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Karpetis et al.

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(54) **FLUID BEARING SYSTEMS AND METHODS**

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F16C 29/02	(2006.01)
F16C 35/00	(2006.01)

(52) **U.S. Cl.**
CPC ***F16C 32/0622*** (2013.01); ***F16C 29/025*** (2013.01); ***F16C 35/00*** (2013.01); *F16C 2326/00* (2013.01)

(58) **Field of Classification Search**
CPC .. B61B 1/02; B61B 3/00; B61B 13/00; B60V 1/00; B60V 1/11; F16C 32/06; B64B 1/02
See application file for complete search history.

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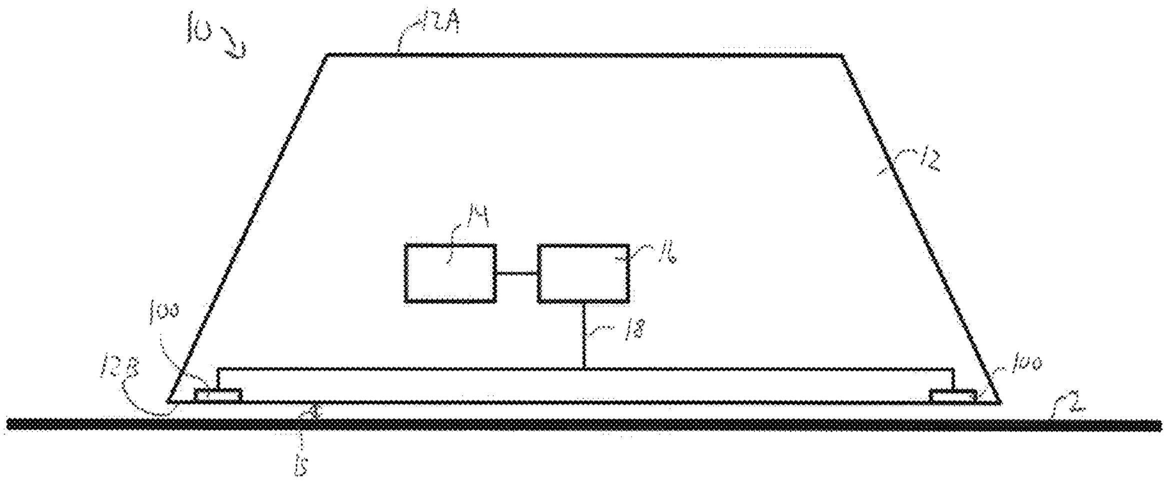
(57) **ABSTRACT**

A fluid bearing includes a housing including an internal plenum disposed in the housing and an inlet in fluid communication with the plenum, wherein the inlet is configured to provide fluid to the plenum from an external source, a cushion surface facing away from the housing and the plenum, one or more nozzles positioned between the cushion surface and the housing, wherein the one or more nozzles extend from the plenum to the surrounding environment, wherein the one or more nozzles are configured to produce an annular curtain of fluid flowing at a velocity of at least Mach 1 and disposed about the cushion surface in response to a fluid flow entering the plenum from the inlet.

20 Claims, 10 Drawing Sheets



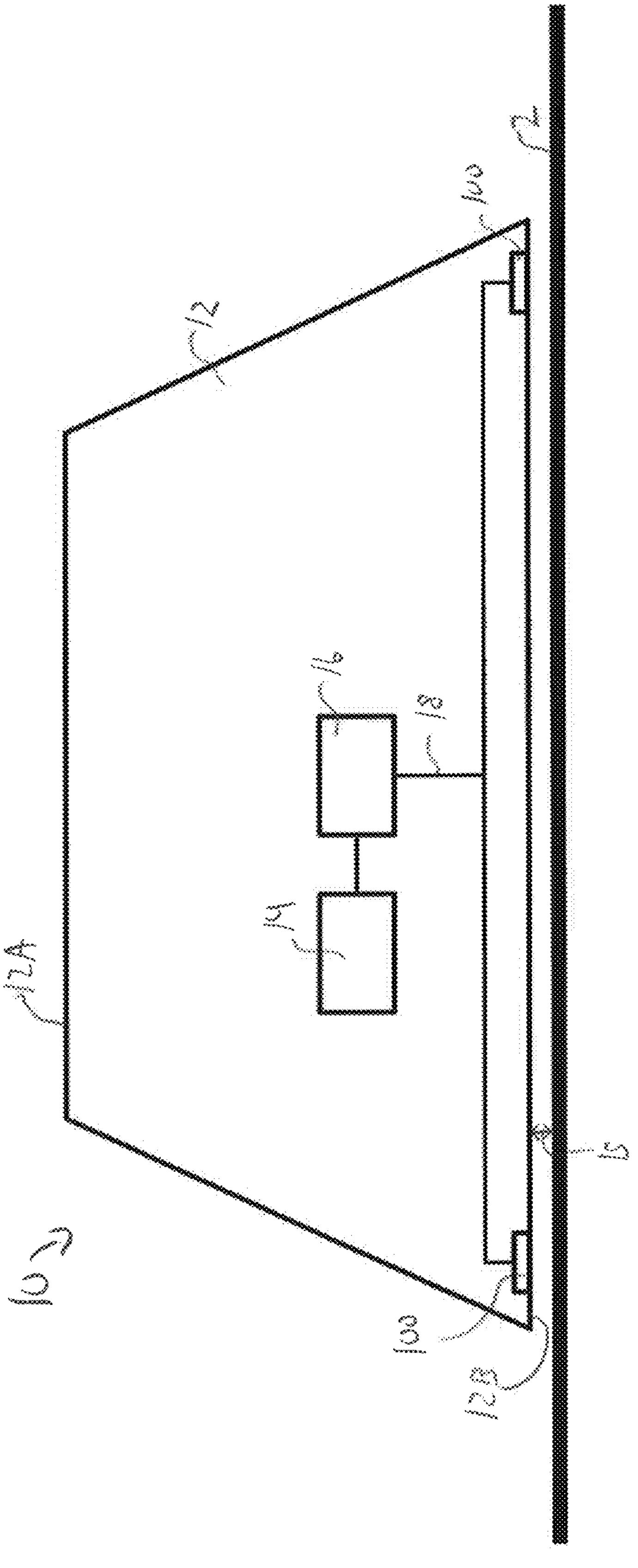
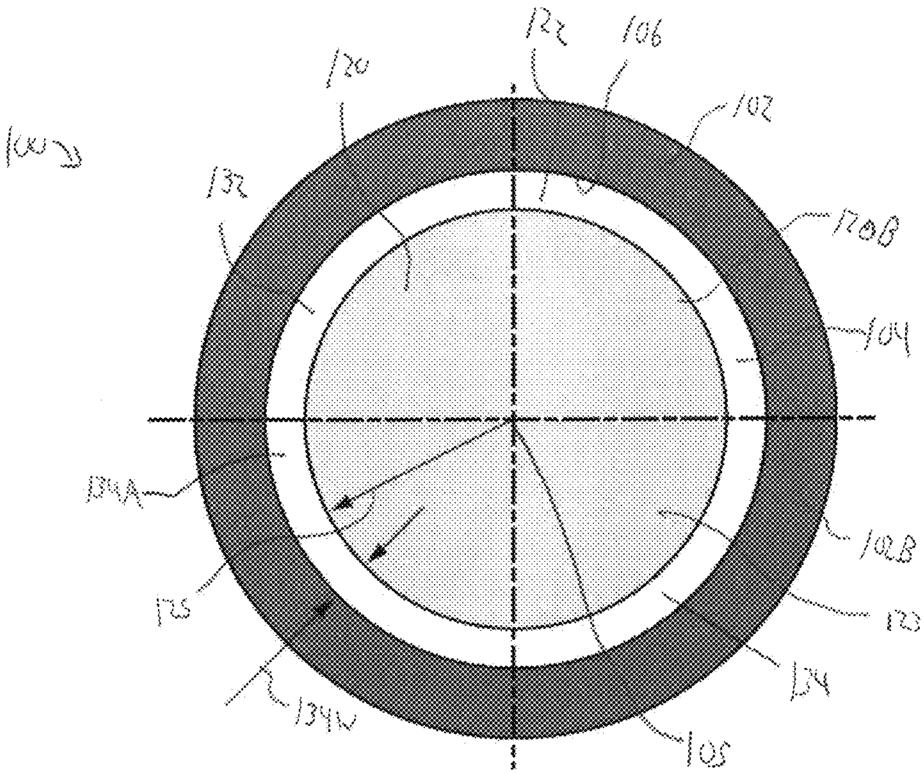


FIG 1


100
122
106
102
120
132
120B
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102B
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123
134
134W
105

FIG 2

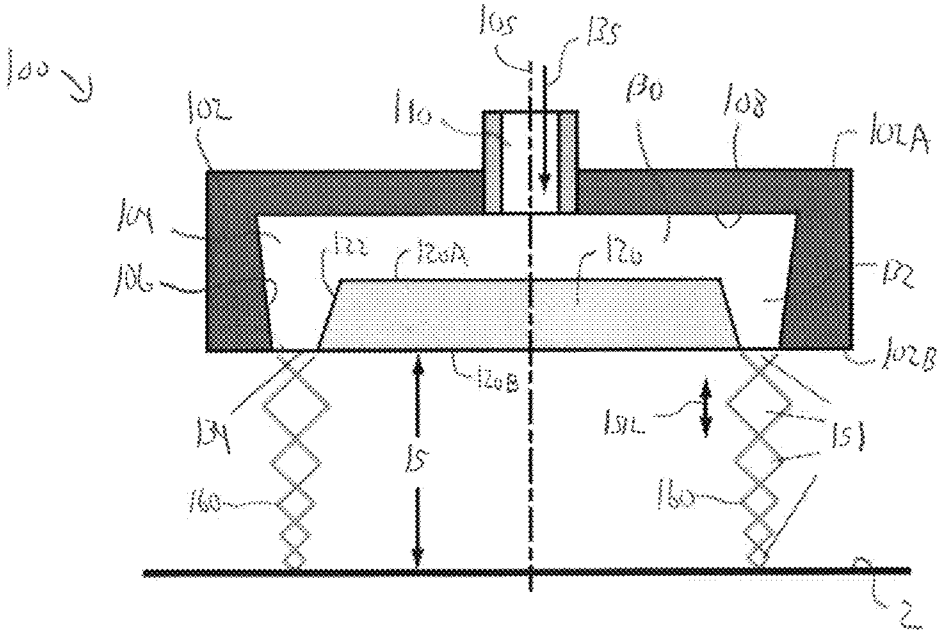
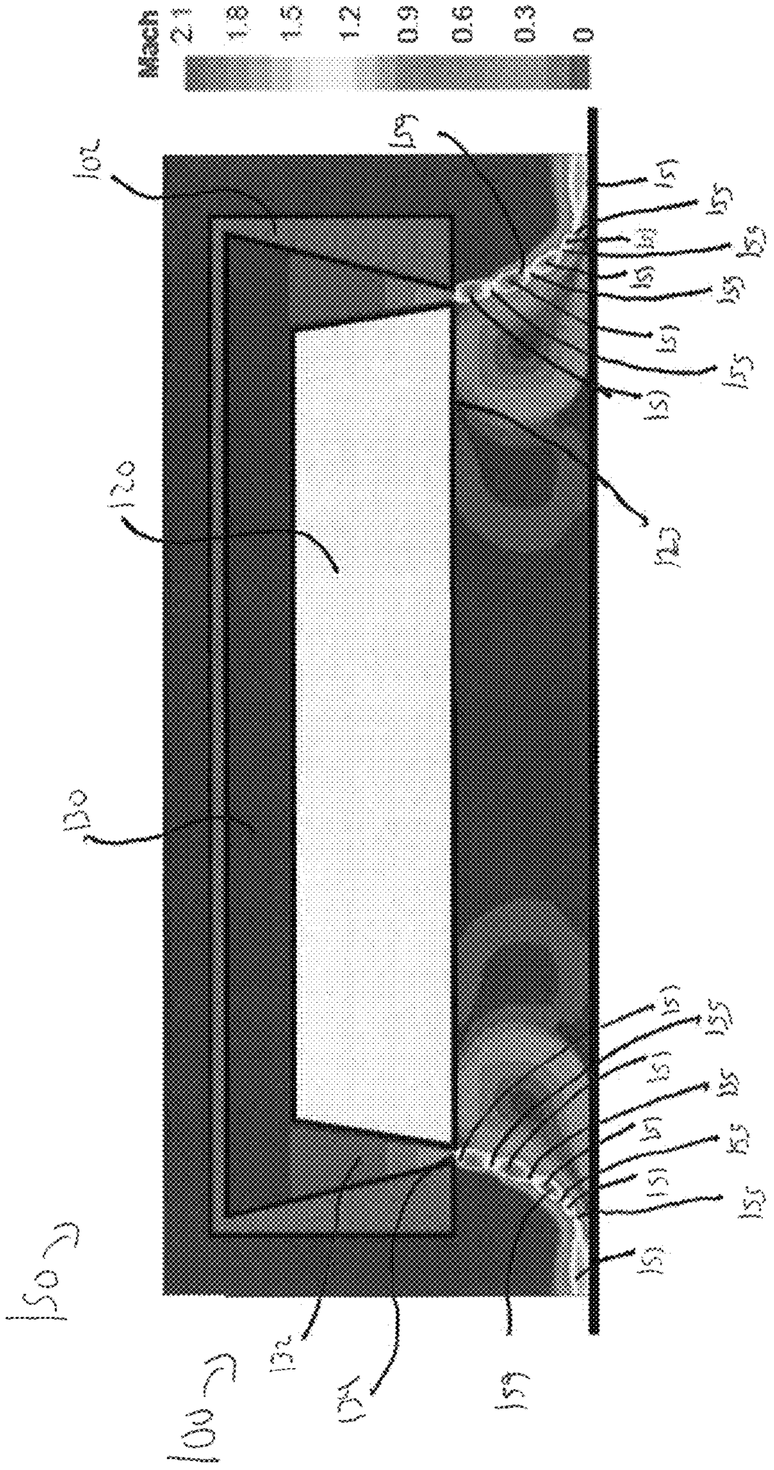

105
135
100
102
110
130
108
102A
104
106
122
120A
120
132
102B
120B
134
15
151L
151
160
160
2

FIG 3


Mach
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
102
159
151
155
161
155
161
155
151
155
151
125
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151
155
151
155
151
155
151
155
151
150
100
132
124
159

FIG 4

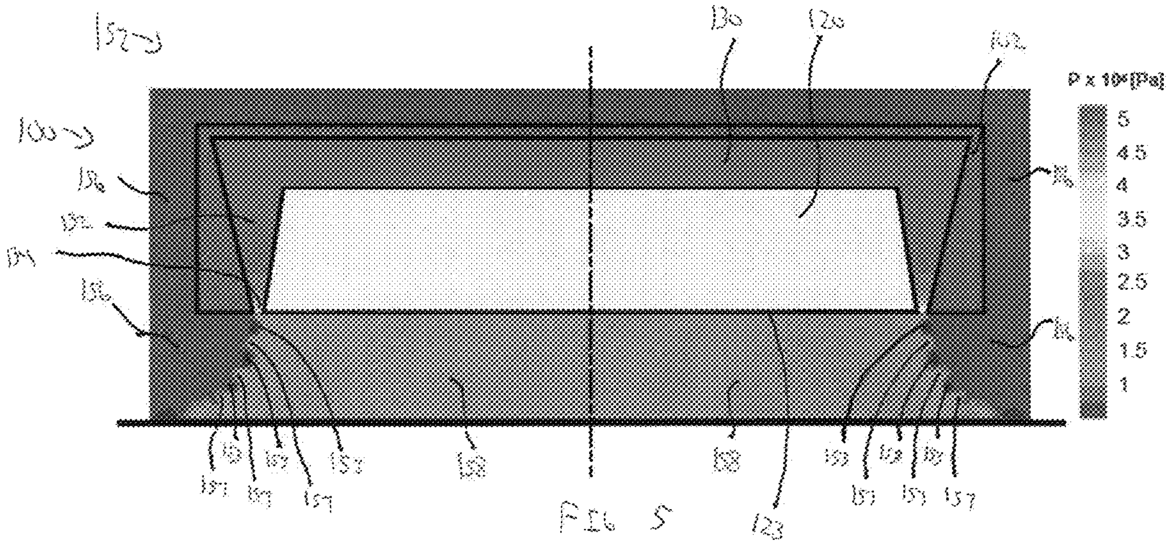

152
130
120
102
100
136
132
134
136
136
136
P x 10⁶ [Pa]
5
4.5
4
3.5
3
2.5
2
1.5
1
157
161
159
167
157
153
158
158
123
153
157
159
157
161
157

FIG 5

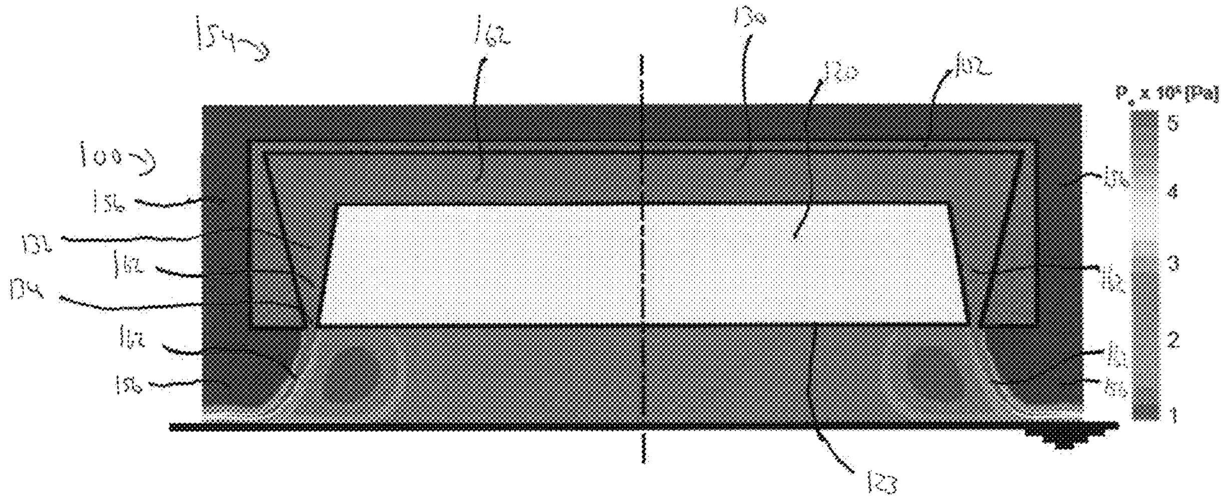

154
162
130
120
102
100
136
132
162
134
162
136
136
162
162
136
P_o x 10⁶ [Pa]
5
4
3
2
1
123

FIG 6

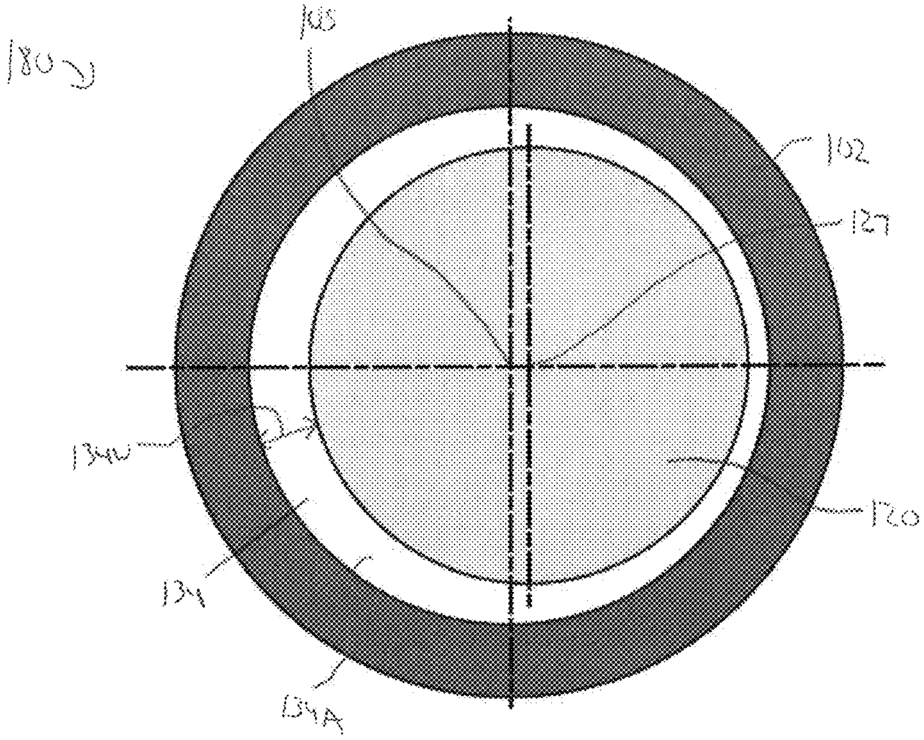
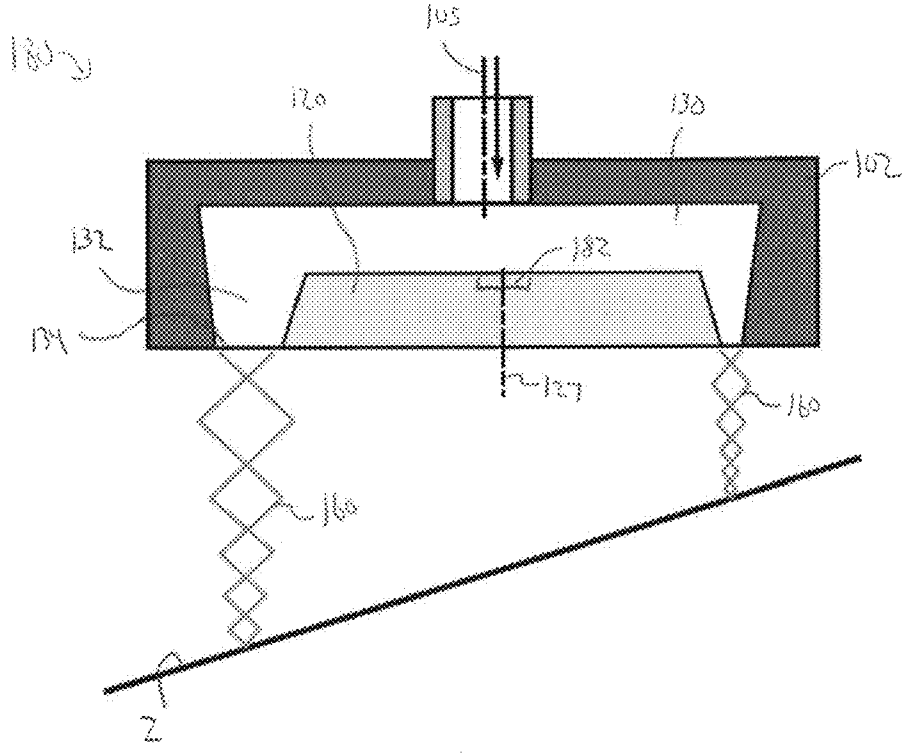

180
105
102
127
134U
120
134
134A

FIG 7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105
120
130
102
132
182
134
127
160
160
2

FIG 8

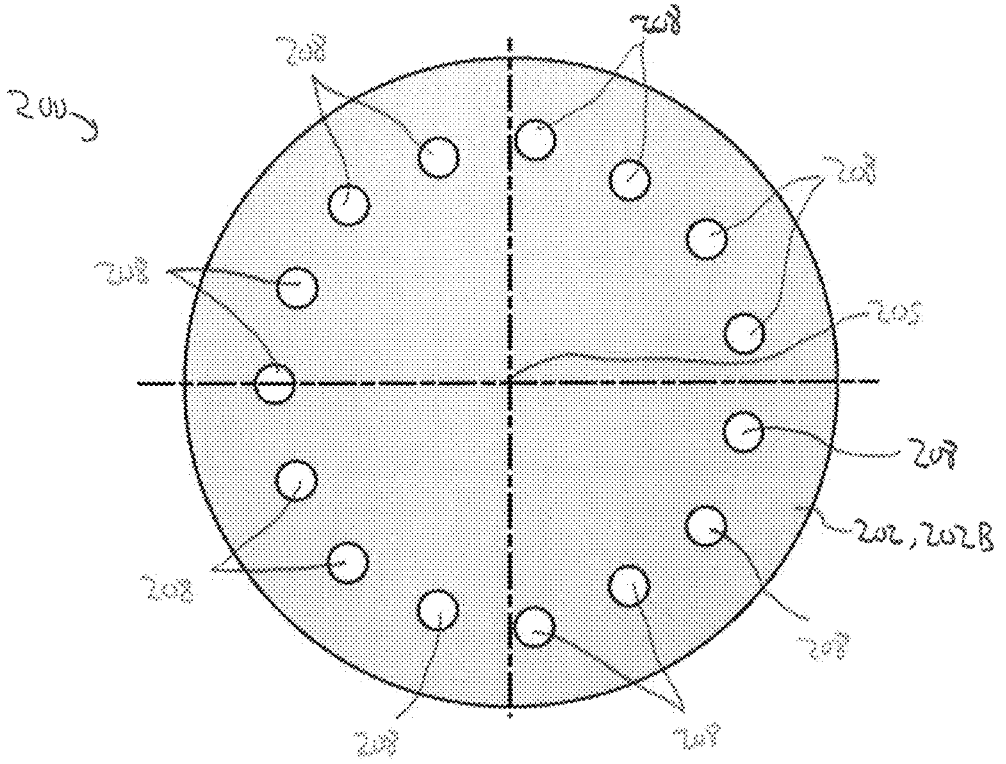
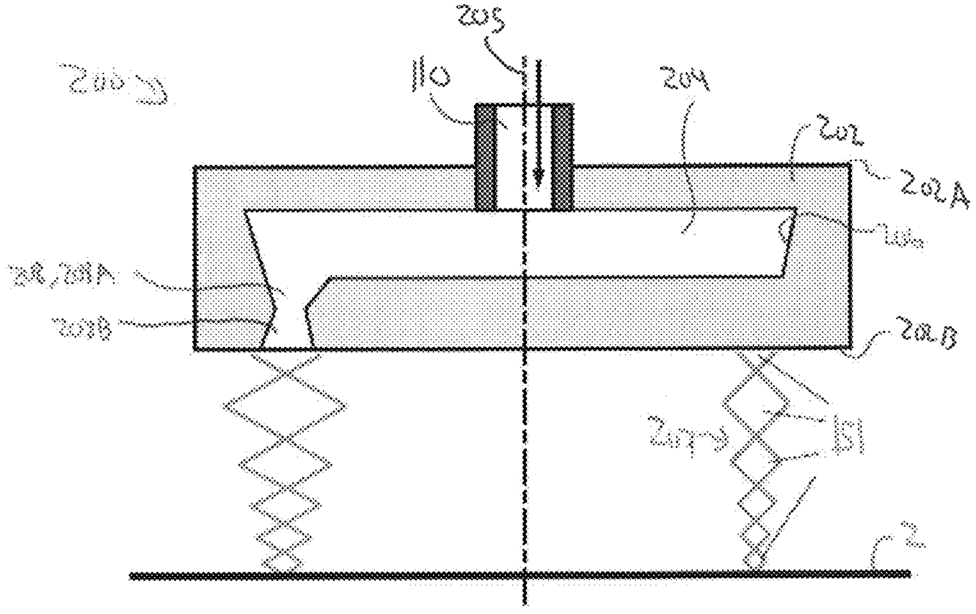

200
208
208
208
208
205
208
202, 202B
208
208
208
208

FIG 9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200
110
204
202
202A
206
208, 208A
208B
202B
207
151
2

FIG 10

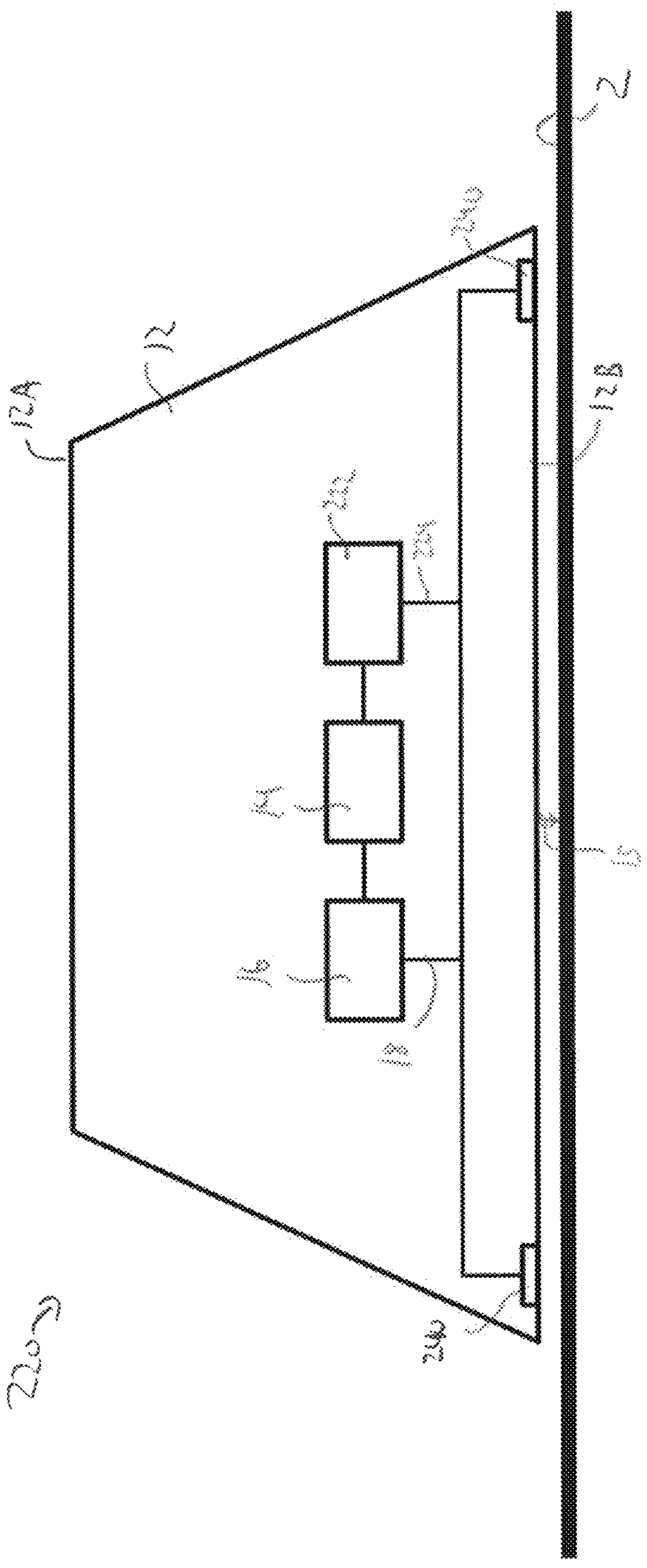

FIG. 11

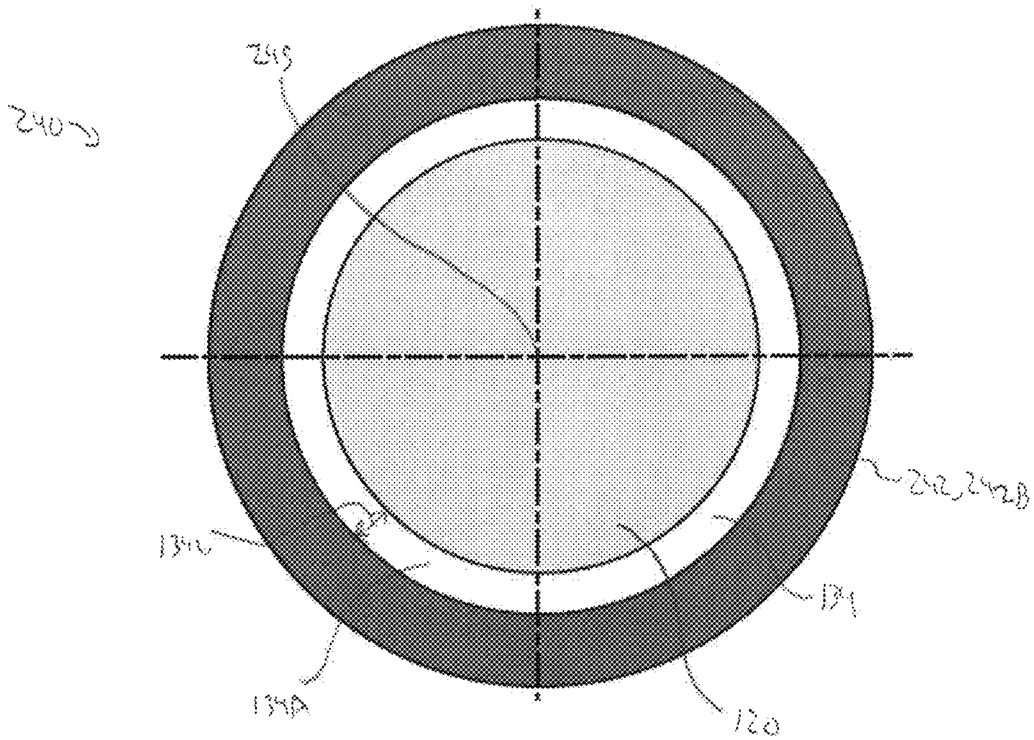
245
240
242, 242B
134C
134
134A
120

FIG 12

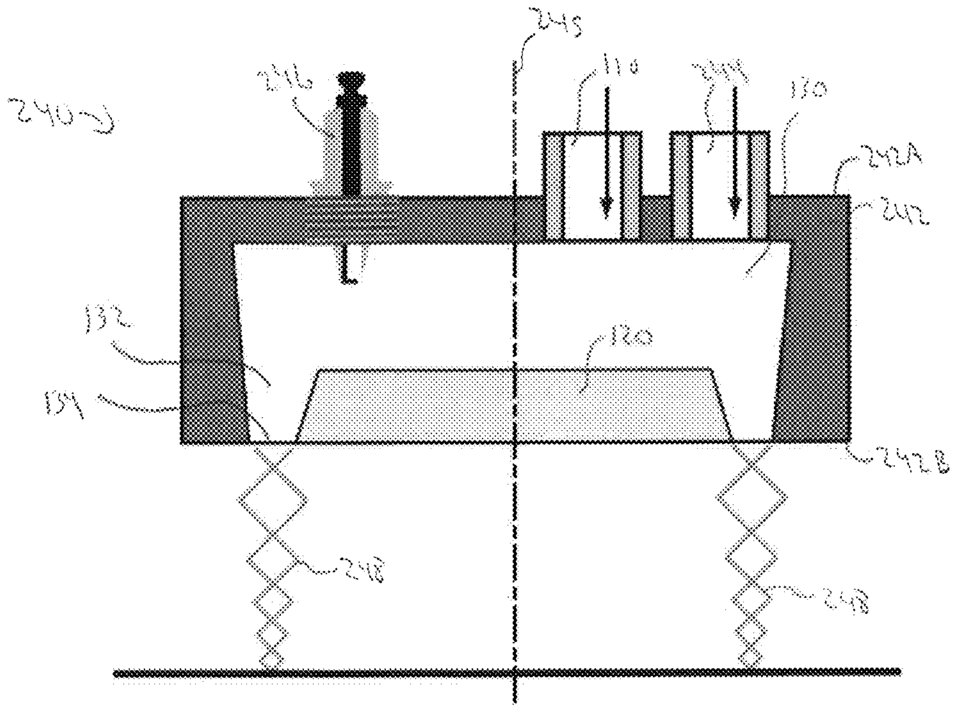
245
246
110
244
130
240
242A
242
132
134
120
242B
248
248

FIG 13

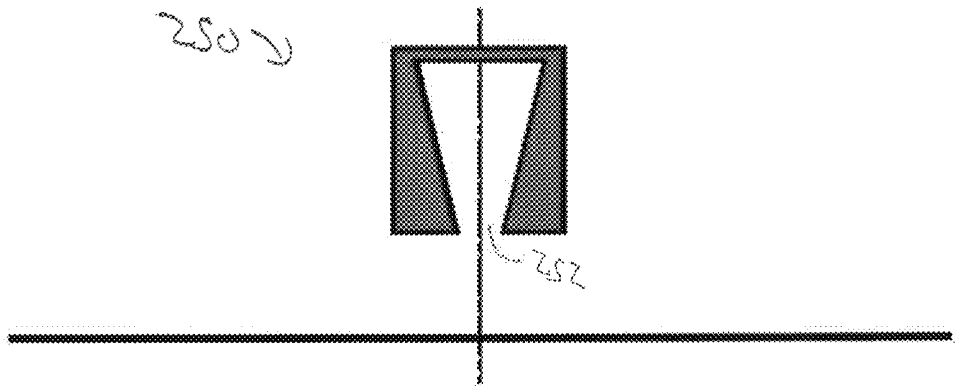

FIG 14

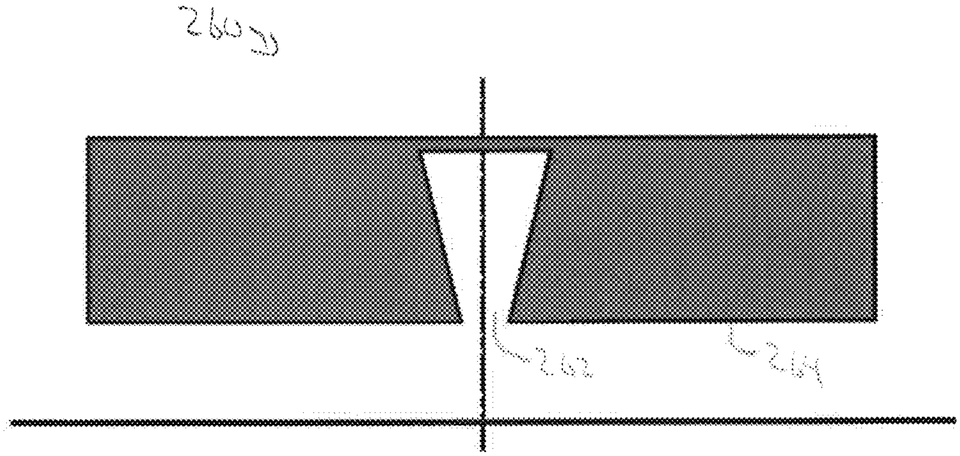

FIG 15

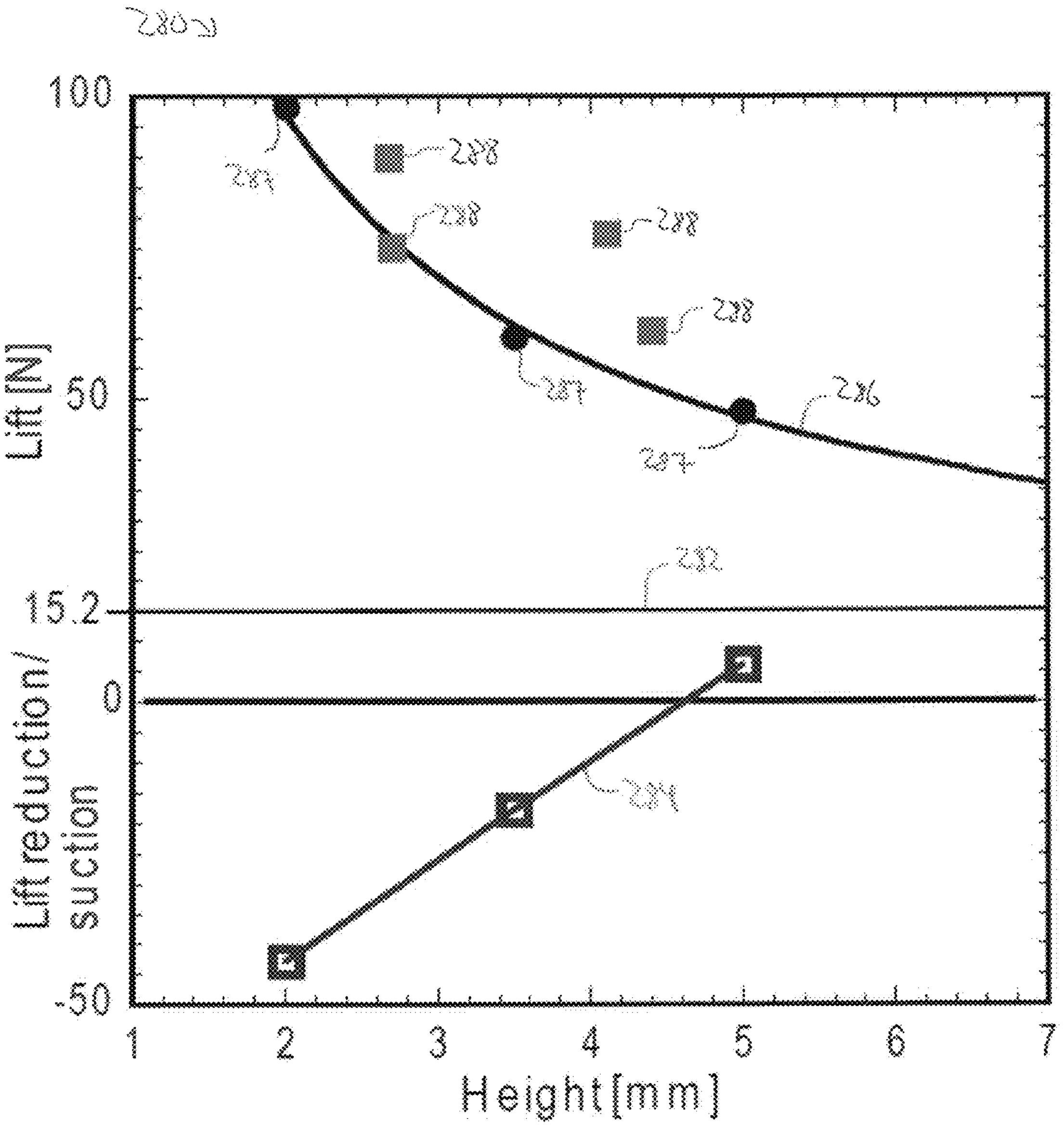
280a
100
50
15.2
0
-50
Lift [N]
Lift reduction/ suction
287
288
288
288
288
287
286
287
282
284
1
2
3
4
5
6
7
Height [mm]

FIG 16

FLUID BEARING SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. provisional patent application Ser. No. 62/394,626 filed Sep. 14, 2016, and entitled "Non-Contact Bearing Systems and Methods," which is hereby incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND

This disclosure relates generally to bearing systems and methods. More particularly, this disclosure relates to non-contact, fluid bearing systems and methods.

Fluid bearing systems may be used in vehicular or transport systems, including high-speed transport systems for reducing friction between the moving vehicle and an adjacent surface over which the vehicle travels. For example, the Hyperloop system is a recent concept that has the potential to become a new, "fifth mode" of transportation, after the classic four: automobiles, trains, ships, and planes. The Hyperloop system may rely on the high-speed, near transonic movement of a vehicle or pod, resembling a train, in a tube that carries human passengers and/or cargo. Space requirements, cost arguments, and other practical considerations may limit the types of propulsion and the amount of thrust available for pod motion inside the tube. Therefore, for the Hyperloop system to come to fruition, all sources of drag resisting pod motion may be minimized. Two major sources of drag include aerodynamic drag, and rolling friction due to wheel contact. Aerodynamic drag may be addressed by evacuating the Hyperloop tube to low pressures, while rolling friction may be addressed by levitating the pod and thus eliminating contact friction altogether.

Levitation of a vehicle may be achieved by relying on electromagnetic means, i.e., by utilizing some type of inductive force generation, or arrangements of rotating magnets, as for example in the Halbach array. However, such devices require electrical power that is carried onboard (e.g. batteries), or is supplied to the moving pod from the ground. A second levitation method may employ gas (e.g., air, etc.) bearings that rely on the presence of compressed gas onboard the pod. One of the more significant problems of air bearing technology is the very small levitation height that can be generated for realistic gas pressure and flowrate conditions. In some applications, commercially available gas bearings may produce a levitation height on the order of few tens of micrometers (i.e., few thousands of an inch). This relatively minimal levitation height may be insufficient to support travel over rough or uneven terrain at high speeds.

BRIEF SUMMARY OF THE DISCLOSURE

An embodiment of a fluid bearing comprises a housing including an internal plenum disposed in the housing and an inlet in fluid communication with the plenum, wherein the inlet is configured to provide fluid to the plenum from an external source, a cushion surface facing away from the housing and the plenum, one or more nozzles positioned between the cushion surface and the housing, wherein the one or more nozzles extend from the plenum to the surrounding environment, wherein the one or more nozzles are configured to produce an annular curtain of fluid flowing at a velocity of at least Mach 1 and disposed about the cushion surface in response to a fluid flow entering the plenum from the inlet. In some embodiments, the one or more nozzles comprises an annular nozzle extending about the cushion surface. In some embodiments, the annular nozzle comprises a converging annular nozzle. In certain embodiments, the one or more nozzles comprises a plurality of circumferentially spaced nozzles disposed about the cushion surface. In certain embodiments, each of the plurality of circumferentially spaced nozzles is a converging-diverging nozzle. In certain embodiments, the fluid bearing further comprises an ignitor extending into the plenum, wherein the ignitor is configured to ignite the fluid entering the plenum. In some embodiments, the curtain of fluid is configured to provide an air cushion beneath the cushion surface that is at a pressure greater than the surrounding ambient pressure in response to a fluid flow entering the plenum from the inlet. In some embodiments, the curtain comprises a plurality of Mach diamonds. In certain embodiments, the fluid bearing further comprises a cushion member positioned in the plenum, wherein a bottom of the cushion member defines the cushion surface, and an actuator coupled to the cushion member and configured to adjust a lateral offset between a central axis of the cushion member and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member.

An embodiment of a hover vehicle for travelling over a surface comprises a chassis, a fluid source supported by the chassis, and a fluid bearing supported by the chassis and configured to produce an annular curtain of fluid flowing at a velocity of at least Mach 1 for levitating the hover vehicle above the surface in response to receiving fluid from the fluid source. In some embodiments, the fluid bearing comprises a housing comprising an internal plenum disposed in the housing and an inlet in fluid communication with the plenum and the fluid source, a cushion surface facing way from the housing and the plenum, and one or more nozzles positioned between the cushion surface and the housing, wherein the one or more nozzles extend from the plenum to the surrounding environment, wherein the one or more nozzles are configured to produce the annular curtain disposed about the cushion surface in response to a fluid flow entering the plenum from the inlet. In some embodiments, the hover vehicle further comprises a fuel source supported by the chassis, wherein the fluid bearing comprises a fuel inlet in fluid communication with the fuel source and an ignitor extending into the plenum, wherein the ignitor is configured to ignite the fluid and fuel in response to fuel and fluid entering the plenum. In some embodiments, the curtain of fluid is configured to provide an air cushion beneath the cushion surface that is at a pressure greater than the surrounding ambient pressure in response to a fluid flow entering the plenum from the inlet. In certain embodiments, the curtain of fluid comprises a plurality of Mach diamonds. In certain embodiments, the fluid bearing comprises a cushion member having a central axis and wherein a bottom of the cushion member defines the cushion surface, and an actuator coupled to the cushion member and configured to adjust a lateral offset between the central axis of the cushion member and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member, wherein the fluid bearing is configured to adjust an attitude of the vehicle in response to the actuator adjusting the lateral offset.

An embodiment of a method for levitating a vehicle travelling over a surface comprises suppling a fluid to an inlet of a fluid bearing of the vehicle, flowing the fluid into a plenum disposed in a housing of the fluid bearing, flowing the fluid through one or more nozzles extending from the plenum and into the surrounding environment, and ejecting the fluid from the one or more nozzles to form an annular curtain flowing at a velocity of at least Mach 1 and extending continuously around a cushion surface of the fluid bearing. In some embodiments, the method further comprises forming a fluid cushion enclosed by the curtain of fluid that is at a greater pressure than the surrounding ambient pressure. In some embodiments, the method further comprises forming a sonic jet comprising a plurality of alternating supersonic regions and subsonic regions. In certain embodiments, the method further comprises adjusting the attitude of the vehicle by adjusting a lateral offset between a central axis of a cushion member comprising the cushion surface and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member. In certain embodiments, the method further comprises igniting the fluid flowing into the plenum.

Embodiments described herein comprise a combination of features and characteristics intended to address various shortcomings associated with certain prior devices, systems, and methods. The foregoing has outlined rather broadly the features and technical characteristics of the disclosed embodiments in order that the detailed description that follows may be better understood. The various characteristics and features described above, as well as others, will be readily apparent to those skilled in the art upon reading the following detailed description, and by referring to the accompanying drawings. It should be appreciated that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes as the disclosed embodiments. It should also be realized that such equivalent constructions do not depart from the spirit and scope of the principles disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of various exemplary embodiments, reference will now be made to the accompanying drawings in which:

FIG. **1** is a schematic cross-sectional view of an embodiment of a vehicle comprising fluid bearings in accordance with principles disclosed herein;

FIG. **2** is a bottom view of one of the fluid bearings of the vehicle of FIG. **1**;

FIG. **3** is a side cross-sectional view of the fluid bearing of FIG. **2**;

FIGS. **4**-**6** are representations of separate computational fluid dynamics (CFD) analyses of the fluid bearing shown in FIGS. **2** and **3**;

FIG. **7** is a bottom view of an embodiment of a fluid bearing in accordance with principles disclosed herein that can be used in the vehicle of FIG. **1**;

FIG. **8** is a side cross-sectional view of the fluid bearing of FIG. **7**;

FIG. **9** is a bottom view of an embodiment of a fluid bearing in accordance with principles disclosed herein that can be used in the vehicle of FIG. **1**;

FIG. **10** is a side cross-sectional view of the fluid bearing of FIG. **9**;

FIG. **11** is a schematic cross-sectional view of an embodiment of a vehicle comprising fluid bearings in accordance with principles disclosed herein;

FIG. **12** is a bottom view of the fluid bearing of the vehicle of FIG. **11**;

FIG. **13** is a side cross-sectional view of the fluid bearing of FIG. **12**;

FIG. **14** is a side cross-sectional view of an embodiment of a fluid bearing in accordance with principles disclosed herein;

FIG. **15** is a side cross-sectional view of an embodiment of a fluid bearing in accordance with principles disclosed herein; and

FIG. **16** is another representation of a CFD analysis of the fluid bearings shown in FIGS. **2**, **3**, **14**, and **15**.

DETAILED DESCRIPTION OF DISCLOSED EMBODIMENTS

The following discussion is directed to various exemplary embodiments. However, one of ordinary skill in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment.

The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . . ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection of the two devices, or through an indirect connection that is established via other devices, components, nodes, and connections. In addition, as used herein, the terms "axial" and "axially" generally mean along or parallel to a given axis (e.g., central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the given axis. For instance, an axial distance refers to a distance measured along or parallel to the axis, and a radial distance means a distance measured perpendicular to the axis.

Embodiments of the present disclosure generally relate to novel fluid (e.g., liquid, gas, or combinations thereof) bearings configured to support levitation at heights on the order of millimeters (e.g., 1-2 tenths of an inch), approximately 100 times higher than what may be accomplished by current air bearings. In some embodiments, the fluid gas bearing generates a sonic curtain of gas (e.g., air) that creates a high-pressure cushion isolated from the surrounding atmosphere. Embodiments of the present disclosure describe a levitation method at relatively large (e.g., 3-4 mm, etc.) heights. In some applications, the relatively large levitating height provided by the disclosed fluid bearings may enable friction-less levitation systems for vehicles, such as the proposed Hyperloop pod. The present disclosure offers a significant advance when compared to classic air bearings which can levitate at relatively small heights (e.g., 0.050-0.100 mm, etc.); the disclosed embodiments also compare favorably to current electromagnetic levitation systems, such as Halbach array devices which require batteries for levitation and hence incur a higher weight penalty. In some embodiments, the fluid bearings mimic a hovercraft by creating a supersonic curtain in place of the solid ones used by those devices. Embodiments disclosed herein allow for the levitation of a vehicle travelling at very high speeds (e.g., near sonic) over relatively rough terrains (e.g. 0.500 mm), which may be required in some vehicular applications, such as the Hyper loop system.

In some applications, traditional air bearings rely on extremely small levitation heights (e.g., 0.050-0.100 mm, etc.) for their operation. Particularly, this small height is necessary before a low-Reynolds number "creeping flow" can be established in the bearing gap, which in turn is responsible for the generation of lift and levitation. Increasing the levitation height may eliminate this effect in traditional air bearings, and may even create suction in place of lift. Therefore, past efforts to increase the levitation height of gas bearings by following the traditional air bearing design concept have been plagued by the "ground effect" issue. Alternative traditional designs for levitating a vehicle include hovercraft devices that rely on the presence of a solid, yet flexible curtain that creates air confinement and generates a small overpressure that ultimately leads to lift and levitation. Hovercraft systems generally travel at relatively slow velocities (i.e., 10-20 mph) and may be difficult to control. Embodiments disclosed herein dispense with the flexible curtain, and instead, utilize a supersonic curtain for confining gas underneath the bearing, which creates overpressure and lift. Further, unlike hovercraft applications that rely on a physical curtain, the disclosed embodiments are configured to allow for very high speed (e.g., 700 mph) travel. Additionally, disclosed embodiments are configured to provide the largest possible area underneath the gas bearings to maximize lift, and are also configured to operate via the presence of a continuous supersonic curtain.

As described above, the present disclosure relates generally to the generation of a sonic/supersonic curtain that creates a region of confinement and overpressure, ultimately resulting in lift and levitation. In some embodiments, high-pressure gas is fed into a plenum and then is ejected through a converging, or converging-diverging nozzle creating a sonic/supersonic jet. If the jet forms a closed surface, the enclosed area of confinement may be at a higher pressure than the local atmosphere, resulting in overpressure, lift, and hovering. The levitation height may be related to the size and number of supersonic jet features known in the art as "Mach diamonds," which are in turn may be related to the ratio of pressures between the plenum and atmosphere, as well as the size of the gap creating the jet.

Referring to FIG. **1**, an embodiment of a hover vehicle **10** for travelling over a surface **2** and including fluid or gas bearings **100** is shown. In the embodiment of FIG. **1**, vehicle **10** generally includes a support structure or chassis **12**, a power source **14**, a gas or fluid source **16**, and a plurality of fluid bearings **100**. Chassis **12** has an upper end or top **12**A, a lower end or bottom **12**B, and physically supports the power source **14** and gas source **16**. In some embodiments, chassis **12** is also configured to physically support passengers of vehicle **10** and/or cargo as vehicle **10** is transported over surface **2**. Gas source **16** comprises a source or storage tank of compressed gaseous fluid. In this embodiment, gas source **16** comprises air; however, in other embodiments, gas source **16** may store other gasses. Power source **14** supplies power to gas source **16** for compressing the gas stored therein and providing the gas as needed to fluid bearings **100** via gas supply lines **18**. In some embodiments, power source **14** provides power for other components of vehicle **10**.

Fluid bearings **100** are positioned at or proximate to the bottom **12**B of chassis **12** and are configured to, upon actuation, levitate vehicle **10** at a levitation height **15** from the surface **2** as vehicle **10** travels over surface **2**. In some embodiments, fluid bearings **100** levitate vehicle **10** at a levitation height **15** of one millimeter (mm) or more (e.g., 2-5 mm, etc.) over surface **2**. In certain embodiments, fluid bearings **100** levitate vehicle **10** at a levitation height **15** of one mm or more as vehicle **10** travels at high speeds (e.g., near sonic) over relatively rough terrain (e.g., roughness value of 0.5 mm).

Referring to FIGS. **2** and **3**, one fluid or gas bearing **100** of vehicle **10** is shown with the understanding the other bearings **100** of vehicle **10** are the same. In this embodiment, fluid bearing **100** has a central axis **105** and generally includes a cylindrical outer housing **102** and a cylindrical cushion member **120**. In some embodiments, housing **102** and cushion member **120** comprise a single, integrally or monolithically formed member; however, in other embodiments, housing **102** and cushion member **120** comprise separate members that are coupled together to form fluid bearing **100**. In this embodiment, housing **102** has a first or upper end **102**A, a second or lower end **102**B, and a central chamber **104** extending into housing **102** from lower end **102**B and defined by a frustoconical inner surface **106**. Chamber **104** of housing **102** terminates therein at a terminal end **108**. In this embodiment, inner surface **106** has a negative draft geometry in which the radius of frustoconical inner surface **106** (measured perpendicular to axis **105**) decreases moving axially away from terminal end **108** to lower end **102**B. Additionally, housing **102** includes a gas inlet **110** at upper end **102**A that is in fluid communication with chamber **104**.

Cushion member **120** of fluid bearing **100** has a first or upper end **120**A, a second or lower end **120**B, and a frustoconical outer surface **122** extending between ends **120**A, **120**B. In this embodiment, cushion member **120** is affixed to housing **102** such that relative rotational and/or translational movement between cushion member **120** and housing **102** is restricted. In some embodiments, elongate members or spokes extend axially between first end **120**A of cushion member **120** and the terminal end **108** of chamber **104** to couple cushion member **120** with housing **102**. In other embodiments, elongate members or spokes extend radially between outer surface **122** of cushion member **120** and inner surface **106** of housing **102**. The radius of outer surface **122** (measured perpendicular to axis **105**) increases moving from upper end **120**A to lower end **120**B. In this embodiment, lower end or bottom **120**B of cushion member **120** defines a cushion surface of fluid bearing **100**. Central axis **105** of fluid bearing **100** extends perpendicularly to cushion surface **120**B. A generally cylindrical plenum **130** defined by inner surface **106** of housing **102** is formed or disposed in chamber **104**, where plenum extends axially between terminal end **108** of chamber **104** and the upper end **120**A of cushion member **120**. Cushion surface **120**B of fluid bearing **100** faces away from plenum **130**. Additionally, an annular nozzle **132** is also formed in chamber **104** of housing **102**, where nozzle **132** extends axially between the upper end **120**A of cushion member **120** and the lower ends **102**B, **120**B, of housing **102** and cushion member **120**, respectively. Annular nozzle **132** is positioned between cushion surface **120**B and housing **102**. A radially outer end of annular nozzle **132** is defined by the inner surface **106** of housing **102** while a radially inner end of annular nozzle **132** is defined by the outer surface **122** of cushion member **120**. Given that inner surface **106** and outer surface **122** each comprise frustoconical surfaces, the radial width of annular nozzle **132** (measured perpendicular to axis **105**) gradually decreases from a maximum located axially at the upper end **120**A of cushion member **120** to a minimum located axially at the lower ends **102**B, **120**B, of housing **102** and cushion member **120**, respectively. Thus, in this embodiment, annular nozzle **132** comprises a converging nozzle. The converging width of annular nozzle **132** forms an annular exit or throat **134** between the lower ends **102**B, **120**B of housing **102** and cushion member **120**, respectively.

During operation of vehicle **10** and fluid bearing **100**, pressurized gas is provided to fluid bearings **100** via gas supply **16** and gas supply lines **18**. Gas flow into plenum **130** via gas inlet **110** of housing **102** (indicated by gas flowpath arrow **135**) where pressure in plenum **130** (P_o) is maintained at stagnation pressure. The pressure P_o in plenum **130** is higher than the atmospheric pressure P_a. Gas disposed in plenum **130** flows through annular nozzle **132** and exits chamber **104** of housing **102** via throat **134**. The pressure differential between the pressure P_o in plenum **132** and atmospheric pressure P_a produces the fluid flow from plenum **130** to throat **134**, where the pressure of the gas as it flows through throat **134** may be obtained through isentropic calculations. For instance, and not being bound by any particular theory, the pressure (P_e) of gas exiting throat **134** may be calculated according to equation (1) presented below:

$$p_e = p_t = p^* = p_o\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \tag{1}$$

If the pressure P_o in plenum **130** is large enough, choking (e.g., a sonic condition) is obtained at throat **134**, where the Mach number M (e.g., in this embodiment, Mach number M=u/a where u is the local flow speed and a equals the local speed of sound) becomes unity and pressure in throat **134** attains the critical value P* where γ of equation (1) is the heat capacity ratio (c_p/c_v). When a choked flow is produced through throat **134**, the pressure in throat **134** is also greater than atmospheric pressure P_a.

Referring to FIGS. **4**-**6**, representations of separate CFD analyses of gas flow through fluid bearing **100** are shown. Particularly, an exemplary axisymmetric flow simulation **150** illustrating the Mach number of the gas flow is shown in FIG. **4**, an exemplary turbulent flow simulation **152** illustrating the pressure of the gas flow is shown in FIG. **5**, and an exemplary compressible flow simulation **154** illustrating the total (stagnation) pressure distribution is shown in FIG. **6**. In this embodiment, flow simulations **150**, **152**, and **154** are produced using the Fluent software tool provided by ANSYS; however, in other embodiments, other CFD software tools may be used to produce flow simulations, **150**, **152**, **154**. In this embodiment, flow simulations **150**, **152**, **154** include gas compressibility and turbulent flow models configured to capture the gas flow through fluid bearing **100** in a realistic fashion. Additionally, in performing flow simulations **150**, **152**, **154**, a wide variety of operating parameters were explored, including gas composition, the annular area **134**A (shown in FIG. **2**) of throat **134**, the annular width **134**W (shown in FIG. **2**) of throat **134**, a cushion area **123** (shown in FIG. **2**) comprising the area of the lower end **120**B of cushion member **120**, a cushion radius **125** (shown in FIG. **2**) comprising the radius extending between central axis **105** and the outer surface **122** of cushion member **120** at lower end **120**B, levitation height **15**, stagnation pressure P_o of plenum **130**, as well as other factors. For instance, in an embodiment, the cushion radius **125** ranges approximately from 50 mm to 760 mm, the pressure P_o in plenum **130** ranges from the pressure P* where choking occurs up to approximately 150 pounds per square inch (PSI), the annular width **134**W ranges approximately from 25 micrometers to 5 mm, and levitation height **15** ranges from approximately 15 micrometers to 125 mm. However, the flow simulations **150**, **152**, and **154** are exemplary and may change in result of changes to the above described operating parameters, as well as to changes in other factors.

In this embodiment, the gas flow exiting throat **134** of fluid bearing **100** (illustrated by flow simulations **150**, **152**, and **154**) first expands to a supersonic condition (M>1) in a supersonic region forming a supersonic structure or Mach diamond **151** (shown in FIGS. **3** and **4**) through a Prandtl-Meyer expansion fan in a sub-atmospheric pressure region (e.g., $P<P_a$) **153** (shown in FIG. **5**). As the gas travels farther from throat **134** it develops shock waves, including oblique and normal shock waves, which produce a subsonic condition (M<1) in a subsonic region **155** (shown in FIG. **4**) in a supra-atmospheric pressure region (e.g., $P>P_a$) **157** (shown in FIG. **5**). In some embodiments, this flow process may continue for a number of iterations along the gas flowpath extending from throat **134** to the surface **2**, ultimately forming a flow pattern resembling, for instance, the exhaust of a jet engine or rocket nozzle. Thus, flow simulation **150** includes a plurality of alternating Mach diamonds **151** and subsonic regions **155** and flow simulation **152** includes a plurality of alternating sub-atmospheric pressure regions **153** (coinciding in location with Mach diamonds **151**) and supra-atmospheric pressure regions **157** (coinciding in location with subsonic regions **155**).

Flow simulation **150** of FIG. **4** also indicates the presence of an annular sonic or supersonic line or jet (e.g., M≥1) **160** extending continuously between throat **134** and surface **2** (encapsulating Mach diamonds **151** and subsonic regions **155**), which forms an annular sonic or supersonic curtain **159** (e.g., fluid velocity equal to at least Mach 1) (shown in FIG. **5**) extending between throat **134** and surface **2**. Particularly, an upper end of supersonic curtain **159** located at, or proximal to, throat **134** extends about the cushion area **123** of cushion member **120**, and increases in diameter moving from the upper end of supersonic curtain **159** to a lower end of supersonic curtain **159** located at, or proximal to, surface **2**. Additionally, an inner radius or "surface" of supersonic curtain **159** extends convexly between the upper and lower ends of supersonic curtain **159**, and thus, supersonic curtain **159** increases in diameter nonlinearly moving from the upper end of supersonic curtain **159** to the lower end thereof. Flow simulation **152** of FIG. **5** also indicates the separation produced by the supersonic curtain **159** between an atmospheric pressure region **156** surrounding supersonic curtain **159** and the housing **102** of fluid bearing **100**, and a generally cylindrical supra-atmospheric pressure region **158** extending between the lower end **120**B of cushion member **120** and the surface **2** and contained within the supersonic curtain **159**. In certain embodiments, the pressure differential between supra-atmospheric pressure region **158** and the surrounding atmospheric pressure region **156** applies a lifting force against the lower end **120**B of cushion member **120** to thereby levitate fluid bearing **100** (as well as vehicle **10**) at the levitation height **15**.

In some embodiments, the amount of lifting force produced by fluid bearing **100** depends on the degree of total (stagnation) pressure inside plenum **130**. Flow simulation

154 indicates a maximum total or stagnation pressure region **162** that extends throughout plenum **130**, nozzle **132** (including throat **134**), and the supersonic curtain **159** extending between throat **134** and a location at, or proximate to, the surface **2**. The maximum total pressure region **162** is substantially uniform or constant in total pressure throughout, and in this embodiment, comprises approximately five atmospheres (e.g., approximately 73.5 PSI). Turbulent shear layers develop parallel to the supersonic curtain **159**, forming an interaction region between supersonic curtain **159** and its subsonic surroundings. The turbulent shear layers slowly decrease the value of total pressure along a longitudinal axis of supersonic curtain **159** until the supersonic curtain **159** can no longer be formed by Prandtl-Meyer expansions. The local total pressure at the lower end of supersonic curtain **159** drops below the maximum total pressure **162**, thus terminating supersonic curtain **159**. In this embodiment, levitation height **15** depends on the axial length of supersonic curtain **159** (e.g., the length between upper and lower ends of curtain **159**), with an increase in axial length of supersonic curtain **159** resulting in a corresponding increase in levitation height **15**. Thus, in this embodiment, levitation height **15** may be defined by the location in space where total pressure losses in supersonic curtain **159** to the turbulent boundary layers and oblique shock waves have reached the center of supersonic curtain **159**.

In some embodiments, the number of Mach diamonds **151**, and their overall length and width, depend on the maximum level of overpressure encountered at throat **134**, and ultimately, an overpressure ratio between maximum total pressure region **162** and atmospheric pressure region **156** (e.g., P_o/P_a). In certain embodiments, the flow pattern of alternating supersonic (e.g., Mach diamonds **151**) and subsonic regions **155** is separated from the surroundings everywhere by the sonic line **160**, or in other words, by a regions of sonic flow where M=1). Not being bound by any particular theory, the presence of the sonic line **160** implies that information or knowledge of the flow may be communicated from the low-speed surroundings (e.g., atmospheric pressure region **156**) to the interior (e.g., supra-atmospheric pressure region **158**) of the jet flow. In other words, the pressure of supra-atmospheric pressure region **158** is unaffected by the atmospheric pressure of atmospheric pressure region **156**. Thus, by shaping the supersonic flow in a closed pattern, thereby forming supersonic curtain **159**, the atmospheric pressure of atmospheric pressure region **156** cannot be communicated through supersonic curtain **159** to the supra-atmospheric pressure region **158**. In this manner, supersonic curtain **159** separates a region of high pressure (e.g., supra-atmospheric pressure region **158**) to the lower atmospheric pressure (e.g., atmospheric pressure region **156**). In some embodiments, cushion area **123** of cushion member **120** forms a surface from which the cushion of gas disposed in supra-atmospheric pressure region **158** may act against to lift fluid bearing **100** to a levitation height **15** of at least 15 micrometers. In some embodiments, the levitation height ranges between 15 micrometers to 125 mm. Thus, supersonic curtain **159** functions in a similar manner as a fluidic or aerodynamic analogue to the solid, flexible curtain used in hovering ground vehicles ("hovercrafts"), thereby mitigating the problems of low speed and inadequate stability of those devices.

In some embodiments, throat area **134**A is sized to be small enough to secure choking at throat **134**, and thus, ensuring the development of a supersonic flow. Not being bound by any particular theory, throat area **134**A may also be related to the mass flowrate ($\dot{m}$) of the gas flow, which forms supersonic curtain **159**, as depicted in equation (2) below, where R is the specific gas constant, T_o the total (stagnation) temperature of the gas in plenum **130**, and A_e is throat area **134**A:

$$\dot{m} = \frac{A_e p_o \gamma}{(\gamma R T_o)^{1/2}} \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \tag{2}$$

In this embodiment, the mass flowrate $\dot{m}$ of gas is provided by gas source **16**, where gas source **16** has sufficient capacity to accommodate the continuous loss of gas $\dot{m}$ while supplying gas to fluid bearing **100** at high pressure (e.g., having a total pressure equal to pressure in maximum total pressure region **162**). Throat area **134**A may be related to throat width **134**W by simple geometry ($A_e \approx 2\pi r_c l_e$), where r_c refers to cushion radius **125** and l_e refers to throat width **134**W. In some embodiments, and not being bound by any particular theory, a length **151**L (shown in FIG. **3**) of each Mach diamond **151** is related linearly to throat width **134**W, as can be seen from simple experimental correlations valid for supersonic air jets and the following equation (3) shown below, where L refers to Mach diamond length **151**L:

$$L \simeq l_e \sqrt{\frac{p_o}{p_a} - 1.9}\,. \tag{3}$$

In some embodiments, levitation height **15** is associated with the presence of supersonic curtain **159**, and the formation of supersonic curtain **159** depends on the formation of Mach diamonds **151**. Further, in some embodiments, the total number of Mach diamonds **151** and their respective lengths **151**L depend on the overpressure ratio between maximum total pressure region **162** and atmospheric pressure region **156** (e.g., P_o/P_a). Additionally, levitation height **15** may increase with an increase in the overpressure ratio due to an increase in number of Mach diamonds **151** and an increase in their respective lengths **151**L. In certain embodiments, altering throat width **134**W may also affect levitation height **15** in a number of ways. For instance, if throat area **134**A is held constant to keep the mass flowrate $\dot{m}$ through fluid bearing **100** constant, while throat width **134**W is increased to increase the levitation height **15**, the cushion radius **125** of cushion area **123** must decrease as a result, with a concomitant decrease in overall lift produced by fluid bearing **100**. In other words, and has been verified by CFD analyses, under a constant mass flowrate $\dot{m}$ being supplied to fluid bearing **100**, bearing **100** will hover at a levitation height **15** that is inversely proportional to the lift generated by fluid bearing **100**.

Referring to FIGS. **7** and **8**, another embodiment of a fluid or gas bearing **180** that can be used in connection with vehicle **10** (e.g., in place of bearing **100**) is shown. Fluid bearing **180** includes features in common with fluid bearing **100** shown in FIGS. **2**-**6**, and shared features are labeled similarly. Particularly, in the embodiment of FIGS. **7**, **8**, fluid bearing **180** includes an actuator **182** configured to displace cushion member **120** relative to housing **102**. Particularly, actuator **182** is configured to move cushion member **120** laterally relative to housing **102** such that a central axis **127** of cushion member **120** (axis **127** extending perpendicularly relative to cushion surface **120**B) may become radially or laterally offset from a central axis **105** of housing **102**, where central axis **127** of cushion member **120** is oriented parallel to central axis **105** of housing **102**. Misalignment between axes **127** and **105** causes the width **134**W of throat **134** to vary in size along the circumference of throat **134**.

Although, in this embodiment, width **134**W of throat **134** may not be uniform along the circumference of throat **134**, supersonic curtain **159** may still be maintained along the entire circumference of throat **134** even when central axis **127** of cushion member **120** is laterally offset from central axis **105** of housing **102**. Thus, in other embodiments that do not include actuator **182**, diverse or non-symmetrical shapes may be used when forming housing **102** and cushion member **120** to conform with varying vehicular requirements.

In this embodiment, throat exit area **134**A and the mass flowrate $\dot{m}$ through fluid bearing **180** may be minimized. The length **151** of each Mach diamond **151** may also change as a result of equation (3), and consequently the overall levitation height **15** may also depend on the local throat width **134**W. As shown particularly in FIG. **8**, the non-uniform throat width **134**W varies the attitude of fluid bearing **180** with respect to the surface **2**, thus allowing for pitch and roll control of vehicle **10** using fluid bearing **180**. In other embodiments, instead of changing throat width **134**W, a similar effect may be obtained by directing the sonic line **160** at an angle with respect to central axis **105**, thus effectively lowering part of fluid bearing **180**. In some embodiments, these methods of pitch control may be implemented in real time using a closed loop controller configured to sense or measure the attitude of fluid bearing **180** (e.g. using a laser sensor, etc.) and correct the attitude by pushing one component of fluid bearing **180** to one side (via actuator **182**), thereby changing the throat width **134**W locally, or rotating cushion member **120** of fluid bearing **180** in such a way as to change the angle of supersonic curtain **159** and thereby change the levitation height **15**.

In other embodiments, gasses other than air may be fed to the fluid bearings (e.g., bearings **100**, **180**) of vehicle **10**. For instance, equation (2) above illustrates the dependence of the mass flowrate $\dot{m}$ on the type of gas via the effects of γ and the molecular weight (MW) of the gas, where the specific gas constant R is related to the universal gas constant R_U by the simple formula $R=R_U/MW$, which shows that R increases with decreasing MW creating a number of operating possibilities. For example, while keeping the mass flowrate ($\dot{m}$, kg/s of gas) and throat area **134**A fixed, reducing the MW of the gas, such as by substituting Helium (MW=4) for air, allows for an increase in pressure in the maximum total pressure region **162** and an increase in the overpressure ratio, providing an increased levitation height **15**.

Referring to FIGS. **9** and **10**, another embodiment of a fluid or gas bearing **200** that can be used in connection with vehicle **10** (e.g., in place of bearing **100**) is shown. Fluid bearing **200** includes features in common with fluid bearing **100** shown in FIGS. **2**-**6**, and shared features are labeled similarly. In the embodiment of FIGS. **9**, **10**, fluid bearing **200** has a central axis **205** and generally includes a housing **202** having a first or upper end **202**A, a second or lower end **202**B, and a central cylindrical chamber or plenum **204** disposed therein and defined by a frustoconical inner surface **206**. Central axis **205** of fluid bearing **200** extends perpendicularly relative to lower end **202**B of housing **202**. In this embodiment, lower end **202**B of housing **202** comprises a cushion surface of fluid bearing **200**. Housing **202** also includes a plurality of circumferentially spaced nozzles **208** extending axially between plenum **204** and the lower end **202**B of housing **202**. Each nozzle **208** includes a converging section **208**A extending from plenum **204**, and a diverging section **208**B extending from a lower end of the converging section **208**A to the lower end **202**B of housing **202**. Thus, each nozzle **208** comprises a converging-diverging nozzle **208**.

In this embodiment, supersonic curtain **159** comprising Mach diamonds **151** may be formed without having a continuous throat **134**. Instead, each nozzle **208** creates a sonic or supersonic jet **207** extending between nozzle **208** and the surface **2**. The Mach diamonds **151** emanating from each nozzle **208** may interact with the Mach diamonds **151** of adjacently positioned nozzles **208** due to the relatively close circumferential spacing of nozzles **208**, potentially allowing for the formation of the enclosed supersonic curtain. In this embodiment, fluid bearing **200** may be configured such that jets **207** each comprise Mach diamonds **151** having a relatively large diameter to assist with potentially creating interactions between the Mach diamonds **151** of different nozzles **208**. In some embodiments, large Mach diamonds **151** are formed by employing a relatively large overpressure ratio with a simple converging channel, or, as is shown in FIG. **4**, by forming each nozzle **208** to include a converging-diverging shape.

Embodiments of fluid bearings described herein may comprise a simple converging channel/nozzles (e.g., nozzle **132** of fluid bearing **100**) configured to create an under-expanded jet structure immediately after exiting throat **134**, a converging-diverging channel/nozzles (e.g., converging-diverging nozzles **208** of fluid bearing **200**) configured to create an over-expanded jet structure at its exit, a channel/nozzles configured to create a perfectly expanded jet structure at its exit. Each of these cases may form a supersonic jet comprising Mach diamonds that alternate in character between over-expanded and under-expanded regions. Thus, the choice of channel shape may be dictated by the required exit pressure condition (P_e) (e.g., the pressure at throat **134** or the exit of nozzles **208**, etc.) as well as the necessary size of the supersonic structures required for the particular application. The use of nozzles **208** in this embodiment provides the benefit of creating supersonic curtain **159** through a smaller total exit area (e.g., the total exit area of the exits of nozzles **208**), which may reduce the gas flow rate required for producing a fixed maximum total pressure **162** (total pressure in plenum **204**, in this embodiment) and fixed levitation height **15**, as predicted by equation (2) above.

Referring to FIG. **11**, an embodiment of a hover vehicle **220** for travelling over a surface **2** and including fluid bearings **240** is shown. Vehicle **220** includes features in common with vehicle **10** shown in FIG. **1**, and shared features are labeled similarly. Particularly, vehicle **220** includes a fuel source **222** for providing a combustible fuel stored therein to a plurality of fluid bearings **240** via fuel lines **224**.

Referring to FIGS. **12** and **13**, the fluid or gas bearing **240** of vehicle **220** is shown. Fluid bearing **200** includes features in common with fluid bearing **100** shown in FIGS. **2**-**6**, and shared features are labeled similarly. In the embodiment of FIGS. **12** and **13**, fluid bearing **240** has a central axis **245** (extending perpendicularly relative to cushion surface **120**B of cushion member **120**) and includes an outer housing **242** having a first or upper end **242**A and a second or lower end **242**B. Along with gas inlet **110**, housing **242** includes a fuel inlet **244** for supplying fuel from fuel source **222** to plenum **130**. Additionally, housing **242** includes an ignitor **246** configured to ignite or combust a mixture of gas and fuel disposed in plenum **130**.

In some applications, the mass flowrates $\dot{m}$ of gas required for levitation may be quite substantial, necessitating use of high pressure gas tanks for carrying the required mass of gas. However, fluid bearing **240** may reduce the mass requirements significantly by, instead of relying on simple isentropic flow for the creation of a sonic or supersonic jet, reacting gas with fuel supplied from fuel source **222** of vehicle **200** to combust the fuel and gas supplied from gas source **16** in response to spark ignition from ignitor **246**. The ignited fuel and gas mixture may create a high pressure and temperature environment within plenum **130**. Particularly, heat release due to combustion may result in significant increase in the fluid properties within plenum **130**, including increases in temperature T_o, pressure P_o, and density (ρ_o) therein. Additionally, equation (2) above shows that for a fixed flowrate of gas $\dot{m}$ and throat area **134**A, an increase in temperature T_o within plenum **130** due to combustion corresponds to an increase in pressure P_o within plenum **130**. Therefore, small mass flowrates of gas $\dot{m}$ that may not result in choking at throat **134** without ignition may lead to a choked flow at throat **134** and the generation of supersonic curtain **159** after ignition from ignitor **246**. Variation of the fuel stoichiometry inside fluid bearing **240** allows for variation of temperature T_o in plenum **130**, and therefore the ability to control pressure P_o in plenum **130** (e.g., behaving as~the square root of plenum **130** temperature T_o), and in-turn, the length **151** of Mach diamonds **151** and the levitation height **15**.

In some embodiments, a gas generator may be provided in lieu of supplying gas from gas source **16**. For instance, part of plenum **130** may be constructed from a solid monopropellant material similar to that used in rocket motors. Upon ignition gas products of the reaction may be generated to create a high temperature and pressure environment in plenum **130**. Those properties, along with the mass flowrate $\dot{m}$ generated by the fluid bearing may be predicted using formulas from rocket science. A fluid bearing comprising its own gas supply could be used for hovering for short duration (e.g., in the order of a few tens of seconds), depending on the total charge (mass) of the propellant. Additionally, providing a fluid bearing with its own supply of gas may provide the advantage of not requiring an external tank (e.g., gas source **16**), nor any associated equipment used for gas storage, relying instead on the high-density solid propellant charge to store the mass that will be converted into gas during combustion.

Referring to FIG. **16**, a graph **280** depicting comparisons between CFD analyses and experimental data pertaining to lift amplification due to the cushion effect of the supersonic curtain **159** of fluid bearing **100** is shown. Graph **280** contrasts the performance of fluid bearing **100** with a first central jet **250** shown in FIG. **14** and a second central jet **260** shown in FIG. **15**. Particularly, first central jet **250** includes a central nozzle **252** for creating a sonic or supersonic jet **248**. Second central jet **260** includes a central nozzle **262** for creating sonic jet **248**, and, unlike central jet **250**, also includes an annular cushion **264** disposed about and surrounding nozzle **262**.

Graph **280** of FIG. **16** depicts lift/suction force (Newtons) on a Y-axis and levitation height 15 (millimeters) on an X-axis. Graph **280** includes a lift curve **282** of first central jet **250** and a lift curve **284** of second central jet **260**, each estimated using flow simulations from CFD analyses. Additionally, graph **280** includes a lift curve **286** of fluid bearing **100** from CFD analyses and exemplary experimental data **288** provided by an exemplary embodiment of fluid bearing **100**. Particularly, prototypes of fluid bearing **100** were constructed with different throat areas **134**A, throat widths **134**W, cushion areas **123**, and cushion radii **125**. A series of experiments were conducted so as to verify the validity of the concept and explore the fluid dynamical aspects of fluid bearing **100**. Results of these experiments comprise the experimental data **288** of graph **280**. Particularly, in the embodiment of FIG. **16**, the throat area **134**A of fluid bearing **100** comprises 52.5 millimeters squared (mm^2), cushion area **123** comprises 1,600 mm^2, plenum pressure Po (e.g., pressure of the maximum total pressure region **162**) of plenum **130** is 3 atmospheres, and the mass flow rate $\dot{m}$ of gas supplied to fluid bearing **100** is 38.4 grams per second (g/s). In the embodiment of FIG. **16**, the throat or exit area of central jets **250** and **260** (e.g., the area of the exit or throat of nozzle **252** and the area of the exit or throat of nozzle **262**, respectively) are each also 52.5 mm^2. Additionally, in the embodiment of FIG. **16**, the cushion area of second central jet **260** (e.g., the area of annular cushion **264**) is 1,600 mm^2.

As shown in FIG. **16**, neither of the central jets **250**, **260**, provide additional lift compared with fluid bearing **100**. Additionally, in this embodiment, fluid bearing **100** does not produce suction (e.g., negative lift). First central jet **250** comprises a baseline case, where the lift generated by first central jet **250** is known from rocket science as the theoretical reaction thrust of a choked nozzle (L_{th}). Not being bound by any particular theory, the baseline case comprises two terms, the main "momentum thrust" (L_{mom}), and the secondary "pressure thrust" (L_{press}), which may be represented in a simplified form in the following equation (4), where V_e is the exit sonic velocity (e.g., $V_e=(2\gamma T_o/(\gamma+1))^{1/2}$), and P_e is the exit pressure calculated from equation (1):

$$L_{th}=L_{mom}+L_{press}=\dot{m}V_e+(p_e-p_a)A_e \tag{4}$$

In this embodiment, first central jet **250** generates a lift of 15.2 N irrespective of levitation height **15**. Further, not being bound by any particular theory, the embodiment of fluid bearing **100** of FIG. **16** generates an amount of lift in excess of the baseline case (e.g., first central jet **250**) from the cushion effect described above with respect to FIGS. **2**, **3**, and **4-6**. Thus, not being bound by any particular theory, the lift generated by the embodiment of fluid bearing **100** of FIG. **16** may be represented, in a simplified manner, using the following equation (5):

$$L=L_{mom}+L_{press}+L_c=\dot{m}V_e+(p_e-p_a)A_e+L_e \tag{5}$$

The lift generated by the embodiment of fluid bearing **100** of FIG. **16**, as estimated by the simplified model of equation (5), is represented on graph **280** by points **287**. Thus, both the theoretical estimations indicated by points **287** and experimental data indicated by points **288**, show a substantial cushion effect of the supersonic curtain **159** generated by fluid bearing **100**. Additionally, in the embodiment of FIG. **16**, while reducing the levitation height **15** of fluid bearing **100** results in increase of the cushion lift (L_c) in an almost inverse linear fashion ($h \approx 1/h^{0.8}$, where h=levitation height **15**). Further, lift curve **282** of second central jet **260**, where second central jet **260** comprises an inverse configuration (e.g., a central jet with surrounding annular cushion) to the configuration of fluid bearing **100** (e.g., annular jet with a central cushion), shows the presence of an opposite force, which results in lift reduction and even in the generation of a net suction (e.g., negative lift) when the levitation height is decreased substantially (e.g., levitation height of less than 5 mm). The suction effect produced by second central jet **260** corresponds to the detrimental effect of traditional hovering vehicles, sometimes referred to as "ground effect" in the art. Thus, unlike traditional hovering vehicles, fluid bearing **100** reverses the ground effect, thereby creating an aerodynamic curtain (e.g., supersonic curtain **159**) that separates the cushion area from the surroundings, and substantially increases the lift generated by reaction between the aerodynamic cushion and fluid bearing **100**. As described above, increasing the pressure in plenum **130**, throat area **134**A, and/or mass flowrate $\dot{m}$ of gas may result in further increases of the generated lift produced by fluid bearing **100**.

While exemplary embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the disclosure. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims. Unless expressly stated otherwise, the steps in a method claim may be performed in any order. The recitation of identifiers such as (a), (b), (c) or (1), (2), (3) before steps in a method claim are not intended to and do not specify a particular order to the steps, but rather are used to simplify subsequent reference to such steps.

What is claimed is:

1. A fluid bearing, comprising:

a housing including an internal plenum disposed in the housing and an inlet in fluid communication with the plenum, wherein the inlet is configured to provide fluid to the plenum from an external source;

a cushion surface facing away from the housing and the plenum;

one or more nozzles positioned between the cushion surface and the housing, wherein each nozzle comprises a converging section, wherein the one or more nozzles extend from the plenum to the surrounding environment, wherein the one or more nozzles are configured to produce an annular curtain of fluid flowing at a velocity of at least Mach 1 and disposed about the cushion surface in response to a fluid flow entering the plenum from the inlet.

2. The fluid bearing of claim **1**, wherein the one or more nozzles comprises an annular nozzle extending about the cushion surface.

3. The fluid bearing of claim **2**, wherein the annular nozzle comprises a converging annular nozzle.

4. The fluid bearing of claim **1**, wherein the one or more nozzles comprises a plurality of circumferentially spaced nozzles disposed about the cushion surface.

5. The fluid bearing of claim **4**, wherein each of the plurality of circumferentially spaced nozzles is a converging-diverging nozzle.

6. The fluid bearing of claim **1**, further comprising an ignitor extending into the plenum, wherein the ignitor is configured to ignite the fluid entering the plenum.

7. The fluid bearing of claim **1**, wherein the curtain of fluid is configured to provide an air cushion beneath the cushion surface that is at a pressure greater than the surrounding ambient pressure in response to a fluid flow entering the plenum from the inlet.

8. The fluid bearing of claim **1**, wherein the curtain comprises a plurality of Mach diamonds.

9. The fluid bearing of claim **1**, further comprising:

a cushion member positioned in the plenum, wherein a bottom of the cushion member defines the cushion surface; and

an actuator coupled to the cushion member and configured to adjust a lateral offset between a central axis of the cushion member and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member.

10. A hover vehicle for travelling over a surface, comprising:

a chassis;

a fluid source supported by the chassis; and

a fluid bearing supported by the chassis and comprising one or more nozzles, wherein each nozzle each includes a converging section, and where the one or more nozzles are configured to produce an annular curtain of fluid flowing at a velocity of at least Mach 1 for levitating the hover vehicle above the surface in response to receiving fluid from the fluid source.

11. The hover vehicle of claim **10**, wherein the fluid bearing comprises:

a housing comprising an internal plenum disposed in the housing and an inlet in fluid communication with the plenum and the fluid source;

a cushion surface facing way from the housing and the plenum; and

the one or more nozzles positioned between the cushion surface and the housing, wherein the one or more nozzles extend from the plenum to the surrounding environment, wherein the one or more nozzles are configured to produce the annular curtain disposed about the cushion surface in response to a fluid flow entering the plenum from the inlet.

12. The hover vehicle of claim **11**, further comprising:

a fuel source supported by the chassis;

wherein the fluid bearing comprises a fuel inlet in fluid communication with the fuel source and an ignitor extending into the plenum, wherein the ignitor is configured to ignite the fluid and fuel in response to fuel and fluid entering the plenum.

13. The hover vehicle of claim **11**, wherein the curtain of fluid is configured to provide an air cushion beneath the cushion surface that is at a pressure greater than the surrounding ambient pressure in response to a fluid flow entering the plenum from the inlet.

14. The hover vehicle of claim **11**, wherein the curtain of fluid comprises a plurality of Mach diamonds.

15. The hover vehicle of claim **11**, wherein the fluid bearing comprises:

a cushion member having a central axis and wherein a bottom of the cushion member defines the cushion surface; and

an actuator coupled to the cushion member and configured to adjust a lateral offset between the central axis of the cushion member and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member;

wherein the fluid bearing is configured to adjust an attitude of the vehicle in response to the actuator adjusting the lateral offset.

16. A method for levitating a vehicle travelling over a surface, comprising:

suppling a fluid to an inlet of a fluid bearing of the vehicle;

flowing the fluid into a plenum disposed in a housing of the fluid bearing;

flowing the fluid through one or more nozzles extending from the plenum and into the surrounding environment; and ejecting the fluid from the one or more nozzles to form an annular curtain flowing at a velocity of at least Mach 1 and extending continuously around a cushion surface of the fluid bearing.

17. The method of claim **16**, further comprising forming a fluid cushion enclosed by the curtain of fluid that is at a greater pressure than the surrounding ambient pressure.

18. The method of claim **16**, further comprising forming a sonic jet comprising a plurality of alternating supersonic regions and subsonic regions.

19. The method of claim **16**, further comprising adjusting the attitude of the vehicle by adjusting a lateral offset between a central axis of a cushion member comprising the cushion surface and a central axis of the housing, wherein the central axis of the housing is oriented parallel to the central axis of the cushion member.

20. The method of claim **16**, further comprising igniting the fluid flowing into the plenum.

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