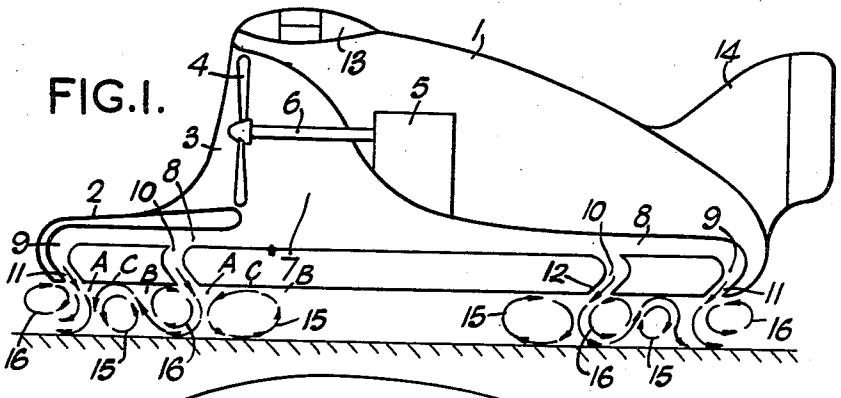
Jan. 14, 1964 C. S. COCKERELL 3,117,644

GROUND EFFECT MACHINE WITH FLUID CURTAIN FORMING AND MAINTAINING MEANS

Filed March 22, 1960 2 Sheets-Sheet 1

FIG. 1.



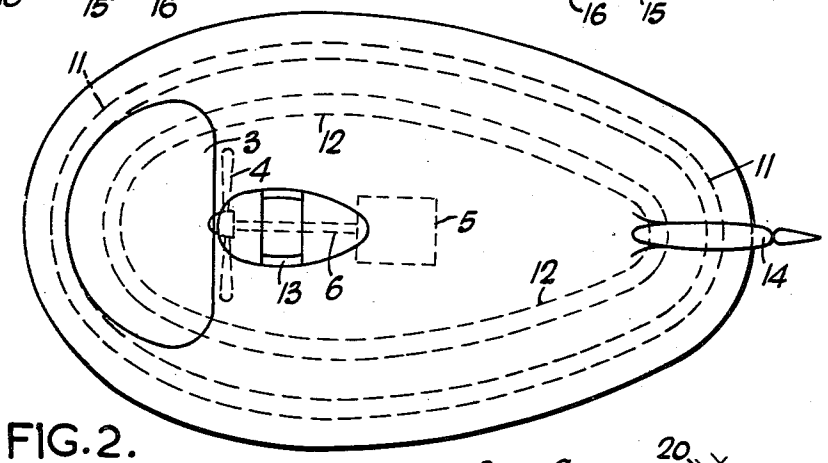
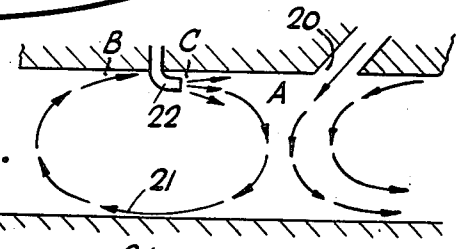


FIG. 2.

FIG. 3.



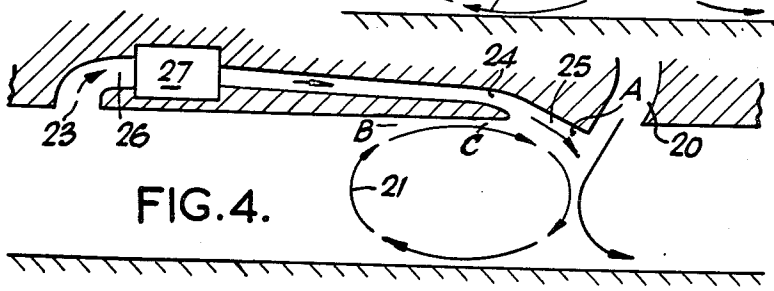


FIG. 4.

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Jan. 14, 1964 C. S. COCKERELL 3,117,644

GROUND EFFECT MACHINE WITH FLUID CURTAIN FORMING AND MAINTAINING MEANS

Filed March 22, 1960 2 Sheets-Sheet 2

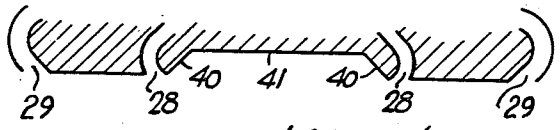


FIG.7a.

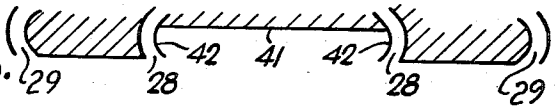


FIG.7b.

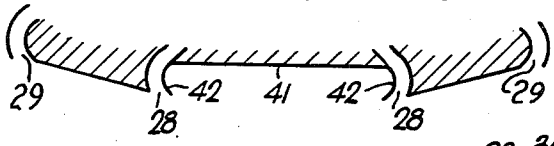


FIG.7c.

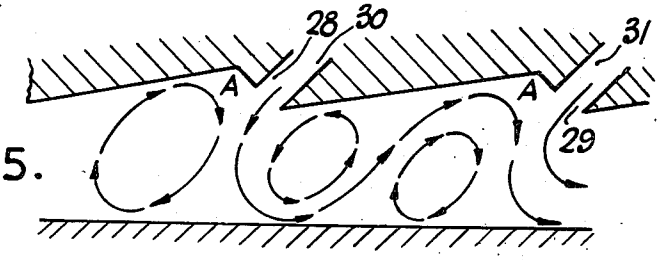


FIG.5.

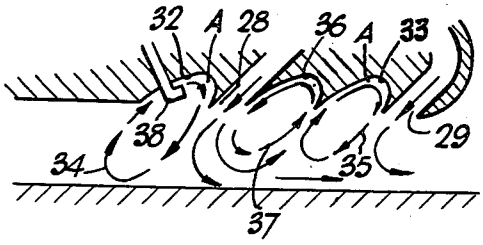
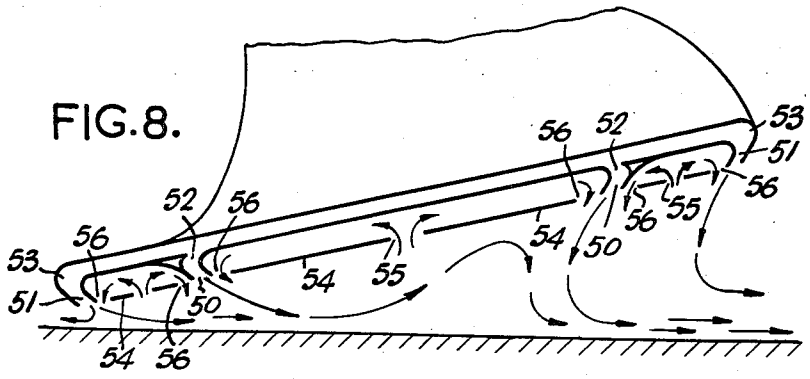


FIG.6.

FIG.8.



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United States Patent Office 3,117,644 Patented Jan. 14, 1964

3,117,644

GROUND EFFECT MACHINE WITH FLUID CURTAIN FORMING AND MAINTAINING MEANS

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Filed Mar. 22, 1960, Ser. No. 16,797
Claims priority, application Great Britain Mar. 26, 1959
13 Claims. (Cl. 180—7)

The specification of co-pending patent application No. 627,925, filed December 12, 1956, describes a vehicle which comprises an intake for a fluid, means for drawing fluid through the intake and causing it to issue from the lower part of the vehicle in such a way as to result in the formation and maintenance of at least one curtain of moving fluid which travels across the gap that in operation exists between the surface over which the vehicle is to hover or travel and the structure of the vehicle and, together with the said structure and surface, encloses a space into which the said fluid, or a gas other than the said fluid, flows so as to result in the formation of a pressurised cushion or cushions by which the vehicle is wholly or partly supported, the pressure of the cushion causing, and in its turn being contained due to, a change of direction of the moving fluid which results in a curvature of the curtain, and in which the total cross-sectional area through which the fluid is taken in is a number of times smaller than the plan area of the said pressurised cushion or cushions, and the means for forming the curtain are such that in cruising conditions the thrust due to the stream of fluid finally leaving the vehicle is substantially less than the weight of the vehicle when loaded.

The same system of support is applicable to a mobile platform and the term vehicle as used herein is to be understood, where the context permits, as including a mobile platform.

It will be understood from the aforesaid application that the correct operation of the vehicle described therein requires that the pressure built up within each curtain shall cause the jet forming the curtain to be bent from its initial direction inwards, or downwards, so that when equilibrium is established it presents a convex face to the cushion within the curtain. In certain conditions, however, this mode of flow of the fluid forming the curtain is interrupted or does not occur, the fluid forming the curtain becoming re-attached to the bottom of the vehicle or clinging to the bottom of the vehicle due to the well known "Coanda" effect.

Such malfunctioning of the curtain forming jet, or jets, is caused at least in part by the creation of a region or regions adjacent to but inboard of a curtain, having a pressure lower than the mean pressure of the cushion contained by that curtain, the lower pressure being due to entrainment of air from the said region or regions by the jet or jets.

The present invention is based on my discovery that by facilitating or enhancing the flow of air to these regions the drop in pressure caused by this effect can be reduced thus obviating at least in part the malfunctioning of the curtain forming jet. The invention accordingly consists in a vehicle for travelling over land and/or water, provided with means for causing a fluid to issue from the lower part of the vehicle in such a way as to result in the

formation and maintenance of at least one curtain of moving fluid which travels across the gap that in operation exists between the surface over which the vehicle is to hover or travel and the structure of the vehicle so that a gaseous pressurised cushion is enclosed by the said structure and surface and by the curtain, or the innermost curtain if more than one is provided, and further gaseous pressurised cushions are enclosed by the structure and surface and adjacent curtains when more than one curtain is provided, the vehicle being mainly supported by the said cushion or cushions, and with means for supplying fluid or facilitating the supply of fluid to any region of the said cushion adjacent to but just inboard of the point of issue from the vehicle of the curtain forming the outer boundary of that cushion at which the pressure is below the mean pressure of that cushion whereby the pressure at the said region is increased.

Supply of fluid to the region or regions of low pressure can be effected or facilitated in various ways. One convenient way is to eject a fluid into or adjacent to the said region or regions, and according to a feature of the invention a vehicle of the type described is provided with a supply port or ports opening into the said region or regions, means also being provided for the supply of fluid to the supply port or ports. A suitable source of fluid for supplying to the supply port or ports is the main volume of the cushion itself, an inlet port, or inlet ports, being formed in the bottom of the vehicle and opening into the main volume of the cushion and being connected to the supply port or ports by a duct or ducts.

An alternative method of facilitating the supply of fluid to the said region is to form the bottom of the vehicle with a profile which will accommodate the vortex which forms inboard of the curtain so that the flow of air in the vortex increases the pressure, and according to a further feature of the invention a vehicle of the type described above is provided with an annular step, projecting from the bottom of the vehicle adjacent to and inboard of the curtain.

The invention will be more readily understood from the following descriptions of various embodiments of the invention in conjunction with the accompanying drawings in which:

FIGURE 1 is a diagrammatic vertical cross section of a vehicle illustrating the idealised air flow pattern beneath the vehicle,

FIGURE 2 is a diagrammatic plan view of the vehicle illustrated in FIGURE 1,

FIGURE 3 is a vertical cross section of part of the bottom of a vehicle on an enlarged scale illustrating one embodiment of the invention,

FIGURE 4 is a vertical cross section similar to FIGURE 3, illustrating an alternative form of the embodiment shown in FIGURE 3,

FIGURE 5 is another vertical cross section of part of the bottom of a vehicle, illustrating another embodiment of the invention,

FIGURE 6 is a further vertical cross section illustrating a modification of the embodiment shown in FIGURE 5,

FIGURES 7*a*, 7*b* and 7*c* comprise three further vertical cross sections of bottoms of vehicles illustrating diagrammatically further embodiments of the invention, and

FIGURE 8 is a diagrammatic vertical cross section of

the lower part of a vehicle illustrating a further embodiment of the invention.

Referring to FIGURES 1 and 2 of the drawings, there is shown a vehicle for travelling over land and/or water having a main body portion 1 and a base portion 2. At the front of the vehicle there is an air intake 3, in which there is mounted a propeller 4 driven by a motor 5 through a shaft 6. The inlet 3 communicates via a duct 7 with a chamber 8 formed in the base portion 2 and communicating via ducts 9 and 10 with two annular ports 11 and 12 formed in the bottom of the vehicle. The outermost port 11 is adjacent to the periphery of the bottom of the vehicle, the inner port 12 being spaced from and substantially parallel to the outer port 11, as seen in FIGURE 2. A cockpit 13 for a pilot is provided, the main body 1 of the vehicle in addition to containing the motor 5 providing freight or passenger accommodation. A tailplane 14 may also be provided at the rear of the vehicle to assist in steering the vehicle.

In operation, the motor 5 rotates the propeller 4, a large volume of air being forced through the duct 7 into the chamber 8 and eventually, via ducts 9 and 10, issuing from the ports 11 and 12 in the form of curtains. Initially the air from the ports 11 and 12 flows substantially horizontally under the vehicle. As the pressure in the space beneath the vehicle rises it will tend to deflect the curtains and will also tend to lift the vehicle. Eventually an equilibrium position will be achieved in which the pressure of the cushions of air contained beneath the vehicle is sufficient to support the vehicle clear of the surface, the pressure of the cushions deflecting the curtains so that they follow a curved path with a mean radius of curvature equal to about half the height of the bottom of the vehicle from the ground, the centre of curvature of each curtain being disposed outside the curtain and substantially vertically beneath the port from which the relevant curtain issues. This can readily be seen in FIGURE 1.

The flow of air through the ports 11 and 12 causes entrainment of air along the surfaces of each jet of air forming a curtain, and in particular at the regions A, thus causing a reduction of pressure in those regions. Air therefore flows in the direction BC and is carried round by the jets so as to form, if the system is operating correctly, vortices 15. Further vortices 16 are formed outside each curtain.

Under normal condtions of operation, the system of flow illustrated in FIGURE 1 is stable so long as the pressure at A is greater than the pressure outside the relevant curtain, although a phenomenon described hereinafter, called for convenience cross-flow, also affects the flow system. If, however, the pressure at A falls sufficiently an alternative mode is possible, the jet switching to a different flow pattern wherein it is not deflected otuwards but maintains its inward direction, either re-attaching itself or clinging to the bottom of the vehicle due to the aforementioned "Coanda" effect. This results in a loss of lift due to a reduction of cushion pressure. The magnitude of the pressure at A depends on certain parameters of the vehicle design, for example, the ratio of jet pressure to cushion pressure, the angle of emergence of the jet and the shape of the bottom of the vehicle. It also depends on certain operating conditions of the vehicle and although a vehicle may have a stable mode of flow as shown in FIGURE 1 when it is in correct trim, when it is tilted the flow may switch to an unwanted mode locally in the region at which the vehicle is lowered. The resulting loss of lift at that locality will tend to cause the vehicle to tilt further, causing the lowered portion of the vehicle to go even lower.

By reducing the adverse effect due to the entrainment of air by the curtain jet the switching of the flow pattern from the wanted mode to the unwanted mode may be retarded or even prevented. One way of reducing the effect of entrainment is illustrated in FIGURE 3. The jet of air forming a curtain issues from a port 20 flowing

first downwards and inwards, then being deflected outwards by the cushion, as shown. A vortex 21 is formed in that part of the cushion adjacent to the inside of the curtain. Additional air is introduced beneath the vehicle by nozzles or similar means 22. This additional air is introduced adjacent to and inboard of the region A, the nozzles 22 having their outlets facing towards this region. The air introduced through the nozzles may be provided from any suitable source provided it is at a pressure above that which occurs in the region A and is preferably at a pressure higher than the mean pressure of the cushion contained by that curtain. The air from the nozzles flows into the regions A raising the pressure thereof, the flow into these regions acting also to energise the vortex 21, the nozzles being preferably located at about the highest point of the vortex, and the air issuing tangentially with respect to the vortex. Thus the pressure in the region A is raised above that which would normally occur and the energising of the vortex also assists in reducing the tendency of the curtain to adopt the unwanted mode in which it either reattaches itself or clings to the bottom surface of the vehicle.

Although the nozzles 22 of FIGURE 3 have been considered as being separate they can be arranged as a single continuous annular nozzle. Alternatively, the nozzle or nozzles can be replaced by a duct and port in the bottom surface of the vehicle as shown in FIGURE 4. In this example air is supplied through a duct 24 to a port 25. This port 25 is inboard of the curtain forming port 20 but it is closer to the port 20 than in the example shown in FIGURE 3. The duct 24 and the port 25 are arranged so that the air issues in a direction towards the port 20, and the air flows directly into the region A but with a smaller re-energising effect on the vortex 21.

The air supply to the duct 24 and port 25 of FIGURE 4, and also to the nozzles 22 of FIGURE 3, may be provided by a separate pressure supply or from the or any pressure supply which is used to form the curtain or curtains, or, by suitable ducting, from the main body of the cushion which is being retained by the relevant curtain or from some other cushion at a higher pressure. Where a multiple curtain system is provided, as shown in FIGURE 1 for example, the air supplied to the region A associated with the outer curtain may come from the air supplying either of the curtain forming ports 11 and 12, from a separate pressure supply or from either of the cushions, that is the inner primary cushion retained by the inner curtain or the outer annular secondary cushion retained by the outer curtain. Energising means may also be provided in any duct feeding air to the ducts or nozzles to raise the pressure of the air flowing therein. Thus in FIGURE 4 air from the cushion flows through a port 23 into a duct 26. The duct 26 communicates with the duct 24 through a compressor 27 which re-energises the air from the cushion.

A further factor which tends to assist in the creation of low pressures at the regions A is the existence of a geometrical configuration which restricts the access of air to the regions, that is which restricts the movement of air from B to C as shown in FIGURE 1. Instead of, or additional to, supplying extra air as described in the previous examples, which extra air will decrease the effect of such restriction, the bottom of the vehicle can be so shaped that the access of air to the regions A is facilitated. One such shaping of the bottom of the vehicle is shown in FIGURE 5, the bottom having a stepped construction. FIGURE 5 illustrates a two-curtain system, air issuing from ports 28 and 29 being supplied to these ports by ducts 30 and 31 respectively. The bottom surface of the vehicle is sloped first upwards as it approaches each port, then sloped more sharply downward to the inner edge of each port. Due to this shaping of the vehicle bottom adjacent to the inner edge of the ports 28 and 29, the separation of the curtain from the bottom of the vehicle is enhanced, the actual

size of the regions A is reduced and air can also flow more readily into such of the regions as remains.

FIGURE 6 illustrates a further shaping of the bottom of the vehicle, which gives a further improvement in access to the regions A. The bottom surface of the vehicle is recessed at 32 and 33 inboard and adjacent to the inner edges of the ports 28 and 29 respectively. The recesses are curved and are of a vertical profile that is substantially identical to the top portion of the vertical profile of the vortices 34 and 35 which are formed inside each curtain. The recesses are so positioned that the vortices 34 and 35 fit into them and it will thus be seen that the size of the regions A is much reduced and air is readily supplied to these regions by the vortices. Preferably the bottom of the vehicle, between the outer edge of the inner port 28 and the outer recess 33, is also recessed, as at 36, the vortex 37 which forms between the inner curtain from port 28 and the vortex 35 fitting into this recess. As explained below the inner curtain of a multiple curtain system is the one most likely to switch to the unwanted mode and therefore the recess 32 is the most important one in a construction as is shown in FIGURE 6, and the remaining recesses can be omitted. Where, in such a vehicle, it is intended to supply fluid, as is done by the nozzles 22 in FIGURE 3, the nozzles can be positioned in the recess or recesses. Thus in FIGURE 6 a series of nozzles 38 situated in the recess 32 as shown, the air added through the nozzles energising the vortex 34, and being also fed to the region A. The nozzles may be provided for only the inner curtain or for both curtains, or where the configuration of the bottom of the vehicle makes it desirable, the outer curtain only. By positioning the nozzles in the recess, or recesses, they are shielded from possible damage due to contact with any obstacles over which the vehicle travels.

FIGURES 7*a*, 7*b* and 7*c* illustrate diagrammatically various forms which the bottom of the vehicle may take with a recess, or other shaping of the bottom of the vehicle, provided only for the vortex immediately within the inner curtain. In FIGURE 7(*a*) the bottom of the vehicle is sloped first upwards and inwards from the inner edge of the inner port 28, for a short distance as at 40, the highest points of these sloping portions being connected by a horizontal portion 41, to form a recess in the bottom of the vehicle within the inner curtain port. The effect of this formation is essentially as the inner step in FIGURE 5. In FIGURE 7(*b*) the bottom of the vehicle immediately within the inner curtain port is in the form of a concave curve, 42, again connected by a horizontal portion 41 to give a recessed bottom. The vortices formed inboard of the inner curtain fit into the curved edges of the recess and is very similar in effect to the inner recesses 32 in FIGURE 6. FIGURE 7(*c*) illustrates a construction similar to FIGURE 7(*b*) but with the bottom of the vehicle between the inner and outer curtains sloped upwards from the inner curtain to the outer curtain.

An alternative way of obtaining the effect of FIGURE 5 is shown diagrammatically in FIGURE 8. In this construction the ports 50 and 51 are at the ends of ducts 52 and 53 which project below the bottom of the vehicle. In order to make the ducts 52 and 53 sufficiently strong to withstand occasional contact with the surface over which the vehicle is operating, they are supported by plates 54. If however, these plates were solid the construction would have the same effect as that shown in FIGURE 1. The plates therefore are provided with slots or grills 55 in the central parts, approximately corresponding to the centres of the respective cushions and slots or grills 56 in the peripheral parts, so that air can flow from the former to the latter. Thus the air at the centre of the main or primary cushion enters the slots or grill 55 in the centre of the central plate 54 and flows outwards towards the duct 52. The inner wall of the duct is curved in a vertical plane, the air from the cushion flowing above the plate 54 until it reaches the inner wall of the duct and then curving round and flowing downwards on the inside of the curtain formed by the air issuing from the port 50. Similarly air from the annular cushion formed between the curtains flows up through the slots or grills 55 in the centre of the outside plate 54, some of the air flowing outwards towards the outer curtain duct 53 and some flowing inwards to the inner duct 52. The outer wall of the duct 52 is curved so that the air flowing from the cushion flows smoothly round emerging adjacent to the outside of the inner curtain. The inner wall of the outer duct 53 is curved similarly to that of the inner duct 52, so as to provide a smooth flow of air. The curving of the inner walls of the ducts 52 and 53, reduces the size of any region of low pressure which may form and facilitates the flow of air to those regions.

It has been mentioned that switching of the air flow to the unwanted mode is most likely to occur at a point on the vehicle which is lowered relatively to the remainder. This is partly due to the fact that the change in the geometrical configuration may result in a restricted passage for the flow of air to the region or regions of low pressure and partly to the fact that all or a part of the air forming the curtain, or curtains where a multiple curtain system exists, tends to flow across the bottom of the vehicle to the region which is relatively higher from the surface. This flow is called, for convenience, cross-flow and is illustrated in FIGURE 8. This cross-flow of air is at a smaller angle to the bottom than is the jet forming the curtain and further restricts the flow of air necessary to produce the vortex which prevents the air from clinging to the bottom of the vehicle. In multiple curtain systems this switching from one mode to another is more likely to occur, and is likely to occur earlier, for the inner curtain system, than in single curtain systems. The reason for this is as follows: When a vehicle, having a multiple curtain system, tilts causing a local lowering of one point of the vehicle, the pressure in the cushion or cushions formed between the various curtains increases. This is explained more fully in co-pending application No. 16,677, filed March 26, 1960, corresponding to British application No. 9900/59. Therefore the pressure at region A inside the inner curtain is more liable to fall below that outside the inner curtain and this curtain will thus more readily switch to the unwanted mode. It is possible, however, to vary this. If the outer port, through which flows the fluid forming the outer curtain, is physically higher than the inner port, through which flows the fluid forming the inner curtain, tilting the craft may cause a restriction between the inner port and the surface and prevent or reduce the effect on the inner curtain, of any pressure rise in the cushion or cushions formed between the curtains. The inner curtain will not therefore switch so readily to the unwanted mode. Switching is still likely to occur at those parts of a vehicle having only a single curtain and of course at any part of the circumference of a vehicle which has only one curtain system all round the vehicle. It is equally liable to occur in vehicles having curtain systems of more complex form than those described, including those in which all or part of the supply air is recovered for further use.

I claim:

1. A vehicle for travelling over land and/or water comprising means for causing a fluid to issue from the lower part of the vehicle in an inward direction relative to the periphery of the vehicle and to form at least one curtain of moving fluid which travels across the gap that in operation exists between the surface over which the vehicle is to hover or travel and the structure of the

vehicle so that a gaseous pressurised cushion is enclosed by the said structure and surface and by the curtain, the vehicle being mainly supported by the said cushion, and means for inducing fluid to flow outwards to any region of the said cushion adjacent to but just inboard of the point of issue from the vehicle of the inwardly directed curtain forming the outer boundary of that cushion at which the pressure is below the mean pressure of that cushion, whereby the pressure at the said region is increased, said last named means including at least one port positioned within the cushion and so constructed and arranged as to discharge fluid in an outward direction into said region, and means for supplying to said port fluid having a pressure higher than that existing in said region.

2. A vehicle for traveling over land and/or water comprising means for causing a fluid to issue from the lower part of the vehicle in an inward direction relative to the periphery of the vehicle and to form at least one curtain of moving fluid which travels across the gap that in operation exists between the surface over which the vehicle is hovering or travelling and the structure of the vehicle so that a gaseous pressurised cushion is enclosed by said structure and surface and by the curtain, the vehicle being mainly supported by said cushion, and means for inducing fluid to flow outwards to any region of said cushion adjacent to but just inboard of the point of issue from the vehicle of the inwardly directed curtain forming the outer bounardy of said cushion at which region the pressure is below the mean pressure of said cushion, whereby the pressure at said inboard region is increased, said last named means comprising a first port opening into said inboard region, and means for supplying fluid to said first port including a second port opening into the main volume of the cushion, and a duct joining the second port with the aforesaid port opening into the said inboard region, whereby the higher mean pressure of the cushion is directed to said region.

3. A vehicle as claimed in claim 2 wherein the means for supplying fluid to said first port includes means for energising the fluid flow through the said duct.

4. A vehicle as claimed in claim 1 wherein the curtain of moving fluid entrains fluid from the said inboard region and causes the entrained fluid to form a vortex, and the port is constituted by the mouth of a nozzle situated near the bottom of the vehicle and directed towards said curtain and substantially tangentially of the vortex formed by the fluid entrained by the curtain.

5. A vehicle as claimed in claim 1 wherein the curtain of moving fluid entrains fluid from the said inboard region and causes the entrained fluid to form a vortex, and including a recess in the bottom of the vehicle which is so positioned and shaped as to accommodate the vortex formed by the fluid entrained by the curtain.

6. A vehicle for travelling over land and/or water comprising a body, means for causing a fluid to issue from the lower part of said body in an inward direction relative to the periphery of said body and form at least one curtain of moving fluid travelling across the gap existing between said body and the surface over which the vehicle is hovering or travelling, said curtain in combination with said body and said surface enclosing a cushion of gas having a mean pressure sufficient to at least partially support the vehicle out of contact with said surface, said cushion including a region adjacent to but just inboard of the point of issue from the vehicle body of the inwardly directed curtain forming the peripheral boundary of said cushion at which region the pressure tends to drop below said mean pressure, and means for causing fluid to flow to said region so as to reduce any such pressure drop at said region, said last named means including an annular port in the lower part of the vehicle body positioned inboard of said curtain and so directed as to discharge fluid in an outward direction into said region, and means for supplying to said port fluid having a pressure higher than that existing in said region.

7. A vehicle for travelling over land and/or water comprising a body, means for causing a fluid to issue from the lower part of said body in an inward direction relative to the periphery of said body and form at least one curtain of moving fluid travelling across the gap existing between said body and the surface over which the vehicle is hovering or travelling, said curtain in combination with said body and said surface enclosing a cushion of gas having a mean pressure sufficient to at least partially support the vehicle out of contact with said surface, said cushion including a region adjacent to but just inboard of the point of issue from the vehicle body of the inwardly directed curtain forming the peripheral boundary of said cushion at which region the pressure tends to drop below said mean pressure, and means for causing fluid to flow to said region so as to reduce any such pressure drop at said region, said last named means comprising a series of ports in the lower part of the vehicle body positioned inboard of said curtain and so directed as to discharge fluid in an outward direction into said region, and means for supplying to said ports fluid having a pressure higher than that existing in said region.

8. A vehicle for travelling over land and/or water comprising a body, means for causing a fluid to issue from the lower part of said body in an inward direction relative to the periphery of said body and form at least one curtain of moving fluid travelling across the gap existing between said body and the surface over which the vehicle is hovering or travelling, said curtain in combination with said body and said surface enclosing a cushion of gas having a mean pressure sufficient to at least partially support the vehicle out of contact with said surface, said cushion including a region adjacent to but just inboard of the point of issue from the vehicle body of the inwardly directed curtain forming the peripheral boundary of said cushion at which region the pressure tends to drop below said mean pressure, and means for causing fluid at a pressure higher than that existing at said inboard region to flow to said region so as to reduce any such pressure drop at said region, said last named means comprising an annular port in the lower part of the vehicle body opening into said inboard region, and means for supplying fluid to said annular port including a second port in the lower part of the vehicle body opening into the main volume of the cushion, and a duct joining said second port whereby the higher mean pressure of the cushion is directed to said region with said annular port.

9. A vehicle as claimed in claim 8 wherein said means for supplying fluid to said annular port also includes means for energising the fluid flow through said duct.

10. A vehicle as claimed in claim 6 wherein the curtain of moving fluid entrains fluid from the said inboard region and causes the entrained fluid to form a vortex, and said annular port is constituted by the mouth of a nozzle situated near the bottom of the vehicle and directed towards said curtain and substantially tangentially of the vortex formed by the fluid entrained by the curtain.

11. A vehicle as claimed in claim 7 wherein the curtain of moving fluid entrains fluid from the said inboard region and causes the entrained fluid to form a vortex, and the series of ports opening into the said inboard region are constituted by the mouths of nozzles situated near the bottom of the vehicle and directed towards said curtain and substantially tangentially of the vortex formed by the fluid entrained by the curtain.

12. A vehicle as claimed in claim 6 including an annular step projecting from the bottom of the vehicle adjacent to the inboard side of the curtain.

13. A vehicle as claimed in claim 6 wherein the curtain of moving fluid entrains fluid from the said inboard region and causes the entrained fluid to form a vortex, and including a recess in the bottom of the vehicle which is so positioned and shaped as to accommodate the vortex formed by the fluid entrained by the curtain.

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