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WINGED GROUND EFFECT MACHINES

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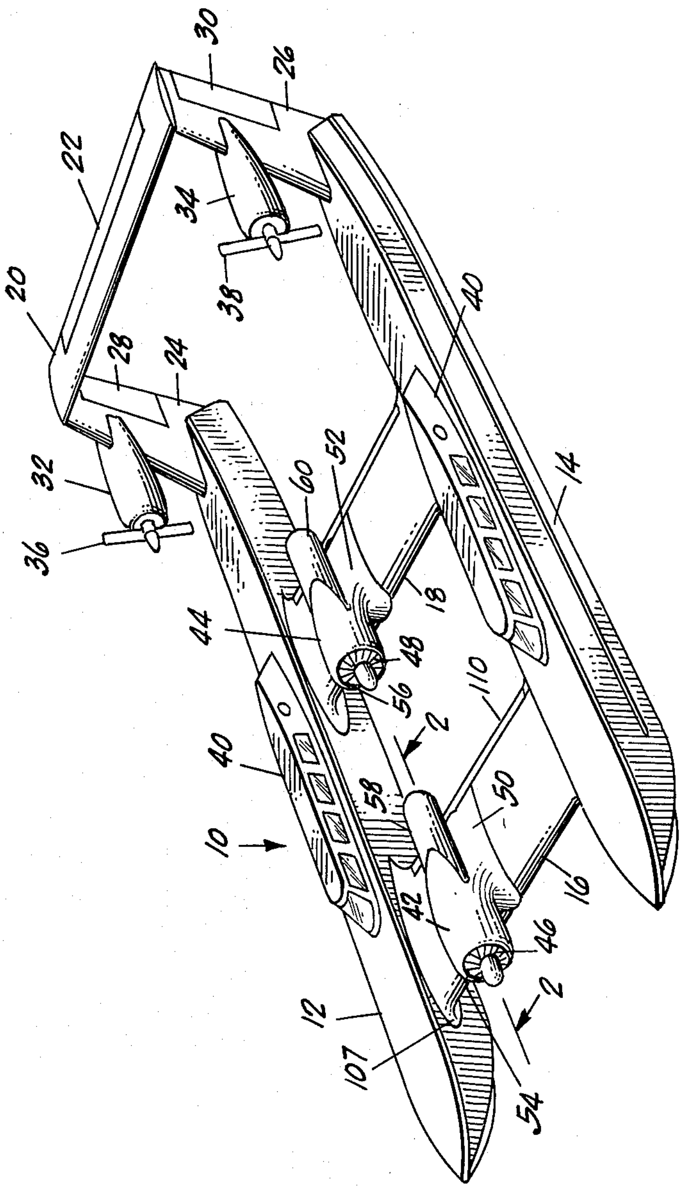

Fig. 1

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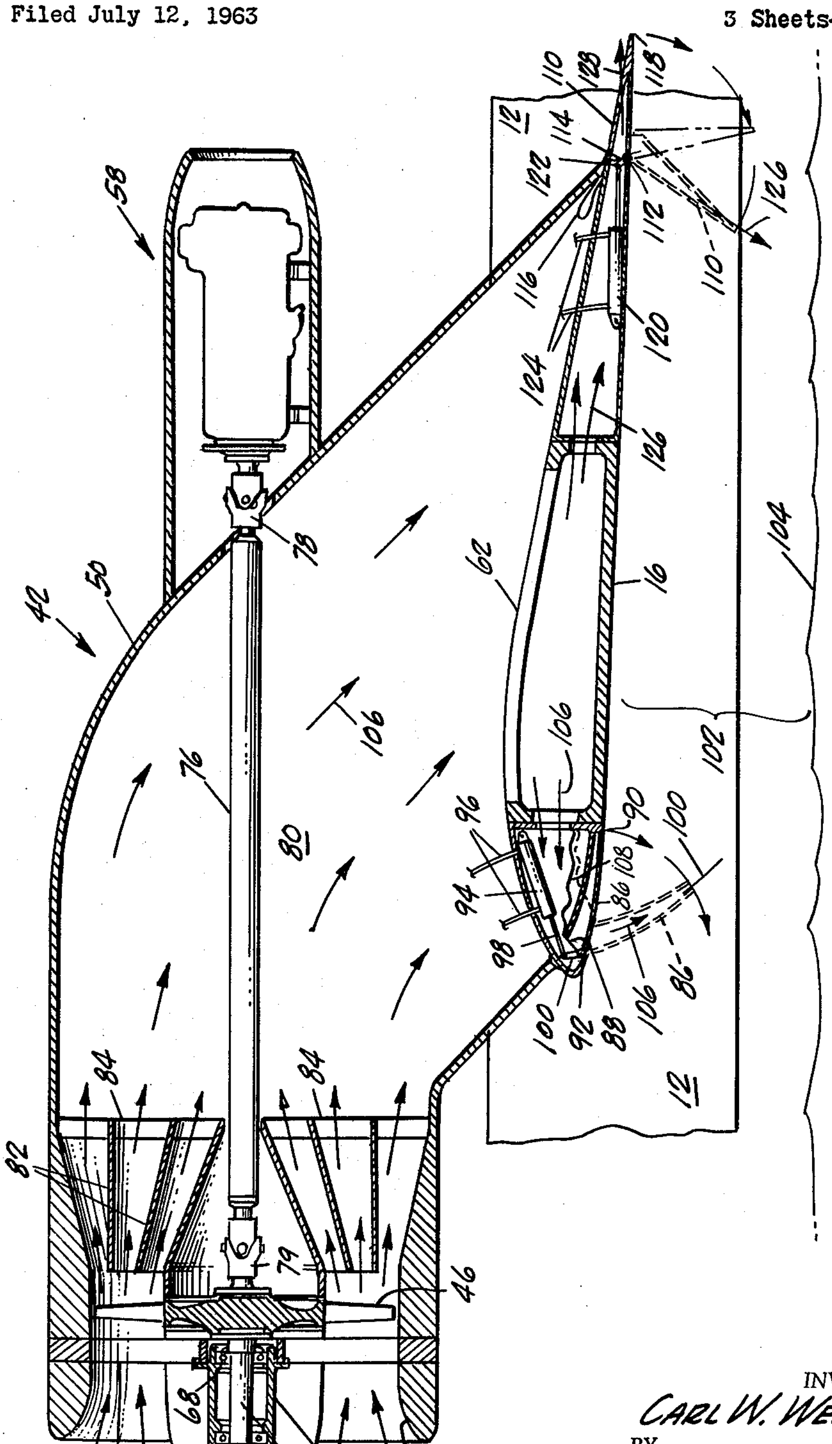

Fig. 2

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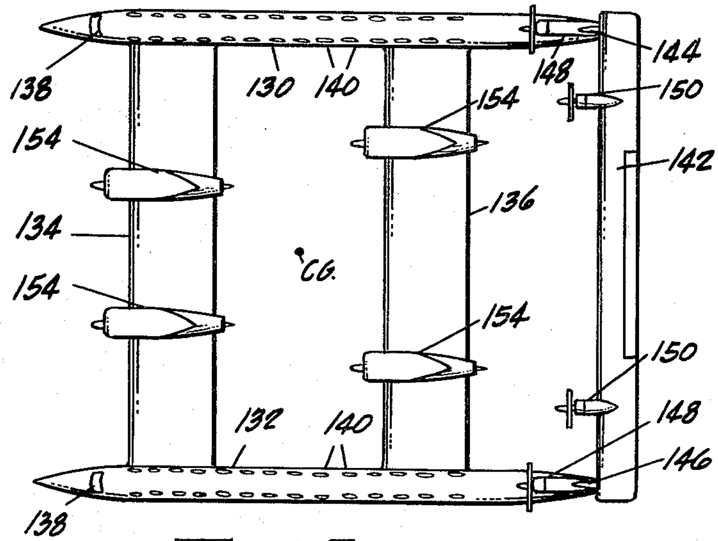

Fig. 3.

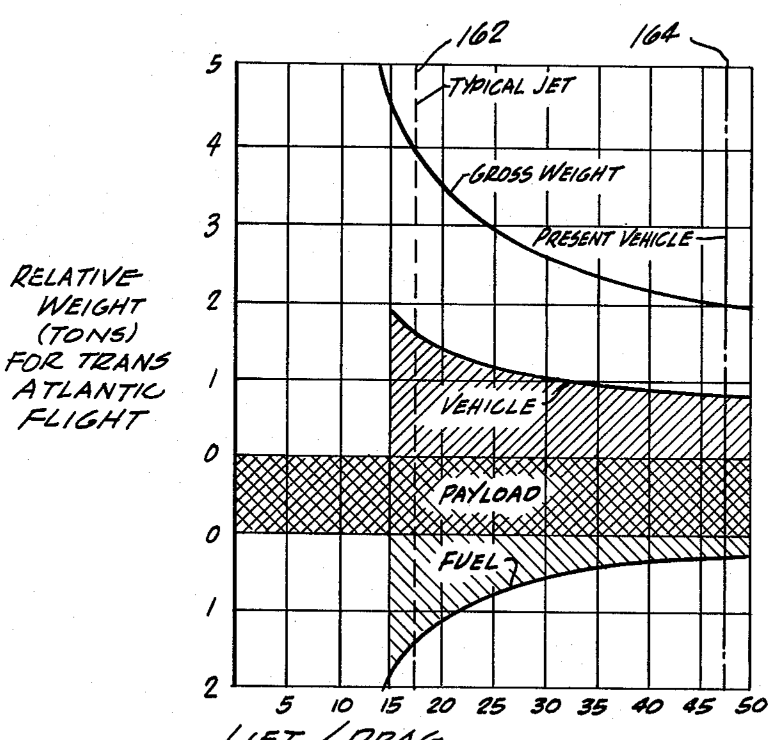

Fig. 4.

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WINGED GROUND EFFECT MACHINES

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This invention relates generally to airborne ground effect vehicles and more particularly to such airplanes and hydroplanes which utilize fixed wings to provide lift for the vehicle.

Ground effect principles have been known for a great number of years and have been demonstrated in a variety of practical utilizations and mechanisms. In typical non-wing ground effect vehicles, a fan system is provided which directs a flow of air downwardly to form, between the vehicle and the ground surface, a cushion of air capable of supporting the vehicle and a payload. The thickness of the supporting cushion is usually limited, by practical design considerations, including peripheral sealing requirements, fuel economy and vehicle attitude stability, to a few feet. With such limitations it is apparent that if forward thrust is provided the vehicle must either travel slowly or over only relatively smooth terrain or water.

In fixed wing ground effect machines, the lifting cushion is dynamically created beneath a wing by its forward velocity over the ground or water. The lifting pressure in the cushion is achieved by the under surface of the wing having a definitely positive angle of attack which effectively funnels or rams a large volume of air into a smaller volume toward the trailing edge of the wing, between the wing and the ground.

Although both of these general types of ground effect machines are useful, they each suffer from a number of disadvantages or deficiencies which limit their broad acceptance and utilization. Briefly, in wingless types of ground effect machines it is relatively difficult to maintain attitude stabilization; and all the lift must be provided at all times by a fan system. The efficiency for forward travel is therefore relatively poor.

In wing-types of ground effect machines, the problems of conventional airplanes are in large measure repeated, for example: large take-off areas are needed; lift always depends upon forward velocity; they must have wheeled landing gear if they are to land on solid ground because of their inherently high landing speeds; and the necessarily fast approach gives rise inherently to a safety disadvantage.

In winged ground effect machines, one further problem is encountered. In order to obtain necessary lift, the wing must have forward motion. When operating in water, the desired rate of forward motion is difficult to obtain due to the drag of water in which the vehicle may be operating. Means must therefore be provided effectively to reduce such drag to enable adequate forward speed whereby to establish the necessary dynamic condition and associated lift. Prior machines have not adequately met this problems.

Accordingly it is an object of the present invention to provide an airborne ground effect vehicle which is not subject to these and other disadvantages of the prior art.

It is another object to provide such a vehicle which is capable of vertical takeoff and substantially zero velocity landing approach thereby obviating the need for complex landing gear while at the same time providing a truly amphibious craft.

It is another object to provide such a vehicle which has an extremely high lift to drag ratio and which is relatively highly efficient for long-range commercial operation.

It is another object to provide such a ground effect machine which is, with respect to conventional aircraft, including fixed and rotary wing types thereof, profoundly

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simpler and less expensive to build, operate and maintain.

It is another object to provide such a vehicle which is inherently highly stable while being capable of speeds in the forward direction ranging in magnitude from the order of hundreds of miles per hour to hovering.

It is another object to provide such a vehicle having high safety and comfort factors for both passengers and cargo.

Briefly, these and other objects are achieved in accordance with one example of the invention which includes a twin hulled machine interconnected symmetrically by fore and aft hollow wing members and a horizontal stabilizer elevator. Each wing member includes at least a single fan unit for generating a reservoir of air pressure within the hollow wing.

Further, each wing includes retractable plenum forming vanes which, when extended, form, in cooperation with the under surface of the wing, a plenum chamber which creates a ground effect supporting air cushion between the wing and the surface of the terrain below.

Nozzles or other wing openings are provided through the under surface of the wing to provide air flow communication from the hollow wing reservoir to the plenum chamber below.

The two wings are placed forwardly and aft of the center of gravity of the craft; and, in operation, the plenum vanes are extended, the fans actuated, and the craft lifted clear of the terrain by the resulting "static" lift cushion of air.

Once the craft is vertically clear of the terrain, forward thrust is provided by conventional propulsion means. As the forward air speed increases, the wings develop lift due in part to their conventional airfoil effect and due to their positive angle of attack which creates a "dynamic" supporting air cushion independently of the aforementioned static effect in the plenum, thus permitting retraction of the vanes and thereafter normal aerodynamic operation and functions.

Further details of these and other features and their principles of operation as well as additional objects and advantages of the invention will become apparent and be best understood from a consideration of the following description taken in connection with the accompanying drawings which are all presented by way of illustrative example only and in which:

FIG. 1 is a perspective view of an example of a fixed wing ground effect vehicle constructed in accordance with the principles of the present invention;

FIG. 2 is a longitudinal sectional view of a portion of one wing and fan unit structure of FIG. 1 taken along the lines 2—2 thereof;

FIG. 3 is a plan view of an alternative example of the invention; and

FIG. 4 is a graph of the relative weights associated with various types of airborne vehicles as a function of their lift to drag ratios.

Referring to the drawings in more detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and structural concepts of the invention. Specifically the detailed showing is not to be taken as a limitation upon the scope of the invention which is defined by the appended claims forming, along with the drawings, a part of this specification.

In FIG. 1 a fixed wing ground effect vehicle **10** is shown which includes a pair of symmetrically disposed streamlined hulls, **12**, **14**. The hulls are laterally interconnected by a forwardly disposed wing member **16** and an after disposed fixed wing member **18**. A horizontal stabilizer **20** which, in this example, may include a movable horizontal elevator **22** is also interposed laterally between the two hulls **12, 14** and is shown affixed intermediate the uppermost extremities of a pair of vertical stabilizers **24, 26** which are each affixed to the rearward end of a respective one of the streamlined hulls. Each of the vertical stabilizers may include a movable rudder **28, 30** respectively.

Forward thrust producing means in the form of conventional engines **32, 34** with variable pitch propellers **36, 38** are shown affixed to the rigid portions of the vertical stabilizers **24, 26** respectively.

One or both of the hulls **12, 14** may be adapted to carry passengers, crew and/or cargo and may thereby include a cabin **40** having side ports, appropriate wind shields, and windows therein as shown.

The fixed wings **16, 18** are disposed forwardly and aft respectively of the center of gravity of the craft **10** and each is adapted to form a ground effect plenum chamber below it between its under surface, its leading and trailing edges, and the water or terrain below the craft. Each of the wings is hollow and carries a nacelle **42, 44** which serves to enclose a ducted fan **46, 48** respectively and which forms a duct **50, 52** which communicates between an intake port **54, 56** and the hollow interior of the wing member **16, 18**, respectively. Each of the fans **46, 48** is driven by a rotary machine **58, 60**, each of which in this example is an internal combustion turbine engine.

Referring to FIG. 2, a longitudinal sectional view of the nacelle **42** is presented. The duct **50** is shown as extending from its intake port **54** to an opening **62** in the top surface of the hollow wing **16** to which the after end and bottom of the nacelle **42** is affixed in a substantially airtight sealed relationship. The hub or rotor of the fan **46** is shown as mounted on a forwardly extending shaft **64** which is journaled within and supported by a pair of axially spaced bearings **66, 68** which are in turn carried by a hub support member **70** mounted within the nacelle **42** by a plurality of supporting struts **72**. Rotary motive power from the engine **58** is supplied through a drive shaft **76** coupled to an output shaft from the engine **58** and to the fan shaft **64** respectively, through a pair of universal joints **78** and **79**.

The interior area **80** of the duct **50** defines a relatively large volume pressure reservoir for storing the energy imparted to the air by the ducted fan **46**. A plurality of diffuser elements **82**, which may be in the form of a thin-walled cylinder or truncated cone, are supported within the duct **50** between the fan **46** and the interior area **80** by a plurality of radial supporting struts **84**. The diffuser elements **82** serve to convert the kinetic energy of the fan driven air into the "static" energy of the pressurized reservoir of air in the area **80** of the duct.

A retractable plenum forming vane **86** in the form of a hollow elongated panel which is open at its leading edge **88** and at its trailing edge **90** is pivotally affixed to the underside of the wing **16** along its leading edge by a hinge **92**. The plenum forming vane **86** is extensible as shown in dotted lines or retractable as shown in solid lines and its outer surface in the latter disposition is coextensive with the surrounding under surface of the wing **16** to form a substantially continuous, smooth airfoil section. A hydraulic actuator cylinder **94** is shown mounted in the leading edge region of the hollow wing **16** and is connected to hydraulic feed lines **96**, shown schematically. The feed lines **96** are adapted for coupling to a suitable control such as a hydraulic pump and associated control means to provide a remote control for the extension and retraction of the plenum forming vane **86**, through the pivotal connection of its piston **98** with a lever extension **100** of the vane **86**.

When the vane **86** is extended, as shown by the dotted lines, air flow communication is provided between the pressurized reservoir portion **80** and the plenum region **102**, formed between the under surface of the wing **16** and the terrain or water surface **104**, through the hollow wing and through the hollow vane **86** as shown by the arrows **106** in FIG. 2. A flexible, preferably elastic sheet of material **108** is affixed between the upper edge of the leading edge **88**, the sheet being shown here schematically, to direct the air from the hollow wing **16** through the hollow vane **86**. The sheet **108** also serves to provide a seal for the space normally occupied by the vane **86** when the vane is in an extended position.

Similarly a hollow vane **110** is hingedly affixed to the trailing edge of the hollow wing **16** by a hinge **112**; and the upper edge of its leading edge **114** is sealed to a flexible sheet **116** so that air flowing from the reservoir portion **80** through the trailing edge of the wing **16** must pass through the hollow elongated vane **110**. It may be noted that the upper surface of the trailing edge **118** of the hollow vane **110** is ported in a manner such that the air passing through the hollow vane **110**, when it is extended as shown by the dotted lines, is ejected from the rear surface thereof. As with the forwardly disposed hollow vane an actuating cylinder **120** is mounted within the wing and is coupled to a lever extension **122** of the vane **110** for extending or retracting it in response to hydraulic action exerted through the hydraulic lines **124** from a suitable control as described hereinbefore.

In operation, air flow communication between the interior pressurized area **80** of the duct **50** and the plenum region **102** is provided as shown by the arrows **126** when the vane **110** is extended downwardly as shown by the dotted lines. It may be noted that when the vane **110** is in its retracted position, its shape conforms with the air foil of the remainder of the wing **16** and any pressure differential between the duct **50** and the external atmosphere is readily relieved by the flow of air as shown by the arrow **128** through the trailing edge of the combined wing assembly.

It may thus be seen that the plenum region adjacent the lower surface of the wing **16** is defined, when the vanes **86** and **110** are in their extended position, by the under surface of the wing intermediate the vanes, as well as the outer surface of the flexible sheet **108**. The forward edge of the plenum region is defined by the inner surface of the vane **86** while the rearward edge of the region is defined by the inner surface of the vane **110**. Inasmuch as the wing **16** is attached at each lateral end, by means of a suitable fairing **107** (FIG. 1), to the inner opposed surfaces of the hulls **12** and **14** respectively, the surfaces of the hulls beneath the wing attachment points also serve to define lateral ends of the plenum region. Operation of the craft in association with the various positions of the vanes **86** and **110** will be described in detail hereinafter.

Referring to FIG. 3, an alternative example of the present invention is illustrated in the plan view. A pair of streamlined hulls **130, 132** are shown to be symmetrically interconnected by a forward wing **134** and an after wing **136**. Each of the streamlined hulls includes a forwardly exposed windshield **138** and a plurality of portholes or windows **140**. A horizontal stabilizer **142** is also connected between the two hulls and is affixed as in the previous examples to the top portions of a pair of vertical stabilizers **144, 146**, affixed respectively to the hulls **130, 132**. A horizontal thrust producing engine **148** is mounted on each of the vertical stabilizers and a plurality of similar engines **150** are in this example mounted on the horizontal stabilizer **142**.

It is to be noted that the wings **134, 136** are preferably spaced forward and aft respectively of the center of gravity of the craft by a distance which provides significant lever arms between the wings and the center of gravity.

Each of the wings in this example includes a pair of fan units enclosed in suitable nacelles **154**, each of which may be substantially similar in all important aspects to the structure illustrated and discussed in connection with the example of FIG. 2.

It is apparent that the example of the invention illustrated in FIG. 3 is larger and is designed for carrying a relatively large number of passengers or weight of cargo or both as compared with the capabilities of the smaller example indicated in FIG. 1. However, for purposes of description and discussion of the principles and operation of the invention, the example of FIG. 1 will be again referenced.

While two examples of the craft of the present invention are shown respectively in FIGS. 1 and 3, it is to be understood that many different configurations may be used without departing from the spirit and the scope of the present invention. The various configurations, numbers and locations of engines, as well as numbers and locations of ducted fan units, are a matter of choice, depending largely upon the type of service in which the craft is to be employed. Additionally, various sizes of craft having generally the described proportional relationships will be used where different terrain conditions are encountered, or where it is anticipated that operation must be over waves or swells in ocean terrain of particular maximum anticipated heights. Operation of the vehicle of FIG. 1, for example, is intended primarily for over relatively calm waters or, for example, over inland waters, whereas larger versions similar to the example illustrated in FIG. 3 may be used over major oceans wherein substantial wave heights may be encountered.

With reference then to FIG. 1 the operation of the fixed wing ground effect vehicle **10** is as follows. It may be assumed as a starting point that the vehicle is at rest and floating in water with all four engines idling and with the variable pitch propellers **36** adjusted to a pitch to produce zero forward thrust. For takeoff, the plenum forming vanes **86, 110** (see FIG. 2) are extended to their downward position as shown by the dotted lines in the figure, and the fan units **46, 48** are driven by their respective engines **58, 60** to produce high velocity airflow. The resulting airflow into the plenum region **102** produces an air cushion in accordance with conventional principles of ground effect machines, resulting in an increase in pressure over that of the ambient atmosphere and the vehicle **10** is lifted to a hovering position above the terrain surface **104**. The hovering altitude is of course a function of the pressure differential within the portion **80** of the nacelles **42, 44** and the resulting magnitude of airflow through the interior of the vanes **86, 110**. In practice, it is found that altitudes of approximately 10 times the slot width of the output of the vanes **86, 110** are readily and economically achieved under conditions of useful cargo loading.

With the craft thusly maintained in a hovering attitude and disposition it may be seen that the attitude stabiliy of the craft is inherently relatively high. For example if the craft tends to pitch rearwardly the lifting effect under the wing **18** becomes greater while that under wing **16** becomes lesser and forces are immediately applied to the craft to compensate for the tendency to pitch. The roll stability of the craft is manifest in the exact same manner; if the craft tends to roll to the left, the lifting effect under the left-hand side becomes greater in a manner to compensate for the tendency to roll. Accordingly, full automatic control is achieved without use of movable controls or attention thereto by either a pilot or automatic control equipment.

During the hovering attitude the forward thrust producing engines **32, 34** may be accelerated and the pitch of the propellers **36, 38** may be adjusted to provide forward acceleration of the vehicle **10**. As the forward velocity of the craft is increased, a dynamic ground effect is created beneath the wings **16, 18** which, with increasing speed, gradually supplants that created by the plenum fan units **46, 48**. Accordingly the plenum forming vanes **86, 110** may be gradually retracted to their airfoil positions in the hollow wings **16, 18**, and the fans may be idled or shut down for the duration of the forward motion, cruising portion of the voyage.

In making a landing approach, the process of transition from the dynamic ground effect lift to that due to the plenum fan units **46, 48** and the plenum chambers below the wings is achieved in a gradual process which is exactly the reverse described in the takeoff procedure. In both takeoff and landing, there may also be some overlapping of functions to create smooth characteristics and to gain greater economy of operation. In other words, forward motion may be induced before or during the rise to hovering altitude, with the vanes **86, 110** being retracted as soon as the dynamic ground effect is achieved.

It may thus be seen that due to the combination of wing and plenum chamber ground effect lift, the vehicle **10** is truly amphibious and is relatively extremely simple in its construction and maintenance. Regarding its operation, it may be noted that as related to conventional heavier than air aircraft and particularly other hovering vehicles, such as helicopters, the inherent stability of the craft constructed in accordance with the principles of the present invention is relatively exceedingly high. Accordingly, the operation is relatively simple, since the only aerodynamic control surfaces with which the pilot must be concerned are the movable elevator **22** and the movable rudders **28, 30**, the former, of course, provides trim adjusting capabilities while the latter provides both lateral guidance and trim adjustment to compensate for cross winds. The safety features of the present vehicle due to its watertight hulls, its low altitude operation and its ability to hover or fly at low speeds are deemed to be readily apparent without further amplification.

In operation, where the present craft is utilized for carrying cargo or other payload, the efficiency which it obtains by virtue of the increased lift without increased drag, due to the ground effect mechanism, provides a striking advantage over conventional airplanes. This advantage is demonstrated in part in the graph of FIG. 4 wherein the weight of fuel and vehicle, separately as well as combined as a gross weight for carrying a given payload are graphically shown as a function of the lift to drag ratio, for a spectrum of different types of aircraft, ranging from approximately 13 to 50. The vertical scales in the graph are normalized to one ton of payload for a transoceanic flight.

As indicated by the dotted line **162**, a typical jet transport, such as, for example, of the Douglas Aircraft Company, Inc. DC–8 class must carry one and one-half tons of fuel and have a vehicle weight of approximately one and one-half tons totalling a gross weight of four tons (including the payload) for each ton of payload for the transoceanic flight, if the vehicle has a lift to drag ratio of 17 which is typical for such aircraft.

The performance of the present vehicle is indicated by the dotted line **164** and illustrates that with its lift to drag ratio of approximately 47, which is typical for constructed examples thereof, the one ton of payload may be carried across the Atlantic Ocean, for example, with a third of a ton of fuel and two-thirds of a ton of vehicle weight, resulting in a gross weight of the loaded and fueled vehicle of only two tons per ton of payload.

While the various aircraft type vehicles described herein are intended primarily for operation in the ground effect region over either dry or wet terrain, such vehicles are also capable of limited gliding operation. An example of such use resides in the ability to launch vehicles of this type from a surface ship having a deck at an altitude above the surrounding terrain that is substantially greater than the altitude at which the vehicle operates while in ground effect. In such instances, the present vehicle may be launched as by catapulting. Prior to such launch and forward motion producing engines are energized, not only to assist in the launch, but to continue to propel the vehicle in a forward direction. Sufficient speed is gained during such launch to enable the wings to support the vehicle even though slight altitude is lost until the vehicle reaches the ground effect region, at which time normal flight may be continued. Attitude control during such a launch is not only maintained in the manner described by the tandem wings, but also through normal control of the elevator and laterally disposed rudders.

A further aspect of the vehicles of the present invention resides in the position of the horizontal stabilizer and, in some cases, the elevator movably attached thereto, at a location that is substantially higher than the tandem wings on the vehicle. This particular location places these elements in a free air stream containing little or no turbulence which might otherwise be encountered through placement of the control elements longitudinally substantially in line with the wings. In the present instances, it is to be noted that the horizontal stabilizer and/or rudder are disposed intermediate the extreme upper ends of the vertical stabilizers, the latter being carried on the aft end of the laterally spaced hulls. This particular structure also aids in the described gliding characteristics to enable launch from an altitude above that wherein normal ground effect is encountered.

There have thus been disclosed a number of examples and structural aspects of a fixed wing ground effect transport vehicle which illustrate the principles and concepts of the invention and which achieve the objects and exhibit the advantages set forth hereinabove.

What is claimed is:

1. A fixed wing ground effect vehicle of the character to travel contiguously over terrain surfaces comprising:
- a pair of discrete spaced, substantially parallel streamlined hulls having opposed, inwardly disposed side surfaces;
- a pair of substantially horizontally disposed hollow wings spaced fore and aft of the center of gravity of said vehicle affixed to said hulls therebetween and having approximately planar under surfaces with leading edge and trailing edge regions extending along a major portion of the length of each said wing;
- power driven fan means disposed in air communication relationship with the interior of each of said hollow wings;
- first air plenum forming vane having hinged connecting means therefore affixed to each of said wings contiguously to said leading edge region;
- second air plenum forming vane having hinged connecting means therefor affixed to each of said wings contiguously to said trailing edge region thereof,
- each of said vanes having passageways in communication with its respective hollow wing and being ported to form ports along its edge remote from its respective hinged connecting means;
- means connected to each of said wings for extending and retracting its respective said first and second vanes in a manner to define, when extended, downwardly directed air passageway means which, cooperatively with said power driven fan means and with the terrain surface below said vehicle, form, by conducting air from the interior of each of said hollow wings through its aforesaid respective passageways and ports to the space therebelow, an air cushion for lifting said vehicle; each said wing being effectively ported to each of its respective first and second air plenum forming vanes.

2. The invention according to claim 1 which includes a horizontal stabilizer and supporting means therefor affixed to the rear portion of each of said hulls.

3. The invention according to claim 2 in which said supporting means comprises a vertical stabilizer.

4. The invention according to claim 3 in which said hollow wings are affixed with positive angle of attack to the opposing side surfaces of said hulls at a substantially common predetermined horizontal level with respect to said vehicle.

5. The invention according to claim 4 in which said horizontal stabilizer is mounted substantially higher than said predetermined horizontal level whereby said horizontal stabilizer is disposed, during operation, substantially above the slip stream and turbulence of said wings.

6. The invention according to claim 4 in which said predetermined horizontal level is vertically spaced above the bottoms of said hulls whereby a portion of each of said opposed, inwardly disposed side surfaces contiguously to the under surface of each of said wings defines a lateral boundary for each end of each of said air plenums.

7. The invention according to claim 4 which further includes forward propulsion thrust producing means mounted on at least one of said stabilizers.

8. The invention according to claim 4 in which each of said second air plenum forming, edge ported vanes forms, when retracted, auxiliary forward thrust producing means.

9. The invention according to claim 4 which further includes air flow diffuser means interposed between said power drive fan means and said interior of each of said hollow wings for converting the kinetic energy of the fan driven air into a reservoir of air pressure potential within each said hollow wing.

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