US 20150285270A1

(19) **United States**

(12) **Patent Application Publication**

Buckland et al.

(10) **Pub. No.: US 2015/0285270 A1**

(43) **Pub. Date: Oct. 8, 2015**

(54) **PUMP**

(71) Applicant: **THE TECHNOLOGY PARTNERSHIP PLC**, Mebourn, Royston Hertfordshire (GB)

(72) Inventors: **Justin Rorke Buckland**, Comberton (GB); **Richard Wilhelm Janse Van Rensburg**, Great Cambourne (GB); **Alex William Wilber**, Cambridge (GB)

(21) Appl. No.: **14/441,879**

(22) PCT Filed: **Nov. 13, 2013**

(86) PCT No.: **PCT/GB2013/052992**

§ 371 (c)(1),
(2) Date: **May 11, 2015**

(30) **Foreign Application Priority Data**

Nov. 14, 2012 (GB) 1220471.5

Publication Classification

(51) **Int. Cl.**
F04D 33/00 (2006.01)

(52) **U.S. Cl.**
CPC *F04D 33/00* (2013.01)

(57) **ABSTRACT**

A fluid pump comprising a flow channel containing an fluid inlet and a fluid outlet and bounded by two side walls, a substantially planar flap positioned inside the flow channel, and an actuator capable of transmitting an oscillating force or torque to the flap, where the side walls extend from the inlet to the outlet and are substantially planar and parallel to the flap and extend beyond the downstream end of the flap towards the outlet by a distance such that $l_d \geq l_f/2$, where l_f is the length of the flap, where the side wall separation, h, length, l_w, and width, w_w, satisfy the relationships: $l_w >_h$ and $w_w > h$, whereby in use, the actuator drives oscillatory motion of the flap in a direction substantially perpendicular to the side walls with motion of the flap having larger amplitude near the outlet than near the inlet.

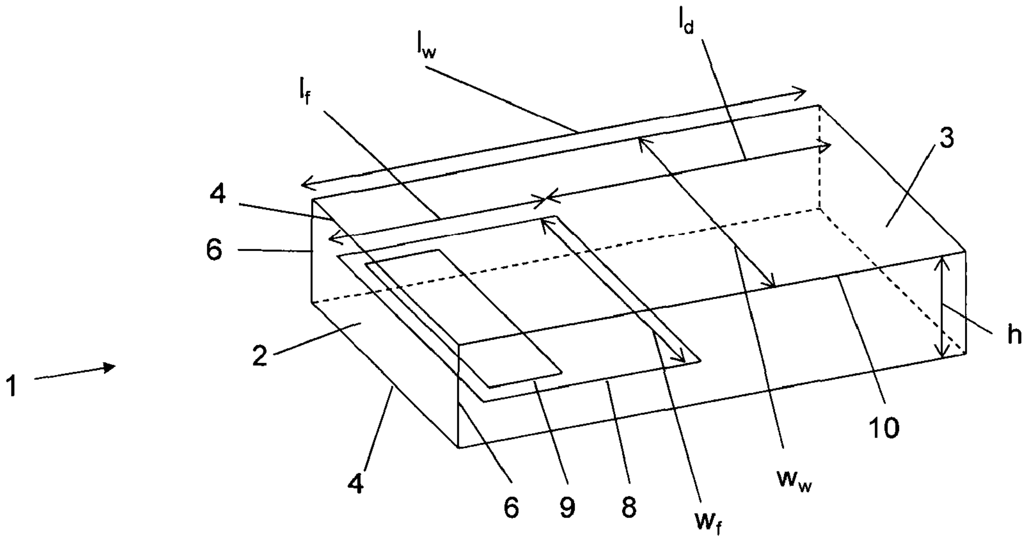


Figure 1

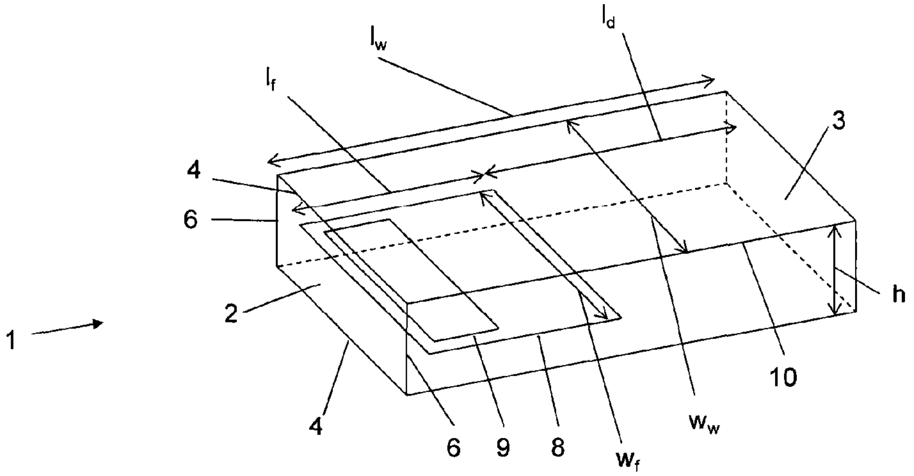


Figure 2

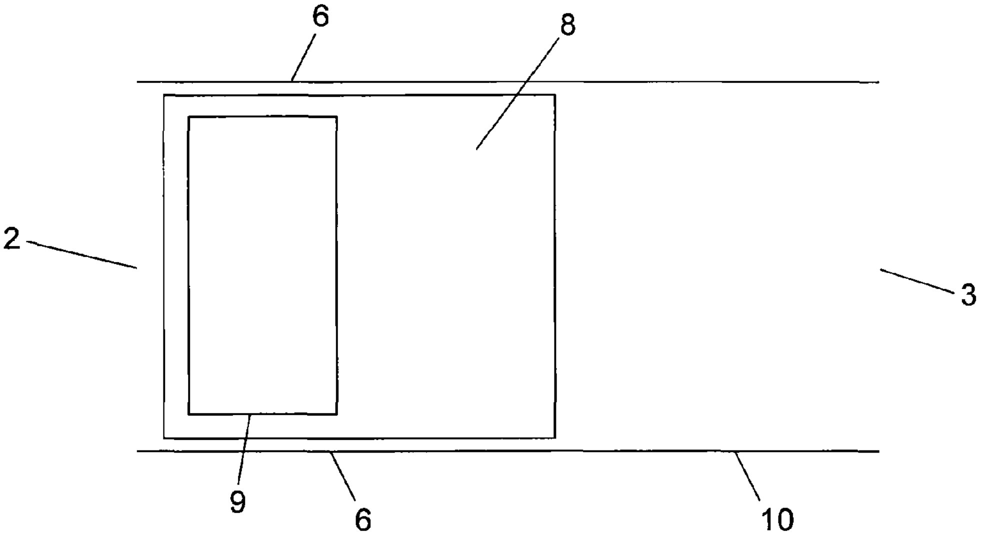


Figure 3

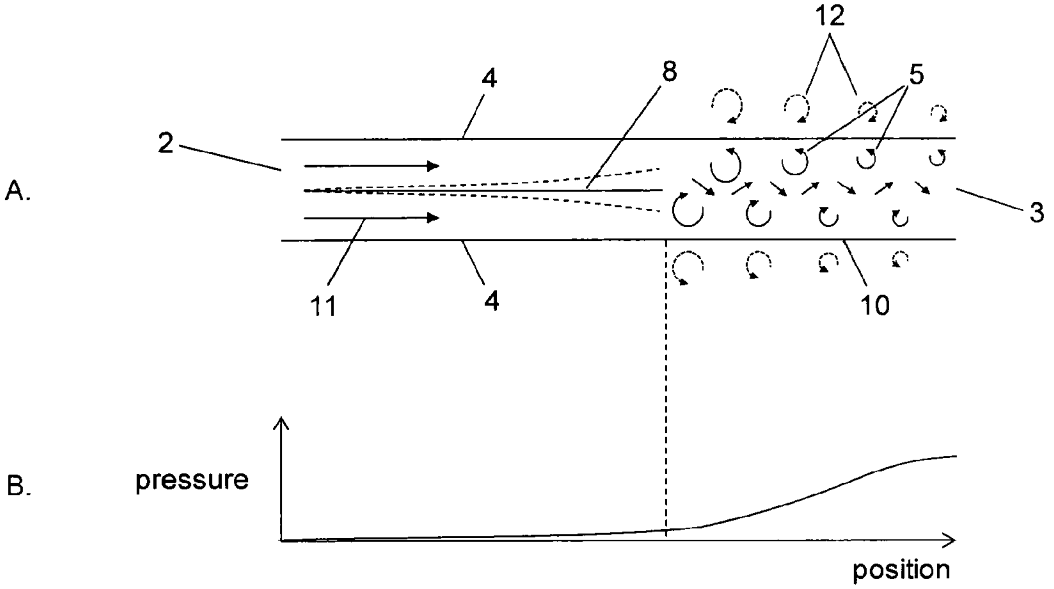


Figure 4

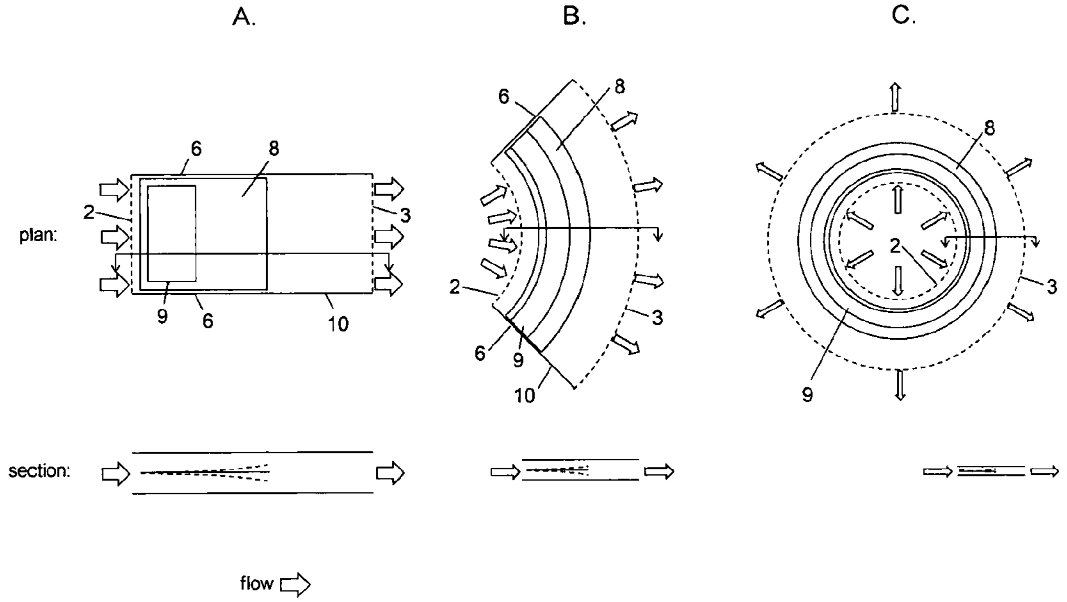


Figure 5

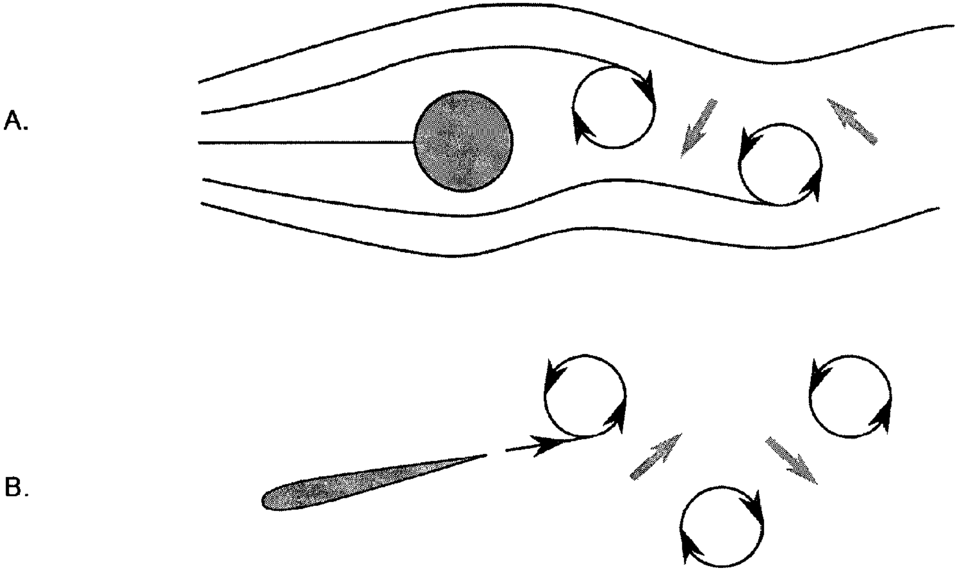


Figure 6

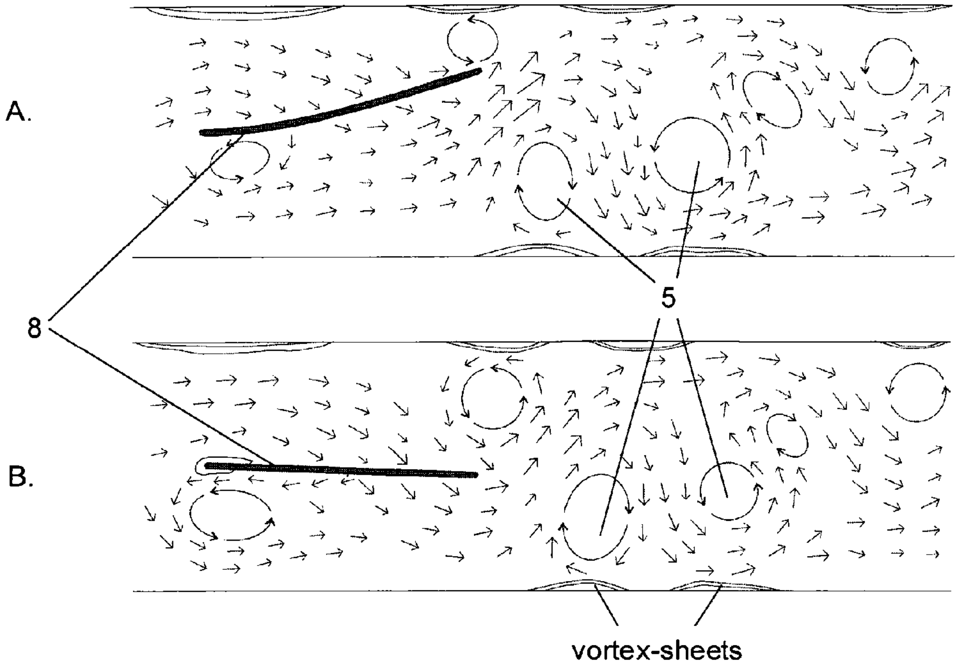


Figure 7

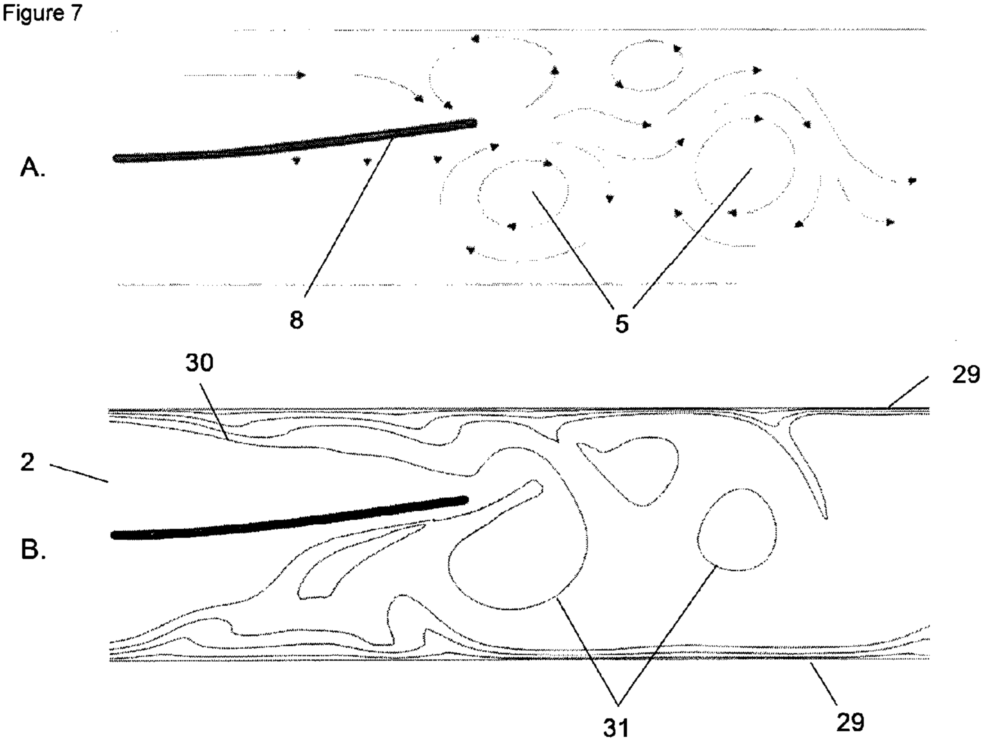


Figure 8

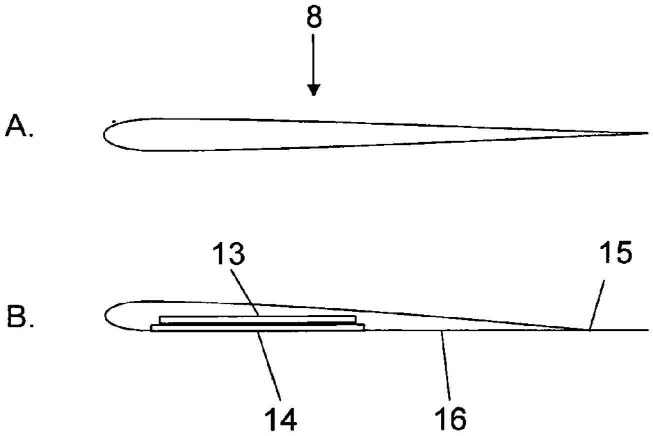


Figure 9

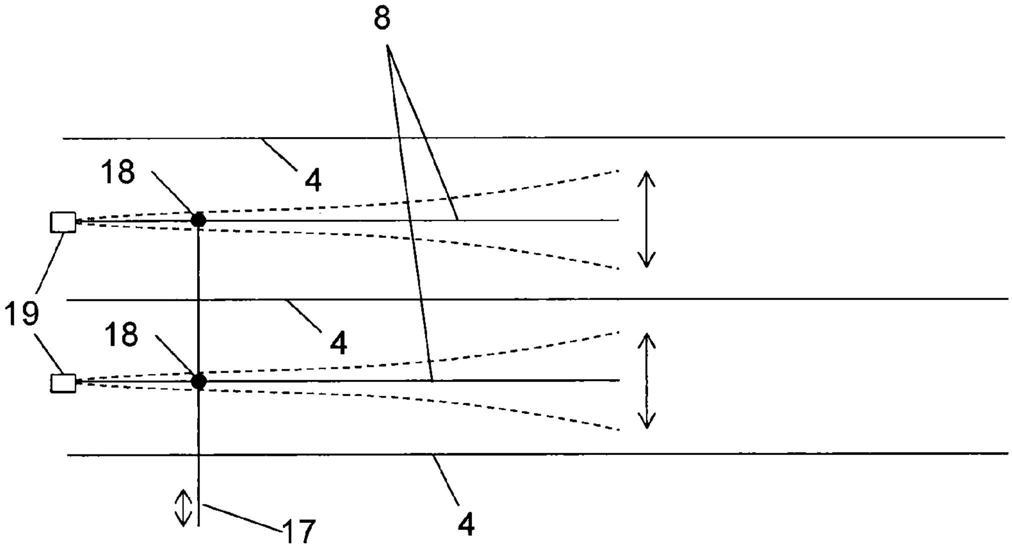


Figure 10

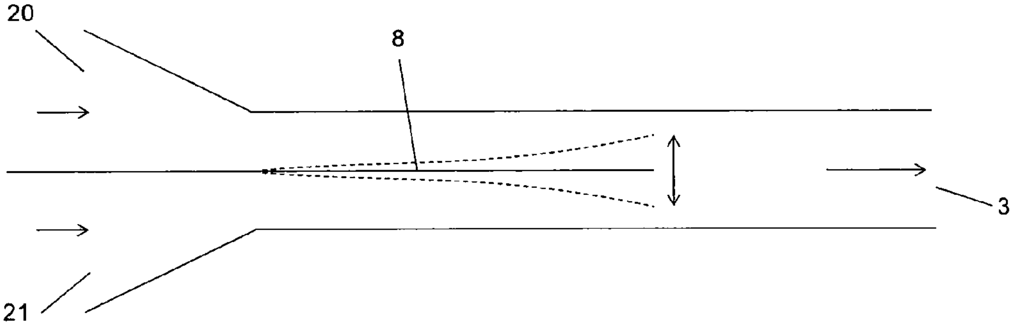


Figure 11

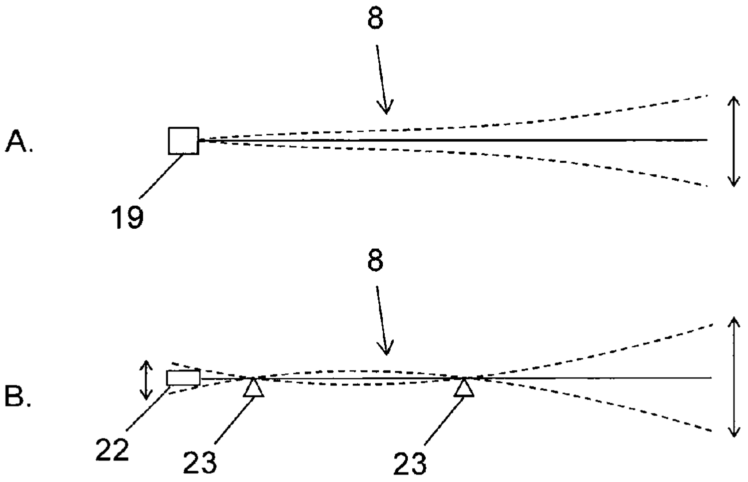


Figure 12

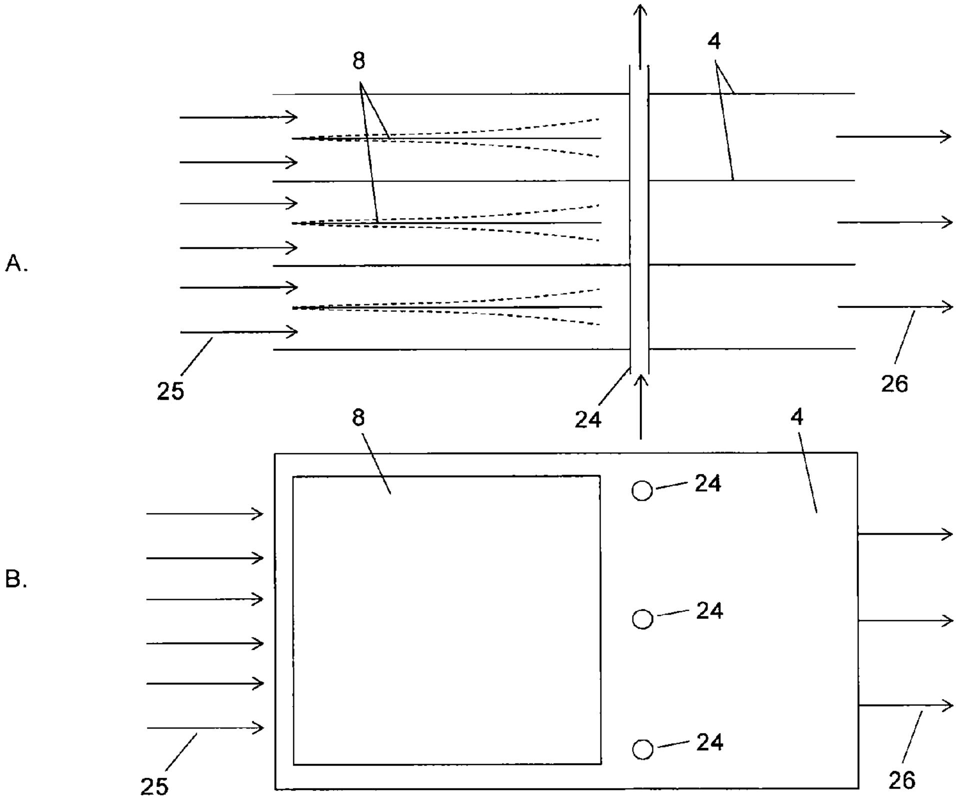


Figure 13

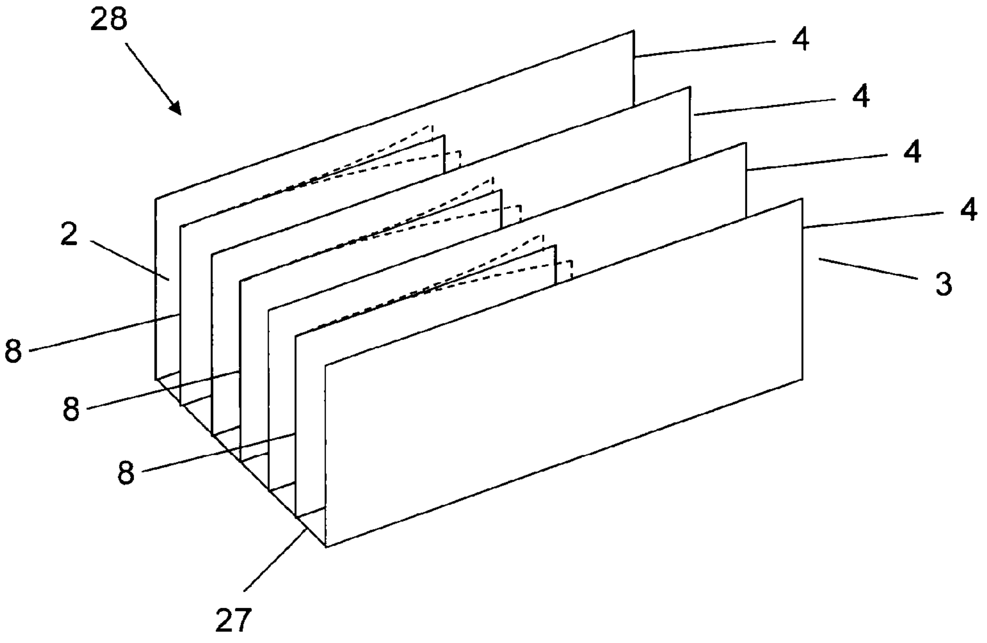


Figure 14

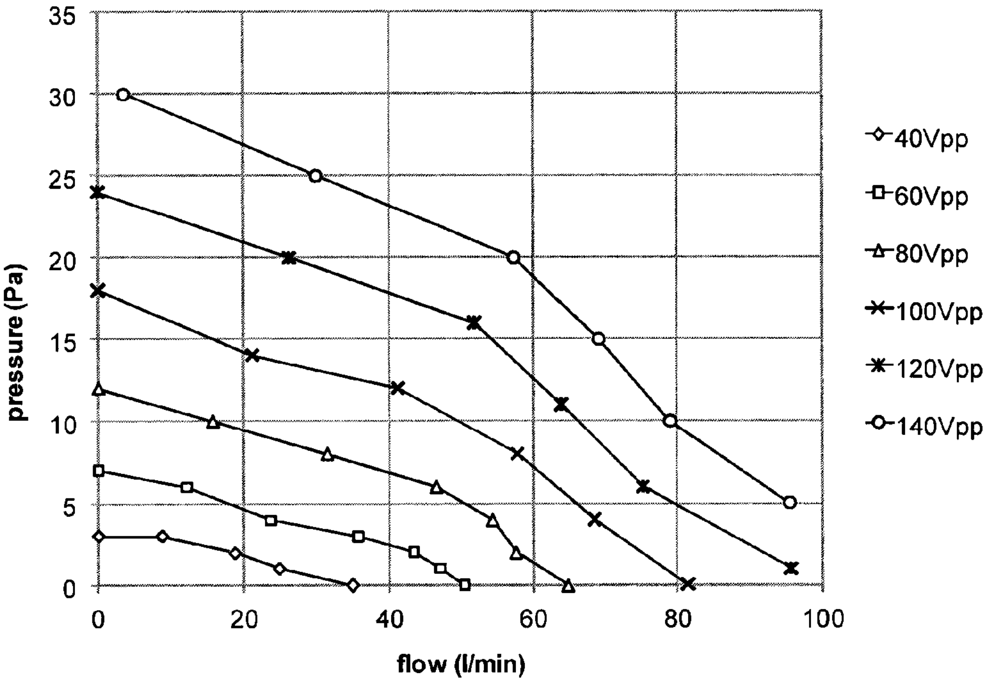


Figure 15

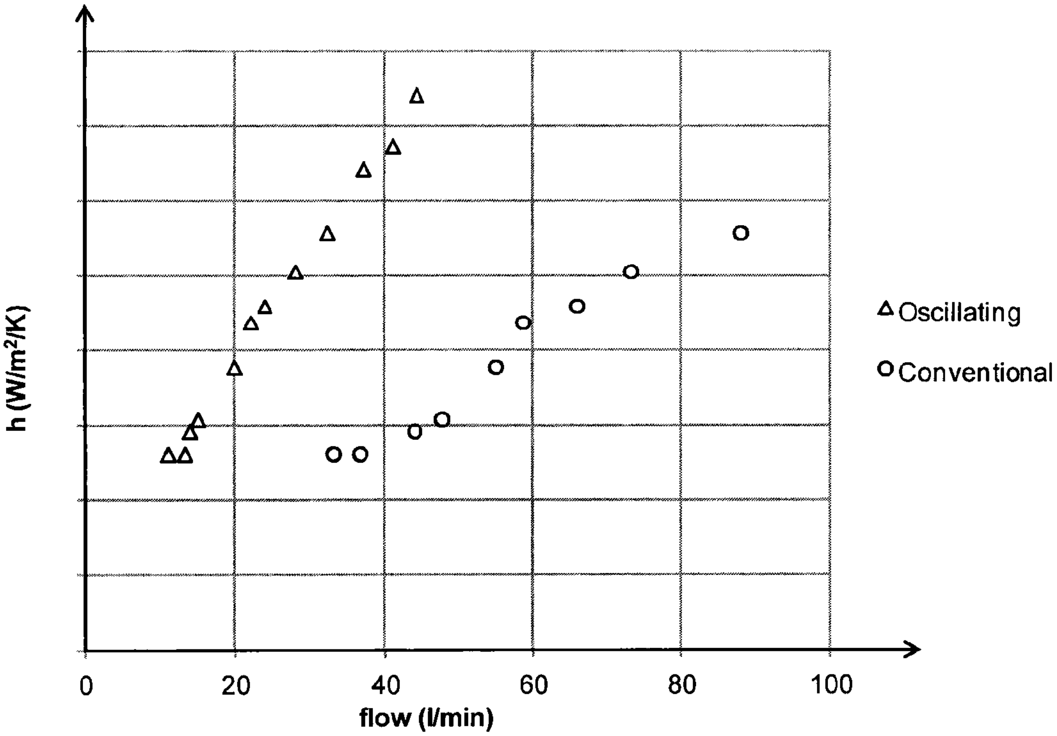


Figure 16

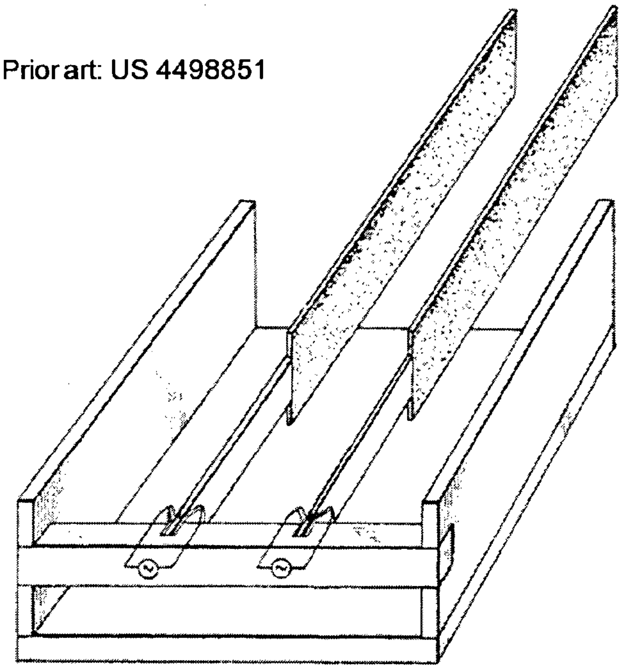


Figure 17

Prior art: US 5861703

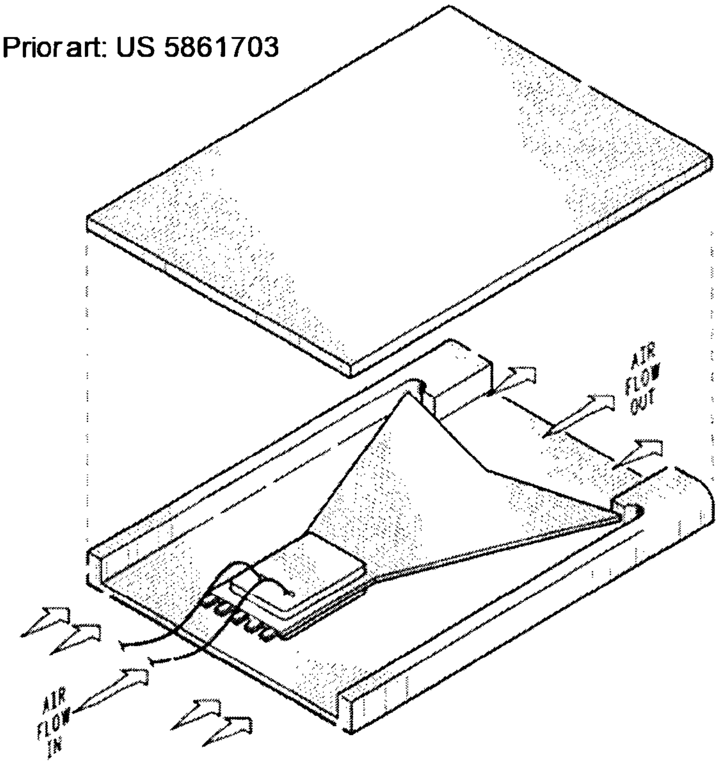


Figure 18

Prior art: US 4923000

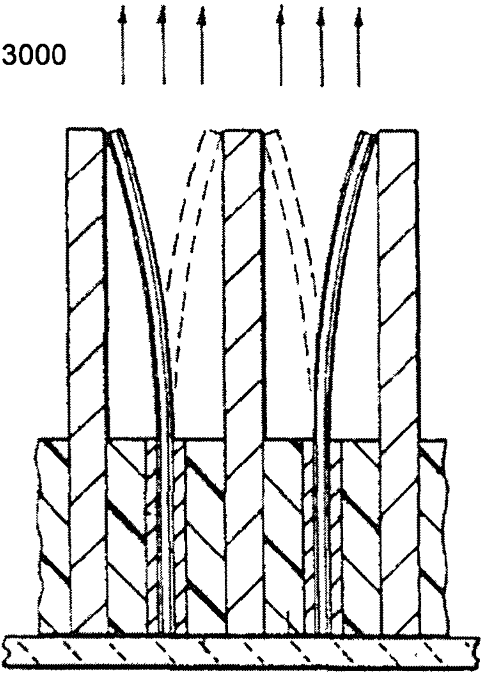
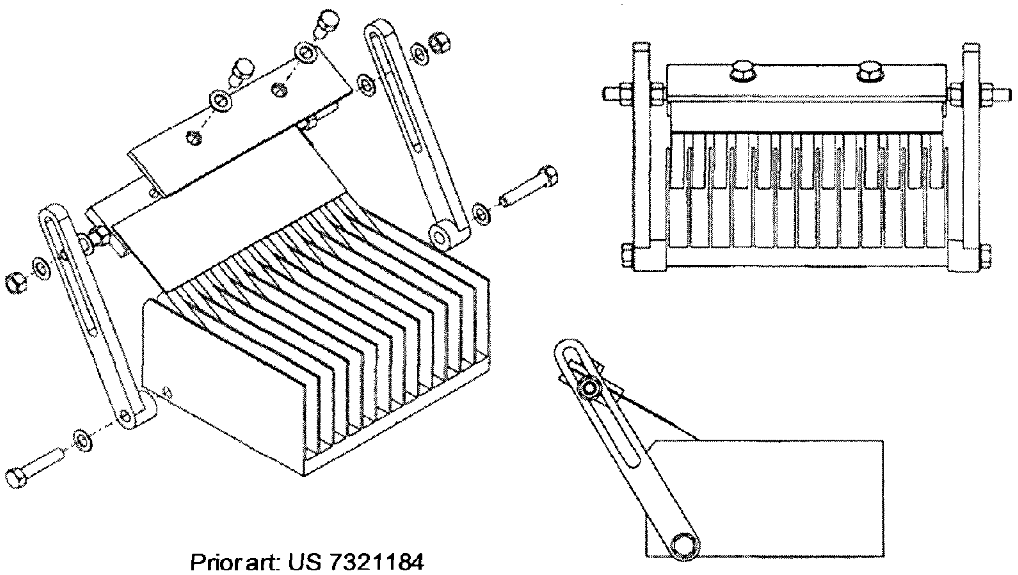


Figure 19



Prior art: US 7321184

Figure 20

Prior art: US 4834619

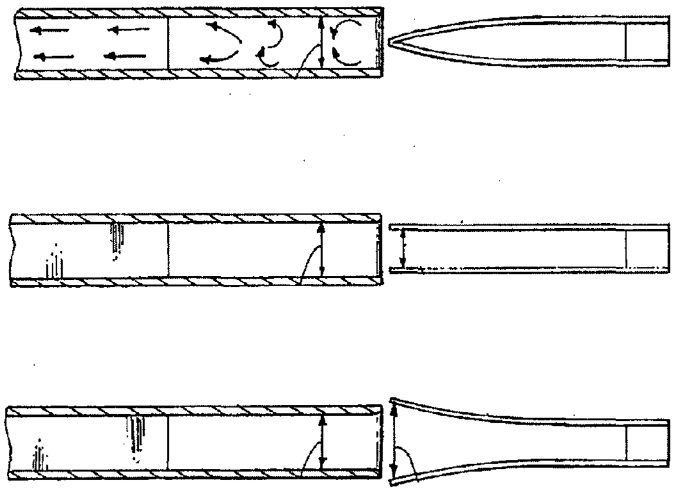
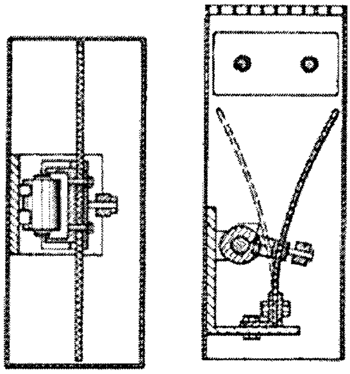
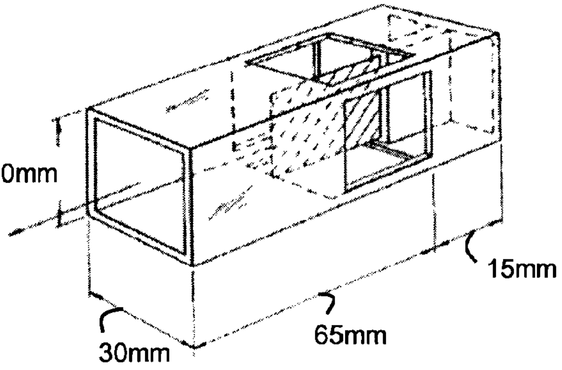


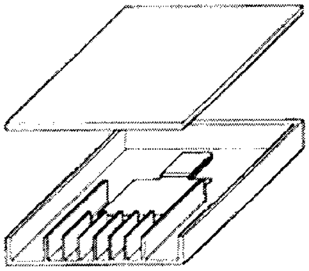
Figure 21



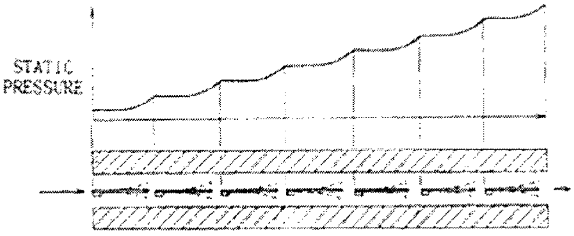
Prior art: FR2528500A1



Prior art: JPH0312493U



Prior art: JP2002339900A



Prior art: US5941694A

PUMP

[0001] This invention relates to a pump in which fluid is propelled by the oscillating motion of a flap. The flap is contained within a flow channel with side walls substantially parallel to the flap. In use, the flap motion generates a series of counter-rotating vortices which interact with the side walls, with the flap and with each other to generate a fluid flow. The vortices also have a mixing function and the pump can be used to exchange heat between the fluid being pumped and the side walls. The pump can also be used as a mixer to combine two inlet fluid flows to form a well-mixed outlet fluid flow.

[0002] We use the term fluid to refer to both gases and liquids. We use the term pump to refer to a device to create a flow of a fluid from an inlet to an outlet where the outlet pressure is higher than the inlet pressure, including liquid pumps, air pumps and air fans.

[0003] Rotating fans and pumps are well known for pumping gases and liquids. However the efficiency of these pumps tends to decrease as their size becomes small (typical dimensions of less than 5 cm), due to motor losses, bearing friction, viscous drag and blade tip leakage. The use of a rotating mechanism requires a bearing which may need lubrication, have a limited lifetime, or be vulnerable to dust.

[0004] Rotating fans and pumps are not well suited to generating in-plane fluid flow in thin devices, as axial flow fans and pumps generate flow perpendicular to their plane of rotation, and centrifugal fans and pumps require an axial inlet flow and tangential outlet flow. Therefore it is difficult to package rotating fans in a thin format suitable for laptop computers, portable electronic devices, and heat exchangers for semiconductor devices.

[0005] Rotating fans and pumps are often used to provide a fluid flow through a heat exchanger containing a set of heated or cooled fins. Use of separate fluid moving and heat exchange parts requires additional space and leads to reduced heat exchange performance by not making use of rotational fluid flows generated by the pump or fan to enhance thermal mixing and heat exchange performance.

[0006] Rotating fans and pumps usually have rotation speeds and blade passing frequencies in the audible range (100 Hz to 20 kHz), generating periodic noise. Rotating fans and pumps may also require high blade tip velocities (often greater than 10 ms), generating noise with a broad frequency spectrum. These noise sources can be undesirable in many situations.

[0007] Oscillating flap fans and pumps are known, in particular piezoelectric fans which often operate at frequencies of 50 Hz or 60 Hz. The low frequency requires a large amplitude of motion to achieve flap velocities of >1 ms which are typically required to generate significant flow. The large amplitude of motion limits use in thin devices. Currently known piezoelectric fans may be combined with a heat exchanger but are not optimised in choice of flow channel geometry surrounding the flap, oscillation frequency and amplitude, and use of aerodynamic flap profiles. This combination of factors results in currently known piezoelectric fans generating relatively weak fluid flows, in particular with low stall pressure.

[0008] The aim of the present invention is to overcome the disadvantages of the fans and pumps described above.

[0009] This invention relates to a fluid pump in which a substantially planar flap is positioned within a flow channel having an inlet and an outlet and bounded by two side walls. The side walls extend from the inlet to the outlet and are substantially planar and parallel to the flap. The height of the flow channel, h, is defined by the separation of the side walls.

[0010] The flow channel may also be bounded by a second pair of walls perpendicular to the side walls and parallel to the flow direction. We use the term edge walls to refer to this second pair of walls. The edge walls extend along the length of the flow channel from the inlet to the outlet. Preferably the flap extends across the entire width of the flow channel, save for a small gap to avoid contact between the flap and the edge walls.

[0011] The flap and flow channel may have several forms: rectangular, sector annular where the sector angle is less than 360°, or full (360°) annular. In the sector annular and full annular cases, the direction of fluid flow is in a radial direction and the lengths of the flap, side walls, edge walls and flow channel mean their respective dimensions in a radial direction and the widths of the flap, side walls and flow channel mean their dimensions in a circumferential direction.

[0012] The flow channel has height h and is bounded by side walls with length l_w and width w_w and separation h, where $l_w>h$ and $w_w>h$.

[0013] The flap has length l_f in the direction parallel to the fluid flow and width w_f in the direction perpendicular to the fluid flow such that $w_f>h$ and preferably $l_f>2h$ and $w_f>2h$. In the case of a flap having a sector annular or full annular form, the width of the flap w_f is taken to be the length of the edge of the flap nearest the outlet, taken along a circumferential path.

[0014] The pump may exploit a geometric flow velocity amplification effect in which the ratio of fluid flow velocity to flap velocity increases in proportion to l_f/h, so it is preferable to increase the ratio l_f/h in order to increase pump performance.

[0015] It is also preferable to minimise fluid flows in directions perpendicular to the flow direction as these are wasteful and may reduce the pump performance and efficiency. These perpendicular flows may occur between the sides of the flap and the edge walls of the flow channel, and their negative impact on pump performance and efficiency can be reduced by increasing the ratio of the flap width w_f to the flow channel height h such that $w_f>2h$. It follows that the flow channel width which is wider than the flap it encloses is also substantially greater than the flow channel height.

[0016] In order to generate a strong flow and pressure rise, it is important that the side walls extend downstream of the flap by a distance l_d where $l_d>l_f/2$ and preferably $l_d>2h$. Within the length l_d downstream of the flap the side walls are continuous and the flow channel between the side walls is substantially free from additional structures. The substantially unobstructed flow channel downstream of the flap is required to allow space for interactions of vortices with each other and with the side walls. These interactions generate a pressure rise downstream of the flap and increase the pump performance.

[0017] Individually some of these features are known in the prior art:

[0018] U.S. Pat. No. 4,498,851 describes oscillating flaps to generate a fluid flow.

[0019] U.S. Pat. No. 4,923,000 shows walls parallel to flaps but not extending downstream of the flap.

[0020] U.S. Pat. No. 5,861,703 shows walls parallel to flap but not extending significantly downstream of the flap.

[0021] U.S. Pat. No. 7,321,184 shows walls perpendicular rather than parallel to the flap.

[0022] U.S. Pat. No. 4,834,619 shows walls downstream of the flap and parallel to the flap but not forming a flow channel surrounding the flap.

[0023] FR2528500A1 shows an oscillating flap in a flow channel, but the flow channel does not have an unobstructed region downstream of the flap.

[0024] JP2002339900A shows an oscillating flap in a flow channel, but the downstream region of the flow channel contains additional structures and which form smaller channels not satisfying the condition that channel width is substantially greater than channel height. US20110064594A1 also cites the design described in JP2002339900A as an example of prior art.

[0025] JPH0312493U shows an oscillating fan in a channel with square cross-section, while the current invention requires a flow channel and flap with width greater than the height. Additionally, JPH0312493U shows inlets beside the flap while the current invention requires side walls in this region.

[0026] U.S. Pat. No. 5,941,694A shows multiple flaps in a flow channel but these flaps to not have an unobstructed region of flow channel extending downstream by more than twice the side wall separation.

[0027] A flow channel with an unobstructed region immediately downstream of the flap is required to provide a space for interaction of vortices with each other and with the side walls to provide a pressure rise downstream of the flap and thereby to improve the pump performance. In this invention we describe a combination of geometry of flow channel and geometry and motion of oscillating flap that is required for high pump performance, and this combination is not known in the prior art.

[0028] A further benefit of the unobstructed region of flow channel downstream of the flap is to provide space for the vortices to mix the fluid, which is useful in the case where the pump acts as a mixer or heat exchanger.

[0029] The pump is equipped with an actuator which provides an oscillating force or torque to drive oscillatory motion of the flap.

[0030] In use, the direction of flap motion is substantially perpendicular to the side walls and the motion of the flap has larger amplitude near the outlet than near the inlet, causing the flap to create and shed vortices in the fluid being pumped, with interaction of the vortices with each other, with the flap and with the side walls creating a fluid flow and pressure rise downstream of the flap. The side walls contain the vortex street generated by the flap oscillation and increase the fluid flow and pressure, compared to a piezoelectric fan not provided with side walls of the geometry shown in FIG. **1**.

[0031] The mechanism of generating fluid movement for propulsion by oscillating motion of flaps or aerofoils is well known in nature and is used by fish and birds for swimming and flying. This mechanism has also been investigated for ship propulsion and for micro-aerial vehicles. In the present invention, the flapping propulsion mechanism is enhanced by providing static side walls that extend downstream of the oscillating flap.

[0032] A qualitative explanation of the flow generation mechanism is given below, in terms of vortices generated by the flap and their interactions with the side walls. The side walls can be conceptually replaced by image line and sheet vortices. The image line vortices have the opposite sense of rotation to the real vortices in the flow channel, such that the wall-perpendicular velocity components of a real and image vortex pair sum to zero. The image sheet vortices at the wall locations provide zero slip at the walls. These vortex sheets occur in pairs separated by stagnation points at the wall. The sheet vortices exert shear forces on the fluid in the flow channel and diffuse into the flow channel at a rate depending on the fluid viscosity. The net effect of the sheet vortices is to exert a downstream force on the fluid, causing fluid in the flow channel to move from the inlet to the outlet.

[0033] The cross-section of the flap and flow channel perpendicular to the width direction may be substantially uniform across the width of the pump, so that different designs with increased or decreased width and flow rate can be created easily and can share common manufacturing processes.

[0034] The flap may have an aerodynamic or aerofoil shape or a thin trailing edge to enhance vortex formation and shedding and to reduce drag.

[0035] There may be a piezoelectric or magnetostrictive bending actuator incorporated into or mounted on the flap.

[0036] The flap may be driven by a remote actuator using a mechanical connection or a hydraulic or pneumatic drive.

[0037] The flap may be driven by electrostatic or magnetic forces.

[0038] The flow channel inlet may be divided into two regions to combine two fluid inlet streams, such that in use, the motion of the flap generates vortices and causes the two inlet fluid streams to be pumped and mixed downstream of the flap.

[0039] There may be a temperature difference applied between one or both side walls and inlet fluid stream, such that in use, the motion of the flap generates vortices causing the inlet fluid stream to be pumped and to exchange heat with one or both side walls, with the circulating flow of the vortices enhancing heat transfer. The motion of the flap may be driven at ultrasonic frequencies (>20 kHz) to provide operation inaudible to humans.

[0040] The motion of the flap may be driven at low frequencies (<400 Hz), below the frequency of peak sensitivity of the human ear, to provide quiet operation

[0041] The flap may have maximum peak-to-peak displacement, A, between 10% and 70% of the side wall separation. In any case, it is preferable that the flap does not impact the side walls during operation.

[0042] The flap oscillation frequency, f, may be chosen to give a Strouhal number, $St=fA/U$ between 0.1 and 0.5, where U is the average fluid flow speed in the flow channel. A Strouhal number in this range is found to provide efficient propulsion for a wide range of swimming and flying animals.

[0043] The amplitude of flap motion may be amplified by mechanical resonance of the flap.

[0044] The flap may be clamped at the edge near the inlet. Alternatively the flap may oscillate with fixed centre of mass and be supported by two pivot supports at nodal locations, or the flap may be supported by a flexible vibration isolating support.

[0045] An electromechanical actuator mounted on the flap may be provided with electrical connections using flexible support wires, or by a flexible circuit acting as a vibration isolating support.

[0046] The flap may have a flexible construction such that fluid loading causes non-sinusoidal motion of the flap.

[0047] The pump may contain two or more flaps, where the flaps move with out of phase motion to avoid noise and vibration.

[0048] The flap may be fabricated from a folded sheet metal structure with a laser-welded seam.

[0049] The pump may consist of an array of oscillating flaps contained within flow channels. A single actuator may drive multiple flaps.

[0050] The pump may contain an array of multiple flaps fabricated from a single sheet.

[0051] The pump may contain an array of flaps supported by a common support frame.

DESCRIPTION OF THE FIGURES

[0052] FIG. **1** shows a fluid pump **1** comprising a flow channel **10** with an inlet **2** and outlet **3**. The flow channel is bounded by side walls **4** and edge walls **6**. The flow channel contains a flap **8** with actuator **9** attached to the flap. The flap has length l_f and width w_f where preferably $w_f>2h$. The side walls and flow channel extend downstream of the flap by a distance l_d, where $l_d \geq l_f/2$ and preferably $l_d>2h$. It is preferable for the flap length l_f to satisfy the condition $l_f>2h$. The side walls have length l_w and width ww and satisfy the relationships $l_w>h$ and $w_w>h$.

[0053] FIG. **2** shows a plan view of the pump and flow channel, showing inlet **2**, outlet **3**, edge walls **6**, flap **8** and actuator **9** attached to the flap.

[0054] FIG. **3**A shows a side view of the pump and flow channel, showing inlet **2**, outlet **3**, side walls **4**, and flap **8**. The flap oscillates towards the side walls and the extreme positions of the flap are shown by dashed lines. The motion of the flap is larger at the end nearer the outlet **3** and this motion generates a series of counter-rotating vortices **5** forming a reverse von Kárman vortex street. In an inviscid approximation, the side walls can be replaced by image vortices **12** with opposite sense of rotation to the real vortices **5**. FIG. **3**B shows the variation of pressure with position along the flow channel. There is a pressure rise from inlet to outlet, indicating fluid pumping function. A substantial part of the pressure rise occurs downstream of the flap due to the interaction of the vortices with the side walls and due to the interactions of alternating vortex pairs which form jet flows oriented downstream.

[0055] FIG. **4** shows three forms of the pump in plan and section views, with the fluid flow directions indicated by arrows. FIG. **4**A show a rectangular form pump. FIG. **4**B shows a sector annular form pump, with the same topology as the rectangular form pump but formed into a curved shape. FIG. **4**C shows a full annular form pump in which the air flows radially outwards. It is also possible to create an annular pump in which the inlet and outlet locations are reversed with respect to those shown in FIGS. **4**B and **4**C, and the flap is arranged so as to generate a radial flow travelling inwards towards the inner edge of the pump.

[0056] FIG. **5**A shows a von Kárman street created by flow past a cylinder. The bluff body generates a drag wake composed of staggered counter-rotating vortices with interspersed jet flow oriented upstream. FIG. **5**B shows a streamlined foil which generates a reverse von Kárman street. This actively generated wake produces jet flow between alternating vortex pairs that is oriented downstream (after INTEG. AND COMP. BIOL., 42:243-257 (2002)).

[0057] FIGS. **6**A and **6**B illustrate the fluid flow in the flow channel at two points in time. Fluid velocity is indicated by arrows and contours of magnitude of vorticity are indicated by solid lines. The flap is also shown. FIG. **6**B illustrates the fluid flow and flap position at time approximately one quarter period of flap oscillation later than FIG. **6**A. Each vortex generates a vortex sheet at the wall to counter slip velocity induced by an image vortex of the type described in FIG. **3**. Generation of a new vortex pulls the previous vortex over to same side, so the resulting vortex pair generates a pair of wall sheet vortices of opposing senses separated by a stagnation point. The pair of sheet vortices exert shear forces on the fluid with opposite directions, but the downstream shear forces dominate creating a net downstream force on the fluid and generating a fluid flow.

[0058] FIG. **7**A shows fluid motion generated by an oscillating flap **8**. Time-averaged fluid flow is from left to right and vortices **5** generated by the oscillating flap are shown downstream of the flap. FIG. **7**B shows temperature contours **31** in the fluid flow generated by an oscillating flap in the case where there is a temperature difference between heated or cooled side walls **29** and the fluid at the inlet **2**. Upstream of the flap a boundary layer **30** grows in thickness, slowing heat transfer. Downstream of the flap, vortices disrupt the boundary layer and speed up heat transfer.

[0059] FIG. **8**A shows the cross-sectional shape of an aerodynamically shaped flap **8**. FIG. **8**B shows a similarly shaped flap containing a bending actuator containing a piezoelectric or magnetostrictive layer **13** and an elastic layer **14**.

[0060] The aerodynamic shape can be created by folding a sheet of material **16** and joining the sheet to itself at a line **15** located between the bending actuator and the downstream end of the flap.

[0061] FIG. **9** shows two oscillating fans **8** driven by a single actuated rod **17** connected to each fan by a pivot support **18**. Clamps **19** prevent movement at one end of the flaps, while the couple generated by the combination of clamping force and driving force causes motion at the other end of the flaps.

[0062] FIG. **10** shows a pump with two inlets **20**, **21** and one outlet **3**. Flow is driven from the inlets to the outlet by an oscillating fan **8** which also causes the inlet fluid flows to become mixed by the vortex-rich flow generated by the oscillating fan.

[0063] FIG. **11**A shows an oscillating fan **8** supported by a clamp **19** at one end and oscillating in a fundamental bending mode at the other end. FIG. **11** B shows an oscillating fan **8** vibrating about its centre of mass, supported by two pivot supports **23** which do not constrain the angle of the fan, and with a mass **22** attached to one end of the fan such that the amplitude of motion at the other end of the fan is larger.

[0064] FIG. **12** shows a heat exchanger with inlet fluid flow **25** driven by oscillating fans **8** between static walls **4**. The static walls are in thermal contact with pipes **24**. The pipes may contain a pumped circulating flow of heat-carrying fluid, or they may be heat pipes containing liquid and vapour transported by evaporation and condensation processes and capillary forces, or they may be solid conductors. FIG. **12**A shows a side view and FIG. **12**B shows a plan view.

[0065] FIG. **13** shows a heat exchanger **28** with integrated array of fans **8** and static walls **4** which also serve as heat sink fins, conducting heat to or from the base of the heat exchanger **27**. A fluid flows from the inlet **2** to the outlet **3**. When used as a heat sink, heat flows from the fins to the fluid. When used as a device to cool a fluid, heat flows from the fluid to the fins. The motion of the fins **8** is indicated by dotted lines and is substantially perpendicular to the static walls.

[0066] FIG. **14** shows load curves for an oscillating fan device driven at voltages from 40 Vpp to 140 Vpp using a piezoelectric bimorph bending actuator oscillating at approximately 250 Hz. In this case fluid being pumped is air and the approximate dimensions of the device are:

side wall separation, h:	9 mm
flap width, w_f:	63 mm
flap length, l_f:	31 mm
side wall width, w_w:	64 mm
total side wall length, l_w:	80 mm
downstream length, l_d:	49 mm

[0067] FIG. **15** compares the heat transfer provided by the oscillating fan with the heat transfer provided by a conventional rotating fan, as a function of air flow rate through a heat exchanger. The oscillating fan provides significantly greater the heat transfer than a rotating fan operating at the same air flow rate.

[0068] FIGS. **16**, **17**, **18**, **19**, **20** and **21** show examples of the prior art.

1. A fluid pump comprising:

a flow channel containing an fluid inlet and a fluid outlet and bounded by two side walls,

a substantially planar flap positioned inside the flow channel, and

an actuator capable of transmitting an oscillating force or torque to the flap,

where the side walls extend from the inlet to the outlet and are substantially planar and parallel to the flap and extend beyond the downstream and of the flap towards the outlet by a distance such that $l_d \geq l_f/2$, where l_f is the length of the flap,

where the side wall separation, h, length l_w, and width, w_w, satisfy the relationships: $l_w > h$ and $w_w > h$,

whereby in use, the actuator drives oscillatory motion of the flap in a direction substantially perpendicular to the side walls with motion of the flap having larger amplitude near the outlet than near the inlet.

2. A pump according to claim **1**, where the region of flow channel between the flap and the outlet is substantially unobstructed.

3. A pump according to claim **1**, wherein the flap length l_f satisfies the condition $l_f > 2h$.

4. A pump according to claim **1**, where the side walls extend beyond the downstream end of the flap towards the outlet by a distance l_d such that $l_d > 2_h$.

5. A pump according to claim **1**, where the where the flap width, w_f, satisfies the condition $w_f > 2h$.

6. A pump according to claim **1**, where the flap and flow channel have sector annular forms.

7. A pump according to claim **1**, where the flow channel is also bounded by one or more edge walls, where the edge walls are perpendicular to the side walls and parallel to the flow direction.

8. A pump according to claim **1**, where the flap and flow channel have full annular forms.

9. A pump according to claim **1**, where motion of the flap causes creation and shedding of vortices into the fluid being pumped, with interaction of the shed vortices with the side walls, with each other and with the flap creating a pressure rise downstream of the flap.

10. A pump according to claim **1**, where the flap has an aerodynamic or aerofoil shape or a thin trailing edge.

11. A pump according to claim **1**, where the flap has substantially uniform cross-section perpendicular to the width direction.

12. A pump according to claim **1**, where a piezoelectric or magnetostrictive bending actuator is incorporated into or mounted on the flap.

13. A pump according to claim **1**, where the flap is driven by a remote actuator using a mechanical connection or a hydraulic or pneumatic drive.

14. A pump according to claim **1**, where the flap is driven by electrostatic or magnetic forces.

15. A pump according to claim **1**, where the flow channel inlet is divided into two regions to combine two fluid inlet streams and, in use, the motion of the flap generates vortices causing the two inlet fluid streams to be pumped and mixed downstream of the flap.

16. A pump according to claim **1**, where a temperature difference is applied between the side walls and inlet fluid stream, such that in use, the motion of the flap generates vortices causing the inlet fluid stream to be pumped and to exchange heat with one or both side walls.

17. A pump according to claim **1**, where the motion of the flap is driven at ultrasonic frequencies (>20 kHz).

18. A pump according to claim **1**, where the motion of the flap is driven at low frequencies (<400 Hz).

19. A pump according to claim **1**, where maximum peak-to-peak displacement of the flap, A, is between 10% and 70% of the side wall separation, h.

20. A pump according to claim **1**, where the oscillation frequency, f, is chosen to give a Strouhal number, $St = f\,A/U$ between 0.1 and 0.5, where U is the average fluid flow speed in the flow channel.

21. A pump according claim **1**, where the amplitude of flap motion is amplified by mechanical resonance of the flap.

22. A pump according to claim **1**, where the flap is clamped at the edge near the inlet.

23. A pump according to claim **1**, where the flap oscillates with fixed centre of mass and is supported by two pivot supports at nodal locations or is supported by a flexible vibration isolating support.

24. A pump according to claim **1**, where an electromechanical actuator mounted on the flap is provided with electrical connections by using flexible support wires or a flexible circuit acting as a vibration isolating support.

25. A pump according to claim **1**, where the flap has flexible construction such that fluid loading causes non-sinusoidal motion.

26. One or more pumps according to claim **1**, including a total of two or more flaps, where the flaps move with out of phase motion to avoid noise and vibration.

27. A pump according to claim **1**, where the flap includes a folded sheet structure with a welded or adhesive bonded seam.

28. An array of pumps according to claim **1**.

29. A heat exchanger containing an array of devices as claim **1**.

30. An array of devices according to claim **1** where a single actuator drives multiple taps.

31. An array of devices according to claim **1** where multiple flaps are fabricated from a single sheet.

32. An array of devices according to claim **1** where multiple flaps are supported in a common support frame.

* * * * *