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Hale et al.

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(54) **ENHANCED AERIAL DELIVERY SYSTEM**

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(51) **Int. Cl.**
B64D 1/16 (2006.01)

(52) **U.S. Cl.** **244/136**; 239/171; 169/53; 137/899.2

(58) **Field of Classification Search** 244/118.1, 244/118.2, 136; 239/137, 171; 137/899.2; 169/53; 222/67
See application file for complete search history.

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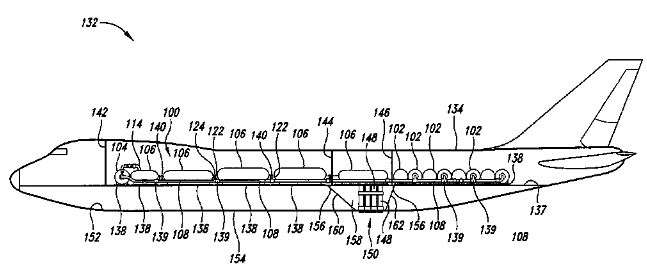
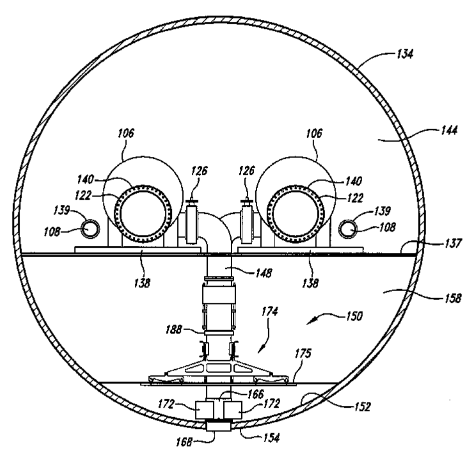
(74) *Attorney, Agent, or Firm*—Davis Wright Tremaine LLP; George C. Rondeau, Jr.

(57) **ABSTRACT**

An enhanced aerial delivery system addresses issues raised when large quantities of fluids, powders, and other agent materials are to be transported in and aerially dispersed by aircraft. Some aspects include positioning and securing of tanks aboard the aircraft to facilitate management and safety of the tanks and aircraft. Other aspects address coupling of the tanks and associated piping to lessen structural effects upon the aircraft. Further aspects deal with channeling, containing, and dumping stray agent materials that have escaped from the agent tanks on board the aircraft.

9 Claims, 11 Drawing Sheets





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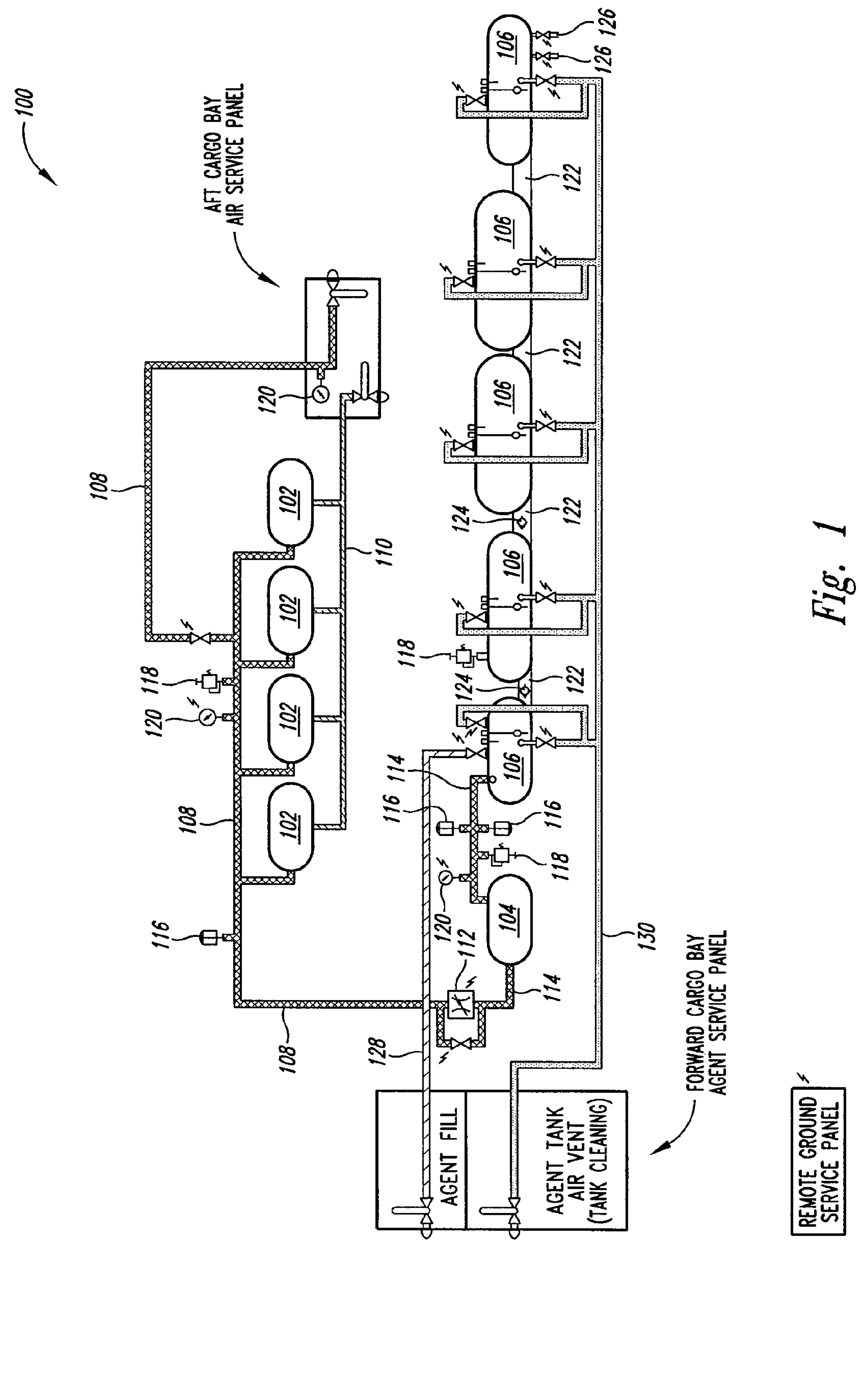
100
AFT CARGO BAY
AIR SERVICE PANEL
FORWARD CARGO BAY
AGENT SERVICE PANEL
AGENT FILL
AGENT TANK
AIR VENT
(TANK CLEANING)
REMOTE GROUND
SERVICE PANEL
102
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110
112
114
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126
128
130

Fig. 1

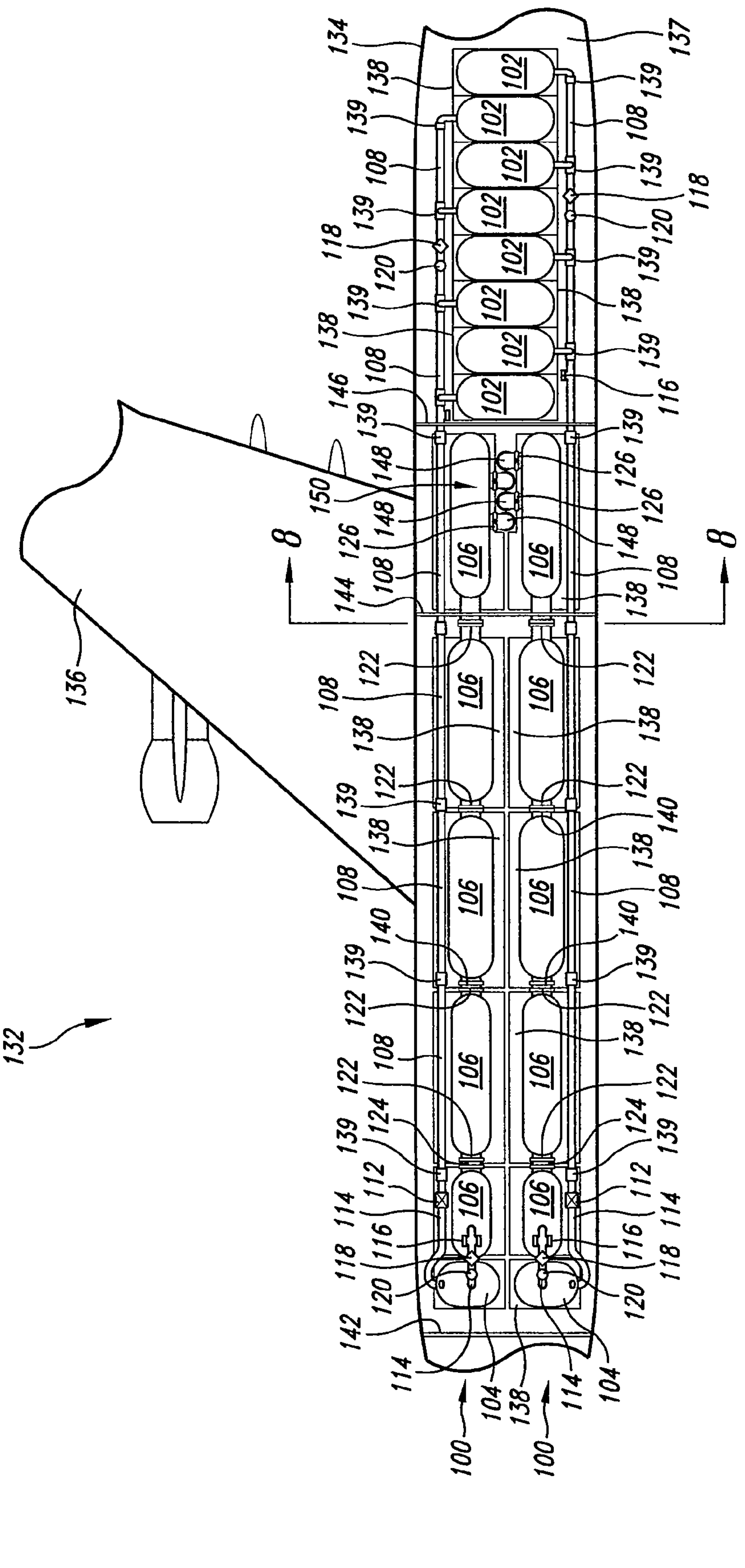
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Fig. 2

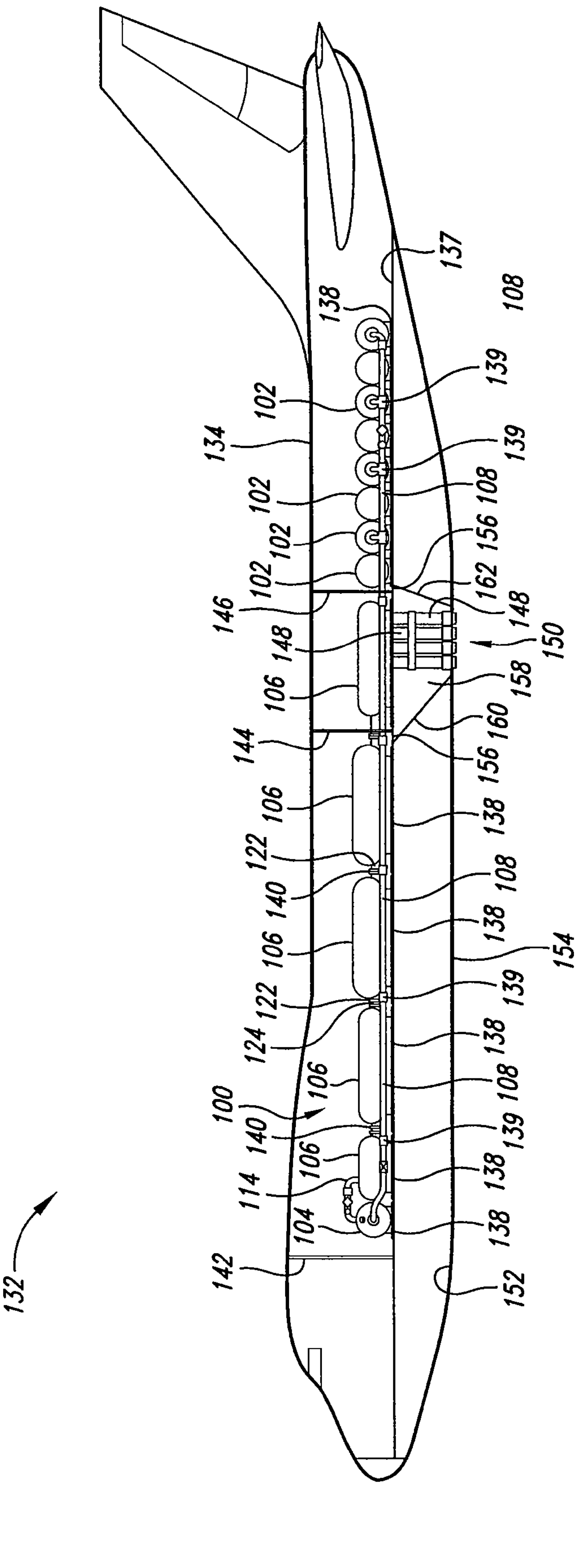
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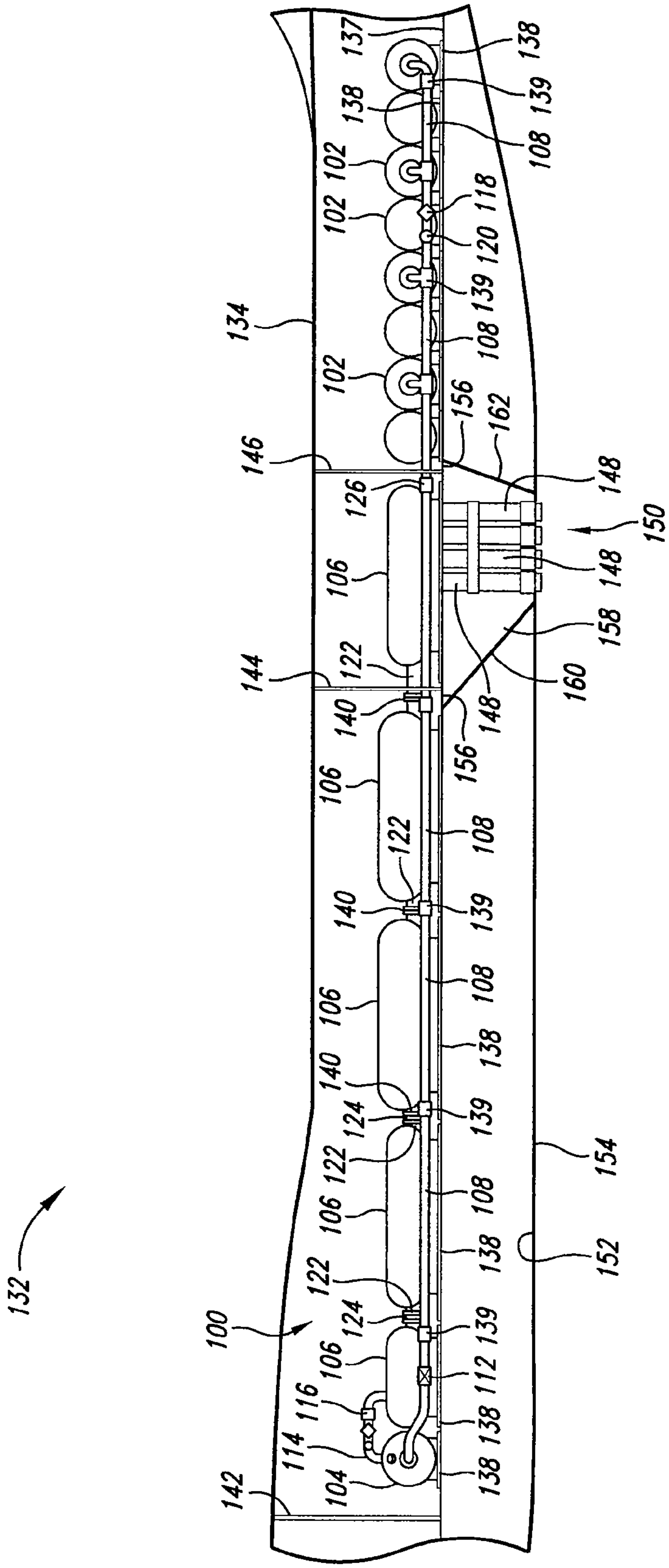
Fig. 3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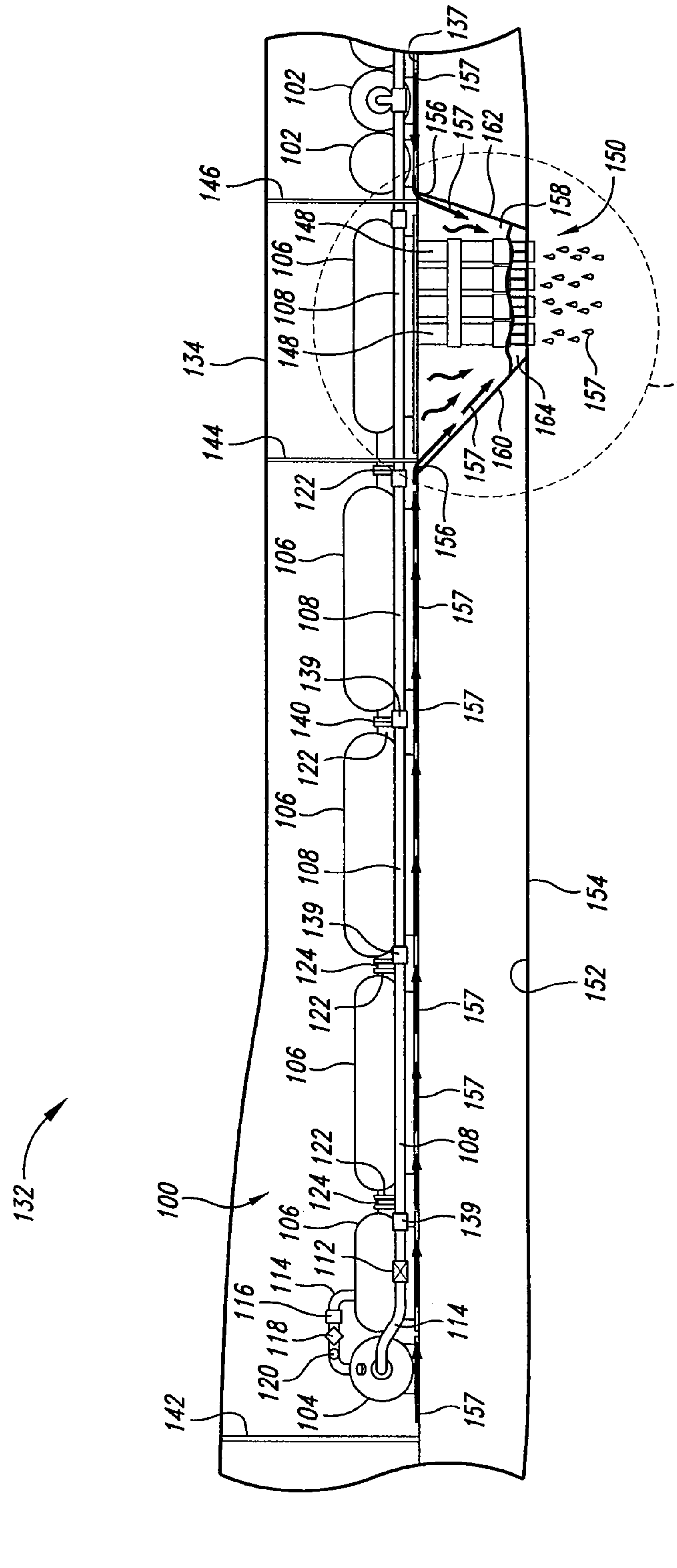
142

Fig. 4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148
106
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122
156
106
108
157
139
140
157
122
106
108
154
139
124
152
122
157
106
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132
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106
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112
114
116
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142
157

Fig. 5

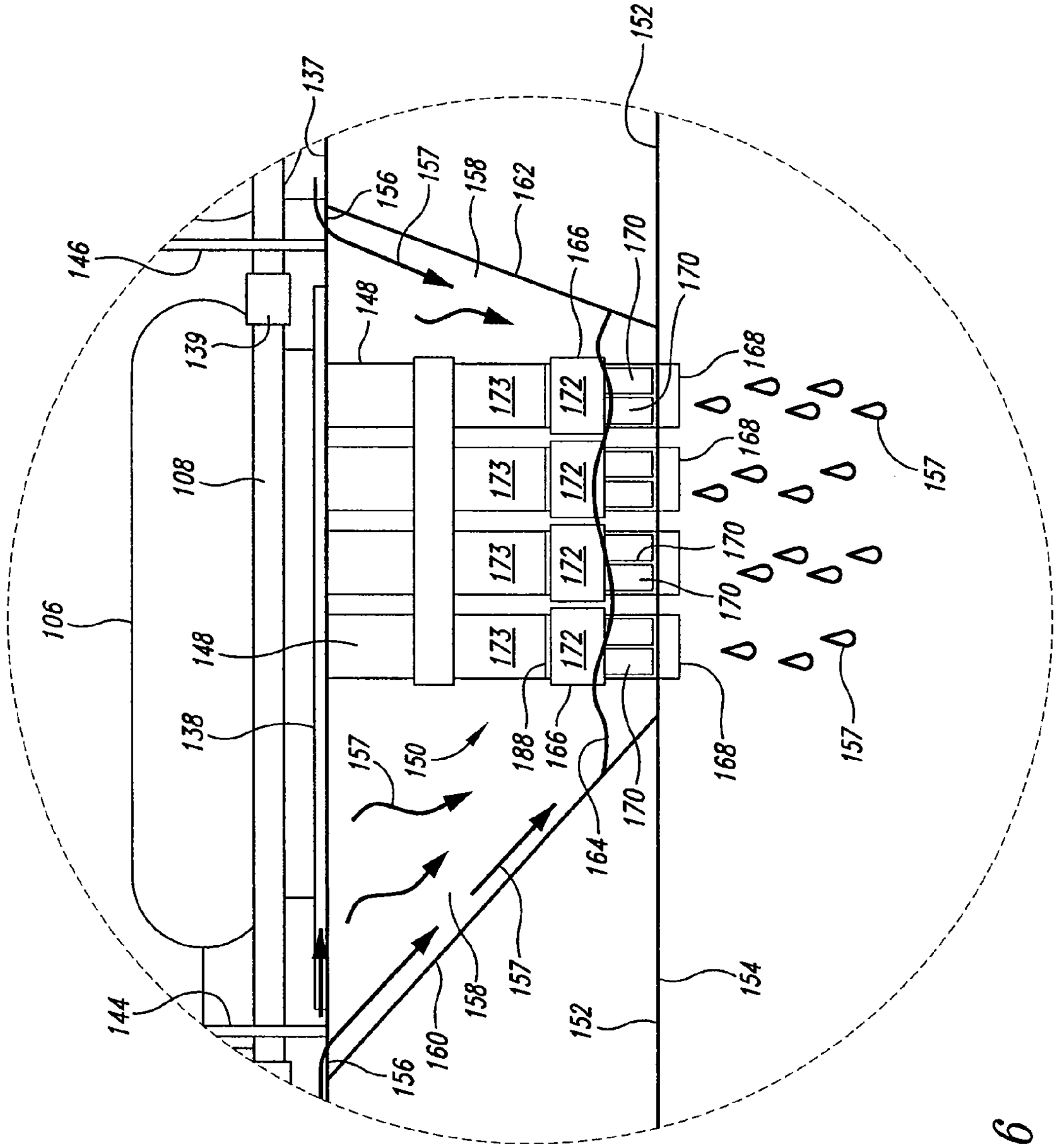
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Fig. 6

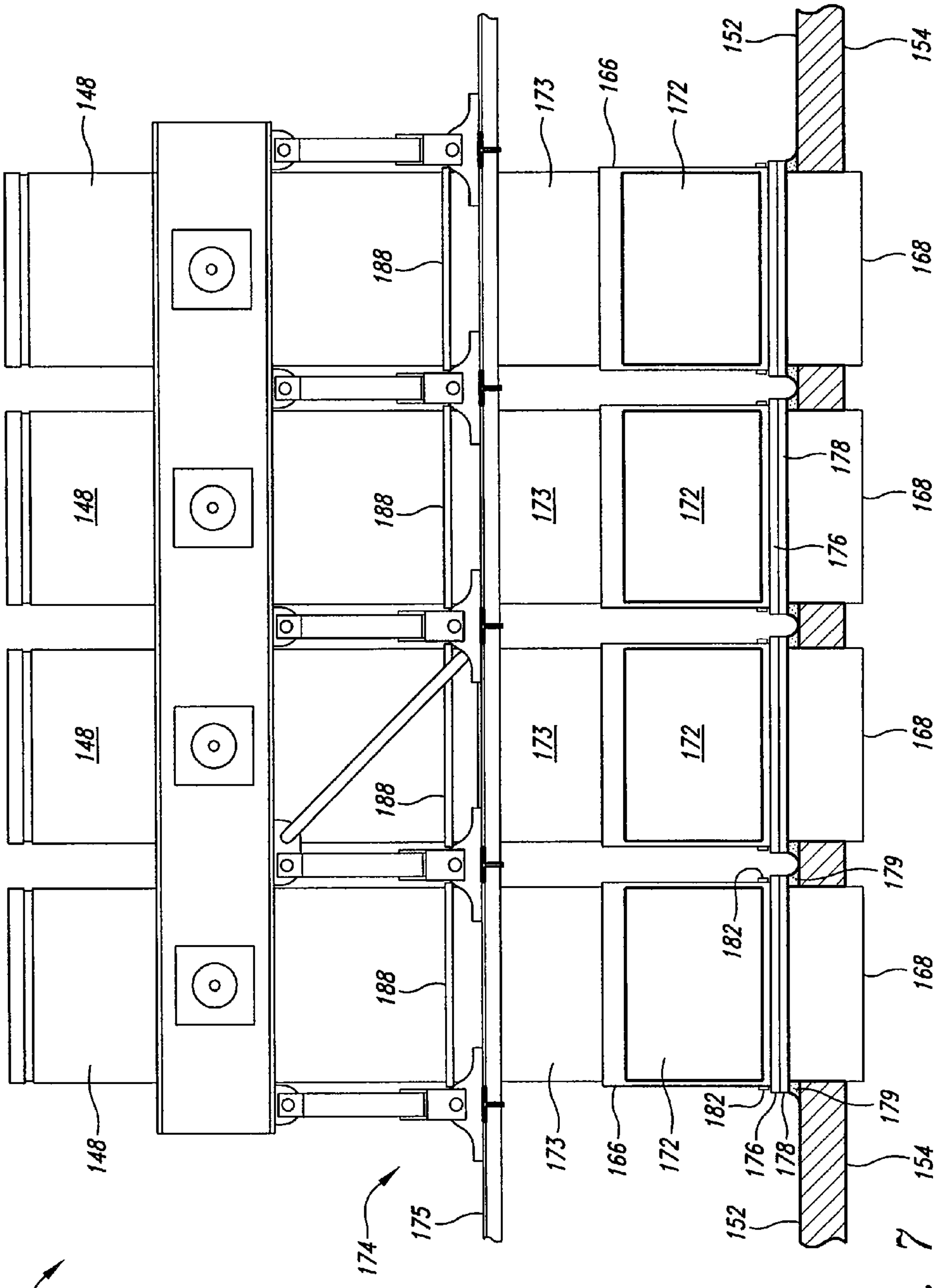

Fig. 7

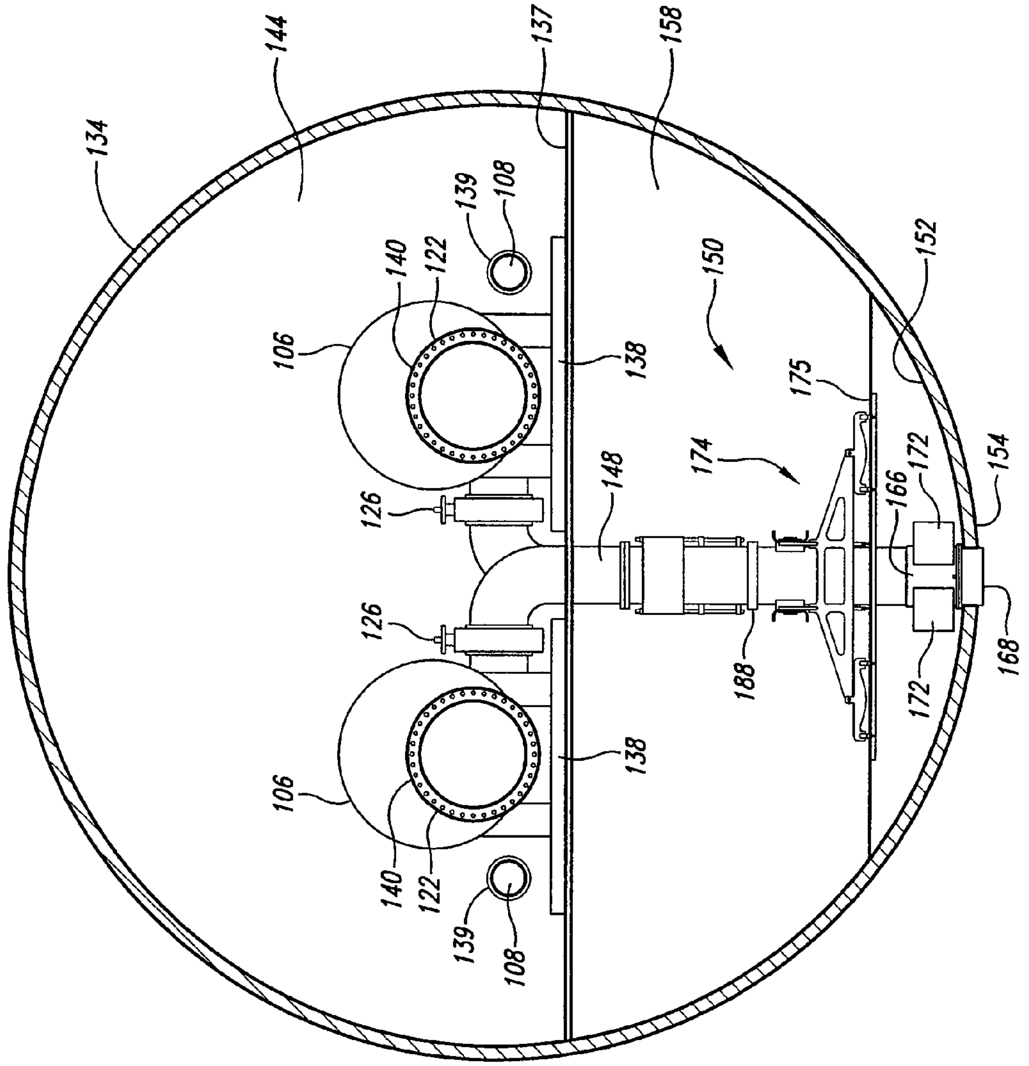
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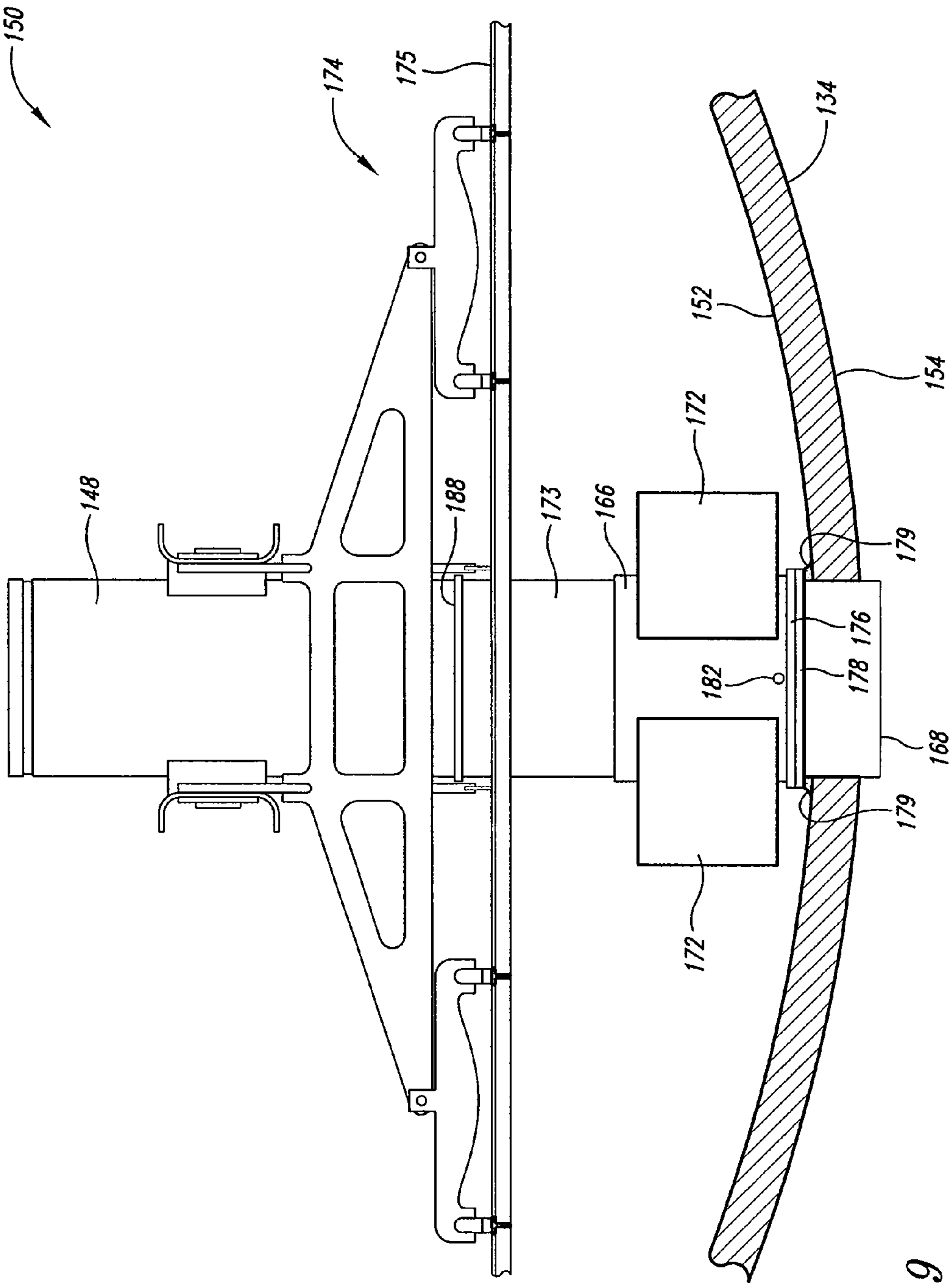
Fig. 8


150
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178
182
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172

Fig. 9

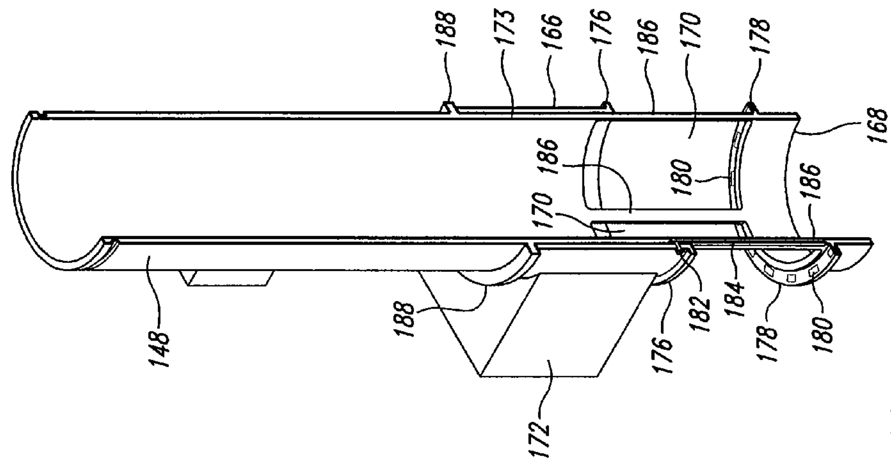
188
173
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Fig. 11

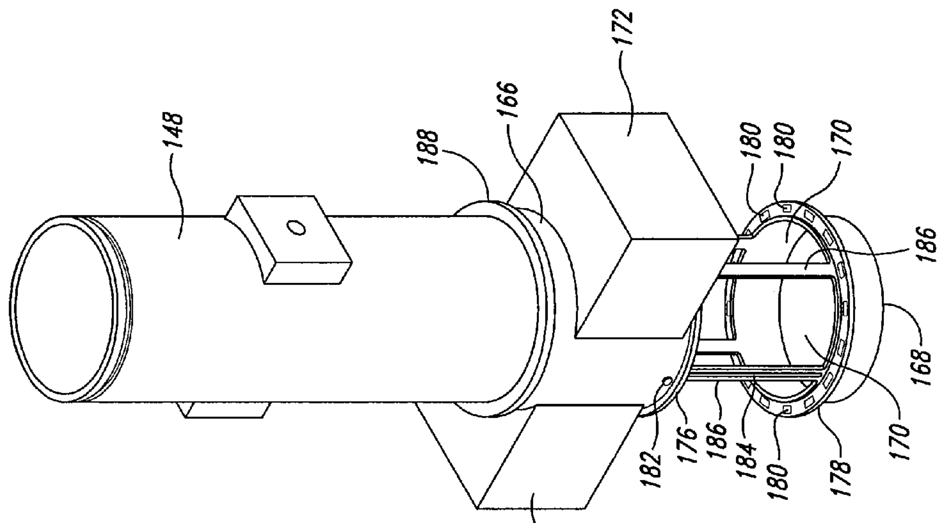
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Fig. 10

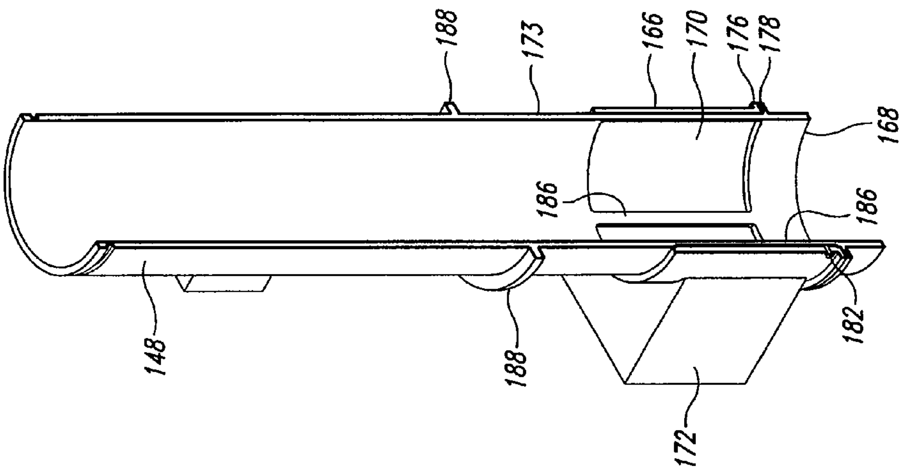
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Fig. 13

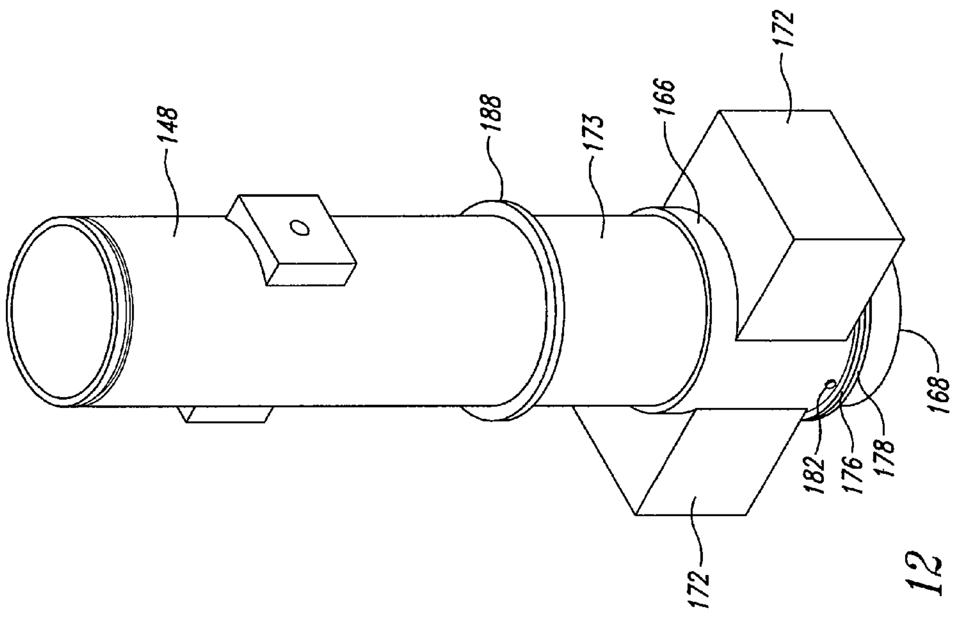
148
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Fig. 12

ENHANCED AERIAL DELIVERY SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed in general to aerial delivery systems.

2. Description of the Related Art

In general, aerial delivery systems receive, transport, and disperse fluids, powders, or other substances from aircraft to terrain below for various reasons. In certain cases including fire fighting, weather control, decontamination exercises, and geotechnical applications, it is desirable for large quantities of materials to be dispersed with each trip of the aircraft since areas for dispersion of the materials can be vast, travel distances between receiving and dispersion points can be great and response time to complete a job can be demanding. These and other applications where large quantities of materials are to be aerially dispersed present particular issues regarding aircraft control, safety and other issues that unfortunately conventional approaches have not addressed.

The invention will best be understood by reference to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings. The discussion below is descriptive, illustrative and exemplary and is not to be taken as limiting the scope defined by any appended claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is a schematic view of an enhanced aerial delivery system.

FIG. **2** is a top plan view of the enhanced aerial delivery system shown positioned within an aircraft.

FIG. **3** is a side elevational view of the enhanced delivery system of FIG. **2**.

FIG. **4** is an enlarged fragmentary side elevational view of the enhanced delivery system of FIG. **3**.

FIG. **5** is an enlarged fragmentary side elevational view of the enhanced delivery system of FIG. **3** better showing an outlet assembly.

FIG. **6** is a further enlarged fragmentary side elevational view of the enhanced delivery system of FIG. **5** better showing detail of the outlet assembly.

FIG. **7** is an enlarged side elevational view of the outlet assembly.

FIG. **8** is a front elevational view of the enhanced delivery system shown positioned within an aircraft taken substantially along lines **8-8** of FIG. **2**.

FIG. **9** is an enlarged fragmentary front elevational view of the enhanced delivery system positioned within the aircraft of FIG. **8**.

FIG. **10** is a perspective view of a portion of the outlet assembly of FIG. **7** shown in an open position.

FIG. **11** is a cross-sectional perspective view of the portion of the outlet assembly of FIG. **10** shown in the open position.

FIG. **12** is a perspective view of the portion of the outlet assembly of FIG. **10** shown in a closed position.

FIG. **13** is a cross-sectional perspective view of the portion of the outlet assembly of FIG. **10** shown in the closed position.

DETAILED DESCRIPTION OF THE INVENTION

An enhanced aerial delivery system is described herein that addresses issues raised when large quantities of fluids, powders, and other agent materials are to be transported in and aerially dispersed by aircraft. Some aspects include positioning and securing of tanks aboard the aircraft to facilitate management and safety of the tanks and the aircraft. Other aspects address coupling of the tanks and associated piping to lessen structural effects upon the aircraft. Further aspects deal with channeling, containing, and dumping stray agent materials that have escaped from the agent tanks on board the aircraft.

A tank circuit **100** is shown in FIG. **1** to include a set of propellant tanks **102**, a proximate propellant tank **104**, and a set of agent tanks **106**. The propellant tanks **102** can supply propellant, such as compressed air, through high pressure propellant piping **108** while the tank circuit **100** is within accessible distance of an air supply generally on the ground at a servicing airport (not shown). A condensate piping **110** is used to carry off condensate from the set of the propellant tanks **102** generally also during a servicing period when the tank circuit **100** is not airborne at a servicing airport.

The high pressure propellant piping **108** is also coupled to a pressure regulator **112** that reduces pressure of propellant going into a low pressure propellant piping **114** to feed the proximate propellant tank **104**. Additional low pressure propellant piping **114** carries propellant from the proximate propellant tank **104** to the set of the agent tanks **106**. Burst disks **116**, pressure relief valves **118**, and pressure sensors **120** are placed at various points in the tank circuit **100** to guard against dangerous over-pressure conditions.

The agent tanks **106** are coupled together with agent piping **122** with the first two sections of agent piping nearest the proximate propellant tank **104** each containing a one way valve **124** that allows the flow of propellant and agent only away from the proximate propellant tank. Outlet valves **126** are coupled to the agent tank **106** in the tank circuit **100** that is farthest from the proximate propellant tank **104**. The outlet valves **126** allow agent and propellant to escape from the tank circuit **100** as described further below.

An agent supply piping **128** is coupled to the agent tank **106** nearest the proximate tank **104** to be used for filling the agent tanks **106** with agent material when the tank circuit **100** is being serviced on the ground. Vent piping **130** is coupled to each of the agent tanks **106** to receive left over agent material and/or propellant when the agent tanks are being flushed with propellant. The vent piping **130** is used to vent the tanks during fill, regulating tank fill levels. The vent piping is used during ground cleaning to direct water to valves on lower portions of the agent tanks **106** to route cleaning agent to spray heads located inside the agent tanks.

An aircraft **132** is shown in FIG. **2** as having a fuselage **134**, center wings **136** (one shown), an upper deck **137** and two of the tank circuits **100** on the upper deck. One of the tank circuits **100** generally occupies a port portion of the aircraft and the other of the two tank circuits occupies a starboard portion of the aircraft. Each of the tanks of the tank circuits **100** are positioned on individual pallets **138**, which are secured to the aircraft using conventional pallet handling methods. As shown in FIG. **2**, flexible couplers **139** are placed along various positions of the high pressure propellant piping **108** and low pressure propellant piping **114**, and flexible couplers **140** are coupled with agent piping **122**. The flexible couplers **139** and the flexible couplers **140** add structural flexibility to the tank circuits **100** so that the tank circuits impose less of a structural impact upon the aircraft **132**.

A forward barrier **142** is located on the upper deck **137** forward of the tank circuits **100** and is used to prevent and/or delay stray agent material that has inadvertently escaped from one or more of the agent tanks from moving on the upper deck into a portion of the aircraft **132** that is forward of the forward barrier. A mid-barrier **144** is located just forward of the two most aft of the agent tanks **106** of the two tank circuits **100** and is used to prevent and/or delay stray agent material forward of the mid-barrier from moving on the upper deck **137** aft of the mid-barrier. An aft barrier **146** is located between the set of the propellant tanks **102** and the set of the agent tanks **106** and is used to prevent and/or delay stray agent material from moving on the upper deck **137** forward of the aft barrier.

The forward barrier **142**, the mid-barrier **144**, and the aft barrier **146** are generally made from high strength to weight materials that can divert flow of fluids. These materials can include various plastics, other polymers, fabrics, other sorts of sheeting, and more rigid materials such as metals, composites and combinations thereof. The outlet valves **126** are fluidly coupled to outlet tubes **148** of an outlet assembly **150** located between the two most aft of the agent tanks **106**. As better shown in FIG. **3** and FIG. **4**, each of the outlet tubes **148** are large vertically oriented tubular structures that pass from the upper deck **137** through a lower deck **152** out through the aircraft bottom **154**.

One or more upper deck openings **156** are located in the upper deck **137** just forward of the mid-barrier **144**, and/or located just aft of the aft barrier **146**, and/or located between the mid-barrier **144** and the aft barrier **146**. The upper deck openings **156** allow stray agent **157** on the upper deck **137** that has been diverted by the mid-barrier **144** and the aft barrier **146** to drain down toward the lower deck **152**, as shown in FIG. **5** and FIG. **6**. Lower deck openings **158** are located in the lower deck **152** typically below the upper deck openings **156** and/or nearer to the outlet assembly **150** to allow stray agent **157** to pass through to the aircraft bottom **154**.

A forward ramp **160** and an aft ramp **162** serve to guide stray agent **157** passing through the upper deck openings **156** and the lower deck openings **158** toward the outlet assembly **150**. Once the stray agent **157** reaches the aircraft bottom **154**, it accumulates having a pool level **164**. As the pool level **164** rises, it serves to lift floatable shutters **166** (see FIG. **6**) or other sorts of door-like members having combined densities to be buoyant relative to the stray agent **157**. The shutters **166** serve as portions of the outlet tubes **148** proximate to outlet ends **168**.

Consequently, as the floatable shutters **166** are lifted, the stray agent **157** passes through tube wall openings **170** into the outlet tubes **148** to exit from the aircraft **132** through the outlet ends **168**, as shown in FIGS. **7-9**. The floatable shutters **166** include floats **172** coupled to or integrally structured with tube wall portions **173** of the assembly **150**. The floats **172** add sufficient buoyancy to the tube wall portions **173** to allow the tube wall portions to be raised up along with a rise of the pool level **164**.

Use of large aircraft, such as a Boeing 747, affords greater material carrying capacity so that large amounts can be dumped onto substantial areas of land at high concentrations given the configurations described above. To handle large volume deliveries, the outlet tubes **148** are sized with relatively large pipe diameters such as having 16 inch diameters in some implementations. With large pipe diameters for the outlet tubes **148** and substantially high pressure levels for the propellant tanks **102**, such as 65 psi, a substantial amount of thrust induced force can result from the material in the material storage agent tanks **106** being shot out from the large diameter outlets at high pressure.

Conventional methods of securing outlets to an aircraft involve common techniques to secure pallets to the aircraft, such as with outer guide locks. Due to the unconventionally high amount of thrust that can result from material being delivered, these conventional outlet securing systems and methods can be inadequate in properly distributing the thrust induced load to an adequately sized portion of the aircraft to safely hold the outlet tubes **148** in place without risking structural damage to the aircraft **132**.

An outlet securing system **174** is depicted in FIG. **8** to properly distribute the unconventionally high thrust induced loads to an adequately sized portion of the aircraft **132**. The outlet securing system **174** couples the outlet tubes **148** to the aircraft by coupling to seat tracks **175** originally designed for securing cargo to the aircraft when the aircraft is used as a passenger airliner. Coupling the outlet tubes **148** to the aircraft by coupling the outlet tubes to the seat tracks **175** allows for a more secure way of imparting the thrust induced load to the aircraft structure than the conventional methods used involving securing pallets to the aircraft. Consequently, the outlet securing system **174** allows for delivery of greater quantities of material with pressures for the propellant tanks **102** substantially higher than used by conventional delivery systems.

As shown in FIG. **9**, the tube wall portions **173** each have a lower flange **176** that rests against an upper flange **178** of a different one of the outlet ends **168**. Sealant **179** is used to seal the upper flange **178** with the fuselage **134**. The upper flange **178** and/or the lower flange **176** contain magnets **180** as shown in FIG. **10** and FIG. **11** that help to seal each floatable shutter **166** in a closed position, such as shown in FIG. **12** and FIG. **13**, when the pool level **164** is not sufficient to raise the floatable shutter. The magnets **180** help prevent the floatable shutters **166** from vibrating and bouncing up and down with aircraft movement.

A pin **182** protrudes from the interior surface of the floatable shutter **166** to engage with a track **184** found in a post **186** of the outlet tube **148**. Each of the pins **182** help to prevent one of the floatable shutter **166** from rotating and thereby prevents the floats **172** from hitting each other. A circumferential ring stop **188** of the floatable shutter **166** is used to prevent travel of the floatable shutter beyond a desired vertical height but allows for sufficient vertical travel so that the floatable shutter can be raised to unblock the tube wall openings **170** as the pool level **164** rises.

The tank circuits **100** are self-contained and reusable and enable aircraft, such as but not limited to cargo/utility aircraft, to carry and dump a load, under control. One example of an aircraft among many, is a Boeing 747. The outlet assembly **150** allows a uniform and narrow material drop from relatively high altitudes compared with conventional approaches and a reduction in the amount of time material is suspended in the air due to its capability of delivering pressurized fluid directed substantially straight downward.

By "downward," it is envisioned that the aircraft bottom **154** will generally be the closest side of the fuselage **134** to the ground when the aircraft **132** is being support on the ground by its wheel system. The pressurized fluid or other material delivered from the outlet tubes **148** is directed straight down and exits the aircraft **132** with the material moving further downward away from the aircraft bottom **154**. The contents are shot substantially vertically toward the ground not just substantially horizontally away from the aircraft and its turbulence.

Possible agents used in the tank circuits **100** can include those for fire fighting, such as used by a "fire bomber", for chemical decontamination, weather modification and oil spill decontamination, among other uses. The tank circuits **100** and outlet assembly **150** for use with a Boeing 747 can drop approximately 25,000 gallons of fluid in approximately 5 seconds from an altitude of approximately 2,500 feet above the ground.

The quantity of material delivered and duration of the deliveries will be controllable by the pilot at any flight regime the aircraft **132** is capable of operating in (i.e., altitude, airspeed, pressurized or unpressurized). The system's load has the ability to be dispersed in segmented drops or at one time.

A portion of the tank circuits **100** and the outlet assembly **150** can be coupled to the aircraft **132** at what is conventionally know as a wing box since it is a reinforced portion of the aircraft. The wing box typically runs through the lower portion of the fuselage **134** and ties the center wings **136** into the rest of the aircraft **132**. Other large aircraft can also be used in addition to the Boeing 747, such as DC 10 aircraft, or Airbus 380 aircraft.

The multiple agent tanks **106** are used to increase the carrying capacity of the aircraft **132** while seeking to maintain a desirable center of gravity of the aircraft. In one aspect, the agent tanks **106** may be made of steel, however, other materials may be used such as polymers, plastics, composites, etc. as conventional practice dictates. Using the two tank circuits **100** provide the capability to premix materials, mix materials on-board or disperse two different materials separately. This would allow for a division of two separate materials, such as a dormant fire retardant material and an activator material. The dormant fire retardant material and the activator would be admixed close to the time of use. The number of valves controlling the outlet tubes **148** that are opened at selected times control the quantity of material ejected.

The propellant can be pressurized at different pressures to match requirements of different materials contained in different ones of the agent tanks **106**. These materials to be stored in the agent tanks **106** include, but are not limited to, water, gels, powders, chemicals and biological agents used for decontamination, neutralization, weather modification, oil spill treatment and firefighting. The specific agent material is directed by pressurized propellant and is propelled through the outlet tubes **148** straight down or at a forward angle away from the aircraft at variable pressures. Ejected material can strike or interact with its intended target either with forward direction or slow into a rain-like state dependant on which pressures and altitudes are used. The propellant tanks **102** can store pressurized air or other gas as the propellant. The stored air (energy) is the propulsion system allowing fluid and/or materials to exit the aircraft. The propellant tanks **102** can be pressurized with bleed air from the airplane, air from an onboard compressor, or air from a ground supply. The agent tanks **106** are able to withstand any pressure delivered from the proximate propellant tank **104**.

The outlet tubes **148** can be dump chutes, nozzles, etc. and can branch out from the outlet assembly **150** and act as the exit mechanism for the material and/or fluids. The outlet valves **126** can open individually, in combination, or all at once to acquire the desired flow rate through the outlet tubes. The control and/or operation of the outlet valves **126** can be by a hydraulic actuator or electromechanical system.

In yet another aspect, a drop controller, such as a microprocessor-based computer device, given flow rate and line length, can be used to calculate how many of the outlet valves **126** to open and at what time to provide exact flow rate management (e.g., levels of coverage, intensity of coverage).

In some implementations, the agent tanks **106** can be progressively sized so that tank size increases the more aft a tank is located. For instance, the forward most tank of each tank circuit **100** can be the smallest, the second forward most tank of each tank circuit can be next largest and so on. In the implementation shown in FIG. **2**, the forward most one of the tank circuit **100** empties first, then the second most one of the tank circuit empties and so on. Emptying of the tanks continues to follow this sequential order from more forward tank to more aft tank until the most aft tank of the tank circuit **100** is emptied.

This particular order of emptying could be re-ordered depending upon how the propellant tanks **102** and/or the proximate propellant tank **104** are coupled to the agent tanks **106**. Whatever the implementation, the agent tanks **106** are sized and positioned according to the order of emptying such that the overall center of gravity of the loaded aircraft stays within a forward most center of gravity limit point and an aft most center of gravity limit point. In a particular implementation, the center of gravity of the aircraft when the agent tanks **106** are full is near the forward most center of gravity limit point and is near the aft most center of gravity limit point when the agent tanks **106** are substantially empty.

It has been found that the sequential ordering of emptying of the agent tanks **106** starting from the forward most pair and ending at the aft most pair tends to have less complication involved so tend to have an acceptable level of reliability. Other scenarios involving more complicated ordering of emptying of the agent tanks **106** may not have an acceptable level of reliability given the influence of emptying of the agent tanks on the center of gravity of the aircraft. Consequently, when additional factors of safety are desired, it may be necessary to limit the number of the agent tanks **106** to a number that would allow a more reliable emptying of the tanks such as a sequential forward to aft emptying order rather than using additional of the agent tanks and thereby causing a more complicated emptying order.

The outlet tubes **148** are generally located along the longitudinal dimension of the aircraft **132** relatively near the trailing edge (the most aft edge) of inboard flaps of the aircraft in their extended position. The extended position of the inboard flaps is taken into consideration since the aircraft is generally traveling at reduced speed with the inboard flaps in an extended position at the time of dumping of the contents of the agent tanks **106**. It has been found that in this area just aft of the trailing edge of the extended inboard flaps there is a minimal amount of turbulence to be dealt with. If the outlet tubes **148** are moved forward of the trailing edge of the inboard flaps or moved more aft toward the tail of the aircraft, there can be more turbulence, which can reduce the ability to delivery content of the agent tanks **106** to the ground generally below the aircraft in sufficient concentrations.

It has been found that using air pressurized in the propellant tanks **102** at over 40 psi, and preferably at over 50 psi and more preferably at or over 65 psi helps to deliver the contents of the agent tanks **106** to the ground at significantly high levels of concentration. For instance, in test runs, delivery concentrations to the ground as high as 14.8 gallons per square feet have been observed for pressures of 65 psi in the propellant tanks **102** with the positioning and orientation of the outlet tubes **148** as discussed above for drops from the aircraft **132** at 400 feet above the ground. The aerial fluid delivery system may be capable of association with an airplane, helicopter, or balloon. Other aspects can include a faring housed over the outlet ends **168**.

The discussion above is descriptive, illustrative and exemplary and is not to be taken as limiting the scope defined by any appended claims.

The invention claimed is:

1. A system to be transported on an aircraft, the aircraft having an interior, an exterior, and a bottom, the system comprising:

an agent tank configured to hold material;

an outlet end providing passage from the interior to the exterior of the aircraft through the bottom of the aircraft; and

a member movably coupled to the outlet end, the member having a closed position and an open position, the member configured to be moved from the closed position to the open position through buoyant contact with a portion of the material released from the agent tank into the interior of the aircraft, in the closed position the member being oriented to block access to the outlet end from within the aircraft, and in the open position the member being oriented to allow access to the outlet end from within the aircraft, whereby the material located substantially adjacent the bottom of the aircraft may exit the aircraft through the outlet end.

2. The system of claim **1** wherein the member includes a shutter with a density less than the material so as to be buoyant relative to the material.

3. The system of claim **1** wherein the member includes a door and a float having a combined density, the combined density of the door and the float being less than the material so as to be buoyant relative to the material.

4. The system of claim **1** further including at least one barrier positioned to direct the portion of the material to pool adjacent to the member.

5. The system of claim **1** further including a pin and a track, the pin extending from the member and the track positioned to receive the pin to guide movement of the member between the open and closed positions.

6. The system of claim **5** wherein track is shaped to direct movement by the pin in a linear direction.

7. A system to be transported on an aircraft, the aircraft having an interior, an exterior, an upper deck, a lower deck, and a bottom, the system comprising:

an agent tank configured to hold material;

an outlet tube coupled to the agent tank to receive a portion of the material from the agent tank, the outlet tube extending through the bottom of the aircraft and having a tube end to direct out of the aircraft through the tube end the portion of the material received by the outlet tube from the agent tank, the outlet tube having a tube wall with a tube wall opening in communication with the interior of the aircraft outside of the outlet tube; and

a member movably coupled to the outlet tube to move between a closed position closing the tube wall opening and an open position opening the tube wall opening, the member configured to be moved between the closed position to the open position through contact with a portion of the material released from the agent tank, and located within the interior of the aircraft and outside of the outlet tube, in the closed position the member being configured to inhibit movement of the material portion through the tube wall opening to the outlet end from within the aircraft, and in the open position the member being configured to allow movement of the material portion through the tube wall opening to the outlet end from within the aircraft and outside of the outlet tube, whereby the material portion may exit the aircraft through the outlet end when the member is in the open position.

8. The system of claim **7** further including an outlet valve and wherein the outlet tube is coupled to the agent tank through the outlet valve to control release of the material from the agent tank into the outlet tube.

9. The system of claim **7** further including a stop circumferentially extending at least partially about the outlet tube and positioned to prevent travel of the member beyond a predetermined vertical height.

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