US 20060065785A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0065785 A1**

Enig et al. (43) **Pub. Date: Mar. 30, 2006**

(54) **HOSE-AND-DROGUE IN-FLIGHT REFUELING SYSTEM**

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(21) Appl. No.: **11/044,199**

(22) Filed: **Jan. 28, 2005**

Related U.S. Application Data

(62) Division of application No. 10/226,134, filed on Aug. 23, 2002, now Pat. No. 6,926,049.

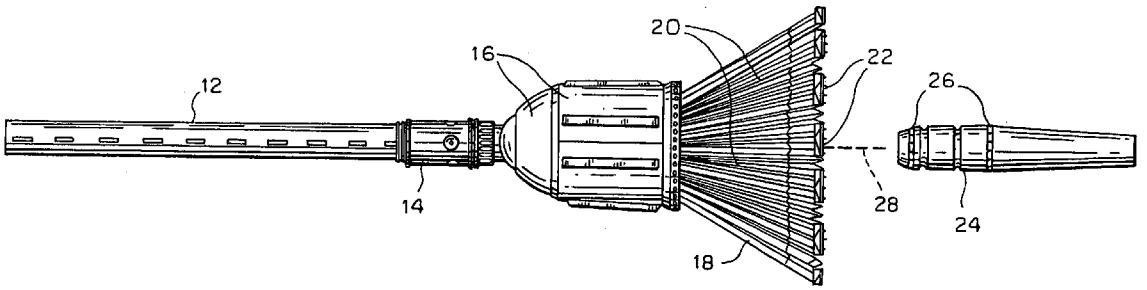
Publication Classification

(51) **Int. Cl.**
B64D 39/00 (2006.01)

(52) **U.S. Cl.** ..... **244/135 A**

(57) **ABSTRACT**

An in-flight hose-and-drogue refueling system composed of: a refueling hose-and-drogue unit extending from a refueling aircraft for engaging with a refueling probe of an aircraft to be refueled and; a drogue steering assembly for steering the drogue, the drogue steering assembly including a plurality of individually controllable, compressed air driven thrusters, and a compressed air supply line extending along the hose for supplying compressed air to the thrusters, wherein the hose and the supply line form a unit having a circular outline.



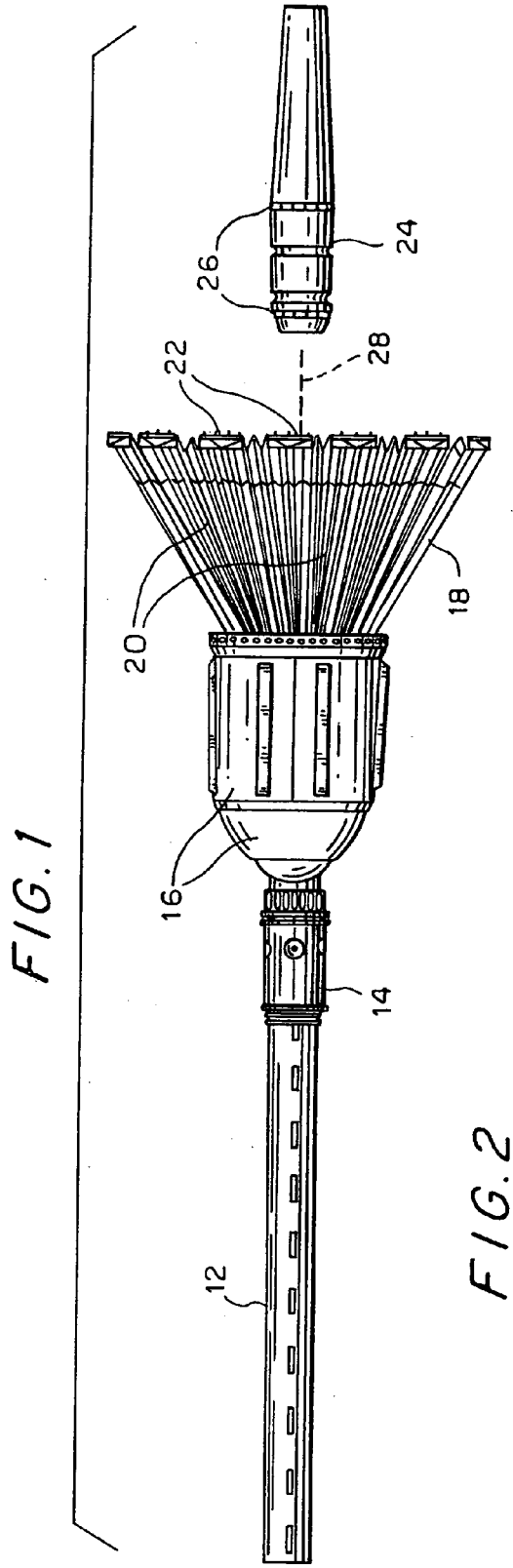


FIG. 1

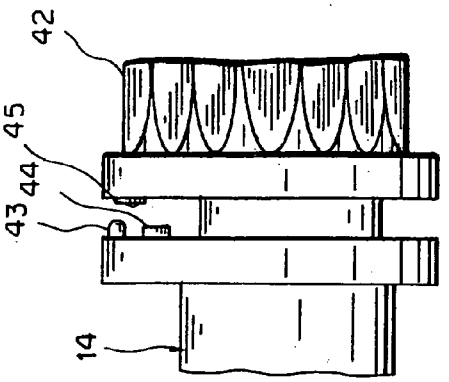


FIG. 2A

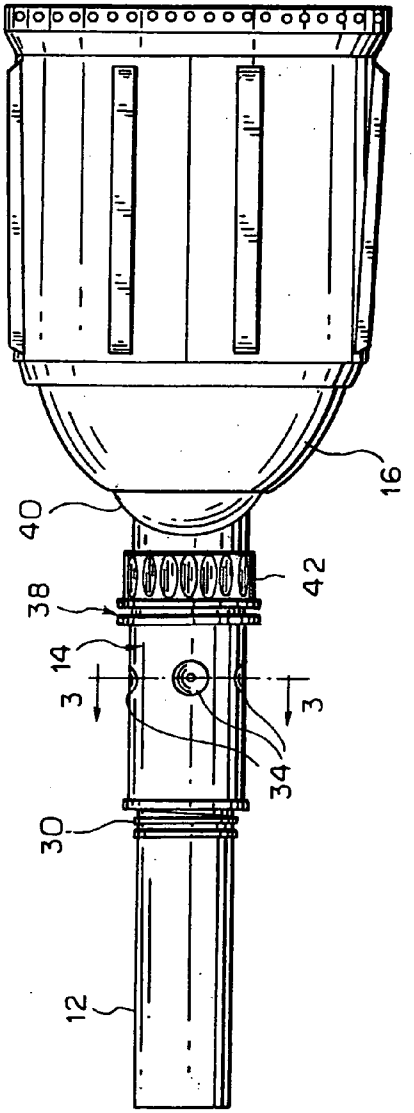


FIG. 2

FIG. 3

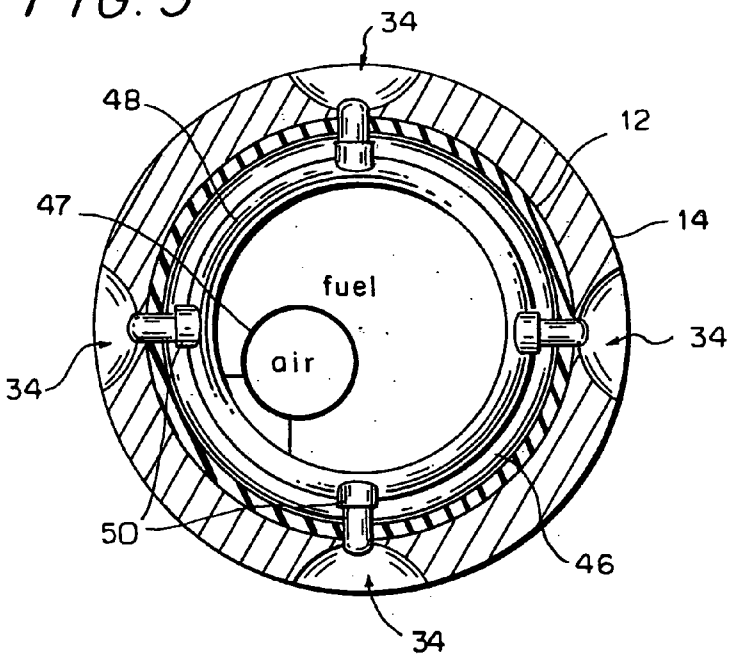


FIG. 3A

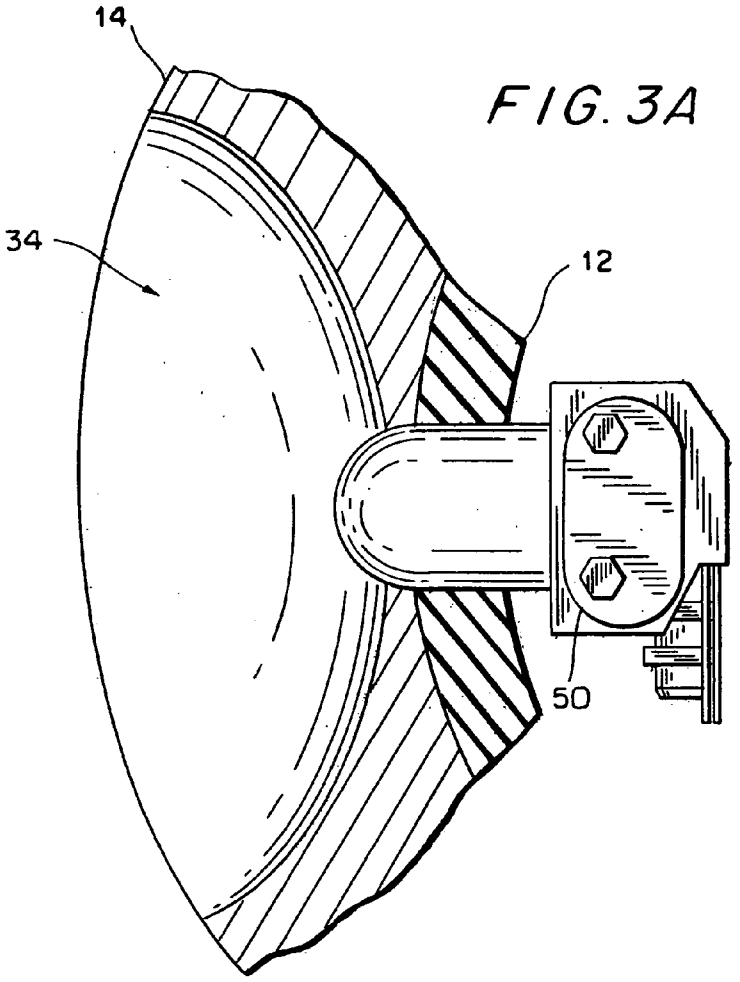


FIG. 4C

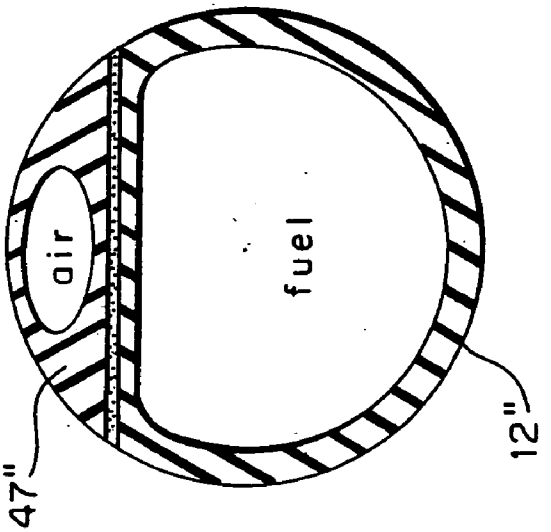


FIG. 4B

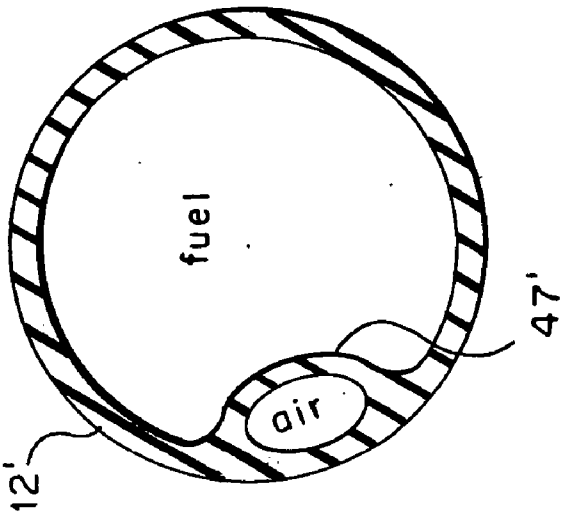
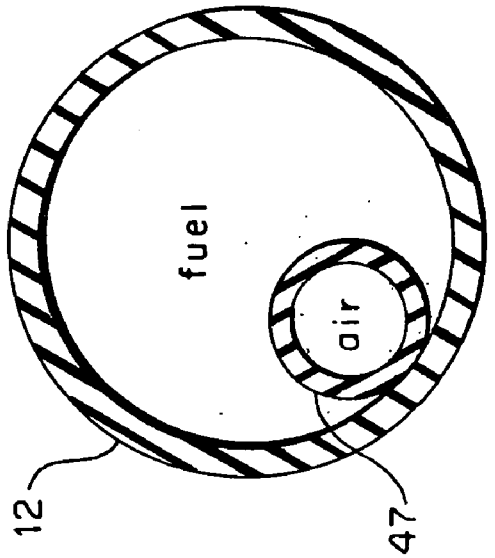


FIG. 4A



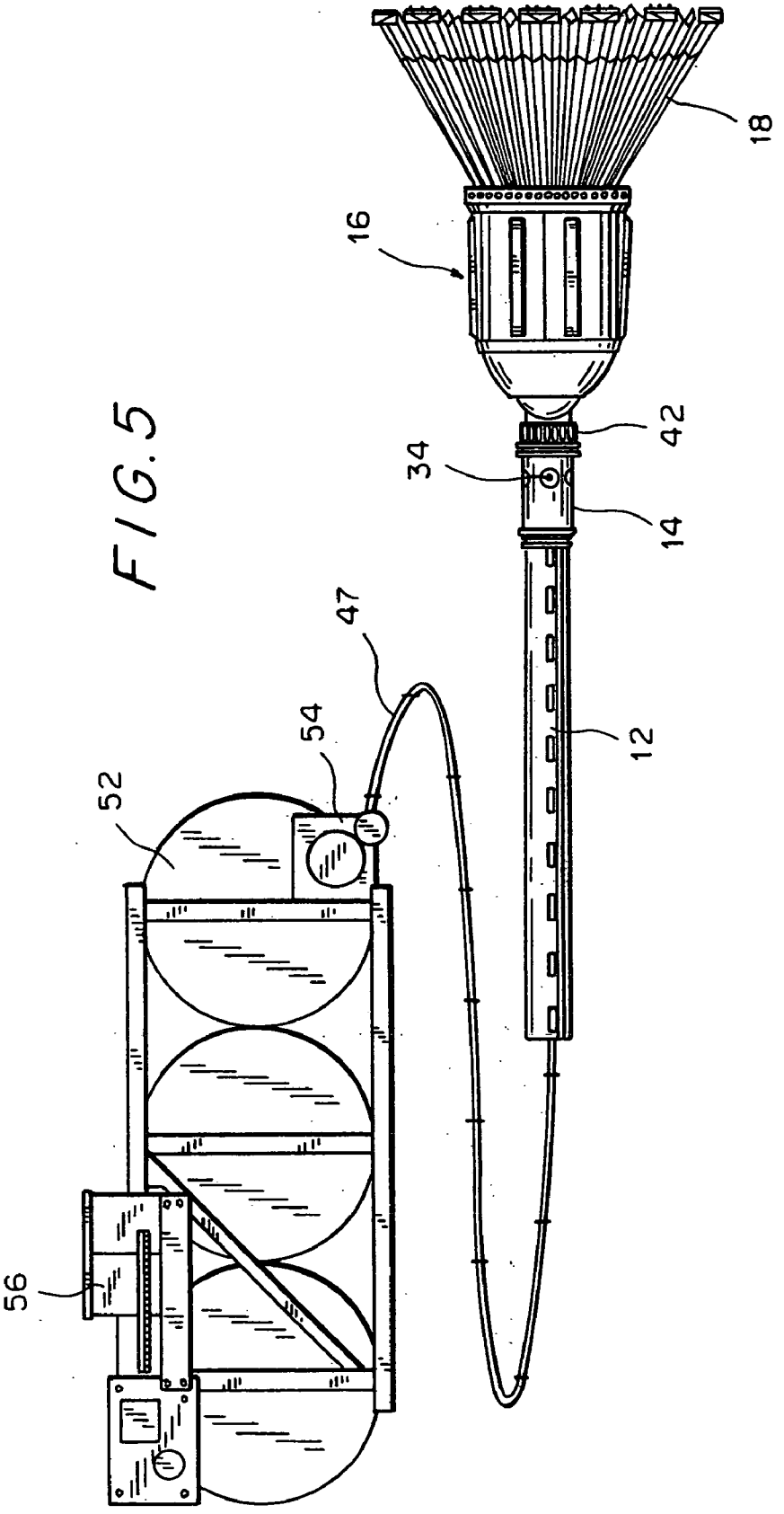


FIG. 5

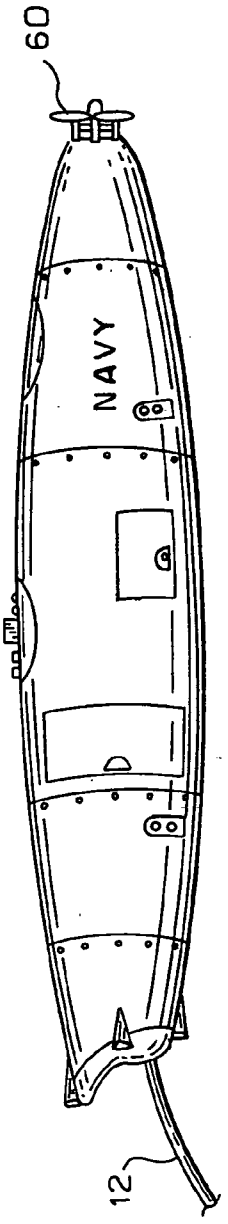


FIG. 6

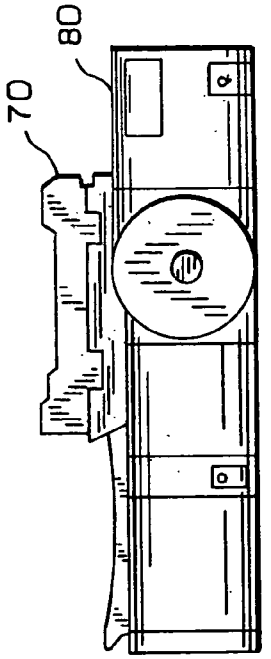


FIG. 7B

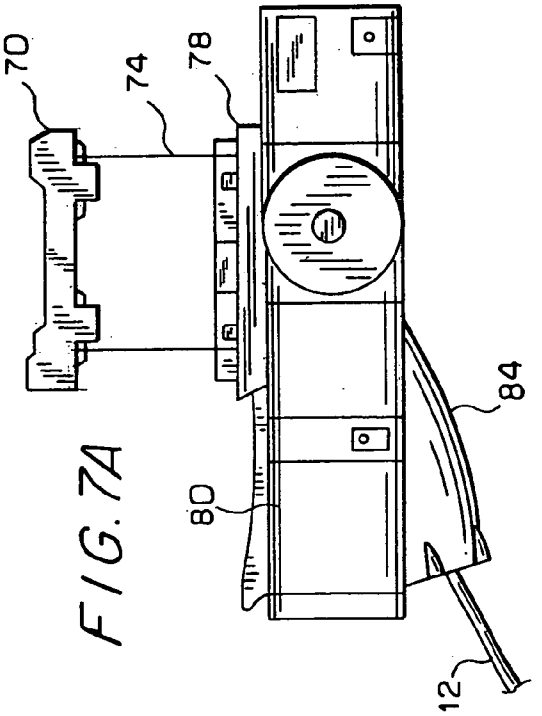


FIG. 7A

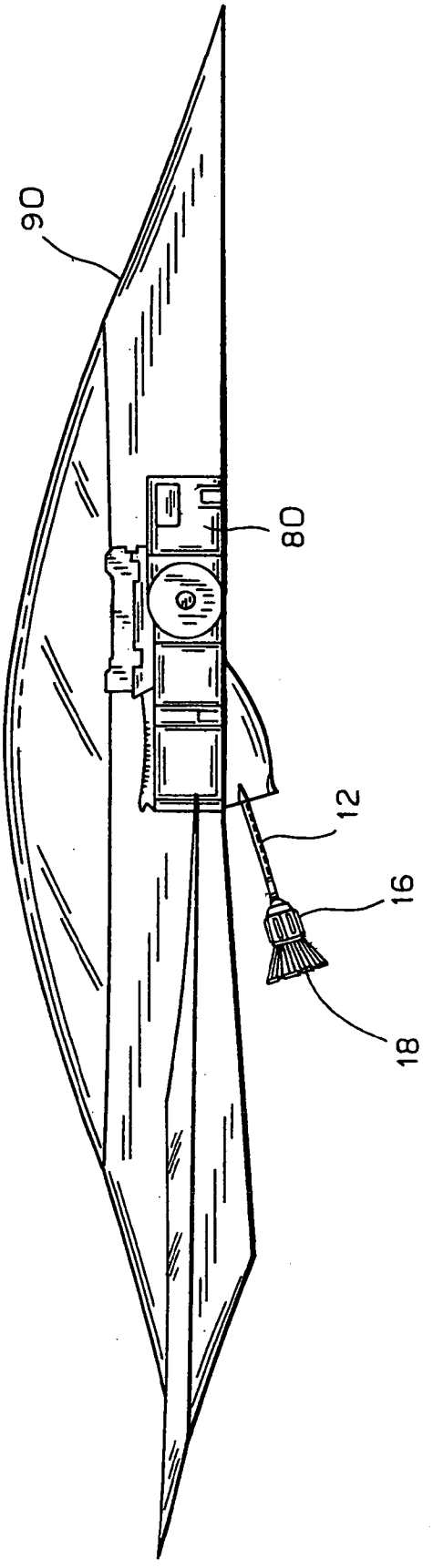
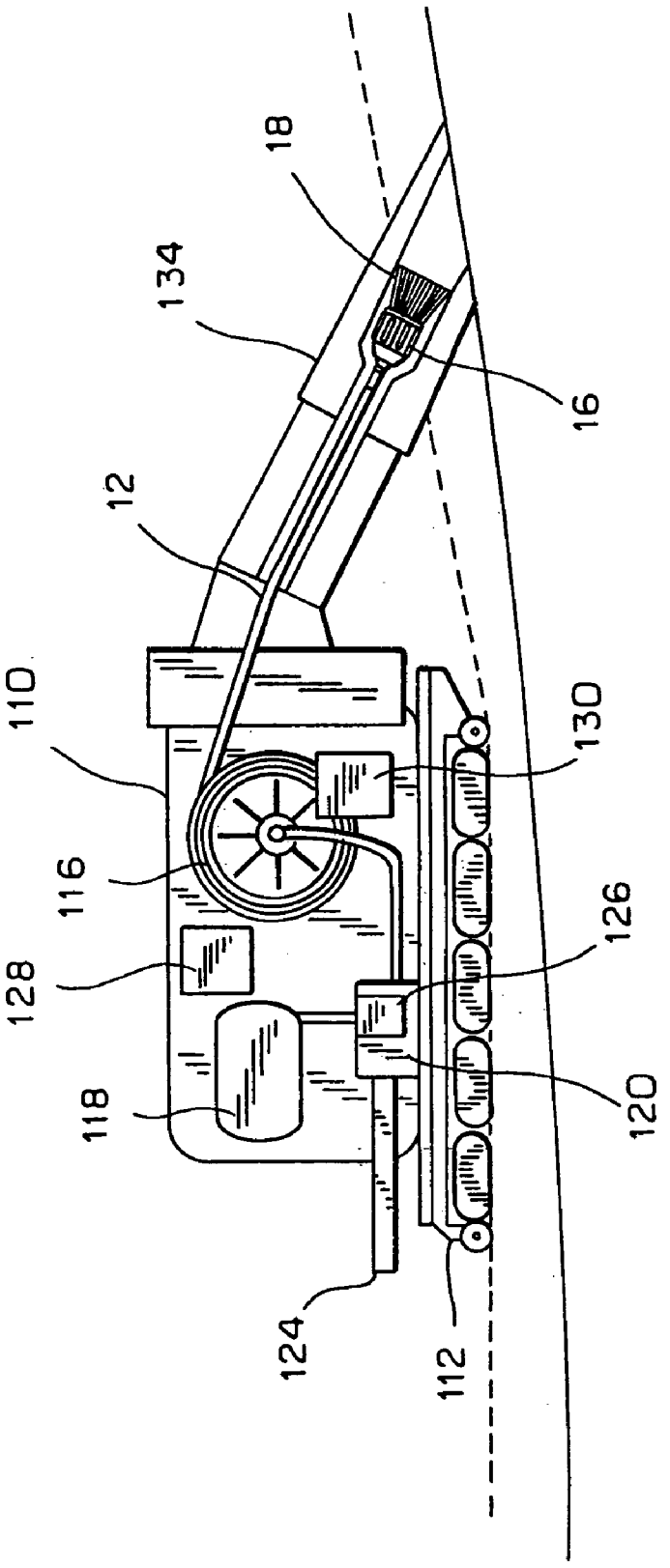


FIG. 8

FIG. 9



HOSE-AND-DROGUE IN-FLIGHT REFUELING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This is a division of application Ser. No. 10/226,134, filed on Aug. 23, 2002, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to automatic hook-up of a hose-and-drogue aerial refueling apparatus to a receiver aircraft probe and, more particularly, to apparatus and methods for in-flight hose-and-drogue refueling using electrooptical technology.

[0003] The usefulness of air refueling became apparent to the military almost as soon as they started using aircraft. The main advantage of air refueling is obvious: it enables aircraft to stay airborne longer. Since most aircraft are incapable of taking off with maximum fuel and full payload, without in-flight refueling there is always a balance to be struck between range, payload, and fuel. Air refueling is more than just a range stretcher: it allows one to carry out missions with a smaller number of sorties, or alternatively, fewer aircraft.

[0004] One approach to in-flight refueling is the hose-and-drogue system, in which a drogue attached to a fuel hose is extended from the refueling aircraft's belly or wings. The receiver aircraft is equipped with a fixed or retractable probe and the receiving aircraft's pilot flies the probe into the drogue.

[0005] The advantages of the hose-and-drogue system are the following: (a) up to three receivers can take fuel simultaneously; (b) if one hose/drogue unit (HDU) becomes unserviceable, the tanker still can offload its fuel; (c) the HDU is inherently safer than the heavy, rigid boom, which is restricted in its movements; (d) it is easier to install on non-purpose-built aircraft; and (e) it is compatible with most receivers, e.g., fixed wings, as well as rotorcraft.

[0006] There were, however, two disadvantages to early hose and drogue system: it has lower fuel transfer rates than the boom system, and the drogue is uncontrollable and is susceptible to winds and gusts. In bad weather conditions and particularly in low level refueling situations the hookup process was very difficult and demanded excessive receiving aircraft pilot maneuvers. Since the aircraft &o be refueled was likely to be already low on fuel, excessive maneuvering could result in the necessity to abandon the aircraft.

[0007] U.S. Pat. No. 5,326,052, which issued to Krispin et al. on Jul. 5, 1994 (hereinafter the '052 patent), and the entire disclosure of which is incorporated herein by reference, discloses a system designed to overcome the problem of drogue instability by providing a system with means for both drogue steering and drogue motion measurement, thus enabling either stabilization of the drogue or, alternatively, fully automatic hookup.

[0008] Specifically, the system disclosed in the '052 patent includes a plurality of miniature, pressurized gas thrusters mounted, preferably equally spaced, on the perimeter of a drogue in such way that activation of any thruster generates a force in a direction perpendicular to the fuel outlet nozzle. In principle, four thrusters are sufficient. Two are required to control the drogue in up-and-down motion and two in the sideways motion. The position of the drogue is measured by electrooptical position-sensing devices.

[0009] The measurement system consists of a plurality of light sources (LS) such as Light Emitting Diodes (LEDs) or Laser Diodes (LDs) mounted at a certain distance from the end of the receiving fuel probe, a plurality of sensors each comprising a lens and a position-measuring photodetector that is mounted on the perimeter of the drogue with its sensitive area directed toward the receiving aircraft, and a processing electronic circuit for calculating the position of the light-source assembly relative to the detector assembly and computing the control commands to the thrusters.

[0010] In accordance with one preferred form of the invention disclosed in the '052 patent, the measured position of the drogue relative to the probe of the receiving aircraft is used to determine the control commands to the thrusters so that the drogue will track the position of the probe in order to achieve automatic hookup. In such an arrangement the pilot of the receiver aircraft is required to approach the vicinity of the tanker aircraft; once the two aircraft have closed to a certain distance, the automatic control system of the drogue is activated and guides the drogue until contact with the incoming probe has been achieved.

[0011] In accordance with an alternative form of the invention disclosed in the '052 patent, measurements are made of the drogue position relative to the tanker aircraft, either belly or wings, and are used to control the motion of the drogue so as to stabilize or, equivalently, to minimize the motion of the drogue relative to the tanker aircraft. In such an arrangement, the pilot of the receiver aircraft is required to track the drogue, which has been stabilized relative to the tanker. The tanker is much less susceptible to wind gusts and turbulence.

BRIEF SUMMARY OF THE INVENTION

[0012] The present invention provides a number of improvements to the systems disclosed in the '052 patent.

[0013] Specifically, the invention provides an in-flight hose-and-drogue refueling system comprising, in combination: a refueling hose-and-drogue unit extending from a refueling aircraft for engaging with a refueling probe of an aircraft to be refueled; and a drogue steering means for steering the drogue, said drogue steering means comprising a plurality of individually controllable, compressed air driven thrusters, and a compressed air supply line extending along the hose for supplying compressed air to said thrusters, wherein said hose and said supply line form a unit having a circular outline.

[0014] The invention further provides a refueling hose-and-drogue unit for airborne refueling of an aircraft, said unit comprising a hose, a drogue, an infitting that attaches said hose to said drogue, and a plurality of thrusters secured to said infitting and operable to control the position of said drogue in flight.

[0015] The invention further provides a refueling probe installable in an aircraft for engaging a drogue to enable the aircraft to be refueled in flight, said probe comprising a light source and electrical wires or optical fibers for supplying

lighting energy to said light source, wherein said probe comprises a tube having a wall and said electrical wires or optical fibers are embedded in said wall.

[0016] The invention further provides an in-flight hose-and-drogue refueling system comprising: a housing configured to be housed in a weapons bay of a military aircraft or to be suspended below an aircraft; and a refueling hose-and-drogue unit installed in said housing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] **FIG. 1** is an elevational view of the distal end of a hose-and-drogue refueling system according the invention.

[0018] **FIG. 2** is an elevational view showing several components of the system of **FIG. 1** to a larger scale.

[0019] **FIG. 2A** is a detail view of a portion of the structure shown in **FIG. 2**.

[0020] **FIG. 3** is cross-sectional view taken along line **3-3** of **FIG. 2**.

[0021] **FIG. 3A** is a detail view of a portion of the structure shown in **FIG. 3**.

[0022] **FIGS. 4A, 4B** and **4**C illustrate three possible forms of construction for a component of a system according to the invention.

[0023] **FIG. 5** is an elevational, pictorial view of one exemplary embodiment of a compressed air supply arrangement for use in a system according to the invention.

[0024] **FIG. 6** is an elevational view of one possible housing for a system according to the invention.

[0025] **FIGS. 7A and 7B** are elevational views of a second possible housing for a system according to the invention in two operating states.

[0026] **FIG. 8** is an elevational view of an aircraft equipped with the housing shown in **FIGS. 7A and 7B**.

[0027] **FIG. 9** is an elevational, pictorial view of a third possible housing for a system according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] **FIG. 1** is an elevational view of the distal end of a hose-and-drogue refueling system according the invention, together with the inlet end of a probe that extends from an aircraft that is to be refueled (not shown). The hose-and-drogue system includes a hose **12** for delivering fuel, an infitting **14** secured to the distal end of hose **12**, a coupler assembly **16** secured to the distal end of infitting **14**, that is the end remote from hose **12**, and a drogue, often referred to as a basket, **18** fixed to assembly **16**. Drogue **18** is provided with a series of ribs **20** that provide aerodynamic stability and carries, at its distal end, a group of position sensing devices (PSDs) **22**. Probe **24** is provided at its fuel-receiving end with two concentric rings of light sources **26** for producing light that is detected by PSDs **22**. The manner in which light sources **26** interact with PSDs **22** is described in detailed in the above-cited '052 patent. Essentially, PSDs **22** produce position signals that are used to actuate the thrusters in a manner to align the longitudinal axis **28** of the drogue with that of probe **24**.

[0029] Light sources **26** are supplied with lighting energy via electrical wires or optical fibers. According to a feature of the invention, probe **24** is constituted by a tube having the electrical wires or optical fibers embedded in its wall. This tube may be made of a suitable composite material.

[0030] Light sources **26** can be IR sources and PSDs **22** can be IR sensors.

[0031] **FIG. 2** is an elevational view showing infitting **14** and coupler assembly **16** to a larger scale. Infitting **14** is provided with at least two gripping rings **30** that are pressed, or crimped, against the outer surface of hose **12** in order to form a secure, nonmovable connection between hose **12** and infitting **14**. Infitting **14** can also be provided at its interior with gripping elements that engage the inner wall of hose **12** to further secure the connection therebetween. Infitting **14** is equipped with thrusters, preferably four in number, that are actuatable to displace the drogue in directions transverse to longitudinal axis **28**. These thrusters include outlet nozzles that constituted by four radial passages **34** that are formed in infitting **14** and are distributed uniformly around the circumference of infitting **14**. Infitting **14** further carries a set of PSDs **38** that are arranged to detect light from a light source carried by the refueling aircraft. PSDs **38** can be coupled to control elements for the thrusters in order to stabilize that drogue relative to the refueling aircraft. Such an arrangement is described in the above-cited '052 patent, particularly with reference to **FIG. 5** of that patent.

[0032] The light source on the refueling aircraft can be an IR source and PSDs **38** can be IR sensors.

[0033] Coupler assembly **16** includes a ball joint **40** that couples assembly **16** to drogue **18** in a manner to permit limited pivotal movement of drogue **18** about two axes perpendicular to longitudinal axis **28** of the drogue. Coupler assembly **16** further includes a joint **42** that forms a rotatable coupling with infitting **14**. This rotatable coupling allows coupler assembly **16** and drogue **18** to rotate about longitudinal axis **28** without twisting hose **12** or infitting **14**, so that the relative orientations of nozzles **34** are not varied and hose **12** is not subject to damage.

[0034] As described in the '052 patent, suitable circuitry is connected between PSDs **38** and the thrusters to allow the position of the drogue to be controlled to maintain the drogue relatively stationary relative to the refueling aircraft.

[0035] PSDs **22** can be constituted by self-contained wireless transmitting devices that transmit signals to wireless receivers (not shown) in infitting **14** to provide information about the position of light sources **26** relative to longitudinal axis **28**. Each transmitting device can have a different carrier frequency or can be digitally coded to be receivable only by a respective one of the wireless receivers. Thus, each wireless receiver produces position signals associated with only one PSD **22**. The wireless receivers have outputs that are supplied to signal processing circuitry in the refueling aircraft. The wires coupling the receivers to the circuitry can be embedded in hose **12**.

[0036] Since coupler assembly **16** and drogue **18** are subject to rotation about axis **28** when being dragged through the air, provision must be made to identify the angular positions of PSDs **22**, and thus of drogue **18**, associated with position signals produced by the wireless receivers.

[0037] One possible arrangement for effecting such identification is shown in **FIG. 2A**. A flange on infitting **14**, which may carry PSDs **38**, is provided with a light source **43** and, adjacent thereto, a light detector **44**. A flange forming part of joint **42**, which will rotate with coupler assembly **16**, carries a small reflecting element **45** having a limited angular extent. Each time element **45** moves opposite light source **43** and light detector **45**, the latter will produce a light detection pulse. This pulse is supplied as a gate signal to the wireless receivers to trigger the delivery of position signals to the signal processing circuitry in the refueling aircraft. Thus, these position signals are associated with a defined angular position of PSDs **22**. Operating power may be supplied to light source **43** by a conductor embossed in hose **12**.

[0038] **FIG. 3** is a cross-sectional view taken along line **3-3** of **FIG. 2**. As shown in **FIG. 3**, infitting **14** further includes an interior gripping ring **46** that presses against the interior wall of hose **12**. Within hose **12** there is carried a compressed air hose **47** having an outlet that is connected in any suitable manner to an annular compressed air distributor manifold **48**. Manifold **48** has four outlets each coupled to a respective thruster control valve **50**, which may be composed of a solenoid and examples of which are already known in the art. Each control valve **50** is connected to control the supply of compressed air to a respective outlet nozzle **34**. One thruster outlet nozzle **34** and control valve **50** are shown in greater detail in **FIG. 3A**.

[0039] **FIGS. 4A and 4B** and 4C illustrate three possible arrangements of the fuel hose and air hose according to the present invention. All of these embodiments have in common that the fuel and air hoses form an assembly having a circular outline. Such an outline is preferred because it facilitates reeling of the assembly into the refueling vehicle.

[0040] In **FIG. 4A** hoses **12** and **47** are separately fabricated and hose **47** can simply extend freely along hose **12**, except at the outlet end of hose **47**, where it is connected to distributor **48** of **FIG. 3**.

[0041] In the embodiment of **FIG. 4B**, fuel hose **12'** and air hose **47'** are formed by coextrusion.

[0042] In the embodiment shown in **FIG. 4C** fuel hose **12"** and air hose **47"** are each formed to have one flat side, along which the two hoses are bonded together by any suitable bonding technique. This bond may be formed in order to separate when a certain tension is created between hoses **12"** and **47"**. Such a tension may be created, for example, if an accidental mechanical rupture occurs in air hose **47"**, resulting in a leakage of compressed air toward fuel hose **12"**. Thus the bond should be formed to cause the hoses to separate when a tension force between the hoses is below that which corresponds to a leakage pressure that would rupture fuel hose **12"**.

[0043] In all of the illustrated embodiments of the invention, because the air hose is filled with air at a high pressure, for example in the range 340-455 psi, the air hose has a rigidifying effect on the fuel hose, thereby reducing the magnitude of transverse movements of the fuel hose while being dragged through the air.

[0044] With regard to the embodiment shown in **FIG. 4A**, air hose **47** can be installed, as noted above, to be freely moveable within fuel hose **12**. Alternatively, air hose **47** can be fixed in position relative to fuel hose **12** by spacers provided at intervals within fuel hose **12**.

[0045] **FIG. 5** is an elevational, pictorial view of one exemplary embodiment of a compressed air supply arrangement for use in a system according to the invention. The arrangement includes a high pressure vessel **52** which, simply by way of nonlimiting example, is composed of three spheres coupled together by suitable fittings. The arrangement further includes a pressure regulator **54** connected between vessel **52** and hose **47** and a miniature high-pressure compressor **56** that is connected to maintain the desired air pressure within vessel **52**.

[0046] According to one feature of the invention, pressure vessel **52** may be either clad or lined with a suitable composite material to prevent the vessel from exploding and from being penetrated by at least some projectiles. Any known composite material that is suitable for this purpose may be used.

[0047] Heretofore, in-flight refueling has been performed by refueling aircraft that are specially equipped to perform this function. This limits the number of aircraft available to perform this function. According to a further feature of the present invention, a refueling system is installed in a vessel, or housing, that can be mounted on or in a variety of aircraft that are configured to be used for other purposes. Two embodiments of such a housing are illustrated in **FIGS. 6 and 7**A and 7B.

[0048] **FIG. 6** illustrates a pod that is constructed to be mounted beneath the fuselage or beneath a wing of a variety of large aircraft and that contains the required high pressure air supply, stabilization system light source, power system, control circuitry and fuel tank. The pod illustrated could include a turbine driven by a propeller **60** located at the front of the pod to generate power for operating the refueling system. Propeller **60** would be rotated by air flowing past the pod when the aircraft to which the pod is mounted is in flight.

[0049] The pod is open at its rear end and hose **12**, containing hose **47**, would be deployed out of the open rear end of the pod.

[0050] **FIGS. 7A and 7B** illustrate a vessel **80** that would be installed in the weapons bay or bomb bay of a military aircraft, which could even be an unmanned, remotely controlled aircraft. The weapons bay can be equipped with a support bracket **70** provided with cables **74** that can be attached to a mounting bracket **78** on vessel **80**. In order to load vessel **80** into a weapons bay, cable **74** would be attached to bracket **80** and would then be wound onto motor driven reels carried by bracket **70** in order to bring vessel **80** into the stowed position shown in **FIG. 7B**. As in the case of the embodiment of **FIG. 6**, vessel **80** would contain a compressed air supply, a stabilization light source, control circuitry and all other equipment required for the refueling operation. The fuel tank can be installed in vessel **80** or in the aircraft. Vessel **80** is equipped with a cowl **84** that is mounted to pivot downwardly into the position shown in **FIG. 7A** when a refueling operation is to be performed. Cowl **84** provides aerodynamic stabilization and provides a passage for deploying hose **12**.

[0051] **FIG. 8** shows housing **80** installed in the weapons bay of an unmanned military aircraft **90**.

[0052] **FIG. 9** shows a housing **110** mounted on a pallet **112** that can be installed in the hold of a cargo or tanker aircraft. Housing **110** is shown with a side removed to allow viewing of all of the components of a refueling system according to the invention, which are installed in the housing. These components include a drum, or reel, **116** on which hose **12** is wound, a source **118** of high pressure air coupled to hose **47**, a fuel pump and pressure supply valve **120** coupled between a fuel supply line **124** connected to a fuel tank in the aircraft and hose **12**, a coupling unit **126** for connecting source **118** to the high pressure air supply hose (not shown in **FIG. 9**), signal processing circuitry **128** and a power supply **130**. The hose-and-drogue unit is shown in a stowed position in a storage tube **134** that opens to the exterior of the aircraft. Circuitry **128** is connected (not shown) by conductors in hose **12** to the various light sources, PSDs, receivers, sensors and thrusters carried by the hose-and-drogue unit. Pallet **112** with housing **110** attached can be easily loaded onto, and secured to, the bulk cargo floor of an aircraft.

[0053] In the embodiments shown in **FIGS. 6-9**, the high pressure air supply vessel could be wrapped in a suitable composite material and sealed with titanium for the purposes described above with reference to **FIG. 5**. In fact, the high pressure vessel assembly shown could be used in the vessels shown in **FIGS. 6 and 7**A, B.

[0054] While the description above refers to particular embodiments of the present invention, it will be understood that many modifications may be made without departing from the spirit thereof. The accompanying claims are intended to cover such modifications as would fall within the true scope and spirit of the present invention.

[0055] The presently disclosed embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims, rather than the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A refueling probe installable in an aircraft for engaging a drogue to enable the aircraft to be refueled in flight, said probe comprising a light source and electrical wires or optical fibers for supplying lighting energy to said light source, wherein said probe comprises a tube having a wall and said electrical wires or optical fibers are embedded in said wall.

2. The probe of claim 1 wherein said tube is made of a composite material.

3. A refueling hose-and-drogue unit for airborne refueling of an aircraft, said unit comprising a hose, a drogue carried by, and rotatable relative to, said hose, and a plurality of thrusters attached to, and nonrotatable relative to, said hose, said thrusters being operable to control the position of said drogue in flight.

4. An in-flight hose-and-drogue refueling system comprising:

a housing configured to be carried by an aircraft and including a cowl mounted to pivot downwardly from a closed position; and

a refueling hose-and-drogue unit stored in said housing and deployable out of said housing when said cowl is pivoted downwardly,

wherein said cowl is disposed below said unit when said cowl is in the closed position and said cowl is pivoted downwardly when a refueling operation is to be performed in order to provide aerodynamic stabilization during deployment of said unit.

* * * * *