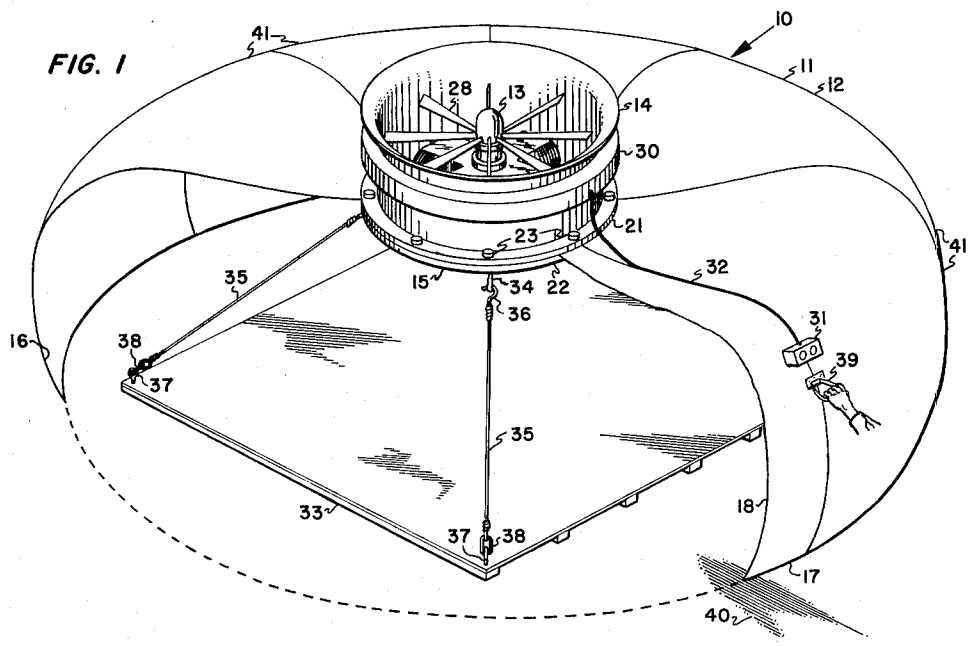
Feb. 8, 1966 L. W. HAVERCAMP 3,233,693

GROUND EFFECT MACHINE

Filed Feb. 17, 1965 4 Sheets-Sheet 1

FIG. 1



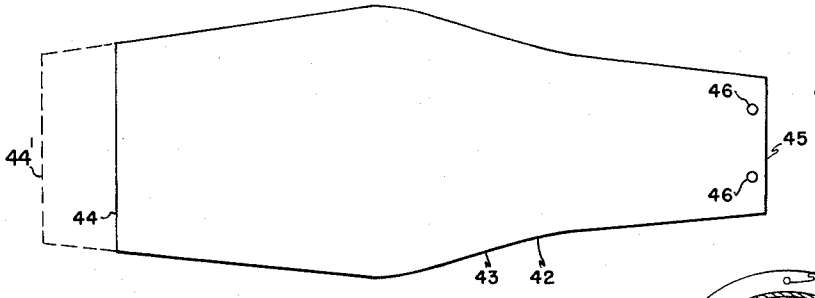


FIG. 4

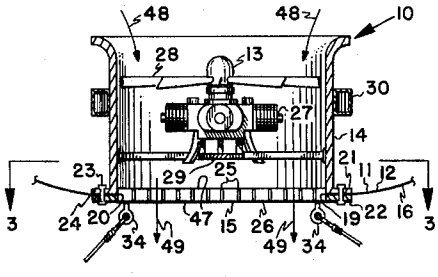


FIG. 2

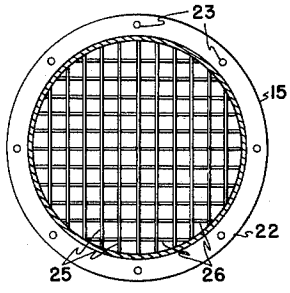


FIG. 3

INVENTOR.
LEWIS W. HAVERCAMP
BY Roger L. Martin
ATTORNEYS

Feb. 8, 1966 L. W. HAVERCAMP 3,233,693

GROUND EFFECT MACHINE

Filed Feb. 17, 1965 4 Sheets-Sheet 2

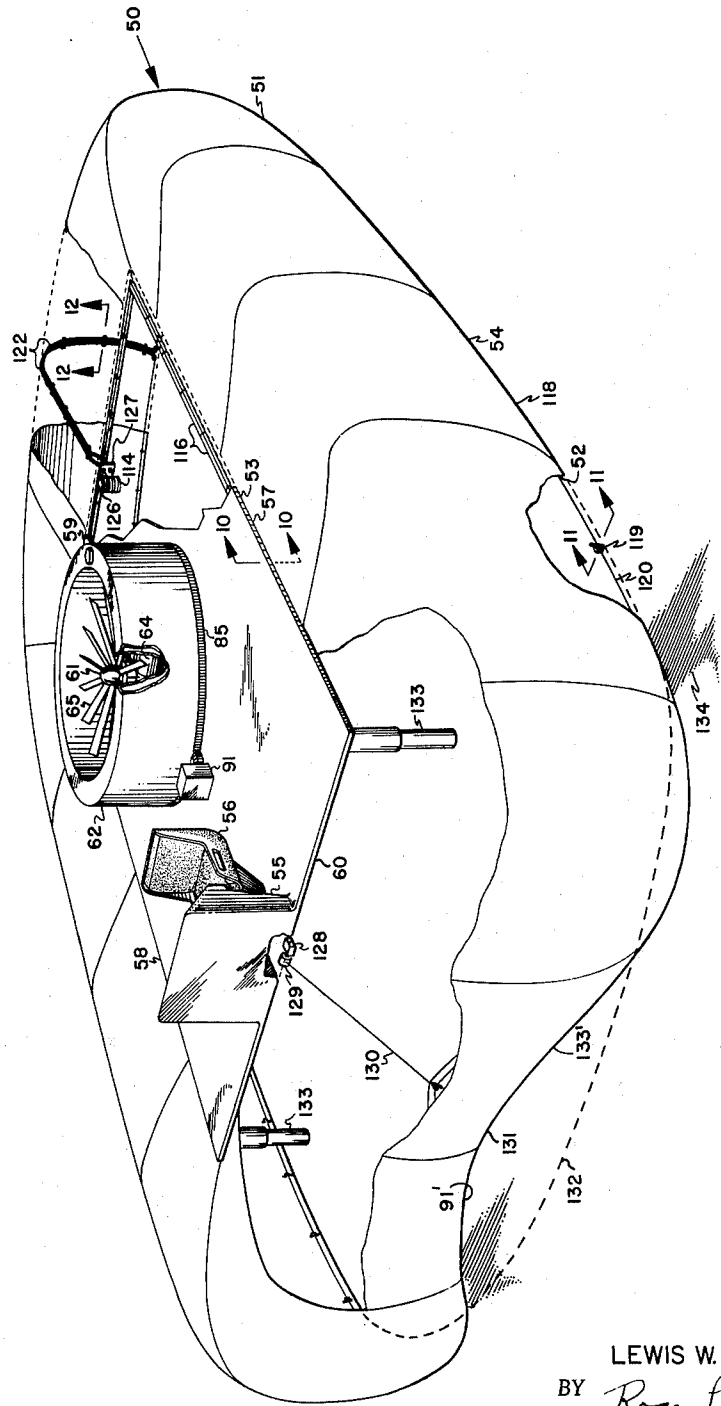


FIG. 5

INVENTOR.
LEWIS W. HAVERCAMP
BY Roger L. Martin
ATTORNEYS

Feb. 8, 1966 L. W. HAVERCAMP 3,233,693

GROUND EFFECT MACHINE

Filed Feb. 17, 1965 4 Sheets-Sheet 3

FIG. 6

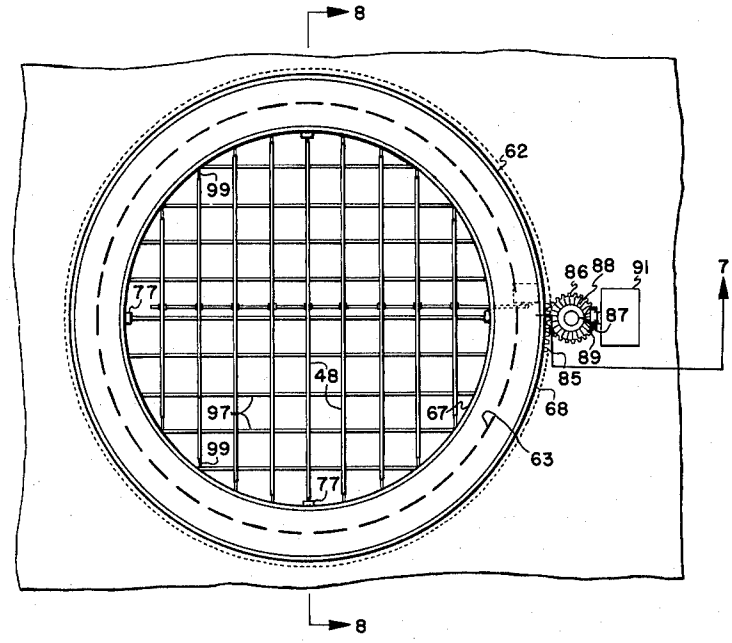


FIG. 7

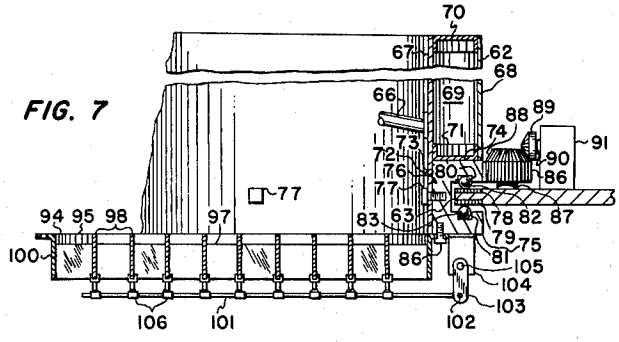


FIG. 8

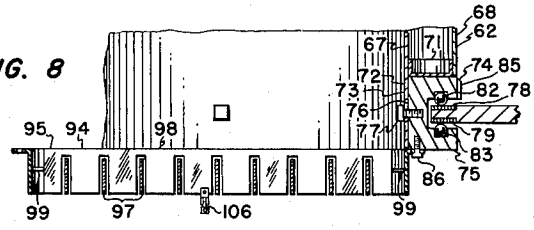
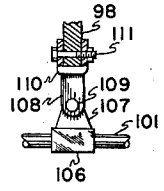


FIG. 9



INVENTOR.
LEWIS W. HAVERCAMP
BY Roger L. Martin
ATTORNEYS

Feb. 8, 1966 L. W. HAVERCAMP 3,233,693

GROUND EFFECT MACHINE

Filed Feb. 17, 1965 4 Sheets-Sheet 4

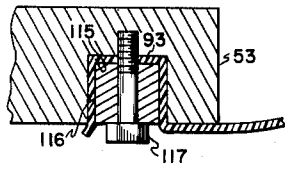


FIG. 10

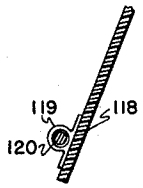


FIG. 11

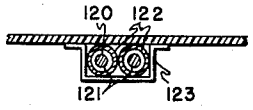


FIG. 12

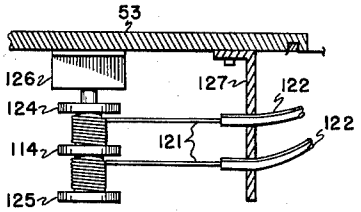


FIG. 13

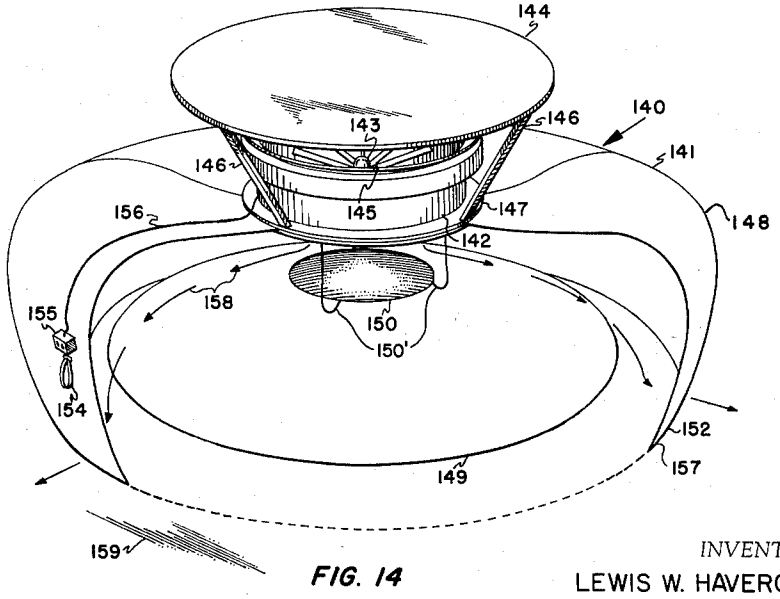


FIG. 14

INVENTOR.
LEWIS W. HAVERCAMP
BY Roger L. Martin
ATTORNEYS

United States Patent Office 3,233,693 Patented Feb. 8, 1966

3,233,693

GROUND EFFECT MACHINE

Lewis W. Havercamp, Rte. 1, Box 115, Freeport, Fla.

Filed Feb. 17, 1965, Ser. No. 433,326
15 Claims. (Cl. 180—7)

This invention relates to aircraft in general and more particularly to aircraft operable in ground effect and utilizing ground cushion phenomenon.

There recently has been much activity not only on the part of private individuals and companies but of Government agencies as well in the development of ground effect machines. Numerous different types of ground effect machines have been devised, among those being the plenum chamber, annular jet, labyrinth seal, levipad, air curtain, air curtain with skegs, integrated air curtain, water curtain, ram air and diffusion recirculation types. The usefulness of these prior art machines is derived from a cushion of sustaining air which is caused to exist between the machine and its supporting surface. This cushion of sustaining air presents very little resistance to relative motion between the machine and the supporting surface at present speeds of locomotion. Most of the power required to operate any ground effect machine is necessary for sustaining the machine above the supporting surface while relatively little power is required for locomotion.

Machines such as the heretofore mentioned prior art devices usually derived the force required for locomotion by changing the direction of the lift forces with respect to the machine's gravity force to obtain the desired magnitude and direction of a force component which is horizontal to the supporting surface. Locomotion for ground effect machines embodying concepts of the invention disclosed herein may be similarly secured.

The prior art ground effect machines serve as a means of transport and are characterized by their ability to move about, but near, supporting surfaces without a solid contact with these surfaces. In most prior art machines, the pressurized chamber or airframe is for all practical purposes rigid in nature and has an air intake or pump orifice and an exit orifice, the latter being adjacent to the ground and through which the air is expelled from the pressurized chamber during use. The air pump is mounted on the rigid airframe in a manner such as to pump air into the airframe through the pump orifice and a cushion of air is formed between the machine and supporting surface as the air is exhausted from the chamber at the exit orifice.

Several shortcomings attend the use of rigid airframes in the above mentioned prior art types. For instance, ground effect machines having a rigid airframe are not portable since they occupy substantially the same space whether they are operating or not. The dimensions of the exit orifice of the rigid airframe members of the prior are ground effect machines are for all practical purposes generally fixed and the fixed nature of the orifice severely limits operational flexibility as is apparent. Such machines are also relatively expensive to manufacture because of the high material costs and stringent material and labor requirement involved. Additionally, they are relatively heavy and this results in poor efficiency and high power requirements to sustain the craft in ground effect during use.

Other shortcomings of the prior art machines include their lack of stability during operation and this is directly attributable to the weighty components that are utilized in manufacturing rigid airframe structures as well as to the design of the aircraft itself. Thus, the center of gravity of the prior art ground effect machine is above the center of sustentation pressure secured during use

and this causes the devices to pitch and roll in a manner such as to, in many instances, preclude the effective and economical use of such machines for commercial purposes in transporting cargo, passengers and the like.

One shortcoming in prior art ground effect machines resides in the fact that the contour of the airframe member in the area of the exit orifice is fixed for all practical purposes. The machine is therefore not adaptable to operating in those areas where unlevel terrain exists. For instance, if a ground effect machine having rigid frame members in the area of the exit orifice encounters a small rise, it tends to lose its sustentation unless large amounts of power are expended to cause the machine to pass above the rise. As a result, the prior art ground effect machines have on many occasions been incapable of operating over such terrain.

The rigid nature of the airframe in the orifice area lends itself to permitting loss of air and thus power for sustentation when the craft operates over uneven ground or irregular surfaces. On the other hand, if the frame was capable of adapting itself to the irregularities of the terrain so as to avoid loss of air from within the airframe structure, much of this problem would be solved.

In most cases of the prior art machines, curtains or skirts of flexible material are used at the exit orifice in an attempt to overcome the inability of the airframe to adapt itself to the contour of uneven terrain and to thus overcome some of these problems. These skirts or "curtains" as they are sometimes called only partly solve the problem, however, and are primarily designed to avoid damage to the machine when the machine encounters terrain having minor irregularities.

Prior art ground effect machines having rigid frame members have been practically excluded from consideration with respect to material warehousing chores such as performed by fork lifts and other material handling apparatuses. This is due to the fact that if a hydraulic or other type of lifting apparatus is attached to the ground effect machine, the combined weight becomes relatively high and this results in very low lifting and carrying capabilities at operating powers deemed economical with today's craft. Furthermore, the hoisting ability attributable solely to craft is limited to the rise above the ground secured when the craft is operating in ground effect.

It has been discovered that one or more of the various shortcomings and deficiencies in the prior art ground effect machines may be overcome through the use of an airframe that at least in part includes a flexible canopy type structure which becomes inflated at the time operation of the device is initiated. The flexible materials that may be used in building the canopy portion of the airframe under such circumstances are practically weightless by comparison to the current material used in the manufacture of the more conventional pressurized chambers. Furthermore, through use of the flexible canopy-like structure, hoisting capabilities can be realized which cannot be secured as a practical matter in the more conventional prior art device. As will be seen hereinafter, the concept may be used in accord with one aspect of the invention to provide a center of sustentation pressure which is above the overall center of gravity and thus provides basis for the heretofore much needed stability that has been lacking in prior art ground effect machines. Other aspects of the invention permit use of the concept in a manner enabling irregular surfaces to be traversed without material loss of power.

It is therefore an object of the invention to provide an improved ground effect machine.

Another object of the invention is to provide an improvement in ground effect machines that permits the size of the orifice area to be varied.

Another object of the present invention is to provide a ground effect machine which is highly efficient and stable when operating over an unlevel supporting surface.

Another object of the present invention is to provide a ground effect machine which is relatively inexpensive, lightweight, and highly efficient.

Another object of the present invention is to provide a ground effect machine which is capable of material handling applications without the necessity of complex lifting components.

Another object of the present invention is to provide a portable ground effect machine which when not operating occupies approximately only a fraction of the space occupied when in use.

Yet another object is to provide a ground effect machine having an airframe which has flexible components permitting the frame to conform to a wide variance in terrain profile.

Another object is to provide a ground effect machine which is adapted for use for material handling chores as, for example, in warehouse work.

Another object is to provide an airframe for ground effect machines in which the heavier components of the machine are suspended from flexible components of the aircraft during use of the machine.

Yet another object is to provide a ground effect machine which is capable of effectively using the principles of ram air during use to transfer power used in propulsion into power for sustentation.

Other and further objects and advantages of the present invention will become apparent to one skilled in the art from a consideration of the following detailed description when read in the light of the accompanying drawings, in which:

FIG. 1 is a perspective view of a ground effect machine used for warehousing chores and which embodies certain principles of the invention, the machine being shown when operating in ground effect; and, with certain parts being broken away to expose other components;

FIG. 2 is a transverse vertical sectional view through the pump housing and adjacent structure;

FIG. 3 is a horizontal section view as seen generally along the line 3—3 of FIG. 2;

FIG. 4 is plan view of a gore used in forming the canopy section of the machine shown in FIG. 1;

FIG. 5 is a perspective view of another ground effect machine embodying principles of the invention, certain parts being broken away to expose other parts of the craft;

FIG. 6 is top view of a fragment of the craft shown in FIG. 5, showing the pump housing and adjacent structure, the pump and supporting structure being removed to better expose the underlying grid assembly.

FIG. 7 is a vertical section view as seen generally along the line 7—7 of FIG. 6 with certain parts broken away or removed.

FIG. 8 is another vertical section view along the line 8—8 of FIG. 6, certain parts also being broken away or removed.

FIG. 9 is enlarged view of a coupling and adjacent structure shown in FIG. 8 and 9.

FIG. 10 is an enlarged section view of a fragment of the craft as seen along the lines 10—10 of FIG. 5 and illustrates the means employed for securing the canopy to a plate component of the craft.

FIG. 11 is an enlarged section view of a fragment of the craft as seen along the line 11—11 of FIG. 5 and illustrates the means used for connecting a drawstring component to the skirt of the canopy at the exit orifice of the craft shown in FIG. 5.

FIG. 12 is an enlarged section view of a fragment of the craft as seen along the line 12—12 of FIG. 5 and illustrates certain resilient tubular elements housing the ends of a drawstring and the means utilized for attaching the elements to the canopy.

FIG. 13 is an enlarged fragment partially in vertical section showing a motor and drum assembly used in the mechanism for varying the exit orifice of the craft shown in FIG. 5.

FIG. 14 is a perspective view of another ground effect machine embodying the invention, certain parts being broken away to expose components housed in the pressure chamber.

Briefly, the subject invention in the preferred embodiment is a parachute like device which hovers above but in proximity with a supporting surface when sufficient air flow is induced through the device. It is parachute-like in general construction and in plan form and has, in the preferred form, an air pump for inducing air flow through the airframe in a direction opposite to the air flow through a parachute. It will hover and move horizontally above its supporting surface when inflated by continuous air flow and the canopy component of the airframe will collapse when air flow is terminated.

A simple version of the invention is seen in FIG. 1 as embodied in a device for handling pallet supported material as for example in warehousing chores.

The ground effect machine is designated generally at 10 and has an airframe 11 that includes a canopy section 12. The air pump 13 is supported in a cylindrical housing 14 that is open at its opposite ends to permit air to be drawn in at the upper end and then discharged through the lower end and into the pressurized chamber or airframe of the machine. A grid assembly 15 is provided at the lower end of the pump housing 14 to more or less uniformly distribute the air into the hollow 16 of the pressurized chamber and to prevent unnecessary channeling of the air in a manner such as to cause undue horizontal tangential force components to be imparted to the apparatus during use and thus to prevent dissipation of power which is otherwise desired for lifting purposes.

The canopy section 12 is preferably impervious to air and is much like a parachute canopy in general construction and plan form. In the embodiment illustrated, it includes a plurality of thin elongated sections or gores 41, one gore 42 being shown detached in FIG. 4. These gores 41 are fastened together, one adjacent the next, along their side edges 43 in the formation of the canopy, and have a greater width dimension at the base end 44 than at the opposite end 45. The width dimension of each gore increases inwardly from the base end 44 to provide a skirt portion 18 in the assembled canopy which cups inwardly toward the edge of the orifice and overhangs the ground 40 laterally and exteriorly of the exit orifice when the canopy is inflated and the machine is operating in ground effect. Above the skirt, the gores of the canopy section as seen by reference to gore 42 progressively diminish in their width dimension as toward the end 45 of the gore 42 so that portions of the gores extend over the exit orifice in the assembled canopy section and thereat form a part of the top wall of the airframe when the machine is supported in ground effect on the air cushion. The canopy section 12 of the ground effect machine's airframe has a circular opening 17 at the lower end as when the canopy is inflated, the opening 17 serving as the exit orifice of the plenum type airframe illustrated. The canopy also has another circular opening 19 at the juncture of the upper ends of the gores 41 that are brought together in the final assembly of the canopy section. This opening 19 is located at the air intake orifice 20 of the airframe.

The air pump housing 14 has a radially extending flange 21 at its lower end and the grid assembly 15 has a flat annular flange 22 which is secured to flange 21 at the air intake orifice 20 by suitable spaced fasteners 23. The edge portion 24 of the canopy at opening 19 is disposed between the flanges 21 and 22 in the assembled machine 10 and is provided with suitable holes as at 46 in FIG. 4 to accommodate the releasable fasteners 23 used in securing the housing, grid and canopy together thereat.

The grid assembly 15 includes one set of parallel and laterally equispaced louvers 25 that are fixed at their opposite ends to flange 22 as best seen in FIGS. 2 and 3. The assembly also has another set of louvers 26 which are also parallel and equispaced more or less in the same plane as louvers 25. Louvers 26 are also fixed at their opposite ends to flange 22 but their longitudinal axes are perpendicularly arranged with respect to louvers 25.

Louvers 25 and 26 are flat elongated elements of equal width dimensions, and are suitably notched to accommodate the louvers elements that are arranged transversely thereto. They are arranged in the grid assembly with their opposite side edges 47 in vertical alignment so that the air which is forced through the grid 15 is deflected into the chamber in a direction more or less parallel with the axis of the pump housing 14. The upper side edges of louvers 25 and 26 are arranged in the grid assembly 15 above flange 22 and are adapted to fit into the opening at the lower end of the pump housing 14 as seen in FIG. 2.

The air pump 13 in the embodiment includes a radial engine 27 that has a fan blade 28 attached to its shaft in a manner such as to draw air into the upper end of the housing 14 during use, as in the direction of arrows 48 and to force this air into the airframe through the grid openings of assembly 15 as in the direction of arrows 49. Pump 13 is axially mounted in the housing on radially extending rigid support elements 29 that are fixed to the interior of the housing adjacent to the air intake orifice of the airframe.

In the illustrated embodiment a compartmented annular housing 30 is fixed to the exterior of the pump housing for storing fuel, starter batteries, etc., for engine 27. Engine 27 is controlled by the hand manipulation of controls mounted in a control box 31 that is suitably connected to the exterior of the canopy section 12 adjacent handle 39. These controls are connected to the engine by suitable components housed in a hollow flexible cable 32 that interconnects the engine 27 and the control box 31.

In FIG. 1, machine 10 is shown in operation and with an empty pallet 33 suspended in the hollow or space occupied by the pressurized air cushion in the pressure chamber. The grid assembly 15 has four spaced and depending eyelets 34 that are fixed to the underside of flange 22. The pallet 33 is connected to the machine by means of four ropes 35 that are connected to the respective eyelets 34 at one end by hook elements 36 and to eyelets 37 respectively fixed at the corners of the pallet at the other end through ring elements 38.

The embodiment shown is primarily used for hoisting and lowering materials stacked on pallets and is motivated from one place to another manually by the user through manipulation of a handle 39 that is fixed to the exterior of the canopy 12 adjacent to the control box 31 as seen in FIG. 1.

The airframe of FIG. 1 operates as an annular airfoil in proximity with the ground when air is pumped through the pump orifice toward the supporting surface 40 in quantities sufficient to provide a pressure in chamber 11 adequate to sustain the machine 10 and its load above the surface 40, and otherwise performs under these conditions in a manner similar to prior art ground effect machines. Air drawn into the housing 14 by pump 13 enters the airframe or pressure chamber through orifice 20 and escapes from the airframe through the exit orifice 17 and between the supporting surface 40 and the edge of the skirt 18.

When the pump 13 is not in operation, the canopy assumes a collapsed position radially outwardly of the grid assembly fiange 15. In the absence of the pallet and elements for its suspension the grid assembly and pump assembly are ground supported through the eyelets 34. When the pump 13 is actuated to draw air into the housing 14 and force it through the grid assembly 15, the canopy section 12 is initially caused to inflate as the

pressure builds up in the airframe 11. Through suitable control of pump 13, the pressure can be caused to increase in the airframe to the point at which the pump and grid assemblies are caused to rise above the ground supported positions. As this transpires, the skirt 18 tends to cling to the ground laterally and exteriorly of the exit orifice and the airframe functions as a deformable compressed air reservoir with the grid assembly and adjacent structure assuming a position above the ground which depends upon the difference in pressure between the inside and outside of the canopy, the particular design of the canopy, and the weight of the heavier components of the machine.

It is believed apparent that while airframe 11 serves as a compressed air reservoir when the skirt is in contact with the ground surface 40, the grid and pump assemblies may be raised and lowered by simply controlling the pump to increase or decrease the pressure internally of the airframe. Hence, by control of the pump, the pallet 33 together with any load thereon may also be raised or lowered if it is attached to the machine within the pressure chamber. Thus, by virtue of the flexible canopy structure, the device can be caused to lift objects without actually leaving the ground to operate in ground effect.

In practice, the pallet and its load are elevated above the supporting surface 40 by initially inflating the canopy and creating a pressure in chamber 11 which is sufficient to draw the pallet to a state of suspension from the machine above the ground and while the air chamber is operating as a compressed air reservoir, i.e., while the skirt of the canopy clings to the ground.

Thereafter, pump 13 is controlled to further increase the pressure in chamber 11 and this causes the machine 10 as a whole to rise above surface 40 and into a state of being supported above the surface 40 on a cushion of air which is escaping from the airframe between the edge of the skirt 18 and the ground 40. Under these conditions, mass flow rates of air through the intake orifice 20 and the exit orifice 17 of the airframe are equal and the height of the machine above the ground can be increased or decreased as in more conventional ground effect machines through increasing or decreasing the pressure in the airframe through suitable control of pump 13.

From the above, it is apparent that by virtue of the illustrated canopy type structure 12, the machine may be so controlled as to cause the canopy to inflate and thereby elevate the air pump and grid assemblies above the supporting surface 40. In practice, the machine 10 may be first controlled to inflate the canopy and elevate these rigid components above the surface and may then be drawn as by manipulation of handle 39 over a load supported on pallet 33, as when the latter is detached from the machine. This can be done when the machine is supported in ground effect relation on a cushion of escaping air or even when the skirt is still in contact with the ground providing the pressure inside the airframe is sufficient to maintain the grid and pump assemblies at a suitable height above the upper extremities of the load on pallet 33. By virtue of the flexible material of the canopy structure, the canopy will more or less conform to the contour of the loaded pallet 33 as a machine is drawn into a position at which the loaded pallet is completely housed in the pressure chamber 11. At this point in its use, the pump 13 of machine 10 may be shut off to permit the canopy to deflate through intake grid 15 and enable the grid assembly and components thereat to come to rest on the loaded pallet. The pallet 33 is then connected to the machine manually by lifting the skirt and connecting the ropes 35 to eyelets 34. Thereafter, the machine is again started and so controlled as to again inflate the canopy, this time to lift the pallet from its ground supported position into a position of suspension from the machine in the pressure chamber. As this happens, the skirt of the canopy, of course, again clings to the ground and assumes the contour thereat until the pressure developed

inside the airframe is such as to permit the machine with its suspended load to become supported on the cushion of escaping air. At this point in the use of the machine, it together with its load may be manually drawn to the desired place for storage of the palletized material and the process of deflation repeated to enable the loaded pallet to be unhooked from the machine.

The canopy section 12 serves as the main component of the pressure chamber or airframe in the illustration and is made of flexible material to permit the contour of the chamber to change as the canopy is inflated. The section may be made of plastic sheet material, fabric reinforced plastic, or other non-rigid or flexible materials that are substantially impervious to air. Several different types of materials have been found to be satisfactory for use in constructing the flexible canopy section, the synthetic polyester marketed by E. I. Dupont Co. under the trademark "Mylar" has been found to possess the desirable characteristics of durability and lightness of weight, and sheets thereof having a thickness of .001 inch may be suitably employed in fabricating the canopy section for many applications. Sail and conventional parachute cloths may also be used.

By increasing the size of the skirt portion and thus the overhang laterally of the exit orifice, the pallet can be caused to rise to a greater height before the machine is fully supported above the ground on the cushion of escaping air. The hoisting ability of the machine while the airframe functions as a compressed air reservoir can thus be increased. This can be accomplished by further extending the skirt end of each gore as illustrated by the broken lines 44' in FIG. 4.

It should be noted, as by reference to FIG. 2, that the heavier components of the machine are actually suspended from the canopy section when the latter is inflated. Thus, in the region of the intake orifice, the weight of the pump draws the adjacent canopy portion downwardly so that the contour of the canopy rises laterally of the pump above the connection with the grid and pump housing. This is advantageous for an appreciable portion of the canopy is actually located above the center of gravity of the machine when the canopy is inflated and provides a cushion contacting surface portion above the gravity center against which the pressurized air in the chamber works in sustaining the machine in ground effect. Consequently, the center of sustentation pressure is above the center of gravity of the machine during operation of the craft and much greater stability against rolling and pitching is realized than in prior art machines.

Yet another advantage lies in the relatively small volume in which the craft can be housed in the deflated condition, and which renders the craft more adaptable to transportation by land vehicles than other prior art ground effect machines.

Yet another embodiment of the invention is shown in FIGS. 5 through 13, the ground effect machine therein being generally designated at 50. In this embodiment, the airframe 51 is again of the plenum chamber type and is equipped with means for varying the size of the exit orifice 52. The machine is also provided with a device for changing the contour of the canopy at the front of the airframe so as to provide an airscoop with an opening that enables the craft to utilize ram air principles during forward motivation.

The airframe 51 comprises a rigid, flat, rectangular plate section 53 which forms part of the top wall of the airframe and an inflatable canopy section 54 which is connected to the edges of the plate. The plate 53 may be made of suitable light weight materials, preferably a resin impregnated fiber glass type structure, and is arranged with its longitudinal axis extending in the direction of normal forward and rearward movement of the draft. The machine 50 has a suitable control panel 55 and seat 56 for the pilot mounted at the front end of the plate 53. A circular hole or opening 63 is provided intermediate the opposite sides 57 and 58 and opposite ends 59 and 60 of the plate to accommodate location and mounting of the air pump 61 of the machine.

The air pump 61 is mounted in a cylindrical housing 62 which in turn is rotatably mounted on the plate 53 in coaxial arrangement with the axis of the plate opening 63. The radial engine 64 of the pump 61 has a suitable fan 65 mounted on its shaft and is coaxially mounted in the housing 62 on a rigid bracket component 66 fixed to the inside of the housing. The housing 62 has an internal cylindrical wall 67 and also an external cylindrical wall 68 which is spaced therefrom to provide a space 69 that is compartmented for fuel storage, starter batteries, and the like. An annular channel member 70 is fixed between the upper ends of the walls 67 and 68 and another annular channel 71 is provided between the lower ends of the walls 67 and 68 of the compartmented housing.

The internal wall 67 has a lower extension 72 that protrudes into the plate opening 63 and the housing is rotatably mounted on the plate 53 through the use of an annular channel component 73 having vertically spaced flanges 74 and 75. The web 76 of the channel 73 is releasably fixed to the exterior surface of the wall extension 72 by spaced fasteners 77, and channel 71 rests on the upper flange 74 of component 73 as seen in FIGS. 7 and 8. The flanges 74 and 75 lap wear strips 78 and 79 provided in recesses at the upper and lower edge portions of plate 53 adjacent opening 63, and are provided with grooves 80 and 81 adjacent the edges to accommodate a plurality of ball bearings 82 and 83 which contact the wear strips and facilitate the provision of a rotatable mounting for the assembly.

Channel 73 may be made in arcuate sections to facilitate disassembly of the apparatus for repair purposes. The outer edge of the upper flange 74 is provided with teeth 85 that mesh with a gear 86 rotatably mounted on a vertical shaft 87. Shaft 87 is suitably fixed to the plate at the front end of the plate opening 63. Gear 86 has an upper section 88 that is beveled and which meshes with a beveled drive gear 89. The latter is fixed to the shaft 90 of an electric motor 91 that is secured to the plate thereat. Motor 91 is a variable speed reversible motor and enables the housing and the attached components to be rotated in either direction through suitable control thereof from panel 55.

The grid assembly 94 for deflecting the air entering the airframe 51 is secured to the lower end of the pump housing and rotates therewith. It includes an annular angle member 95 which is suitably secured to channel 73 in coaxial alignment with the pump housing by spaced fasteners 96. The assembly 94 has a plurality of elongated louvers 97 which are laterally spaced from one another and which are fixed at their opposite ends to the depending leg 100 of circular angle component 95. Another set of louvers 98 that extend transversely of and substantially in the same plane as louvers 97 are also secured to the annular angle component 95. These louvers 98 are provided with aligned pegs 99 at their opposite ends and which are rotatably mounted in the depending leg 100 in a manner such that the louvers 98 can be caused to pivot about their respective longitudinal axes. Louvers 98 are connected in parallel to a rod element 101 which is located below and extends transversely of the louvers 98. The outer end of the rod is pivotally connected by a pivot element 102 to the outer end of a pivot arm 103. The latter is fixed to and adapted to pivot with respect to the axis of the shaft 105 of a motor 104 which is suspended from the lower flange 75 of member 73 so that the arm 103 can be pivoted in either direction about shaft 105 up to about 30° from the position shown in FIG. 7 through control of the motor 104.

Each of the louvers 98 is connected to the rod 101 by a coupling 106 that includes an upright eye element 107

which is secured to and carried by the rod. The eye element 107 fits between the arms of a depending clevis component 108 of the coupling and is pivotally connected to the eye element by a pivot pin 109. Pin 109 extends transversely of the rod. The clevis 108 carries an adapter 110 which laps the lower edge of the louver above the clevis and which is fixed to the louver by a fastener 111. The arrangement is such that movement of pivot arm 103 by motor 104 causes the rod 101 to move generally in the direction of its longitudinal axis and this causes the louvers 98 to pivot in parallel about their longitudinal axes. The air is thus deflected at the air intake orifice (92) of the airframe in a direction which is determined by the combined positions of the louvers 98 and the rotated position of the pump housing per se.

The assembled canopy 54 has an opening which is covered by the plate 53 and is composed of suitable gores. The edge portion 93 of the canopy 54 at the opening extends beneath the edges of plate 53. The latter is provided with a groove 115 along its perimeter as seen in FIG. 10 whereat the edge portion of the canopy is clamped in the groove by a plurality of elongated elements 116 that are disposed in end-to-end relation in the groove around the perimeter of the plate and which are releasably secured to the metal plate by fasteners 117.

The exit orifice 52 is defined by the edge of the skirt 118 of the canopy section. Small ring type eyelets 119 (FIG. 11) that may be made of plastic and heat sealed or otherwise fastened to the skirt are provided for receiving a drawstring 120 that surrounds the exit orifice. The eyelets 119 are spaced along the interior edge portion of the skirt 118. The opposite end sections 121 of the drawstring 120 extend through resilient tubular elements 122 that are capable of bending in accord with any changes in the contour of the canopy at the rear of the canopy. Elements 122 are secured to the canopy by suitable straps 123 as seen in FIGS. 5 and 12. The lower ends of the tubular sections are bent in opposite directions to accommodate reception of the opposite end sections thereat, as seen in FIG. 5. Ends 121 of the drawstring are wound around respective upper and lower sections 124 and 125 of a drum 114 that is fixed to a vertical shaft of an electric motor 126. The motor is fixed to the underside of plate 53 at the rear end of the craft, is reversible, and is controlled through the manipulation of suitable controls on panel 55. The upper ends of the flexible tubes 122 extend through vertically spaced holes in a spacer bracket 127 that is secured dependingly to plate 53 so as to enable the ends to wind uniformly on or off the drum when motor 126 is operated to take in or pay out the opposite ends of the draw string 120. It is believed apparent that by operating the motor to take in or pay out the ends of the drawstring 120 that the size of the exit orifice 52 may be diminished or increased. Machine 50 is seen in FIG. 5 with the drawstring 120 payed out to provide a maximum orifice size. As the string is drawn in, the skirt becomes gathered in the area of the exit orifice and this in effect reduces size of the orifice.

Another electric motor 128 is mounted on the underside of plate 53 at the front end of the ground effect machine. This motor 128 is also reversibly controllable and has a drum 129 which is connected to one end of a drawstring 130. The other end of this drawstring 130 is connected at the edge of the skirt at the midsection 131 of the front portion of the canopy and by controlling motor 128 to draw in on the string 130 during forward motion of the machine, the skirt is drawn inwardly and upwardly as from the normal position shown by dotted line 132 into the position shown. This changes the contour of the skirt and forms a scoop 133' at the midsection 131 with an opening 91' for the admission of air into the pressure chamber at the front end of the machine. As a result, a ram air effect is realized during forward locomotion and which minimizes the amount of power required for sustentation. The air scoop is formed only when the craft is moving forward.

When the ground effect machine is not in use, the canopy section of the machine, of course, is deflated. Under such circumstances, the plate is supported on depending standards 133 that are fixed at the four corners of the plate.

The canopy 54 functions in much the same manner as the canopy in the previously discussed embodiment. The canopy is collapsed when the craft is not operating and is inflated with the skirt overhanging the ground exteriorly of the exit orifice when the craft is operating in ground effect. Another portion of the canopy forms a part of the top wall of the airframe over the exit orifice when the machine is supported on the cushion and like the previous embodiment rises laterally of the pump plate to provide a support surface above the plane of the plate. As operation of the air pump 61 is initiated, the canopy section starts to inflate. As the pressure builds up inside the airframe, the canopy becomes inflated and the plate rises from its ground supported position on the standards. During this period, the lower portion of the skirt 118 remains in contact with the surface of the ground 134 exteriorly of the discharge orifice and the airframe serves as compressed air chamber with the plate 53 being supported above the ground because of the internal pressure causing inflation of canopy section. Thereafter, the pressure can be built up to the point at which the machine 50 rises from the ground and hovers in ground effect on the cushion of air created at the base of the craft and which escapes from the chamber between the edge of skirt 118 and the ground 134.

Provision of a means for varying the size of the exit orifice has various advantages. In the first place, the plate section 53 of the airframe can be caused to ride at a higher elevation above the ground when the exit orifice is made smaller, thus giving the craft greater flexibility in use over irregular terrain. On the other hand, greater loads can be carried on the plate under the same pressure conditions in the airframe when the orifice size is increased in size so as to provide greater surface area for vertical force components to work against for sustentation purposes.

Locomotion as well as braking of the device is accomplished in the instant embodiment by suitably controlling the rotation of the grid assembly about the axis of the housing and by suitable control of the angle at which the louvers deflect the air into the airframe. Thus, by causing the intake air to be deflected in a general rearward direction inside the airframe, an off balance pressure is created within the airframe in a manner such that the pressure differential at the rear of the device is greater than at the front of the device. This causes the machine to tip downwardly at the front end so that the rear end of the device is then elevated above the ground a greater distance than at the front end of the device. This causes locomotion in a forward direction or tends to brake the machine if the machine is moving rearwards. It is believed evident that lateral motion can be imparted by suitably controlling the direction the air is deflected into the chamber.

One of the advantages to using the canopy like structure resides in the ability of the canopy to closely conform to the contour of the sustaining surface in the regions of the skirt area of the canopy section. This enables the craft to be operated over irregular surfaces, both ground and water, without excessive power losses in order to sustain the machine in ground effect.

When the craft is moving in a forward direction through suitable control of the air deflecting louvers, the operator can control motor 128 to draw the front portion of the canopy upwardly into the general position shown in FIG. 5 to create the air scoop 133'. Under such circumstances, the forward movement of the craft causes air to enter the pressure chamber through the

opening 91' rather than being deflected by the airframe. This air which is rammed into the pressure chamber adds to that in the chamber and aids in sustentation of the craft.

The invention is further illustrated by reference to the embodiment shown in FIG. 14.

In this instance, the machine is designated at 140 and includes a flexible canopy 141 and a pump housing 142 like that described with respect to the embodiment shown in FIG. 1. It also has an air pump 143 and a grid assembly (not shown) like that shown in the first described embodiment.

In this embodiment, however, a circular platform 144 for supporting loads is supported spacedly above the air intake opening 145 of the pump housing 142 on four inclined rigid brace components 146. These components 146 are fixed at their upper ends to the underside of platform 144 and at their lower ends to the flange 147 of the housing 142.

The airframe 148 houses an inflatable center body 149 which is inflated when the craft is operating and which as inflated is substantially circular when viewed from the top and substantially oval when viewed in side elevation. The body 149 is hollow and made from flexible material like that used for the canopy and has a small circular opening 150 at the top and which is more or less axially aligned during operation of the craft with the axis of the air pump 143.

The body 149 is connected to the pump housing 142 by means of three spaced ropes 150' which are of suitable lengths to permit substantially free movement of the body in the hollow of the air frame when the craft is operating in a state of ground effect. These ropes merely serve to retain the opening 150 in the center body in the general area of the pump discharge opening when the canopy is deflated so that the opening in the center body will be in position to admit air into the center body when operation of the pump is first initiated. The lower ends of the ropes 150' are connected to the hollow body at the perimeter of the opening 150.

The center body 149 functions as a stabilizer during operation of the machine and serves to keep the plane of the exit orifice 157 parallel to the general plane of the supporting surface 159. Once the body 149 has become inflated and the machine is supported on a cushion of air escaping from the pressure chamber through the discharge or exit orifice 157, the body 149 assumes a floating position within the airframe and seeks the centroid of pressure within the structure. Because of its deformable nature and ability to freely move about in the chamber, it is capable of quickly responding to localized pressure changes in the airflow pattern due to local canopy distortion or changes in orientation of the pump outlet. As such, the body will automatically move and assume a position with respect to the interior surface of the airframe such that the mass flow rate of air on either side of any vertical plane passing through the axis of symmetry of the pressure chamber is exactly equal. Because of the light weight and flexible nature of the material used for the center body, the response to such pressure changes is rapid, and hence the inflatable center body serves to quickly regulate the passage of the air through the airframe to maintain the desired stability.

The embodiment shown has a handle 154 and a control box 155 that is operatively connected to the engine by components housed in a flexible cable 156 as in the first described embodiment.

In the non-operating state, the canopy 141 is collapsed and the center body 149 assumes a deflated position beneath the collapsed canopy. The ropes 150' keep the opening 150 in the body in position to receive air when the machine is started. As the machine is placed in operation, the canopy portion 141 inflates and the skirt 152, as in the prior embodiments, clings to the ground 159 exteriorally of the exit orifices while the structure operates as a compressed air reservoir. As the pressure builds up in the airframe 148, the pump assembly, of course, rises. The air entering the intake orifice of the airframe, causes the center body to inflate and ultimately to take the shape of a balloon like body similar to an oblate spheroid. Thereafter, as the internal pressure in the airframe is increased, the machine rises and is sustained on a cushion of air escaping through the exit orifice 157 and the center body assumes a floating position within the structure and serves as a stabilizer.

Air flow in the airframe is in the direction of arrows 158, the air flowing annularly around the center body 149 between it and the airframe 148 to thereafter escape between the edge of the skirt 152 and the ground 159. The annular flow so formed impinges upon the ground at an acute angle.

The contour of the canopy 141 and the contour of the center body 149 will, of course, change in accord with the load supported on the platform. Due to such changes, the angle of impingement is also changed in accord with loaded condition of the machine and under some conditions the location of the body 149 aids in augmenting the thrust derived from the air discharging through the exit orifice.

The concept of using a center body which is adapted to move within the airframe to seek the center of pressure is not limited to the use of an airframe having a canopy section, nor is it limited to the use of a body which is either inflatable or deformable. Instead, a center body having a rigid structure may be used in an airframe having a rigid structure to maintain stability so long as the center body is substantially free to move about in the airframe to seek the centroid of pressure. Similarly an inflatable center body of the kind shown in FIG. 14 may be housed in an airframe having a rigid structure of the prior art type to provide similar stability. A rigid center body structure may also be used in the embodiment shown in FIG. 14 in lieu of the inflatable type shown therein. However, by using a center body which is inflatable, in combination with a flexible canopy type structure, the full benefit of having a compact structure when the machine is not in use is realized.

It may also be mentioned at this point that suitable means may be provided in the machine to control movement of the center body in the airframe if desired so as to create non-uniform passage of air along the sides of the body and thus to create internal pressure differences that tend to tilt the plane of the exit orifice with respect to the plane of the ground for horizontal locomotion and/or steerage purposes.

From the foregoing description, it is apparent that the various concepts of the invention may be embodied in ground effect machines operating in accord with principles other than the annular flow and plenum chamber types disclosed herein.

By virtue of the collapsible canopy type structure involved, it is apparent that much less space is required for housing the apparatus during non-use and that the principles involved may be readily adapted in providing ground effect machines which are readily portable in the collapsed nonoperating state.

While only certain preferred embodiments of this invention have been shown and described by way of illustration, many modifications will occur to those skilled in the art, and it is, therefore, desired that it be understood that it is intended in the appended claims to cover all such modifications as fall within the true spirit and scope of this invention.

This application is a continuation-in-part of my copending application entitled "Ground Effect Machine" filed June 26, 1961 and assigned Serial No. 119,560.

What is claimed as new and what it is desired to secure by Letters Patent of the United States is:

1. A ground effect machine comprising an airframe

for confining a cushion of pressurized air on which the machine is supportable in ground effect having an exit orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported on the cushion and further having a top wall over the exit orifice which has an opening through which air is admissible to the airframe, and an air pump carried by said top wall for passing air into said airframe through said opening, said airframe comprising a flexible canopy section adapted and arranged to contact the cushion and to be outwardly inflated by air pressure created in said airframe by said airpump and to collapse into the space occupied by the cushion when the air pressure is relieved; said section having a portion constituting at least a part of said top wall and which provides a flexible cushion contacting surface which rises with respect to and laterally of said airpump when the canopy section is inflated and the machine is supported on the cushion; whereby said air pump is suspended from the canopy section when the machine is supported on said cushion.

2. A ground effect machine in accord with claim 1 wherein the center sustentation pressure of the machine when the canopy section is inflated and the machine is supported on the cushion is above the center of gravity of the machine.

3. A ground effect machine in accord with claim 1 further comprising a body housed and substantially free to move about within said airframe to seek the centroid of pressure therein when said machine is operating in ground effect.

4. A ground effect machine in accord with claim 1 further comprising means connected to the airframe for supporting a load thereon.

5. A ground effect machine comprising an airframe for confining a cushion of pressurized air on which the machine is supportable in ground effect having an air discharge orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported on the cushion and further having a top wall over the discharge orifice which has an opening through which air is admissible to said airframe, and an air pump carried on the top wall for pumping air into the airframe through said opening, said airframe comprising a flexible canopy section adapted and arranged to contact the cushion and to be outwardly inflated by the air pressure created in said airframe by said air pump and to collapse into the space occupied by the cushion when the air pressure is relieved, said flexible canopy section having a portion constituting at least a part of said top wall and which provides a cushion contacting surface which rises with respect to and laterally of said pump when the canopy section is inflated and the machine is supported on the cushion and further having a skirt portion adapted and arranged to overhang the ground exteriorly of the discharge orifice when the machine is supported on the cushion whereby the pump is suspended from the canopy section when the machine is supported on the cushion.

6. A ground effect machine in accord with claim 5 further comprising means cooperating with said canopy section for gathering the skirt portion to diminish the size of said discharge orifice.

7. A ground effect machine in accord with claim 5 further comprising means connected to the airframe for supporting a pay load within said airframe.

8. A ground effect machine in accord with claim 5 wherein said machine has a front end, wherein said skirt portion has a section at said front end, and wherein said machine further comprises means cooperating with the skirt portion at said front end for changing the contour of the skirt section thereat to provide an opening for receiving air into the airframe during forward locomotion of said machine.

9. A ground effect machine comprising an airframe for confining a cushion of pressurized air on which the machine is supportable in ground effect having an exit orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported on the cushion, and further having an opening over said exit orifice through which air is admissible to said airframe; and an air pump mounted on said airframe over said exit orifice for pumping air into the airframe through said opening; said airframe comprising a canopy section of flexible material overlying the exit orifice and being adapted to provide an airframe skirt portion at the side of the airframe and which overhangs the ground exteriorly of said exit orifice when the machine is supported on the cushion; said section being adapted and arranged to contact said cushion and to be outwardly inflated by air pressure created in the airframe by said air pump and to collapse into the space occupied by the cushion when the air pressure is relieved, said section having a portion over the exit orifice connected to and surrounding said air pump, whereby the weight of the air pump draws the last mentioned portion downwardly adjacent the attachment and provides a canopy support surface in contact with the cushion above and laterally of the attachment when the machine is supported on the cushion; said machine further comprising load carrying means located within the airframe, said load carrying means being connected to the airframe and adapted and arranged to be lifted above the ground through inflation of the canopy section before said machine is sustained in ground effect relation.

10. A ground effect machine in accord with claim 9 further comprising control means for controlling said air pump, said control means being mounted on the airframe for manual manipulation by an operator standing on the ground adjacent thereto.

11. A ground effect machine comprising an airframe for confining a cushion of pressurized air on which the machine is supportable in ground effect having an air discharge orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported on the cushion and further having a top wall over the discharge orifice which has an opening through which air is admissible to said airframe, and an air pump mounted on the top wall for pumping air into the airframe through said opening, said airframe comprising a flexible canopy section adapted and arranged to contact the cushion and to be outwardly inflated by air pressure created in said airframe by said air pump and to collapse into the space occupied by the cushion when the air pressure is relieved, said flexible canopy section having a portion constituting at least a part of said top wall and further having a skirt portion defining the discharge orifice, said skirt portion being adapted and arranged to overhang the ground exteriorly of the discharge orifice when the machine is supported on the cushion, drawstring means connected to said skirt portion operable to gather the skirt portion thereat, thereby to diminish the size of the discharge orifice, and means carried by the airframe operable to direct advancement of the machine over the ground in a predetermined direction.

12. A ground effect machine in accord with claim 11 further comprising means cooperating with the skirt portion for changing the contour of the skirt portion to provide an opening into the airframe facing the direction of advancement for scooping air into the airframe during such advancement.

13. A ground effect machine comprising an airframe for confining a cushion of pressurized air on which the machine is supportable in ground effect having an air intake orifice and further having an air discharge orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported thereon, an air pump mounted on the airframe for pumping air into the airframe through said intake orifice, and a body housed within said airframe, said body

being moveable in response to local pressure differences within said airframe for maintaining the planes of the discharge orifice and of the ground supporting surface in parallel when the machine is supported on the cushion.

14. A ground effect machine comprising an airframe for confining a cushion of pressurized air on which the machine is supportable in ground effect having an air intake orifice and further having an air discharge orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is suported thereon, an air pump mounted on the airframe for pumping air into the airframe through said intake orifice, and an inflatable hollow body having an opening into said hollow and being housed within said airframe, said body being adapted and arranged for inflation by air pumped into said airframe through said orifice and being movable in response to local pressure differences in the cushion for maintaining the planes of the discharge orifice and of the ground supporting surface in parallel when the machine is supported on the cushion.

15. A ground effect machine comprising an airframe for confining a cushon of pressurized air on which the machine is supportable in ground effect having an air intake orifice and further having an air discharge orifice at which the cushion contacts the ground and through which air escapes from the airframe when the machine is supported thereon, an air pump mounted on the airframe for pumping air into the airframe through said

intake orifice, and a body housed within said airframe, said body being movable in response to local pressure differences in the cushion for maintaining the planes of the discharge orifice and the ground supporting surface in parallel when the machine is supported on the cushion, said airframe comprising a flexible canopy section adapted and arranged to be inflated by air pumped into said airframe by said air pump and having a skirt portion defining said discharge orifice.

References Cited by the Examiner

UNITED STATES PATENTS

1,123,589	1/1915	Porter	180—7
3,042,129	7/1962	Wade	180—7
3,066,753	12/1962	Hurley et al.	180—7
3,118,513	1/1964	Cockerell	180—7
3,139,947	7/1964	Beardsley	180—7

FOREIGN PATENTS

1,238,499	7/1960	France.

OTHER REFERENCES

Design News, May 23, 1960, pages 6 and 7.

FERGUS S. MIDDLETON, *Primary Examiner.*

A. HARRY LEVY, MILTON BUCHLER, *Examiners.*