Nov. 23, 1965 R. W. BRATT ETAL 3,219,134

GROUND EFFECT MACHINE

Filed June 15, 1962 4 Sheets-Sheet 1

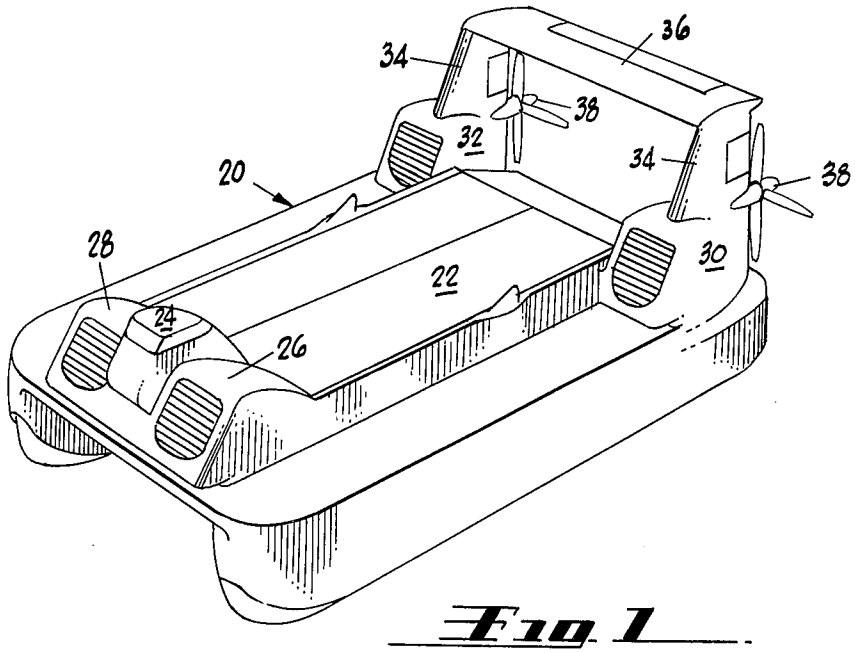


Fig. 1

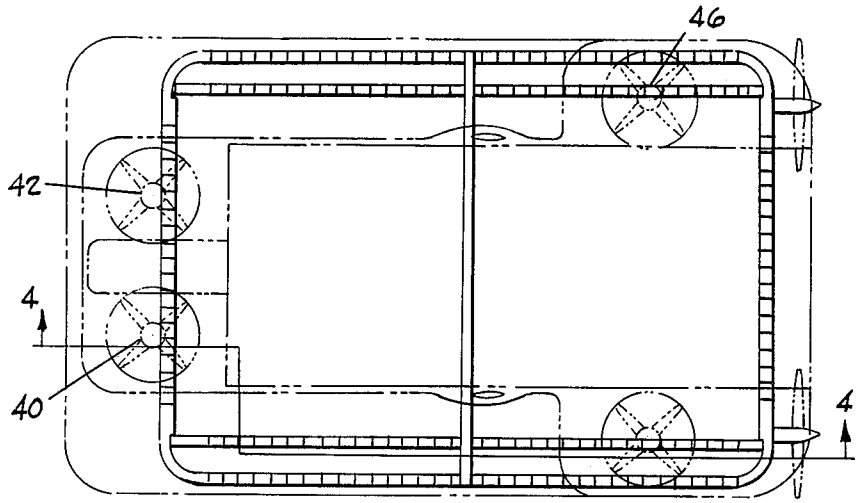


Fig. 2

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GROUND EFFECT MACHINE

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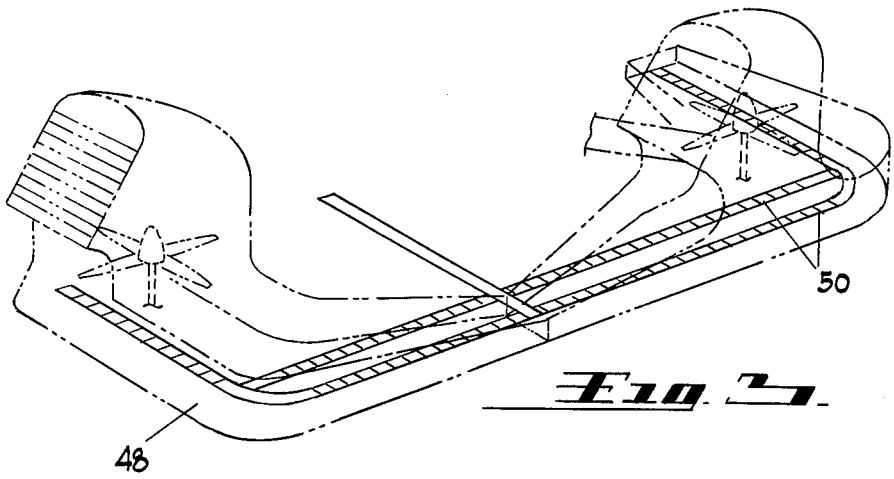


Fig. 3.

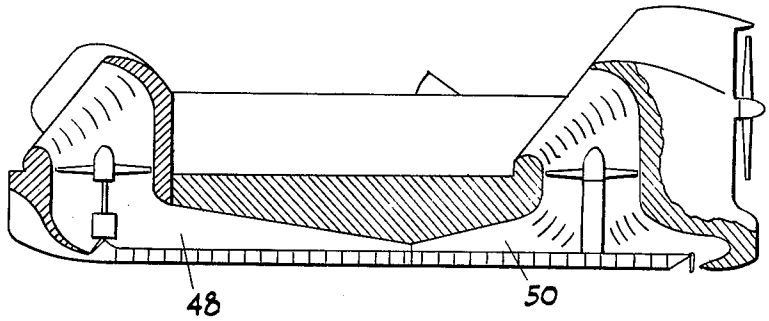


Fig. 4.

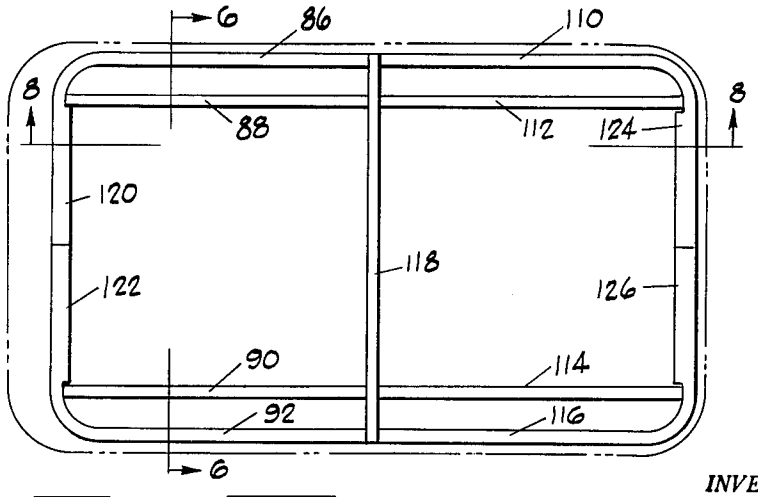


Fig. 5.

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GROUND EFFECT MACHINE

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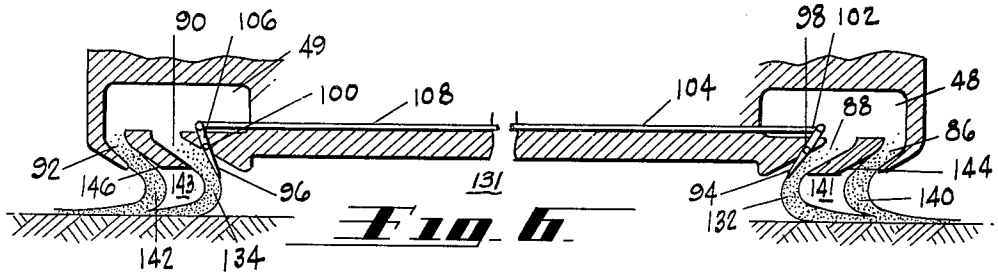


Fig. 6

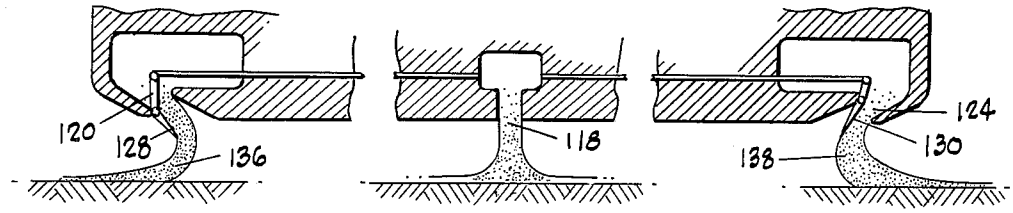


Fig. 8

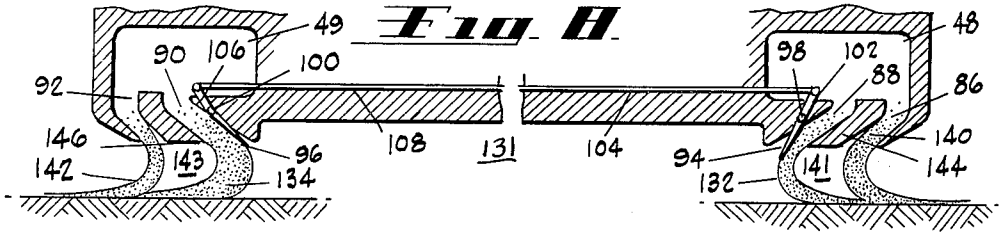


Fig. 7

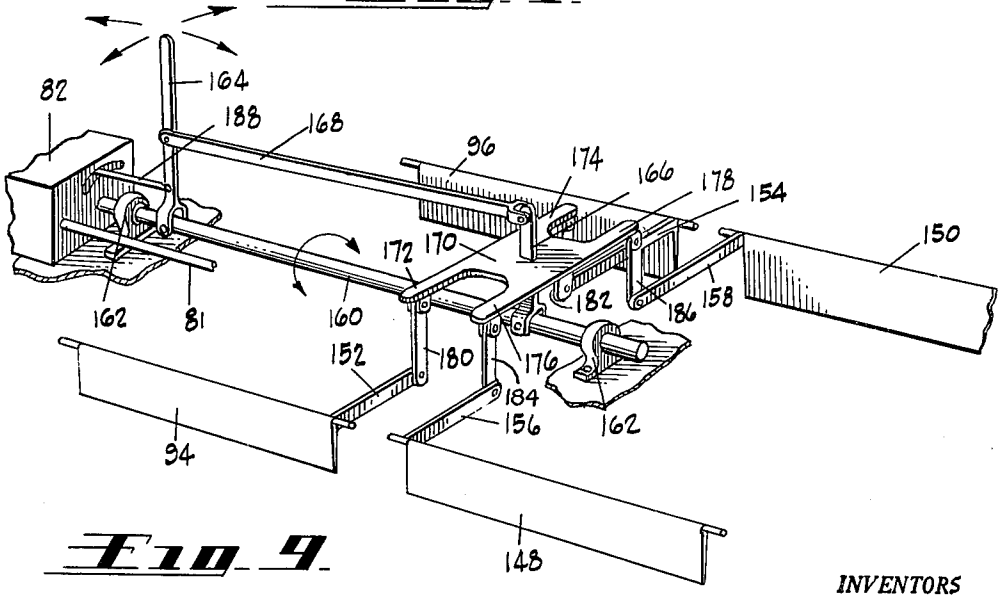


Fig. 9

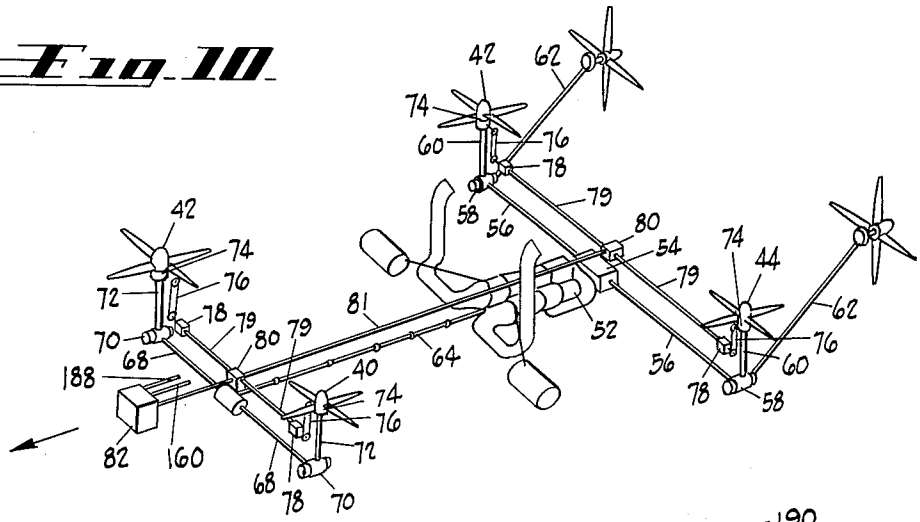
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GROUND EFFECT MACHINE

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Fig. 10



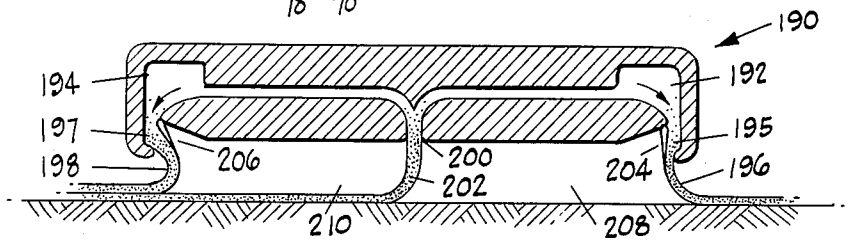


Fig. 11

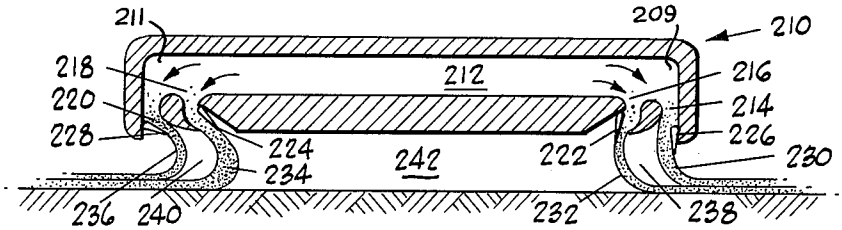


Fig. 12

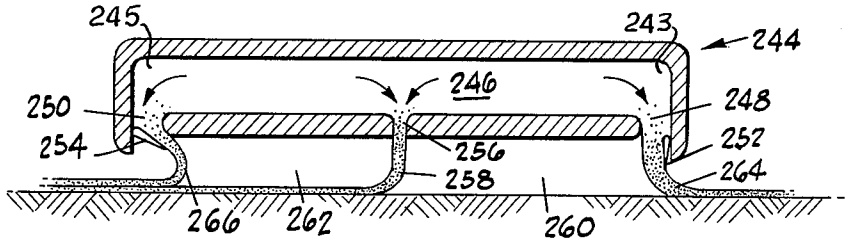


Fig. 13

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United States Patent Office 3,219,134 Patented Nov. 23, 1965

3,219,134

GROUND EFFECT MACHINE

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Filed June 15, 1962, Ser. No. 202,887
13 Claims. (Cl. 180—7)

This invention relates to ground effect machines, which float on a cushion of air a short distance above the ground and may hover or be propelled in various directions. In particular, it relates to new and improved means and methods for producing rolling and pitching moments.

Several types of ground effect machines have been developed and tested with varying degrees of success. These machines all operate on the general principle of producing and maintaining a bubble or cushion of air under the body at a sufficient pressure to support the body at a desired distance above the supporting surface, which may be land or water, the distance varying from a few inches to several feet depending on the type and size of vehicle and the use to which it is to be put. Usually this is accomplished by providing one or more members making up a substantially peripheral air duct, the members having downwardly opening discharge slots or passages. The duct is supplied by a source of air under pressure and the passages discharge a continuous peripheral sheet or curtain of air of suitable thickness downwardly and inwardly toward the center of the vehicle.

This issuing air curtain promptly builds up a subtsantial pressure in the zone bounded by the curtain which then becomes an air cushion supporting the body above the ground. The curtain forms a yieldable barrier resisting the tendency of the cushion to escape to the ambient atmosphere because of the pressure of the air forming curtain and its rate of flow. The pressure of the trapped air in the cushion gradually changes the path of flow of the curtain so that its originally inwardly angled path curves downwardly and outwardly as it approaches the supporting surface, finally flowing out in a substantially horizontal plane.

A machine of this type is highly unstable. It is supported only by a fluid cushion which is restrained only by fluid means. If the vehicle rolls or pitches a slight amount from any cause, such as an unbalancing shift of the center of gravity, the air cushion will tend to escape at the high side and the vehicle can slip down the cushion and strike the supporting surface. Consequently means must be provided to supply the necessary righting moments. Preferably the same means is used to supply adequate moment force for normal pitch and roll control.

One system of obtaining roll control consists in the provision of one or more downwardly directed external air jets at each side of the vehicle which may be actuated when necessary to provide a righting force. The intermittent action does not furnish a smooth operation. If the jets are kept in action continuously and their intensity modified for control purposes they are rather uneconomic since they are not efficient load supporting devices.

Another system for roll control involves a pair of spaced discharge passages extending longitudinally at each side of the vehicle with cross passages at the ends to complete a closed geometric figure. The inner passages of each side pair cooperate with the end passages to confine a central air cushion taking a large part of the weight of the vehicle, and the inner passages cooperate with the outer passages and the cross passages to confine a side air cushion extending longitudinally at each side of the central air cushion. These side cushions support the balance of the weight of the vehicle.

All of these discharge passages are angled inwardly and

downwardly to produce corresponding air curtains as described above in connection with the basic machine. If it is desired to introduce a rolling moment to counteract a lateral imbalance or to bank the vehicle in forward flight the air pressure in the appropriate one of the side cushions is increased with respect to the opposite one. This is accomplished by varying the flow through the side passages and unbalancing the strengths of the air curtains. The resultant side force from the jets does not act in a direction to overcome the centrifugal force developed in a banked turn.

The present invention overcomes the disadvantages mentioned above by virtue of its novel construction and operations and incorporates various other advantageous features which will become apparent hereinafter. In one form of the invention a load supporting body is provided with air discharge slots or passages arranged in substantially the same pattern as described just above to produce a central primary air cushion and laterally spaced secondary air cushions to support the weight of the vehicle. A separate duct or plenum chamber is provided for each quadrant of the generally rectangular pattern and feeds one half of the length of a lateral slot at one end and about one half of the length of the two slots at one side adjacent the lateral slot portion. Each duct has a source of supply of pressurized air in the form of a fan having controllable pitch blades and driven by the prime mover for the vehicle. Although the ducts are separate they approach each other closely enough so that the issuing air merges and forms continuous air curtains.

The outer longitudinal slots or passages are fixed in angular direction and throat width. The inner longitudinal passages are also fixed in angular direction and throat width but are provided with pivoted vanes which may be actuated to vary the effective angle and throat width, thus varying the thickness of the issuing air curtain and its initial angular inclination.

When the vehicle is statically balanced and hovering in neutral attitude the vanes in the inner passage are set to equal and opposite inclinations to direct issuing air curtains of substantially the same thickness and angle of inclination as those issuing from the outer passages. Under these conditions the inner air curtains together with portions of the end air curtains act as a yieldable barrier to trap air in the primary cushion at a pressure somewhat less than the duct pressure. The outer air curtains together with portions of the end air curtains act as a second yieldable barrier to trap air in the secondary cushions at a pressure lower than the primary cushion pressure and higher than the ambient air pressure.

When it is desired to create a rolling moment the vanes are adjusted to modify the inner longitudinal air curtains. The vane or vanes at one side restrict the throat and change its effective direction to issue an air curtain which is thinner and inclined more steeply downward toward the ground or other supporting surface. The vane or vanes at the other side reduce the throat restriction and change its effective direction to issue an air curtain which is thicker and directed at a lesser angle to the ground. At the same time the pressure head in the ducts at the first side is increased by increasing the pitch of the fan blades supplying them and the pressure head in the ducts at the second side is decreased by decreasing the pitch of the fan blades supplying that side.

One result of this maneuver is that the thinner air curtain at the first side will be unable to maintain as great a differential as before and the pressure in the secondary cushion on that side will increase toward that of the primary cushion but will remain at a somewhat lower lever. The higher duct pressure will strengthen the outer air curtain to retain the increased differential between the

secondary cushion pressure and the ambient pressure. The opposite result is achieved at the second side where the inner curtain has become thicker and stronger, maintaining a higher differential which results in a lower secondary cushion pressure. The greater lift at the first side and lesser lift at the second side produce a rolling moment about the longitudinal axis of the vehicle. The magnitude of the moment is determined by the extent of differential adjustment of the vanes and of the duct pressures.

In the maneuver described above, the outer longitudinal air curtains remain substantially unchanged. Their jet reactions oppose each other and produce a resultant lateral or horizontal thrust component due only to differential pressure from one side to the other. However the result is quite different with the inner air curtains. The curtain at the first side is directed more vertically and is weaker so that the lateral component of its jet thrust is reduced. The curtain at the second side is directed more horizontally and is strengthened so that the lateral component of its jet thrust is increased. The net effect is a resultant lateral force component in a direction in consonance with the rolling moment; that is, it is directed toward the inside of a banking turn.

The same general principles may be applied to another form of the invention in which only a single air discharge passage extends longitudinally at each side of the load supporting pattern, which is completed by a laterally extending air discharge passage at each end, and a third air discharge passage extends longitudinally in the plane of the longitudinal axis of the vehicle. The latter passage discharges vertically downward and has a nonadjustable throat width. It divides the total load supporting air cushion into two equal longitudinally extending halves. The side passages discharge inwardly and downwardly as before and are provided with vanes of the same type used in the first embodiment. When the vanes are in neutral position the duct head pressures are the same and the cushion pressures are the same, supporting the vehicle in neutral balanced attitude.

When it is desired to produce a rolling moment, the vanes are so adjusted that the air curtain at the first side is directed more steeply downward toward the ground and is made thinner, while the air cushion at the second side is directed more horizontally and is made thicker. At the same time the duct head pressure is increased at the first side and decreased at the second side. Since the vertical air cushion at the longitudinal axis is capable of maintaining a substantial differential, the higher duct pressure at the first side produces a higher cushion pressure and the lower duct pressure at the second side produces a lower cushion pressure. The difference in total lift of the two air cushions produces a rolling moment just as in the first embodiment. Since the lateral component of the jet thrust of the first air curtain is decreased and that of the second is increased there is a resultant lateral force in a direction in consonance with the rolling moment.

Many other advantages and features of novelty will become apparent as the description proceeds in connection with the accompanying drawings, in which:

FIGURE 1 is a perspective view of a ground effect machine embodying the invention;

FIGURE 2 is a diagrammatic plan view of the machine with portions in phantom lines illustrating the general arrangement of air supply sources and air discharge passages in one form of the invention;

FIGURE 3 is a diagrammatic perspective view, with portions in phantom lines, of the air supply sources, distribution ducts and air discharge passages at one side of the machine;

FIGURE 4 is a sectional view in elevation taken on line 4—4 of FIGURE 2;

FIGURE 5 is a bottom plan view of the machine showing the arrangement of the various discharge passages;

FIGURE 6 is a sectional view in elevation, taken on line 6—6 of FIGURE 5, showing in idealized form the ducts and discharge passages extending longitudinally of the machine;

FIGURE 7 is a view similar to FIGURE 6 showing the passage varying means adapted to produce a rolling moment;

FIGURE 8 is a sectional view in elevation, taken on line 8—8 of FIGURE 5, showing in idealized form the ducts and discharge passages extending across the ends of the machine and across the mid portion;

FIGURE 9 is a diagrammatic perspective view showing in idealized form a mechanism for controlling the discharge passage varying means;

FIGURE 10 is a diagrammatic perspective view showing in idealized form the arrangement of power plant, air supply means and propellers and control means;

FIGURE 11 is a view similar to FIGURE 7, showing one modified form of the invention;

FIGURE 12 is a view similar to FIGURE 7, showing another modified form of the invention; and

FIGURE 13 is a view similar to FIGURE 7, showing a further modified form of the invention.

The ground effect machine 20 depicted in FIGURE 1 comprises a body which is generally rectangular in plan-form and is provided with a centrally located cargo deck 22. Clustered together across the forward portion of the vehicle are the pilots' compartment 24 and left and right air intake hoods 26 and 28. Adjacent the rear portion of the vehicle are a second pair of laterally spaced air intake hoods 30 and 32. Fins 34 support a horizontal stabilizer 36, and conventional rudders and elevator are carried by these elements for controlling the course of the vehicle in forward flight. Thrust propellers 38 are mounted for rotation at the rear of the fins 34.

As will be seen from FIGURES 2, 3 and 4 each of the hoods 26, 28, 30, and 32 serves as the air intake for a fan 40, 42, 44 and 46 respectively and merges with a pressure air duct serving the quadrant of the vehicle in which its fan is located. The shape and arrangement of the left hand ducts 48 and 50 are illustrated in FIGURES 3 and 4. The ducts supply air under pressure from the fans to the various air discharge slots or passages best shown in plan view in FIGURE 5 which illustrates the substantially closed geometric pattern formed by the combination of passages. The detailed construction and operation of these passages will be explained hereinafter.

In the presently preferred embodiments of the invention a single gas turbine 52 located generally amidships provides the power for the four air supply fans and the two thrust propellers. As seen in FIGURE 10, the turbine is connected to a gear box 54 from which two lateral drive shafts 56 extend to gear boxes 58. From these latter gear boxes extend drive shafts 60 to the fans and 62 to the thrust propellers. Another drive shaft 64 extends from the turbine forwardly to gear box 66, and lateral drive shafts 68 extend to gear boxes 70, from which drive shafts 72 extend to the fans.

The pitch of the blades of the various fans may be differentially adjusted in several modes in response to the movement of a pilot operated control as described later. Any suitable and conventional means may be used for this purpose. Pitch change mechanism is contained in each of the housings 74 adjoining the hubs of the fans. Actuating mechanism 76 extends from gear boxes 78 to the housings. Control shafts 79 extend from gear boxes 78 to gear boxes 80 and a control shaft 81 extends from gear boxes 80 to the control transfer box 82, from which further control shafts 160 and 188 lead to a pilot operated control, the details of which will be later described. Suitable known gearing or mechanical linkage may be used in each of the gear boxes to accomplish the desired differential movement.

Turning now to FIGURE 6, there is shown an idealized lateral cross sectional view through a machine of the type under consideration, taken on line 6—6 of FIGURE 5,

Ducts 48 and 49 are supplied with air under pressure by fans 40 and 42. In this view the machine is assumed to be in equilibrium and the fans are operating at the same speeds and with the same blade pitch to produce equal air pressure in the two ducts. Each duct communicates with the exterior by means of a pair of downwardly opening air discharge throats or passages 86, 88, 90 and 92.

The outermost throats or passages 86 and 92 are fixed in dimension and direction, being angled downwardly and inwardly toward the center of the vehicle. An angle of about forty-five degrees has been found to be quite satisfactory although other angles may be used. The inner throats or passages 88 and 90 are also fixed in dimension and direction, being inclined more toward the horizontal, at an angle of the order of sixty to seventy degrees to the vertical. While their actual dimensions and inclinations are fixed, their virtual or effective dimensions and inclinations are variable and are controlled by vanes 94 and 96 pivotally mounted within the throats of these passages on the upper wall of each at pivot mountings 98 and 100 respectively.

Each vane extends substantially throughout the length of its respective passage. The angular position of vane 94 is controlled by the control horn 102 and link 104 leading to the pilot operated control mechanism. The angular position of vane 96 is similarly controlled by control horn 106 and link 108. The vanes are of such length as to extend beyond the opposing edges of their respective discharge slots or throats and accordingly the pressurized air will follow the vane wall and issue at its angle of inclination. It will be noted that, in the neutral attitude of FIGURE 6, the vanes are set at approximately the same angle as that of passages 86 and 92 although this is not essential to successful operation.

It will be observed in FIGURE 5 that the longitudinally extending passages are divided about midway of the length of the vehicle and the passages 110, 112, 114 and 116 are substantial duplicates of those described above, including the control vanes, and are supplied by the two aft ducts. They may be operated in the same or opposite sense as the forward passages for a purpose and in a manner to be later described. A central, laterally extending and vertically discharging passage 118 passes between the adjacent ends of the side passages and may be supplied with pressurized air by any of the four ducts. The generally rectangular geometric pattern is completed by the fore and aft lateral passages made up of passage portions 120, 122, 124 and 126, each fed by the duct in its respective quadrant. These passages are substantially identical to the passages 88 and 90, including vanes 128 and 130 for controlling their effective dimension and inclination. Their construction, as well as that of passage 118, are illustrated in FIGURE 8.

When the vehicle is at rest the main body portion may be supported a short distance above the surface by any suitable means, not shown, such as legs, skids, pontoons or wheels, which may be fixed in position or retractable, as desired. When the prime mover is activated the fans are driven at a proper speed with the blades at sufficient pitch to produce a supply of air at the required pressure. This pressure will vary in accordance with the unit loading of the vehicle but in one present embodiment the duct pressure is in the range of forty to seventy pounds per square inch. Considering first the passages 88 and 90 as seen in FIGURE 6 and the corresponding passages 112 and 114 which are controlled in the same sense, they form together with the end passages 120, 122, 124 and 126 a substantially closed rectangle. These passages discharge air from the four ducts downwardly and inwardly toward the center of the machine in the form of a continuous air curtain surrounding the central zone. The pressure in this zone promptly builds up to form a primary supporting air cushion 131. The value of the cushion pressure is somewhat below that of the duct for various reasons including a loss through the air curtain.

As indicated in FIGURE 6, considering any portion of the air curtain 132 issuing from passage 88, it is deflected by the pressure of the cushion air and gradually bends more steeply downward and then outward, finally issuing in a generally horizontal plane. The pressure drop across the air curtain is a function of its thickness and rate of flow and is made great enough in design and pressure selection to provide the necessary support. If passages 88 and 90 were used without the outer passages, then the pressure and curtain thickness would be so chosen that the air cushion 131 would support the entire weight of the vehicle and its cargo. Since second air curtains are provided for a purpose about to be described, the air cushion 131 actually supports only a part of the load, in this case the major part. Air curtain 134 issuing from passage 90 acts in the same way as air curtain 132. The air curtains 136 and 138 (FIGURE 8) complete the confinement of the central air cushion.

Second air curtains 140 and 142 issue from passages 86 and 92 (and also passages 110 and 116, as above) and act essentially in the same way as the first air curtains, producing and maintaining a differential between the ambient atmospheric pressure and the pressure of the air in the secondary air cushions 141 and 143 formed in the zone between the two curtains and exerting lift on "pads" 144 and 146. The lift of the secondary air cushions plus that of the primary air cushion are sufficient to raise the vehicle and support it at the desired distance above the surface.

Turning now to FIGURE 7, if the center of gravity has shifted to the right, as viewed in this figure, and a trimming moment is necessary or if it is desired to produce a left or counter-clockwise rolling moment for any other reason, the vanes are differentially adjusted to any desired extent such as is here shown. Vane 94 is now at an attitude of about twenty degrees to the vertical and vane 96 is at an attitude of about seventy degrees to the vertical. The vanes in passages 112 and 114, not shown, are adjusted to the same extent so that the entire lengths of the passages will act in the same way. At the same time that the vanes are so adjusted the pitch of the right hand fan blades is increased and that of the left hand fan blades is decreased. The turbine is running at a steady speed and has adequate reserve power. The result is that the pressure in duct 48 is increased and that in duct 49 is decreased.

Air curtain 132 is now much thinner than before and directed more vertically. Although the duct pressure is higher, the curtain cannot maintain as great a differential and consequently the pressure in cushion 141 increases toward that in cushion 131 although it always remains lower. Curtain 140 retains its original direction and thickness and, with the added duct pressure, can now maintain the new and greater differential between cushion 141 and ambient atmosphere. Thus the lifting force of cushion 141 will produce a rolling moment. In addition the vertical component of the jet reaction of curtain 132 and 140 will increase and assist this moment.

A generally opposite action occurs at the left side as viewed in FIGURE 7. Air curtain 134 becomes thicker and is directed more horizontally. It maintains a greater differential and hence the pressure in air cushion 143 becomes lower. The lower pressure in duct 49 reduces the energy in curtain 142 so that it has less ability to maintain a differential. Hence the pressure in air cushion 143 becomes even less and therefore it develops less lift. This is the equivalent of a negative rolling moment. The vertical component of the jet reaction of curtain 134 and 142 is decreased, and contributes to the negative rolling moment. Thus all the changes in moment are in the same sense and the maximum effect is obtained from the maneuver.

In the case of a banked turn it is desirable to have a substantial radial force opposed to the centrifugal force on the vehicle. In the present case there is a horizontal component of the tilted lift vector just as in the case of

a banked airplane. In addition there is a resultant horizontal or lateral force derived from the change in the direction of discharge of the inner air curtains which is in a direction in consonance with the rolling moment; that is, it is a force applied to the body in the direction of the inside of the turn. In FIGURE 7, curtain 132 becomes more vertical and the horizontal component of its jet reaction decreases. On the contrary curtain 134 becomes more horizontal and the horizontal component of its jet reaction increases. Hence there is a resultant lateral force in the proper direction to assist the banked turn maneuver. Also, a net unfavorable lateral force from curtains 140 and 142 is produced due to differential total pressure.

If the laterally extending end passages 120, 122 and 124, 126 are replaced by dual slots or passages of the same type as in FIGURE 6, then pitching maneuvers can be accomplished in the same way. However there is another method of producing pitching moments which can be carried out with the mechanism described above. By proper operation of the controls both vanes 94 and 96 can be swung toward a position more vertical than their original neutral position. If this is done and the pressure is increased both of the secondary cushions increase their lift at the same time. This produces a positive pitching moment. At the same time the vanes in passages 112 and 114 are swung more toward the horizontal and the pressure is reduced, thus decreasing the lift of the secondary cushions and aiding the positive pitching moment. It is necessary to segregate the sets of passages in order to accomplish this result. This is effectively accomplished by means of the vertical air curtain issuing from passage 118 and extending completely across the pattern.

A simple, idealized version of a pilot controlled mechanism for regulating the various vanes together and differentially is shown, by way of example only, in FIGURE 9. Many other known control mechanisms are suitable for the purpose. In this illustration vanes 94, 96, 148 and 150 are shown as pivoted for rotation about parallel longitudinal axes. Fixed to these vanes are arms 152, 154, 156, and 158 respectively. Torque tube 160 is carried in bearings 162 for rotation about its longitudinal axis in response to lateral swinging of control stick 164 which in turn is pivotally mounted on the torque tube for fore and aft swinging with respect thereto.

A post 166 is also pivotally mounted on the torque tube for fore and aft swinging with respect thereto and is joined to the control stick by a link 168 arranged parallel to the torque tube and pivotally connected to the post and the control stick to maintain them in parallel relation. Control plate 170 is rigidly mounted to the post and tilts universally therewith. Its four arms 172, 174, 176 and 178 are pivotally connected to links 180, 182, 184, 186 which in turn are pivotally connected to the crank arms of the vanes. It will be seen that by one appropriate movement of the control stick vanes 94 and 148 may be caused to swing together in one angular direction while vanes 96 and 150 swing together in the same angular direction, the first pair becoming more horizontal as the second pair become more vertical and vice versa. By fore and aft movement of the control stick vanes 94 and 96 can be made to approach each other while vanes 148 and 150 separate, and vice versa. By mixed movement of the control stick the vanes may partake of both motions simultaneously to achieve any combination of rolling and pitching effects.

Torque tube 160 extends into control transfer box 82 and link 188, pivotally connected at one end to the control stick, extends through slot 190 into the box. The motions of these members are translated by any conventional means and applied to shaft 81 which extends rearwardly from the box to control the fan blade pitch angles as described above in correspondence with the operations of the control stick.

As previously stated, air curtains 136 and 138, FIGURE 8, issue from the laterally extending slots or passages at the fore and aft ends to complete the confinement of the primary air cushion. As the craft increases its speed in forward flight, the ram effect of the air reduces the need for these air curtains, particularly the forward one. Therefore, vanes 128 and 130 are gradually swung counter-clockwise as seen in FIGURE 8 so that curtain 136 will be directed almost horizontally rearwardly and curtain 138 will be made very thin and directed substantially vertically. This operation results in a considerable reduction in power required, particularly at speeds in excess of one hundred knots. Conventional means available to the pilot may be used for control of the vanes.

Another embodiment of the invention described above is illustrated in FIGURE 11 where the primary central air cushion has been eliminated and a longitudinally extending vertically directed air curtain on the longitudinal axis divides the total support between two laterally opposed air cushions. In this figure the body 190 is provided with right and left air supply ducts 192 and 194 which receive pressurized air from fans in the same manner as the ducts of FIGURE 6. Only a single air discharge slot or passage is provided at each side, extending longitudinally of the vehicle and divided at about midpoint in the same manner as in the previous embodiment. Again the passages 195 and 197 are angled downwardly and inwardly to discharge air curtains 196 and 198 joined by similar air curtains at each end to form a closed figure to contain a supporting air cushion. Vertically downwardly directed passage 200 discharges a vertical air curtain 202 dividing the support zone into two equal halves at opposite sides of the longitudinal axis. Vanes 204 and 206 are pivotally mounted in the passages and are controlled as previously described.

The vanes when in neutral condition are angled equally toward each other but are here shown as adjusted to produce a counter-clockwise or left rolling moment. When they are so adjusted, the fan blades are also adjusted by the same means as in the previous embodiment to increase the pressure in duct 192 and decrease the pressure in duct 194. This produces an increase in the pressure of the right hand air cushion 208 and a decrease in the pressure of the left hand air cushion 210, the air curtain 202 maintaining the differential between them. The increased energy in air curtain 196 prevents it from breaking down and losing the cushion pressure. Its substantially vertical direction results in a vertical component of the jet thrust reaction which assists the rolling moment, and a decrease in its horizontal component. Curtain 198 is thickened and has no difficulty in maintaining its differential. The vertical component of its jet thrust reaction is decreased and the horizontal component is increased to give a net resultant lateral force in consonance with the rolling moment.

In all other regards this modification is structurally and functionally similar to the form first described. It includes a laterally extending vertically discharging passage at mid-length to divide the zones fore and aft, and vanes 204 and 206 and their counterparts at the opposite end of the body can be differentially operated to obtain pitching and combined rolling and pitching as previously described. Alternatively, dual fore and aft cross passages and vanes can be used in the manner outlined above.

Another embodiment which utilizes the same basic principles as the embodiment of FIGURE 6 but which may be operated without creating a pressure differential in ducts at opposite sides of the longitudinal axis is illustrated in FIGURE 12. Here it will be seen that the body 210 may have its plenum chambers or ducts 209 and 211 interconnected or may have a single duct 212 to supply pressurized air to all of the passages in the system. Longitudinally extending passages 214 and 216 are provided along the right hand side of the body as viewed in FIGURE 12 and similar passages 218 and 220 are provided along the left side. It will be understood that,

in the same manner as the embodiment of FIGURE 6, these passages are divided at about mid-length by a laterally extending vertically discharging passages and that their fore and aft ends terminate at fore and aft lateral passages to complete a closed geometric figure. The same or similar vane controls may be used but the coordinated control for the fan blade pitch is not needed.

It will be seen that the inner passages and their vanes 222 and 224 in this embodiment are substantially identical in construction and function to those of FIGURE 6. However the outer passages 214 and 220 are different. They open substantially vertically downward and are provided with vanes 226 and 228 pivoted on their outer walls. The vanes at each side swing together and in neutral position all of the vanes are inclined inwardly and downwardly at an angle of the order of forty five degrees. At this point the situation is exactly the same as in FIGURE 6, all of the air curtains being substantially equal in strength and inclination.

When a left rolling moment is desired, the vanes are moved to positions such as shown in FIGURE 12 but the duct pressure is not changed. Vane 222 has narrowed air curtain 232 considerably and directed it more vertically so that it cannot maintain as great a differential as before between primary air cushion 242 and secondary air cushion 238. However, vane 224 has enlarged passage 218 and changed its effective direction so that air curtain 234 is inclined more toward the horizontal and is thicker so that it maintains a higher differential between primary air cushion 242 and secondary air cushion 240.

At the same time vane 226 swings down to open passage 214 wider. The issuing air curtain 230 is directed substantially vertically and is thicker and stronger so that it can maintain a higher differential between air cushion 238 and ambient atmosphere. Vane 228, on the other hand swings to a position greatly restricting passage 220 and changing its effective direction so that air curtain 236 is directed more horizontally and is very thin and weak. Hence it can maintain only a small differential between air cushion 240 and the ambient atmosphere. The difference in the secondary air cushion pressures produces a left rolling moment aided by the difference in the vertical components of the jet thrust reactions of the air curtains at the opposed sides. The difference in their horizontal components produces a net resultant horizontal or lateral force in a direction in consonance with the rolling moment. Pitching and mixed pitching and rolling can be accomplished in the same way as in the embodiment of FIGURE 6. Also, alternatively, dual cross passages may be used at the fore and aft ends as with the FIGURE 6 embodiment.

The constant duct pressure system can also be applied to an arrangement having only a single slot or passage at each side as illustrated in FIGURE 13. The slot arrangement is the same as in FIGURE 11 including division of the passages at midlength by a cross passage and the provision of cross passages at the ends to complete the geometric pattern. The body 244 has its various ducts, such as ducts 243 and 245, in communication with each other or is provided with a single duct 246 feeding all of the passages at the same pressure. Right and left passages 248 and 250, as viewed in FIGURE 13, open straight downward and are provided with vanes 252 and 254 respectively pivoted to the outer walls of the passages. A vertically directed passage 256 is located on the longitudinal axis of the vehicle and divides the supporting zone into right and left halves. Vanes corresponding to vanes 252 and 254 are located in the other portions of the longitudinal side passages as in the embodiment of FIGURE 11 and may be operated in the same way by a pilot operated control.

When the controls are in neutral, vanes 252 and 254 are set at equal and opposite angles and air curtains issue downwardly and inwardly all around the periphery of the pattern. Air curtain 258 issues vertically from passage 256 and divides the support zone into two distinct right and left air cushions 260 and 262, exteriorly bounded by air curtains 264 and 266. To create a rolling moment the vanes are moved to an adjusted position such as shown in FIGURE 13. In this situation vane 252 has swung to enlarge passage 248 and air curtain 264 is now thicker and directed more vertically. It can maintain a greater differential between cushion 260 and ambient atmosphere. At the same time vane 254 has been swung to restrict passage 250, and air curtain 266 now issues more horizontally and is much thinner so that it cannot maintain the previous differential. As a result, the pressure in air cushion 260 becomes greater and the pressure in air cushion 262 becomes less, resulting in a rolling moment assisted by the changes in the vertical components of the jet reaction forces of the air curtains. As before, the net resultant of the horizontal components is in a direction in consonance with the rolling moment. The air curtain 258 maintains the differential between the two air cushions. Pitching and combined pitching and rolling are accomplished by manipulation of the various vanes as previously described or, alternatively, by using dual fore and aft cross passages as previously described.

While the air curtain pattern as considered herein is generally rectangular such shape is not essential although it is desirable in most instances. It may be square, round, oval or the like depending to some extent on the shape of the vehicle itself. Also the outermost air curtain pattern need not follow or be very closely adjacent to the edge of the vehicle although it is ordinarily desirable in order to reduce the unit load. The duct and passage system is normally built into the body but it may, for special purposes, be a separate, attachable and removable unit. Separate prime movers may be used for the fans and the thrust propellers. The vanes need not be unitary for the length of the slots but may be made individual or sectional so long as they control substantially the entire lengths of the slots. Adjustable guide vanes may be located in some or all of the passages, particularly the longitudinally extending ones, to orient the air issuing in said curtains in a direction to produce a thrust component in the direction of travel.

It will be apparent to those skilled in the art that various changes and modifications may be made in the invention described above without departing from the spirit thereof, and it is intended that all such changes and modifications shall be embraced within the scope of the following claims.

We claim:

1. A ground effect machine comprising: a load supporting body; a pair of longitudinally extending, downwardly opening air discharge passages laterally spaced to one side of the longitudinal axis of said body; a second pair of longitudinally extending, downwardly opening air discharge passages laterally spaced to the other side of said longitudinal axis; the passages of each pair being laterally spaced from each other to form an air cushion zone between them; laterally extending, downwardly opening discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the throats of all of said passages being angled downwardly and inwardly and being rigid and of fixed dimension; means to supply air under pressure to all of said passages to produce downwardly and inwardly directed air curtains producing and maintaining a central primary air cushion and a pair of laterally spaced secondary air cushions cooperating to support said body; flow control members in the throats of the inner one of each of said pairs of longitudinally directed passages each adapted to vary the thickness and direction of the air curtain issuing from its respective passage; means to differentially actuate said flow control members to decrease the thickness and angle to the vertical of the air curtain on one side and to increase the thickness and angle to the vertical of the air curtain on the other side; and means to

increase the pressure of the air supply to the first side and decrease the pressure of the air supply to the second side; thereby to produce a rolling moment and a lateral resultant thrust component in a direction in consonance therewith.

2. A ground effect machine that is laterally trimmable to an even-keel attitude and is bankable for turns, comprising: an elongate cargo-carrying body having a forward end and an aft end; two pairs of longitudinally extending pressure-air discharging ground-effect passages, one pair being located on each side of the longitudinal center line of said body, the passages of each pair being laterally spaced mutually apart; a laterally extending pressure-air discharging ground effect passage located in each end-portion of said body, each of the last said passages there substantially joining the aforesaid longitudinal passages; each of said longitudinal and lateral passages having a throat that extends downwardly and inwardly; a plurality of plenum chambers and a plurality of sources of pressurized, dynamic air in said body, each source communicating with a corresponding chamber and the latter communicating wtih said passages thereby to establish and contain downwardly and inwardly directed barrier-air curtains so arranged with respect to the underside of said body as to define and maintain a plurality of body-supporting air cushions; said plurality consisting of a substantially central air cushion and a pair of laterally spaced cushions; means in each of said sources and in the throats of the inner ones of said longitudinal passages for increasing the pressure and decreasing the thickness and angle to vertical of the air curtain issuing from said throat on the one longitudinal side of said body while decreasing the pressure and increasing the thickness and angle to vertical of the air curtain issuing from said throat on the opposite longitudinal side of said body whereby to generate a rolling moment on said body directed from the higher to the lower pressure side about its longitudinal axis while concurrently generating an unbalanced, lateral thrust on said body.

3. A ground effect machine comprising: an elongate load supporting body generally rectangular in planform; a pair of longitudinally extending downwardly opening air discharge passages located at a first side of said body and laterally spaced to form an air cushion zone between them; a pair of longitudinally extending, downwardly opening air discharge passages located at the second side of said body and laterally spaced to form an air cushion zone between them; laterally extending, downwardly opening air discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the throats of all of said passages being angled downwardly and inwardly; means to supply air under pressure to all of said passages to produce downwardly and inwardly directed air curtains producing and maintaining a central primary air cushion and a pair of laterally spaced secondary air cushions cooperating to support said body; the throats of the outer one of each of said pairs of longitudinally directed passages being constant in dimension; vane means in the throats of the inner one of each of said pairs of longitudinally directed passages; said vane means being pivotally mounted along their upper edges to the inner walls of said throats and extending in the general flow direction beyond the edges of the outer walls of said throats; and means to differentially actuate said vane means about their pivotal mountings; the down moving vane means constricting its respective throat to decrease the thickness and angle to the vertical of the air curtain issuing therefrom, and the up moving vane means enlarging its respective throat to increase the thickness and angle to the vertical of the air curtain issuing therefrom; thereby to produce a rolling moment and a lateral resultant thrust component in a direction in consonance therewith.

4. A ground effect machine comprising: a load supporting body; means to produce and confine a primary air cushion at a selected pressure under the central portion of the body to support a part of its weight; means to produce and confine a secondary air cushion at a selected pressure less than that of said primary air cushion in zones at each side of said primary air cushion to support the balance of the weight of said body; and means to increase the unit are pressure of a secondary air cushion at one side with respect to one at the other side to produce a rolling moment, including means to produce a horizontal lateral force on said body in a direction from the up moment side to the down moment side.

5. A machine as claimed in claim 4 and, in addition thereto; means to divide each of said secondary air cushions into a fore part and an aft part on opposite sides of the lateral axis of said body; and means to increase and decrease the unit air pressure of the fore portions with respect to the aft portions to produce pitching moments.

6. A ground effect machine comprising: a load supporting body; means to produce and confine a plurality of air cushions at a selected pressure under said body at laterally opposed sides of its longitudinal axis to support at least a portion of the weight of said body; said means including a plurality of laterally spaced, longitudinally extending, downwardly opening air discharge passages, downwardly directed air discharge passages extending laterally betwen and adjacent to the ends of said longitudinally extending passages to form substantially closed geometric figures; each of said passages having rigid, fixed dimensions, outlet throats; and means to supply air under pressure to said passages to produce downwardly directed air curtains; each of said air cushions being bounded by a pair of longitudinaly extending air curtains and a pair of laterally extending air curtains; and controllable vane means in the throat of at least one longitudinally extending passage spaced to each side of said longitudinal axis to change the cross sectional area and effective discharge direction of such throat and thus to vary the thickness and lateral downward angle of discharge of the air curtain issuing from the respective passage; thereby to produce a difference in unit air pressure within said air cushions and a consequent rolling moment and to produce a horizontal lateral force in a direction in consonance therewith.

7. A machine as claimed in claim 6 and, in addition thereto; a laterally extending, downwardly directed air discharge passage at the mid-portion of said body extending across and substantially joining said longitudinally extending passages at their mid-portions; said laterally extending passage being in communication with said air supply to discharge a vertical air curtain dividing each of said air cushions into fore and aft portions; and the fore and aft portions of the controllable vane means in the throats of said longitudinally extending passages for varying the thickness and angle of discharge of the respective air curtains being independently movable and being controllable to increase and decrease the unit air pressure in the fore parts of said air cushions with respect to that in the aft parts to produce pitching moments.

8. A ground effect machine comprising: an elongate load supporting body generally rectangular in planform; a pair of longitudinally extending, downwardly opening air discharge passages located at a first side of said body and laterally spaced to form an air cushion zone between them; a pair of longitudinally extending, downwardly opening air discharge passages located at the second side of said body and laterally spaced to form an air cushion zone between them; laterally extending, downwardly opening air discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the discharge directions of all of said passages being effectively angled downwardly and inwardly in neutral condition; means to supply air under pressure to all of said passages to produce downwardly and inwardly directed air curtains producing and maintaining a central primary air cushion and a pair

of laterally spaced secondary air cushions cooperating to support said body; vane means in the throats of the inner one of each of said pairs of longitudinally directed passages and pivotally mounted along their upper edges to the inner walls of said throats; vane means in the throats of the outer one of each of said pairs of longitudinally directed passages and pivotally mounted along their upper edges to the outer walls of said throats; and means to differentially actuate said vane means about their pivotal mountings; the down moving vane means in the inner passage at a first side of said body constricting its respective throat to decrease the thickness and angle to the vertical of the air curtain issuing therefrom and the down moving vane means in the outer passage at said side enlarging its respective throat to increase the thickness and decrease the angle to the vertical of the air curtain issuing therefrom; the up moving vane means in the inner passage at the second side of said body enlarging its respective throat to increase the thickness and angle to the vertical of the air curtain issuing therefrom and the up moving vane means in the outer passage at said side constricting its respective throat to decrease the thickness and increase the angle to the vertical of the air curtain issuing therefrom; thereby to produce a rolling moment and a lateral resultant thrust component in a direction in consonance therewith.

9. A ground effect vehicle comprising: an elongate load supporting body; a first longitudinally extending, downwardly opening air discharge passage laterally spaced to one side of the longitudinal axis of the body; a second longitudinally extending, downwardly opening air discharge passage laterally spaced to the other side of said longitudinal axis; a third longitudinally extending, downwardly opening air discharge passage substantially on said longitudinal axis; fore and aft laterally extending, downwardly opening air discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the discharge direction of said third passage being substantially vertically downward at all times; the discharge direction of the other passages being effectively angled downwardly and inwardly in neutral condition; means to supply air under pressure to all of said passages to produce a vertical central air curtain and a downwardly and inwardly directed peripheral air curtain, producing and maintaining a pair of laterally opposed air cushions cooperating to support said body; and vane means in said first and second passages operable to decrease the angle to the vertical of the air curtain issuing from one of said passages and to increase the angle to the vertical of the air curtain issuing from the other of said passages.

10. A ground effect vehicle comprising: an elongate load supporting body; a first longitudinally extending, downwardly opening air discharge passage laterally spaced to one side of the longitudinal axis of the body; a second longitudinally extending, downwardly opening air discharge passage laterally spaced to the other side of said longitudinal axis; a third longitudinally extending, downwardly opening air discharge passage substantially on said longitudinal axis; fore and aft laterally extending, downwardly opening air discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the discharge direction of said third passage being substantially vertically downward at all times; the discharge direction of the other passages being effectively angled downwardly and inwardly in neutral condition; means to supply air under pressure to all of said passages to produce a vertical central air curtain and a downwardly and inwardly directed peripheral air curtain, producing and maintaining a pair of laterally opposed air cushions cooperating to support said body; vane means in the throats of each of said first and second passages; said vane means being pivotally mounted along their upper edges to the inner walls of said throats; means to differentially actuate said vane means about their pivotal mountings; the down moving vane means constricting its respective throat to decrease the thickness and angle to the vertical of the air curtain issuing therefrom, and the up moving vane means enlarging its respective throat to increase the thickness and angle to the vertical of the air curtain issuing therefrom; and means to increase the air pressure in the passage carrying the down moving vane.

11. A ground effect vehicle comprising: an elongate load supporting body; a first longitudinally extending downwardly opening air discharge passage laterally spaced to one side of the longitudinal axis of the body; a second longitudinally extending, downwardly opening air discharge passage laterally spaced to the other side of said longitudinal axis; a third longitudinally extending, downwardly opening air discharge passage substantially on said longitudinal axis; fore and aft laterally extending, downwardly opening air discharge passages extending across and substantially joining the fore and aft ends of said longitudinally extending passages; the discharge direction of said third passage being substantially vertically downward at all times; the discharge direction of the other passages being effectively angled downwardly and inwardly in neutral condition; means to supply air under pressure to all of said passages to produce a vertical central air curtain and a downwardly and inwardly directed peripheral air curtain, producing and maintaining a pair of laterally opposed air cushions cooperating to support said body, vane means in the throats of each of said first and second passages; said vane means being pivotally mounted along their upper edges to the outer walls of said throats; and means to differentially actuate said vane means about their pivotal mountings; the down moving vane means enlarging its respective throat to increase the thickness and decrease the angle to the vertical of the air curtain issuing therefrom, and the up moving vane means constricting its respective throat to decrease the thickness and increase the angle to the vertical of the air curtain issuing therefrom.

12. A ground effect vehicle comprising: an elongate load supporting body; a plurality of longitudinally extending, downwardly opening air discharge passages laterally spaced to each side of the longitudinal axis of the body; fore and aft laterally extending, downwardly opening air discharge passages extending across and substantially joining the ends of said logitudinally extending passages; all of said passages discharging air curtains downwardly and inwardly in neutral condition to produce and maintain at least one air cushion therebetween to support said body; vane means in said fore passage pivotally mounted at its upper edge and extending downwardly and rearwardly in neutral condition; and vane means in said aft passage pivotally mounted at its upper edge and extending downwardly and forwardly in neutral condition; the vane means in said fore passage being swingable upwardly and rearwardly and the vane means in the aft passage being swingable downwardly and rearwardly during forward flight of the vehicle to decrease the drag and to produce a favorable horizontal thrust component.

13. A ground effect machine comprising: a load supporting body; means to produce and confine a plurality of air cushions at a selected pressure under said body at laterally opposed sides of its longitudinal axis to support at least a portion of the weight of said body; and means to increase the unit air pressure of a cushion at one side of said axis with respect to a cushion at the other side to produce a rolling moment, including means to produce a horizontal lateral force on said body in a direction from the up moment side to the down moment side; and means to produce and confine an additional air cushion adjacent the fore and aft ends of said body respectively; and means to increase and decrease the unit air pressure of

the fore cushion with respect to the aft cushion to produce pitching moments.

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