United States Patent

Thompson

[15] **3,697,020**

[45] **Oct. 10, 1972**

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[54] **VERTICAL LIFT MACHINE**

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[73] Assignee: **Chandler Evans Inc.,** West Hartford, Conn.

[22] Filed: **Sept. 14, 1970**

[21] Appl. No.: **72,091**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 836,393, June 25, 1969, Pat. No. 3,592,413.

[52] **U.S. Cl.** ....**244/12,** 244/12 C, 244/23 C, 244/42 CC
[51] **Int. Cl.** **B64c 29/00**
[58] **Field of Search** ....244/12 C, 23 C, 42 CC

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[57] **ABSTRACT**

A maneuverable lifting body wherein pressurized gas is discharged at supersonic velocity over the surface of at least three downwardly sloping lifting surfaces, the supersonically flowing gas separating and thereafter reattaching to the surface to provide a low pressure region intermediate the points of separation and reattachment. The low pressure region created on the upper surface, in cooperation with atmospheric pressure on the bottom of the body, results in vertical lifting forces which add to the vertical component of the momentum forces of the gas. Attitude control and maneuverability are accomplished by selectively venting ambient air into the low pressure regions whereby the low pressure region may be selectively destroyed with resultant force unbalance.

13 Claims, 7 Drawing Figures

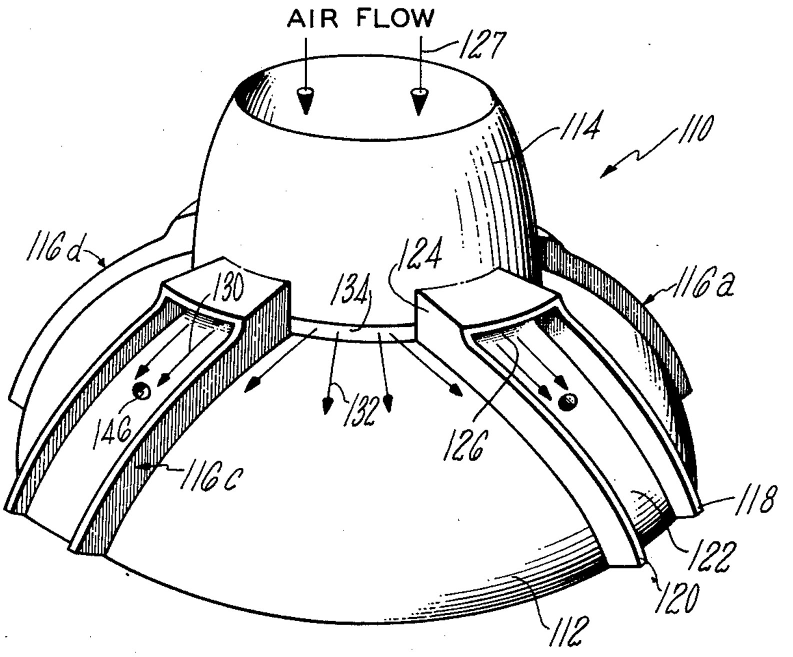

FIG. 1

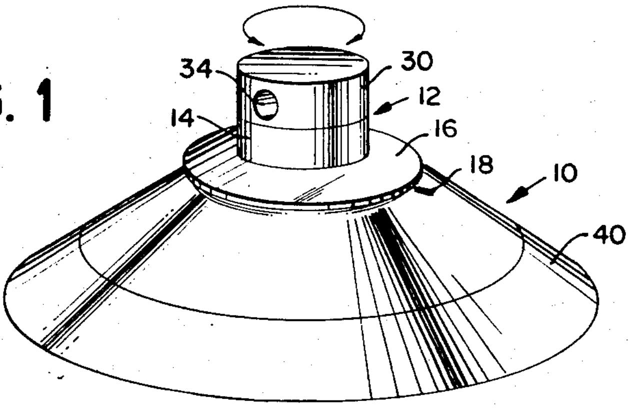

FIG. 2

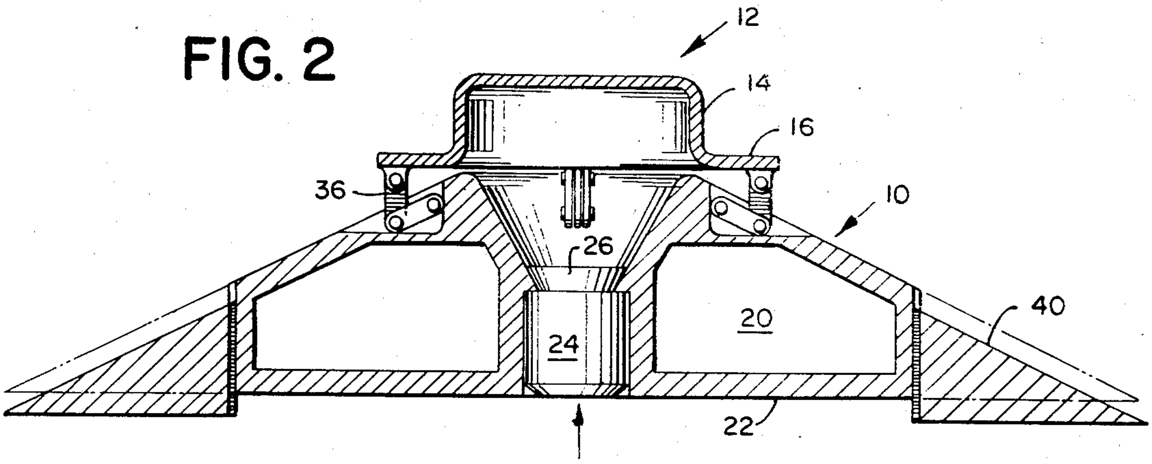

FIG. 3

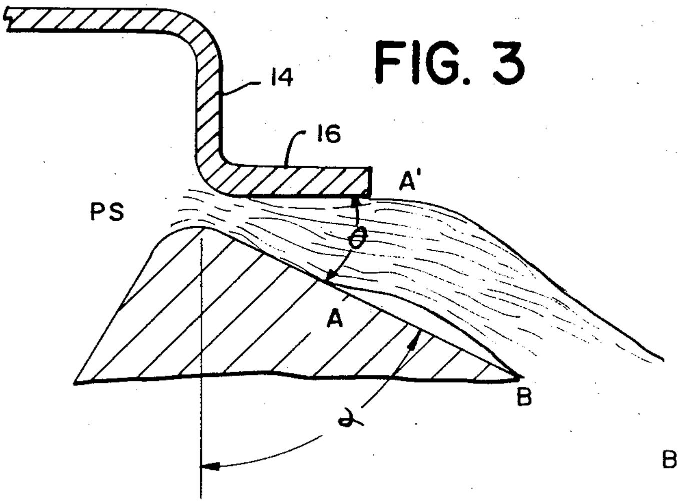

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FIG. 4

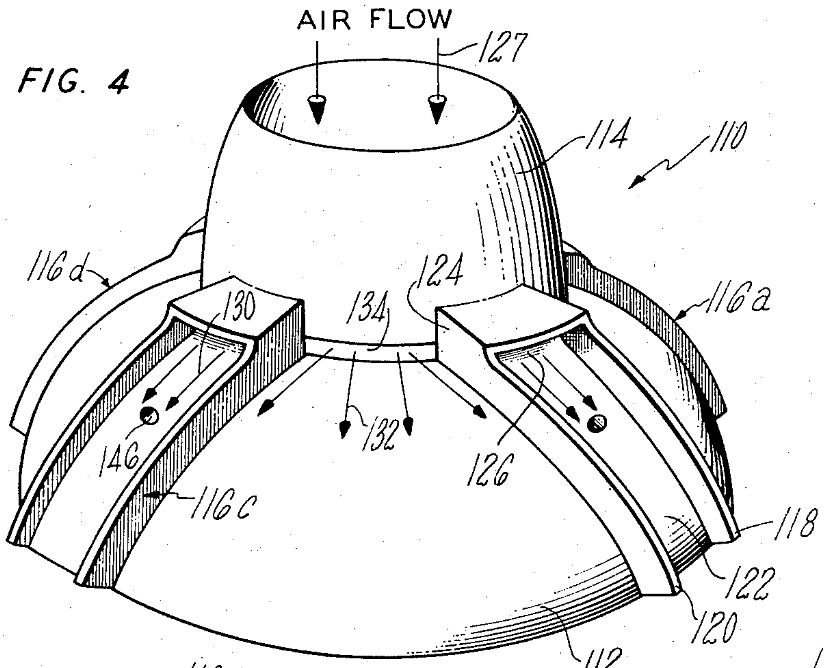
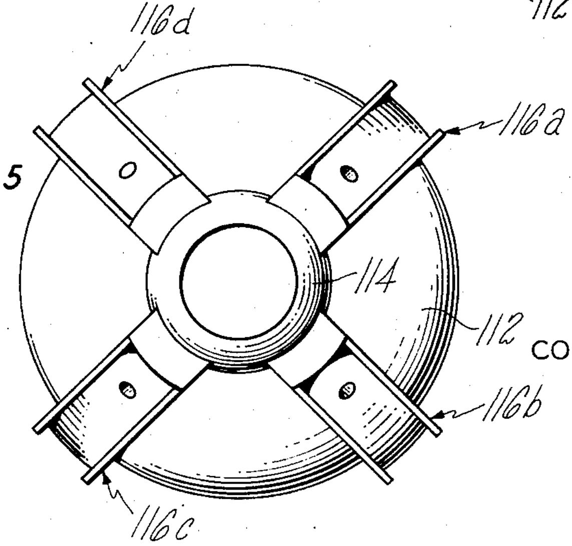


FIG. 5



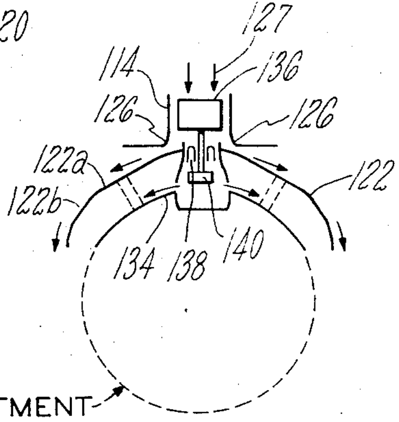


FIG. 6

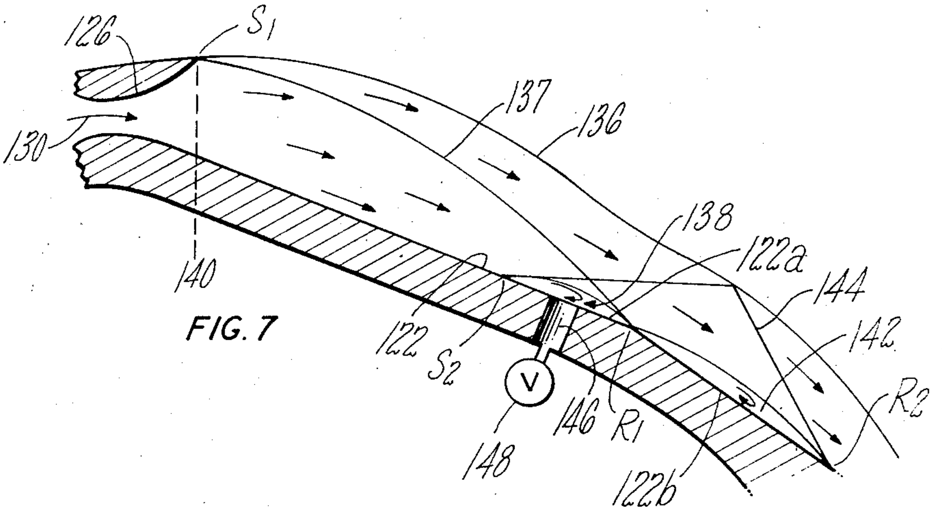


FIG. 7

VERTICAL LIFT MACHINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 836,393 filed June 25, 1969, now U.S. Pat. No. 3,592,413 issued July 13, 1971.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the creation of lifting forces. More specifically, the present invention is directed to vertical lift machines involving boundary layer separation-reattachment control. Accordingly, the general objects of the present invention are to provide novel and improved methods and apparatus of such character.

2. Description of the Prior Art

While not limited thereto in its utility, the present invention is particularly well suited for application to self-lifting bodies, such bodies sometimes being referred to as "hovercraft." It is to be noted that the "hovercraft" must be distinguished from the ground effect machine (GEM) or air cushion vehicle which creates and rides upon an air cushion established by drawing in atmospheric air and directing it downwardly beneath the vehicle. The "hovercraft," the most common example of which may be considered to be the helicopter, is not constrained to operation within a few feet of a surface as is the GEM but rather creates its own lift in somewhat the same manner as a conventional aircraft.

Prior art operational "hovercraft" have been characterized by a rotating airfoil or propeller which has generated the lifting forces in a conventional manner. The complexities of such rotating blade mechanisms, particularly in the helicopter environment where blade pitch must be constantly changing, are well known and will not be discussed herein. In addition to those vehicles which employ a rotating, generally horizontally mounted propeller mechanism, a number of self-lifting bodies have been proposed wherein air would be discharged outwardly in all directions from a region approximating the center of the vehicle over an immobile airfoil structure so as to generate vertical lift. In the latter type apparatus it was generally proposed to blow air over both upper and lower airfoil surfaces, lift being provided in the conventional aerodynamic manner.

The previously proposed lifting bodies of the immobile air-foil type have not been the subject of development due to the obvious inefficiencies in their design. That is, if reduced to practice, prior art designs would inherently provide exceedingly limited lift and thus little or no load carrying capacity. Perhaps more importantly, no practical manner of maneuvering such vehicles has been proposed. The lack of maneuverability, with the exception of relatively expensive helicopter type vehicles, has also characterized the rotating propeller type lifting bodies. Lack of maneuverability is, of course, a serious disadvantage in cases where the device is to be used as an observation platform during military activities or for manned transportation. Previous attempts at using comparatively inexpensive, camera bearing lifting bodies in the field have met with failure since the devices could only be positioned vertically above and connected to the launch site and would thereby reveal the position of the crew.

SUMMARY OF THE INVENTION

The present invention overcomes the above-discussed and other disadvantages of the prior art and, in so doing, provides a novel and improved maneuverable vertical lift machine. In accomplishing the foregoing, the present invention generates vertical lift by creating a pressure differential across a plurality of outwardly and downwardly flaring lift or expansion surfaces. Three or more equally spaced lift machines are used, and the lift surfaces would typically be four in number in a cruciform configuration. Subatmospheric pressure is created at the upper side of the lift surfaces through the use of supersonic flow streams discharging from convergent-divergent nozzles at the entrance to each lift surface. The supersonic flow separates and thereafter reattaches to the lift surfaces to provide low pressure regions on the upper side of each of the lift surfaces intermediate the points of separation and reattachment. Atmospheric pressure acts on the underside of the lift surfaces thereby providing the requisite pressure differential. The vertical lifting forces resulting from this pressure differential and the vertical component of the momentum forces of the supersonic gas stream combine to provide the vertical lift.

The invention presented in this application is further characterized by vent ports which control the introduction of ambient air into the low pressure regions on the lift surfaces to deflect the supersonic stream away from the upper side of the lift surfaces whereby the low pressure region is destroyed. A force unbalance then results whereby pitch and roll attitude control and directional maneuverability can be realized. A balancing of the horizontal components of the forces on the lift surfaces produces a hovering state whereas the force unbalance caused by the venting of a low pressure area on a lift surface to ambient results in selected attitude control or maneuverability. Maneuverability and/or attitude control may also be realized by varying the volume or pressure of the supersonic gas stream flowing over one or more of the lift surfaces.

The present invention is further characterized by contouring of the upper side of the lift surfaces to promote at least two separations and reattachments of the flow stream whereby two low pressure regions are established to substantially augment the total available lift force.

The present invention is further characterized by an upper cap assembly into which pressurized fluid is discharged by the propulsion source, the propulsion source typically comprising a gas turbine engine mounted vertically with its discharge nozzle facing into the cap. The cap may be mounted from the conical plate by means which permit tilting of the cap. In the preferred embodiment the cap and plate cooperate to define the nozzle which creates the supersonic flow. Maneuverability of the vehicle may be achieved by tilting the cap so as to choke the flow at one side of the body. Alternatively, maneuverability may be achieved by release of some of the gas from the cap into a stagnation chamber, the chamber having a horizontally oriented and steerable discharge nozzle.

BRIEF DESCRIPTION OF THE DRAWING

The present invention may be better understood and its numerous objects and advantages will become apparent to those skilled in the art by reference to the accompanying drawing wherein like reference numerals refer to like elements in the various figures and in which:

FIG. 1 comprises an isometric view of a first embodiment of a lifting body in accordance with U.S. Pat. application Ser. No. 836,393 of which the present application is a continuation in part.

FIG. 2 is a cross-sectional, side elevation view of a second embodiment of U.S. Pat. application Ser. No. 836,393 of which the present application is a continuation in part.

FIG. 3 is an enlarged, cross-sectional view of a portion of the embodiments of FIGS. 1 and 2.

FIG. 4 is an isometric view of the lifting body of the present invention.

FIG. 5 is a top plan view of the lifting body of FIG. 4.

FIG. 6 is a schematic representation of the lifting body of the present invention.

FIG. 7 is a schematic representation of an optimized lifting surface configuration.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the interest of presenting the background leading to the present invention, the description in U.S. Pat. application Ser. No. 836,393 is substantially repeated herein with respect to FIGS. 1-3.

With reference now to FIG. 1, a perspective view of a first embodiment of that earlier application may be seen. The embodiment of FIG. 1 is possessed of a generally conical shape and the upper surface of the load carrying portion of the vehicle is defined by a conical metal plate indicated generally at 10. The vehicle body defined in part by plate 10 has an opening at its upper or smaller diameter end. Air under pressure is discharged vertically upwards about the axis of the vehicle through this opening.

Mounted from the vehicle and above the smaller diameter end of plate 10 is a cap assembly indicated generally at 12. Cap assembly 12 is, as may best be seen from FIG. 3, hollow and has a riser portion 14 into which the pressurized fluid from the propulsion source is discharged. The cap assembly 12 also has, about the lower periphery of riser portion 14, an outwardly extending flange 16. The bottom surface of flange 16 and the upper or smaller diameter end of the conical plate 10 cooperate to define an annular convergent-divergent nozzle 18 through which pressurized gases discharged into cap 12 will escape. Fluid flowing through nozzle 18 will, as a result of the pressure within cap 14 and the nozzle design, be discharged down over the exterior of plate 10 at supersonic velocity.

As may be seen from a consideration of the embodiment of FIG. 2, the vehicle may be provided with a load space 20 which is defined in part by the inner surface of conical plate 10 and by a base plate 22. In a typical operational configuration, where the lifting body would be employed as a remotely controlled and unmanned observation platform, electronics including maneuvering control servo systems, controllable television cameras and transreceivers would be mounted in load space 20. Additional load space may be provided on top of cap 12 and cameras may be located in or on such additional space.

Also mounted within the lifting body and coaxial with conical plate 10 will, as can also be seen from FIG. 2, be a propulsion source 24. Propulsion source 24 will comprise a gas turbine engine installed vertically with its discharge nozzle 26 facing the interior of cap assembly 12. The combustion products discharged under pressure to nozzle 26 will be directed into cap 12 and will flow outwardly from the cap through the nozzle 18 as shown diagrammatically in FIG. 3.

In the embodiment of FIG. 1, in the interest of maneuverability, the cap 12 is provided with a rotatable upper section 30. Cap section 30 defines, in its interior, a stagnation chamber which may be placed into communication with the interior of the lower cap section via suitable valving. The stagnation chamber has a discharge nozzle 34 which may be aimed by rotating cap section 30 by means not shown. Accordingly, horizontal maneuvering thrust may be generated by placing the stagnation chamber into communication with the interior of the lower cap section whereby engine exhaust gas will be discharged through nozzle 34 and the cap rotated so as to point the nozzle 34 in the desired direction.

Alternately, or in addition to the employment of a rotatable cap section and associated structure as above described, the maneuvering control of FIG. 2 may be utilized. In the FIG. 2 scheme the cap 12 is mounted from plate 10 by a plurality of linkage mechanisms, such as the double pivot linkage 36. Accordingly, the cap 12 may be tilted to any desired angle relative to a vertical axis through the vehicle to thereby unbalance the horizontal momentum component of the gases exhausting through nozzle 18. The means for moving linkages 36 have been omitted from the drawing in the interest of clarity.

Operation of the lifting body may be best understood by consideration of FIG. 3 which shows a cross section of the discharge nozzle 18. In FIG. 3, P_s represents the supply pressure in cap assembly 12 of a gas being admitted to three-dimensional convergent-divergent nozzle 18. The dimensions of the upper end of the conical plate 10 and the lower surface of flange 16, the plate and flange cooperating to define nozzle 18, are chosen so that assymetric separation of the supersonic gas jet discharging from nozzle 18 will occur along line A—A' at the downstream end of the nozzle. The effect of the flat annular plate 10 attached to the convergent-divergent nozzle 18 is to promote a process of turbulent mixing between the separating jet boundary and the ambient gas trapped adjacent to the plate thereby resulting in a low pressure region. Restated, gas discharged from nozzle 18 flows at supersonic velocity over the surface of plate 10 and, in the manner known in the art, separates from the plate at point A and thereafter reattaches to the plate at point B a substantial distance downstream from point A. Ambient gas trapped between the points of separation and reattachment will be mixed with and entrained in the supersonic stream thereby creating a near vacuum on the surface of the plate between points A and B. Obviously, the combined effect of the low pressure region acting on the upper surface of plate 10 and atmospheric pressure acting on the bottom of the vehicle (plate 22) will create a lifting force. This lifting force, when combined with the vertical component of the momentum of the gases being discharged from nozzle 18, will create sufficient lift whereby the vehicle will rise vertically.

Referring again to FIG. 2 it is to be noted that conical plate 10 may be provided with a vertically movable, outboard section 40. Downward movement of annular section 40 out of the usual plane of plate 10 will increase the length of the vortex between points A and B by moving the reattachment point of the supersonic gas stream downstream. Increasing vortex length will enhance lift by enlarging the area of the near vacuum region created above the surface of plate 10.

Considering again FIG. 3, tests have shown that angle θ defined by the divergent portion of nozzle 18 should be in the range of 30°–50°. This design parameter can, however, be satisfied by making angle α as great as 90°. When angle α is 90°, flange 16 obviously flares outwardly and upwardly and there will be no vertical momentum component to be added to the lift generated by the created pressure differential.

Referring now to FIGS. 4–7, the embodiment of the present invention is shown. The lifting device, which is indicated generally at 110, has a lower body component in the form of a skirt 112 and an upper body component in the form of a shroud 114. Skirt 112 is a generally annular element and it may be approximately hemispherical as shown or frusto-conical. Of course, it might also be formed from a number of flat tapered segments joined together. Shroud 114 is generally cylindrical. Four lift elements 116*a*, 116*b*, 116*c*, and 116*d* are mounted between cylindrical shroud 114 and skirt 112 and are spaced equi-distant about skirt 112 to take on a generally cruciform shape as best seen in FIG. 5. Each of these lifting elements has a pair of side walls 118 and 120, a lift surface 122 contained between the side walls, and an upper housing 124 which defines a nozzle 126 therein communicating with the interior of shroud 114. The nozzles 126 are two-dimensional convergent-divergent nozzles (as indicated generally in FIG. 7), and they extend between the respective side walls 118 and 120 of each lift element.

The lifting device of the present invention is powered by a turbofan type gas turbine engine which is located within shroud 114 and which delivers a supersonic gas stream to flow along the lift surfaces 122 of lift elements 116 whereby lift is created by separation and reattachment of the supersonic stream as will be more fully discussed hereinafter. The portions of skirt 112 between adjacent lift elements may also be employed to create additional lift by flowing either supersonic or subsonic gas streams along their upper surfaces. The air entering shroud 114 to flow through the gas turbine engine is indicated by the arrows 127, and the supersonic air or gas streams flowing over lift surfaces 122 and skirt 112 are indicated by the arrows 130 and 132, respectively. The gas flowing over skirt 112 is delivered from the interior of shroud 114 via a nozzle segment 134 which communicates with the interior of shroud 114 to deliver a stream of gas to the surface of skirt segment 112. There would be a similar nozzle 134 communicating with each of the skirt segments between the adjacent lift elements.

Referring now to FIG. 6, a schematic representation is shown of the device of the present invention. The turbofan gas turbine engine is of well known typical construction having a fan and compressor unit 136, a burner section 138, and a turbine 140. Compressed air is bled from the fan and is delivered through the convergent-divergent nozzles 126 and flows along lift surfaces 122. As will be described in more detail with respect to FIG. 7, the supersonic gas streams separate and reattach to lift surfaces 122 thus generaling localized low pressure areas on the lifting surfaces 122 whereby a vertical lifting force results from the differential between those low pressure areas and the ambient pressure on corresponding areas on the bottom of the lifting device. The turbine discharge gases, or at least parts thereof, may also be passed through nozzles 134 to flow over the segments of skirt 112 in supersonic streams whereby lift is also generated. If the turbine discharge gas is to be passed over the skirts segments in a subsonic stream (which will create a slightly subambient pressure on the upper surface of skirt 112 with resultant lift) nozzle 134 will be convergent; if the turbine discharge gas is to be passed over the skirt segments at supersonic speed, the nozzles 134 will be convergent-divergent, a significantly subambient pressure will exist on the upper surface of skirt 112 resulting from separation and reattachment of the gas stream to generate lift as discussed in parent application Ser. No. 836,393.

Referring now to FIG. 7, an enlarged cross-sectional profile of one nozzle 126 and lift surface 122 is shown. The gas stream 130 passing through nozzle 126 is at a super-critical pressure ratio; that is, the ratio P_0/P_a (where P_0 is the compressive fan bleed pressure upstream of the throat of nozzle 126 and P_a is atmospheric pressure) is greater than 3, and preferably about 10. After passing through the two-dimensional convergent-divergent nozzle 126, the gas expands freely and tends to separate from the walls of the duct. The upper divergent surface of nozzle 126 is physically restricted to a length equal to or slightly less than that corresponding to the point of free separation, S_1, of the immediate boundary layer. The pressure at this point is subambient, and consequently the local free boundary of the jet is acted upon by a transverse pressure gradient which deflects the fluid stream to flow along surface 122, the upper boundary of the stream being indicated at 136. The action of deflecting the fluid jet to flow along surface 122 produces a curved shock 137 extending from the free separation point S_1 to a point R_1 on surface 122.

The same factors which caused the separation of the supersonic air stream from the upper surface of nozzle 126 are also experienced by the stream expanding along wall 122 thus resulting in separation at point S_2 to create a localized entrainment 138 of air at an extremely low pressure. The low pressure on lifting surface 122 in the projected area of entrainment 138 is very much lower than ambient. This low pressure area assists in maintaining alignment of the air stream with surface 122 and it also provides a substantial vertical pressure gradient with respect to the ambient pressure acting on the bottom of the lifting device whereby vertical lift is created. Thus, the supersonic gas stream flowing along surface 122 separates at point S_2 and reattaches at point R_1 creating between those two points an area of localized very low pressure, even approaching a vacuum, whereby a vertical force imbalance exists as a result of the pressure differential between the low pressure on surface **122** and ambient pressure acting on the rear of the surface **122** so that vertical lift is created. Of course, it will be understood that the profile depicted in FIG. 7 extends across the width of each of the lift elements **116** so that, for example, the separation point S_2 and the reattachment point R_1 are actually lines extending the full width of the lift elements, and the pressure differential exists across the width of the lift elements between walls **118** and **120**.

Lift surface **122** extends in a straight line or plane from the mouth **140** of nozzle **126** to reattachment point R_1. If this straight plane were continued at this point, the air stream would remain attached to the surface and no further lift would be generated. However, in accordance with the present invention, lift surface **122** is contoured to bend or incline downward at point R_1 so that the included angle between segment **122*a*** and segment **122*b*** is less than 180°. This contouring results in a further expansion and/or a second separation of the gas stream at point R_1 with reattachment at point R_2 thereby resulting in a second low pressure entrainment **142** and a reflected shock **144**. This second low pressure entrainment **142** results, similarly, in an extremely low pressure area at the projected upper surface of lift surface **122** and a resultant upward force from the pressure differential between this second low pressure area and ambient air on the bottom of the lift device thereby substantially augmenting the vertical lift.

Attitude control and maneuverability of the lift device of the present invention are readily accomplished by a pneumatic switching technique. Each of the lift devices is provided with an ambient vent port **146** which is in direct communication with entrainment area **138** at one end and is normally closed, such as via a valve **148**, at the other end. Valve **148** is connected to atmosphere, and when valve **148** is opened the ambient air, which is at a substantially higher pressure than the greatly reduced pressure in entrained volume **138**, flows into entrained volume **138** whereby the low pressure is destroyed and the stream separates from surface **122**. This destruction of the low pressure entrainment and separation of the stream from lift surface **122** terminates the lift force on that particular surface **122** and causes generation of a lateral steering thrust component. Accordingly, it can readily be seen that a force imbalance is then created with regard to the remaining three lift elements with a resultant change in attitude or direction of the lift device. Closing of the valve **148** cuts off the flow of ambient air and allows the supersonic stream to return to surface **122** for recreation of the low pressure volume **138**. As can be readily understood, the vent valves **148** can be opened or closed in any desired sequence or combination to produce desired attitude control and maneuverability of the lift device.

It is contemplated that a load compartment, either for cargo or passengers would be mounted under skirt **112** (as indicated in FIG. 6), which compartment could be of any desired shape depending upon the intended use for the lift vehicle. The ease with which attitude control and maneuverability can be achieved in the present invention through the use of programmed vent valves results in an extremely compact vehicle which does not have any need for main rotor and tail systems traditionally present in vertical lift devices. The vehicle is, accordingly, readily concealed when not in use and easy to transport if it is desired to move it over ground. Furthermore, since most, if not all of the fan air and turbine exhaust gases are directed outwardly rather than straight down toward the ground, ground erosion effects and injection of dirt laden air into the engine, both of which are problems with traditional vertical lift devices, are substantially eliminated. Accordingly, the lift device of the present invention can be readily used from unprepared landing sites thereby further enhancing its utility.

It will also be readily understood by those skilled in the art that while four lift elements **116** in a generally cruciform array have been shown as the preferred arrangement, any number from three or more, preferably equally spaced around the vehicle, can be used with comparable results.

While a preferred embodiment has been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the present invention. Accordingly, it is to be understood that the present invention has been described by way of illustration and not limitation.

What is claimed is:

1. A lifting device for generating vertical lift, the lifting device including:

a body component;

a plurality of lift elements extending generally radially from and being circumferentially spaced apart about said body component, each of said lift elements having a lift surface;

nozzle means associated with each of said lift elements for delivering a gas stream at supersonic velocity to each of said lift surfaces, each lift surface being positioned with respect to its associated nozzle means to create a subambient pressure region at each of said lift surfaces by separating and reattachment of said gas stream with respect to each lift surface; and

control means connected to each of said lift elements for selectively destroying the subambient pressure at the lift surface.

2. A lifting device as in claim 1 wherein:

said body component is a generally annular member; and wherein

said plurality of lift elements includes at least three lift elements equally spaced apart about said member.

3. A lifting device as in claim 1 wherein said nozzle means includes:

a convergent-divergent nozzle connected to one end of each of said lift elements.

4. A lifting device as in claim 1 wherein:

said body component is a generally annular member; and wherein

said plurality of lift elements includes four lift elements equally spaced about said member in a cruciform array.

5. A lifting device as in claim 1 wherein each of said lift surfaces includes:

a first portion extending from said nozzle means; and

a second portion extending from said first portion and inclined with respect to said first portion at an included angle of less than 180°.

6. A lifting device as in claim 1 wherein each of said lift elements includes:

a pair of side walls bounding said lift surface; and

a housing for said nozzle means.

7. A lifting device as in claim 1 wherein said control means includes:

valve means connected to deliver gas at higher than sub-ambient pressure to said subambient pressure region.

8. A lifting device as in claim 1 wherein said control means includes:

valve means connected to vent ambient air to said subambient pressure region.

9. A lifting device as in claim 8 including:

means for delivering a flow of pressurized gas to said nozzle means at a critical pressure ratio with respect to ambient pressure.

10. A lifting device as in claim 1 including:

gas turbine engine means for delivering a gas flow to said nozzle means at a critical pressure ratio.

11. A lifting device as in claim 10 wherein:

said gas turbine means is a fan engine; and including means for bleeding air from the fan of said engine to said nozzles.

12. A lifting device as in claim 10 including:

second nozzle means for delivering exhaust gas from said engine to flow along the upper surface of said body component between said lift elements to create lift.

13. A lifting device as in claim 1 wherein said body component includes:

a load compartment.

* * * * *