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PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventor: CHRISTOPHER SYDNEY COCKERELL

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COMPLETE SPECIFICATION

Improvements in or relating to Vehicles for Travelling Over Land and/or Water

We, HOVERCRAFT DEVELOPMENT LIMITED, a British Company, of 1, Tilney Street, London, W.1, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

This invention relates to vehicles for travelling over land and/or water and which are supported above the surface of the land or water by one or more cushions of pressurised fluid.

The invention is also applicable to a mobile platform, such as is described and claimed in the specification of Letters Patent No. 893,715, and the term "vehicle" as used herein is to be understood as including, where the context permits, such a platform.

The invention is concerned with the heave stability of the vehicle when travelling over rough water or over ground contoured in a similar manner. When the vehicle is travelling over rough water or ground, the path of the centre of gravity of the vehicle is determined by certain parameters, some of which are design parameters and others depend upon the speed of the vehicle, the length of the vehicle, and the height and spacing of the obstacles forming the rough surface. Dependent upon these parameters, the path of the centre of gravity may be acceptable, but often the combinations of these parameters may result in an unacceptable path, due to such path exhibiting excessive heave, for example a resonant condition or a path which is too far out of phase with the contours beneath the vehicle. These undesirable effects may be reduced by an appropriate dynamic manipulation of some of the design parameters which determine the total upward thrust of the pressurised cushions at any one instant of time, thus enabling the total upward thrust to be varied.

According to the present invention there is provided a vehicle for travelling over a surface and which, in operation, is supported above that surface, at least in part, by a cushion of pressurised gas formed and contained beneath the vehicle, comprising means for reducing the variations in vertical thrust exerted by the supporting gas cushion in the underside of the vehicle which would otherwise occur from variations in volume of the cushion as a result of variations in the height of the vehicle above the surface from a predetermined value.

It is well known that a rough surface, whether it be land or sea can be reproduced by the summation in appropriate phase and amplitude of a series of component waves superimposed upon one another. Thus although a wave formation is in general the result of the superimposition of a number of individual wave formations of different length and height and speed of translation, it is permissible, in order to simplify the analysis, to consider simple formations first of short and then of long waves, it being known that a control system which is suitable for either separately will give a satisfactory performance when more than one is present, and once provided, the amplitudes of the components in combination are within the maximum for which the control is designed.

The problem can be illustrated by considering a number of varying operating conditions. Taking first when the vehicle is traversing plain waves, whose wavelength is short compared with the length of the vehicle, then the integrated lift of its supporting cushion will remain very nearly constant, and

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so the path of the centre of gravity of the vehicle will be very nearly level, and the form of this path will be very little affected by the speed of the vehicle. However, when the vehicle is slowly traversing plain waves whose length is very long compared with the length of the vehicle, the vehicle will heave in phase with the wave so that the height of the vehicle above the surface will be very nearly constant with respect to the mean height of the section of the wave beneath the vehicle in any one instant. Again, when the vehicle is quickly traversing plain waves whose length is very long compared to the length of the vehicle, the vehicle will heave but the phase of its path will lag behind that of the wave so that its mean height halfway down the wave will be greater than its mean height when climbing the next crest. When the vehicle is traversing plain waves of intermediate length the vehicle will heave, in general, by less than the height of the, waves both the amplitude and the phase of this heaving path depending greatly upon the speed of traverse, the length of the vehicle and the natural period or periods in heave of the vehicle and its air cushion. In a further condition, when the vehicle is traversing plain waves of intermediate length and the frequency of encountering them is of the order of the natural frequency of the vehicle in heave, or a multiple of it, the vehicle is excited by the waves and a resonant condition is obtained, resulting in an amplitude of heave which may be far greater than the wave height.

In general, the fluid forming the cushion or cushions is air, and similarly, where fluid curtains are used to contain the cushion or cushions, these are also formed by air, and for convenience hereinafter this will be considered to be the case. However, other fluids, such as exhaust gases and water or steam can be used particularly for forming the curtains.

The invention will be readily understood from the following description of various embodiments in conjunction with the accompanying drawings, in which:—

Figure 1 is a diagrammatic vertical cross-section through a typical surface undulation showing the path followed by the centre of gravity of the vehicle without the application of the invention,

Figure 2 is a vertical cross-section on the fore and aft axis of a vehicle embodying one form of the invention,

Figure 3 is a vertical cross-section similar to that of Figure 2 of a slightly different form of vehicle embodying a similar form of invention as shown in Figure 2,

Figure 4 illustrates a modified form of the vehicle illustrated in Figure 2,

Figure 5 is a similar cross-section to that of Figure 2 illustrating an alternative form of the invention,

Figure 6 is a similar cross-section to that of Figure 3 illustrating the application of an alternative form of the invention as shown in Figure 3,

Figure 7 is a plan view of the vehicle as shown in Figure 2,

Figure 8 is a diagrammatic view of an apparatus for positively controlling the operations of the valves shown in Figures 2 to 5,

Figure 9 is a vertical cross-section of a vehicle, similar to that shown in Figure 2, having an alternative fluid curtain system,

Figure 10 is a vertical cross-section of the front of a vehicle similar to that shown in Figure 4 illustrating a modification thereof,

Figure 11 is a diagrammatic partial cross-section of the bottom part of the vehicle embodying a further form of the invention,

Figure 12 is a modification of Figure 11,

Figure 13 illustrates a further modification of Figure 11,

Figure 14 shows a further form of embodiment shown in Figure 11,

Figure 15 is a partial plan view of the detail of a flap as used in the various forms of the embodiment shown in Figures 11 to 14,

Figure 16 is a diagrammatic partial cross-section of the bottom of the vehicle having yet another embodiment of the invention,

Figures 17A and 17B illustrate diagrammatically a further embodiment of the invention in alternative operating positions,

Figure 18 is a vertical cross-section of part of the periphery of a vehicle illustrating a further embodiment of the invention, and

Figure 19 illustrates a modification of the embodiment illustrated in Figure 18.

As stated above when a vehicle is travelling over an undulating surface, or when a vehicle is hovering over water with waves flowing beneath it, the effect of the variation in height, or clearance, between the bottom of the vehicle and the surface will depend upon the wave length of the undulations compared with the length of the vehicle. Where the wave length is a sub-multiple of the vehicle length, the vehicle will maintain a substantially level course, rising and falling only when encountering isolated taller crests or deeper troughs of such undulations. At the other extreme, where the wavelength is several times the length of the vehicle, the vehicle will follow the profile of the undulations without undue vertical accelerations being imposed on the vehicle. It has been found that the range of wave lengths at which unacceptable vertical accelerations may occur generally lies very roughly between 1 and 2½ times the length of the vehicle, and if provision can be made to cause the vehicle to follow a modified path having a reduced height variation for this range of wave lengths,

the undue vertical accelerations which would otherwise occur can be reduced to an acceptable value, or even almost prevented.

Figure 1 illustrates diagrammatically the profile of an undulating surface, the wavelength being of the order of twice the vehicle length, together with an indication of the path which would normally be followed by the centre of gravity of the vehicle. As described hereinafter, the undulating surface will be considered as being waves in water although it will be appreciated that the invention is applicable to a vehicle travelling over other surfaces having similar characteristics such as sand dunes and the like. Line A represents the profile of a wave and the chain-dotted line B is the path normally followed by the centre of gravity of a vehicle traversing the wave. At the positions indicated at C, D and E the height is that which it is intended to operate the vehicle, that is the cushion volume and mean pressure and the curtain height, are at their correct or datum values. It will be seen that as the centre of gravity of the vehicle passes point C the height of the vehicle relative to the surface increases beyond the mean and there is a corresponding increase in cushion value which causes a decrease in cushion pressure below the mean. This increase in volume and the accompanying decrease in cushion pressure results in a decreased upward thrust on the vehicle which continues until the centre of gravity of the vehicle reaches point D. As the centre of gravity passes point D, the height of the vehicle decreases below the mean, with a corresponding decrease in cushion volume and an increase in pressure beyond the mean, and an increase in upward thrust, until point E is reached. The variation in upward thrust cause variations of the lift exerted on the vehicle which in turn cause vertical accelerations which may be quite large.

To reduce or prevent these variations in lift with the resultant variations in upward thrust the variations in cushion pressure are reduced or prevented. Thus, for example, by providing additional air to the cushion for the period during which the centre of gravity of the vehicle is travelling from C to D, and extracting air from the cushion for the period during which the vehicle is travelling from D to E, its pressure variations can be reduced.

This can be done, in the simplest form of the invention, by means of flap valves, as illustrated in Figures 2 and 3. Figure 2 shows a vehicle in which the cushion 1 is formed and contained around its periphery by a curtain of fluid 2, generally air and referred to hereinafter as such. The air curtain 2 is formed from an annular supply port 3 formed in the bottom of the downward projecting periphery member 4, the air being supplied from a duct 5. In Figure 3 the cushion is contained by a flexible downward projecting peripheral member 6, air being blown into the space occupied by the cushion through a port 7 from a duct 8 in the bottom of the main body of the vehicle, existing air escaping beneath the downward projecting member 6. In both vehicles, one way valves 9 and 10 are provided which in their normal position close ports or ducts 11 through the downward projecting members 4 and 6. The valves 9, at the front of the vehicle, open inwards towards the cushion, the valves 10 at the rear of the vehicle, open outwards. If the pressure of the cushion 1 falls below the atmospheric pressure, the front valves 9 open and admit air to the cushion, reducing the loss of lift and the normal result of the downward drop of the vehicle. Similarly, when the pressure of the cushion 1 exceeds the normal cushion pressure, rear valves 10 open to allow the escape of some of the cushion-forming air to atmosphere. It is advisable to provide a series of ports or ducts 11 as shown in Figure 7 described below to enable large flows of air to take place.

Such a system as shown in Figures 2 and 3 reduces to some extent the pressure variations and the path of the centre of gravity of the vehicle is slightly modified from that shown in Figure 1, but variations in cushion pressure and thus lift will still occur. This is partly due to the fact that no air is admitted to the cushion until it is below atmospheric pressure. A further improvement can be obtained if it is arranged to admit air to the space occupied by the cushion 1 before the pressure drops below atmospheric. A source of high pressure is thus required. Still further improvement is possible if it is arranged to exhaust air from the cushions to a region of reduced pressure. In the vehicles as shown in Figures 2 and 3, this can readily be achieved when the vehicles are in motion as the pressure at the front of the vehicle is above atmospheric, whilst the pressure at the rear of the vehicle is slightly sub-atmospheric.

The vehicles shown in Figures 2 and 3 have the disadvantage that a substantially rigid downward projecting member, comprising the whole of the member 4 in Figure 2 and a comparatively large part of the member 6 in Figure 3, must be provided, increasing the height of the structure.

To avoid this, ducts or ports 12 can be formed in the main body of the vehicle as shown in Figure 4. In this example, ducts 12 are formed in the periphery of the vehicle, valves 13 being provided in the ducts acting in a similar manner to the valves 9 and 10 of Figures 2 and 3. Although Figure 4 illustrates a modification of Figure 2 a similar modification can also be made to Figure 3.

An alternative arrangement is to provide ducts through the body of the vehicle, the ducts serving both for the influx and efflux of air, controlled by a valve capable of opening either way. Such an arrangement is illustrated in Figures 5 and 6, the vehicle shown in Figure 5 being similar to that shown in Figure 2, whilst the vehicle shown in Figure 6 is similar to that shown in Figure 3.

In the vehicles shown in Figures 5 and 6 the duct 15 is formed in the main body 16 of the vehicle, communicating at one end with the space occupied by the cushion 1, and at the other end with the surrounding atmosphere. Two valves 17 normally close the ducts 15 under the action of springs 18 and can rotate one way or the other, as indicated by the dotted lines 19 to allow air to flow into or out of the cushion space. Valves 17 can be so controlled that there is restricted pressure range over which they remain closed. It will be seen that in Figure 5 the supply port 20 can be flush with the bottom surface. In Figure 6 the downward projecting member 21 need not be as long as member 6 in Figure 3. Instead of one large duct 15 being provided a number of smaller ducts can be used.

Figure 7 illustrates diagrammatically the relative position of the ducts 11 in the vehicle illustrated in Figure 2. Ducts 11 are positioned at the front and the rear of the vehicle as shown. The air for the formation of the air curtain 2 enters through intakes 22, being forced by the propellers 23 into the duct 5. A plan view of the vehicle shown in Figure 3 will be very similar, the difference being that the air from the propellers 23 is fed to duct 8 instead. Again, the plan form of the vehicle as illustrated in Figures 5 and 6 will be similar to that of Figure 7 except that for Figure 5 the duct 15 is required for the influx and efflux of the air to and from the cushion, and in Figure 6, the air from the propellors is fed to the duct 8.

The valves, instead of being spring biased or controlled, may be positively actuated by a device or devices controlled, for example, by cushion pressure. Such a device is shown diagrammatically in Figure 8. An hydraulic control valve illustrated generally at 30, controls the flow of pressurised oil from supply inlet 31 to either side of the piston 32 mounted in a cylinder 33. Piston 32 is connected by a suitable linkage 34 to a valve 35, pivotally mounted at 38, and corresponding to the valve 17 of Figures 4 and 5. The cushion pressure P_c is fed by an inlet 36 to the control valve 30. Springs 37 on either side of the piston tend to maintain the piston in central position, in which position the valve 35 is closed.

In operation, variations in cushion pressure are fed by inlet 36 to the control valve 30, oil being supplied to one side or the other of piston 32. The piston moves in the cylinder, rotating valve 35 one way or the other. On return of the cushion pressure to normal the oil supply is cut off and both sides of the piston open to exhaust, whereupon the springs 37 return the piston to its central position, closing the valve 35.

When the valve 35 needs to move only in one direction, as for example in Figures 1 and 2, only a single-sided piston 32 is required. The valves 9, 10 and 17 may also be controlled in accordance with other parameters which vary with variation in the cushion pressure, such as the efflux angle of the curtain 2 in Figures 1 and 3, or by direct height measurement.

Figure 9 illustrates the application of the invention to a vehicle having a more complex form of air curtain, such as described and claimed in the Specifications of Letters Patents Nos. 919,350, 935,824 and 935,826.

In such curtain systems, at least part of the curtain forming air is recovered through recovery ports formed at the bottom of the vehicle, inboard of a supply port. This vehicle is similar to the vehicle illustrated in Figure 5, the air recovered through the recovery ports 40 being re-energised and recirculated back to the supply port 3.

In a vehicle having an air curtain system, such as in Figures 2, 5 and 9, it is possible to reduce the mass flow of the curtain at any convenient position, e.g. at the rear of the vehicle, thus weakening it, when the pressure of the cushion tends to rise above the predetermined pressure. Air from the cushion can then escape beneath the curtain. This is illustrated diagrammatically in Figure 10. A mass flow of air through the supply port 43 can be varied locally by sliding flaps 44 controlled by servo motors 47. In the example shown, flap 44 at the rear of the vehicle, on the right of Figure 10 is restricting the flow of air to the part of the supply port 43 at the rear, locally weakening the curtain of air 45. Air from the cushion is able to flow out beneath the air curtain as at 46. One or more additional air curtains may be formed beneath the vehicle to subdivide the cushion, as shown dotted at 48. The mass flow of the air flowing through the supply port 43 can be increased by sliding the flaps 44 inward so as to open port 43 to its full width.

It will be apparent from the foregoing description of various embodiments of the invention that the invention seeks to reduce or prevent variations in vertical thrust due to the variations in cushion pressure, which would otherwise occur, when travelling over waves and obstacles of similar profile. Thus, when the vehicle leaves a crest of the obstruction and travels over a trough, the cushion pressure is held at a pressure above that which would normally occur, up to the mean pres-

sure, or may be even increased above the mean. However, the curtain height is greater than normal at this time and may not be capable of containing the required cushion pressure. Conversely, when the vehicle after travelling over a trough encounters a rising face of an obstacle, the cushion pressure is held at a pressure below that which would normally occur, down to mean pressure or may be even decreased below the mean. At this time, however, the curtain height is lower than normal and is capable of maintaining and will tend to maintain a cushion pressure above the mean.

According to a feature of the invention, the mass flow of the curtain forming air is increased when the vehicle is over a trough so that the required cushion pressure can be maintained, and the mass flow is decreased when meeting a crest.

The application of the variation of the mass flow of the curtain forming air is similar to the variation of mass flow as described above, with reference to Figure 10. Servo motors 47 are provided to operate the flaps 44 and produce the above described variation of mass flow for the admission of air to, and exhausting of air from, the cushion, the servo motors being controlled by variations in cushion pressure. The control systems, as for example shown in Figure 8 and at 47 in Figure 10, may be actuated by means controlled by a device which is responsive to the vertical velocity of the vehicle or vertical acceleration, and in a phase relationship with one and/or other of these parameters. For example, better operation of the vehicle may be obtained if instead of directly opposing variations in vertical thrust, damping of the dynamic oscillations is provided. To accomplish this, a parameter such as the vertical velocity, the rate of change of cushion pressure, or the rate of change of level height is measured. A force in opposition, and proportional to the parameter measured, is introduced and the oscillations in heave are damped. Such a means of damping may be applied to any of the examples described, but is most readily applied to examples described below in respect to Figures 11 to 19.

The indication of the vertical velocity and/or cushion pressure or vertical acceleration variation may be fed to a summating computer the output of which operates a servo motor connected with, for example, a valve for controlling the flow of additional air to, and the diversion of air from, the curtain forming jet. Where the vehicle is propelled by an air jet separate from the curtain forming jet, it is then advantageous to supply the jet of additional air by diverting a part of the propulsion air to the curtain, and where air is to be moved from the curtain, to divert it to the propulsion jet. It will be appreciated that as the vehicle travels over waves, the air supplied to and diverted from the curtain will be substantially equal over a period of time, so that the average propulsion thrust will not be affected. Depending upon the sensitivity of the devices responsive to variation of vertical velocity and/or cushion pressure or vertical acceleration, the vehicle can be caused to follow the desired path or a path approximating to the desired path.

As stated above the necessity for the control according to the invention decreases as the length of the wave increases, in that with very long waves undue accelerations will not be generated if the vehicle is allowed to follow their contour. Means may therefore be provided, which are responsive for example to the time interval between wave crests, for reducing the response of the control devices of the invention as this time interval increases.

The variation of vertical thrust, or lift, produced by the cushion can also be obtained by varying the area of the cushion. For example, if the cushion pressure has decreased and it is desired to reduce, or prevent, the loss of vertical thrust which would otherwise occur, this can be done by increasing the effective area of the cushion, such as by moving the air curtains outwards or by providing a further curtain out-board of the existing curtain. The converse applies when it is desired to prevent or reduce the increase in vertical thrust which would otherwise occur on an increased cushion pressure. Various ways of varying the effective cushion area are described below.

Figure 11 shows a simple arrangement in which two supply ports 54 and 55 are supplied with air by ducts 56 and 57 respectively. A hinged flap 58 is mounted at the junction of the two ducts 56 and 57, the position of the flap controlling the amount of air fed from a compressor by a duct 59, which enters each of ducts 56 and 57. By rotating the flap one way, anti-clockwise in Figure 11, the amount of air flowing to the inner air curtain is reduced and that flowing to the outer air curtain is increased. This leads to an increase in pressure of the secondary cushion which is formed between the two air curtains and thus increases the effective area of the main cushion. Reverse rotation of the flap has the reverse effect.

Figures 12 and 13 are variations of the system shown in Figure 11. In these examples the outer air curtain is formed from two supply ports 60 and 61, fed by two ducts 62 and 63 respectively, the inner air curtain being formed from a single supply port 64 fed by a duct 65. A hinged flap 66 operates to vary the air flow to the two ducts 63 and 65, the air flow to the duct 62 being separate. Operation of the flap varies the relative air flow to the two supply ports 61 and 64 with the above described effect. In Figure 13 a curved guide vane 67 is hinged

on the flap 66 to give a smooth entry into the duct 65.

In the examples shown in Figure 14 each air curtain is formed from two supply ports, the outer air curtain by supply ports 70 and 71 fed by ducts 72 and 73 and the inner air curtain by supply ports 74 and 75 fed by ducts 76 and 77 respectively. In each pair of ducts the outer duct 72 and 76 is wider than the inner duct. A hinged valve member 78, formed from two parallel flaps, 78*a* and 78*b*, is mounted at the junction of the ducts, movement of the valve member varying the flow of air into the outer duct of each air curtain forming system. Air passes between the parallel flaps 78*a* and 78*b* into the inner duct 73 of the outer air curtain system and flows below the valve into the inner duct 77 of the inner air curtain system. The air flow into each of the inner ducts 73 and 77 is virtually unaffected by any movement of the valve member, only the relative flows to the outer duct 72 and 76 being varied.

In the arrangements as shown in Figures 11 to 14, where the flap or valve is circular it must be made of flexible material or sectors of stiff material with radial joints of flexible material as shown in Figure 15, which is a plan view of a suitable flap for use in Figure 13.

Figure 16 illustrates diagrammatically an alternative method of varying relative flows of air to the supply ports, using a sliding flap or plate. A flat plate 85 is mounted on the bottom surface of the vehicle, arranged to slide inwardly and outwardly over the supply ports 86 and 87. The supply ports 86 and 87 are much wider in the radial direction than is normally the case, and the sliding plate 85 is provided with ports 88 and 89 which act as the actual ports through which the curtain forming air issues. The ports 88 and 89 are slightly wider than normal ports, being sufficiently wider for the issue of the maximum additional air it is intended should be transferred. Ports 88 and 89 are positioned in the plate 85 so that when the plate is in its central position the outer edge of the port 88 is slightly outside the outer edge of the port 86 and the inner edge of port 89 is slightly inside the inner edge of port 87, the unobstructed widths of the ports 88 and 89 being the correct widths for the formation of normal curtains. Air is fed to the ports via a duct 90 and it will be seen that the movement of the plate 85 in or out will vary the relative flows of air out of ports 88 and 89. Vanes may be provided in the wide ports 86 and 87. Whilst the flap plate is shown as being fitted inside the bottom of the vehicle, it can readily be fitted on the outside, but is liable to be damaged. Again, the relative positionings of the wide and narrow ports can be reversed, the narrow ports 88 and 89 being formed in the bottom of the vehicle and the wide ports 86 and 87 being formed in the sliding plate 85.

It will be understood that air is deflected from the inner air curtain system to the outer air curtain system when it is desired to increase the effective area of the cushion to offset any decrease in cushion pressure. The vehicle would normally be arranged to operate with the pressure of the secondary cushion formed between the air curtain systems, at for example, half the pressure of the main cushion. It would then be possible to increase the vertical thrust above the normal or to increase the vertical thrust that would otherwise obtain, by raising the pressure of the secondary cushion, and reduce the vertical thrust by reducing the pressure of the secondary cushion.

Where only a single air curtain system is formed beneath the vehicle then this air curtain can be moved bodily in or out to vary the effective cushion area. Figures 17A and 17B illustrate diagrammatically such a method for moving the position of a port relative to the bottom of the vehicle. The normal narrow port through which the air curtain is formed is replaced by a wide port 91. Mounted over the port is a slidable flap plate 92 having a narrow port 93. Port 93 is equivalent to the normal port formed in the bottom of the vehicle in the previously described vehicles, and where the air is issuing through it forms a primary air curtain, port 73 is in the form of an annulus or is a series of ports in annular configuration. As shown in Figure 17A, the port 93 is in its central position. By moving the plate in or out, in a general radial direction the position of the port and thus the curtain can be varied. If the port 93 is moved inwards towards the centre of the vehicle as shown in Figure 17B, the edge of the cushion will be moved inwards which will have the effect of reducing the area of the cushion. Conversely moving the port 93 outwards away from the centre of the vehicle has the effect of increasing the area of the cushion. The movable plate 92 is easily provided for straight portions of the ports at the bottom of the vehicle; where the ports are curved, it will be necessary to provide for the plates to slide one over the other as they are moved in and out to allow for the variation in circumferential distance. Vanes 94 may be provided in the wide port 91.

An alternative method of varying the effective area of the cushion, as applied to curtain systems in which at least part of the curtain forming air is recovered, is illustrated in Figure 18. A supply port 100 is formed in the bottom of the vehicle at the periphery and a recovery port 101 is also formed in the bottom of the vehicle slightly inboard of the supply port 100. A further

recovery port 102 is formed in the bottom of the vehicle spaced further inboard than the first recovery port 101. The recovery ports 101 and 102 communicate via ducts 103 and 104 respectively with a common recovery duct 105. A sliding vane 106 is mounted between the two recovery ports and acts to vary the opening of the ports. In operation, air issues from the supply port 100, and some of the curtain forming air is recovered through recovery port 101, further air being recovered through recovery port 102. The sliding vane 106 can completely close either of the recovery ports, and if for example, the outer recovery port 101 is closed then the cushion extends, effectively, only as far as the inner recovery port 102. Similarly, if the inner recovery port 102 is closed, the cushion extends as far as the outer recovery port 101. A graduation of the effective cushion area between these two limits can be obtained by varying the sliding vane 106.

Figure 19 illustrates a method of cushion area variation similar to that shown in Figure 18, a rotatable vane 109 being provided to vary the relative amounts of air recovered through the recovery ports 101 and 107, instead of sliding vane 106.

As described above, when the vehicle is quickly traversing plain waves whose length is very long relative to the length of the vehicle, the vehicle is liable to become out of phase with the waves, overshooting at the crests and for at least part of the downward going faces, and undershooting at the troughs and for at least part of the upward going faces of the waves. Under such conditions it is possible that the vehicle will meet obstacles such as small waves imposed on the long waves, which it would normally miss, but which due to the decreased height at certain positions in its path it will hit. This can be prevented if means are provided, for example, for increasing the mass flow of the curtain forming air or increasing the cushion area so that the vehicle will tend to be maintained at its correct height. The converse will apply on the downward going slope of the wave and the mass flow of the curtain air or the cushion area can be reduced at these times.

WHAT WE CLAIM IS:—

1. A vehicle for travelling over a surface and which, in operation, is supported above that surface, at least in part, by a cushion of pressurised gas formed and contained beneath the vehicle, comprising means for reducing the variations in vertical thrust exerted by the supporting gas cushion in the underside of the vehicle which would otherwise occur from variations in volume of the cushion as a result of variations in the height above the surface from a predetermined value.

2. A vehicle as claimed in claim 1 comprising means for supplying gas, or increasing the supply of gas, to the cushion when the height of the vehicle above the surface increases above the predetermined value, and for releasing gas from or decreasing the supply of gas to the cushion when the height decreases below the predetermined value.

3. A vehicle as claimed in claim 2 wherein gas is supplied to the cushion from, and released from the cushion to, the surrounding atmosphere by at least one valve.

4. A vehicle as claimed in claim 3 wherein at least one valve is positioned at the front of the vehicle for admitting air to the cushion and at least one valve is positioned at the rear of the vehicle for releasing gas from the cushion.

5. A vehicle as claimed in any one of the preceding claims comprising means for causing a fluid to issue from the lower part of the vehicle and form at least one curtain of moving fluid to contain, at least in part, the cushion of pressurised gas, wherein means are provided for varying, at least locally, the mass flow of the curtain-forming fluid, the mass flow being increased on increase in the height of the vehicle above the surface to increase the strength of the curtain and being decreased on decrease of the height to decrease the strength of the curtain.

6. A vehicle as claimed in claim 5, wherein the fluid forming the curtain is a gas and in which the increase in the mass-flow of the curtain-forming gas supplies gas to the cushion.

7. A vehicle as claimed in claim 5 or claim 6 wherein the fluid forming the curtain issues from at least one port in the lower part of the vehicle, the means for varying the mass-flow of curtain-forming fluid comprising means for varying the width of the port.

8. A vehicle as claimed in claim 1 wherein the means for reducing the variations in vertical thrust comprises means for varying the area of the cushion, the area being increased when the height of the vehicle increases above the predetermined value and decreased when the height is decreased.

9. A vehicle as claimed in claim 8 comprising means for causing a fluid to issue from at least one port in the lower part of the vehicle and form at least one curtain of moving fluid which forms at least part of the boundary of the cushion of pressurised gas, wherein the means for varying the area of the cushion comprises means for varying the effective position of the curtain.

10. A vehicle as claimed in claim 8 or claim 9 comprising means for forming at least one primary cushion of pressurised gas and one or more secondary cushions of pressurised gas positioned around the primary cushion and at a pressure intermediate the pressure of the primary cushion

recovery port 102 is formed in the bottom of the vehicle spaced further inboard than the first recovery port 101. The recovery ports 101 and 102 communicate via ducts 103 and 104 respectively with a common recovery duct 105. A sliding vane 106 is mounted between the two recovery ports and acts to vary the opening of the ports. In operation, air issues from the supply port 100, and some of the curtain forming air is recovered through recovery port 101, further air being recovered through recovery port 102. The sliding vane 106 can completely close either of the recovery ports, and if for example, the outer recovery port 101 is closed then the cushion extends, effectively, only as far as the inner recovery port 102. Similarly, if the inner recovery port 102 is closed, the cushion extends as far as the outer recovery port 101. A graduation of the effective cushion area between these two limits can be obtained by varying the sliding vane 106.

Figure 19 illustrates a method of cushion area variation similar to that shown in Figure 18, a rotatable vane 109 being provided to vary the relative amounts of air recovered through the recovery ports 101 and 107, instead of sliding vane 106.

As described above, when the vehicle is quickly traversing plain waves whose length is very long relative to the length of the vehicle, the vehicle is liable to become out of phase with the waves, overshooting at the crests and for at least part of the downward going faces, and undershooting at the troughs and for at least part of the upward going faces of the waves. Under such conditions it is possible that the vehicle will meet obstacles such as small waves imposed on the long waves, which it would normally miss, but which due to the decreased height at certain positions in its path it will hit. This can be prevented if means are provided, for example, for increasing the mass flow of the curtain forming air or increasing the cushion area so that the vehicle will tend to be maintained at its correct height. The converse will apply on the downward going slope of the wave and the mass flow of the curtain air or the cushion area can be reduced at these times.

WHAT WE CLAIM IS:—

1. A vehicle for travelling over a surface and which, in operation, is supported above that surface, at least in part, by a cushion of pressurised gas formed and contained beneath the vehicle, comprising means for reducing the variations in vertical thrust exerted by the supporting gas cushion in the underside of the vehicle which would otherwise occur from variations in volume of the cushion as a result of variations in the height above the surface from a predetermined value.

2. A vehicle as claimed in claim 1 comprising means for supplying gas, or increasing the supply of gas, to the cushion when the height of the vehicle above the surface increases above the predetermined value, and for releasing gas from or decreasing the supply of gas to the cushion when the height decreases below the predetermined value.

3. A vehicle as claimed in claim 2 wherein gas is supplied to the cushion from, and released from the cushion to, the surrounding atmosphere by at least one valve.

4. A vehicle as claimed in claim 3 wherein at least one valve is positioned at the front of the vehicle for admitting air to the cushion and at least one valve is positioned at the rear of the vehicle for releasing gas from the cushion.

5. A vehicle as claimed in any one of the preceding claims comprising means for causing a fluid to issue from the lower part of the vehicle and form at least one curtain of moving fluid to contain, at least in part, the cushion of pressurised gas, wherein means are provided for varying, at least locally, the mass flow of the curtain-forming fluid, the mass flow being increased on increase in the height of the vehicle above the surface to increase the strength of the curtain and being decreased on decrease of the height to decrease the strength of the curtain.

6. A vehicle as claimed in claim 5, wherein the fluid forming the curtain is a gas and in which the increase in the mass-flow of the curtain-forming gas supplies gas to the cushion.

7. A vehicle as claimed in claim 5 or claim 6 wherein the fluid forming the curtain issues from at least one port in the lower part of the vehicle, the means for varying the mass-flow of curtain-forming fluid comprising means for varying the width of the port.

8. A vehicle as claimed in claim 1 wherein the means for reducing the variations in vertical thrust comprises means for varying the area of the cushion, the area being increased when the height of the vehicle increases above the predetermined value and decreased when the height is decreased.

9. A vehicle as claimed in claim 8 comprising means for causing a fluid to issue from at least one port in the lower part of the vehicle and form at least one curtain of moving fluid which forms at least part of the boundary of the cushion of pressurised gas, wherein the means for varying the area of the cushion comprises means for varying the effective position of the curtain.

10. A vehicle as claimed in claim 8 or claim 9 comprising means for forming at least one primary cushion of pressurised gas and one or more secondary cushions of pressurised gas positioned around the primary cushion and at a pressure intermediate the pressure of the primary cushion

and atmospheric pressure at the predetermined height of the vehicle above the surface, the secondary cushion or cushions having a common boundary or common boundaries with the primary cushion, wherein means are provided for varying the position of the common boundary or boundaries, the area of the secondary cushion or cushions being decreased on increase in the height of the vehicle above the surface and increased on decrease in the height.

11. A vehicle as claimed in claim 8 comprising means for causing a fluid to issue from at least one supply port in the lower part of the vehicle and form at least one curtain of moving fluid, and in which at least part of the curtain-forming fluid is recovered through at least one recovery port formed in the bottom of the vehicle inboard of the supply port, the curtain forming at least part of the boundary of the cushion, wherein the area of the cushion is varied by varying the position at which the curtain-forming fluid is recovered into the vehicle.

12. A vehicle as claimed in claim 1 comprising means for forming at least one primary cushion of pressurised gas and one or more secondary cushions of pressurised gas positioned around the primary cushion wherein means are provided for increasing the pressure of the secondary cushion or cushions when the height of the vehicle above the surface increases and decreasing the pressure of the secondary cushion or cushions when the height decreases.

13. A vehicle as claimed in claim 12 comprising, means for causing a fluid to issue from the lower part of the vehicle and form at least one inner curtain of moving fluid to define a common boundary or common boundaries between the primary cushion and the secondary cushion or cushions, and means for causing a fluid to issue from the lower part of the vehicle and form at least one outer curtain of moving fluid to define the outer boundary or boundaries of the secondary cushion or cushions wherein means are provided for varying the relative flows of fluid to the inner and outer curtains, at least part of the flow of curtain-forming fluid from the inner curtain being transferred to the outer curtain to increase the pressure of the secondary cushion or cushions and at least part of the flow of curtain-forming fluid from the outer curtain being transferred to the inner curtain to decrease the pressure of the secondary cushion or cushions.

14. A vehicle as claimed in claim 13 in which means are provided to cause two flows of fluid to issue adjacent to one another to form the outer curtain or curtains, wherein the means for varying the relative flows of fluid to the inner and outer curtains varies only the inner flow of the outer curtain.

15. A vehicle as claimed in claim 13 in which means are provided to cause two flows of fluid to issue adjacent to one another to form the outer curtain or curtains and two further flows of fluid to issue adjacent to one another to form the inner curtain or curtains, wherein the means for varying the relative flows of fluid to the inner and outer curtains varies only the outer flows of each of the curtains.

16. A vehicle as claimed in claim 13, or claim 14 or claim 15 wherein the fluid to form the curtains is caused to issue from ports formed in the bottom of the vehicle, the means for varying the relative flows of fluid comprising means for increasing the width of one port and simultaneously narrowing another port.

17. A vehicle as claimed in any one of the preceding claims including means for detecting variations in cushion pressure and for controlling the means whereby the pressure or area of a cushion is varied in accordance with said variations as detected.

18. A vehicle as claimed in any one of the claims 1 to 16 including means for detecting vertical acceleration of the vehicle and for controlling the means whereby the pressure or area of a cushion is varied in accordance with said vertical accelerations so detected.

19. A vehicle substantially as described herein and as illustrated in figures 2 and 7, or any one of the figures 3, 4, 5, 6, 9 or 10.

20. A vehicle substantially as described herein with reference to figures 11 to 15.

21. A vehicle substantially as described herein with reference to figure 16.

22. A vehicle substantially as described herein with reference to figures 17a and 17b or figure 18 or figure 19.

S. T. JELLY,
Chartered Patent Agent,
Agent for the Applicant(s).

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CORRECTION OF CLERICAL ERROR/S

SPECIFICATION NO. 959,825

The following correction is in accordance with the Decision of the Superintending Examiner, acting for the Comptroller-General, dated the 2nd day of November, 1964:-

Page 1, line 52, page 7, line 60, *after* "cushion" *delete* "in" *insert* "on"

THE PATENT OFFICE,
20th January, 1965

D 33650/8