leave it lying around on the table, just casually in a conference room. These things are done, they're planted, and they'll transmit out to a few hundred yards away, and then there's the guy listening. The best thing is I guess.

Student: "Is there such a thing as a (inaudible) device?"
Well, I suppose.
Just go someplace that isn't a conference room, where nobody knows you're going, and talk very quietly. Our ambassador to Kuala Lumpur—I went to call on him one day, when I was there—and his room was a nice big office, big corner office with a sofa and so on. And there were some fluorescent lighting fixtures; this was an office building, fluorescent lighting fixtures that went through from one room to another, and so there is a hole that the tubes have got to go through. They decided to put a partition where there was a lighting fixture, and so they cut out a hole and go around [the light fixture]. I said to him, you don't have any privacy in here, do you? He said no. Just talk very quiet. Very good way to do it. I can't tell you much more except that bugging is an incredible game, and it's almost impossible to beat it. We and the other guys too, we all have the game.

Is there anything else that anyone is curious about? We know all about acoustics now. Well, what interests me about this course, and I've been giving it now for more than 20 years, is the number of people who have left this course and gone out into the world of teaching, and then proceed to teach a course in acoustics. Now go right ahead and do it, more power to you, you know infinitely more about the subject than most other people do. And most of all, just remember the few simple sorts of things we've talked about here: the differences between fuzz and mass and isolation, there is a tremendous misconception about this, everywhere in the world. And all the little things about vibration isolation: about how you go about controlling noise, keeping it where you want it. And making all these mechanical servants that we have real servants, and not overlords that just run us out of the place with noise. If you just remember these things I think you'll do lot better buildings than maybe if you hadn't had this experience. Well, if could have your problem sets too, and if anyone wants to take the makeup quiz, I have them here.

End of Audio File 29B

THE END