Title:	**Ground Effect Aircraft**
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Errata (as corrected in this copy):

SPECIFICATION

1. Paragraph Breaks: Deleted prior to ¶1 and after ¶s 2 and 3; Inserted after ¶s 1 and 2.
2. Moved Text: Item "o." of ¶110 moved to item "i." of ¶111.

DRAWINGS

1. Identifier "7" of Figure 2 was corrected in location.
2. Identifier "9" of Figure 4 was removed; it was an incorrect labeling.
3. Color copy of drawings provided versus B&W for PCT application.
4. Several items moved about 0.2" to assure they are within proper margins.

Abstract

Aerial platforms, especially ground-effect flight platforms, benefit from common aerial platform embodiments having complementary synergies to create lift-drag ratio efficiencies higher than alternative art. For ground-effect applications, a lower cavity is defined by a trailing-edge flap, side fences, and an effective lower-surface average pitch between zero and 3°. The forward surface is configured to provide induced thrust. The effective lower-surface pitch is substantially equal to the pitch of the line going from forward stagnation point and the lowest part of the trailing-edge flap.

TITLE: Ground Effect Aircraft

CROSS REFERENCE TO RELATED APPLICATIONS

[1] This application claims priority on Provisional Appl. Ser. Nos. 63523094 (filed 25-JUN-2023), 63530177 (01-AUG-2023), 63532922 (16-AUG-2023), 63535370 (30-AUG-2023), 63541405 (29-SEP-2023), 63/605,544 (03-DEC-2023), 63/616,719 (31-DEC-2023), 63/554,100 (15-FEB-2024), and 63/649,487 (20-MAY-2024). The content of these applications is incorporated herein by reference.

FIELD

[2] The present invention relates to generation of aerodynamic lift using air flow around lifting bodies. A specific embodiment is a new ground effect aircraft planform.

BACKGROUND

[3] For over a century, the aircraft industry has been without an accurate simple explanation of aerodynamic lift that explains how air flow is transformed into lift pressures. Instant inventors have identified and verified a correct simple explanation, and that explanation enables the accurate extrapolation of observations to new inventions.

[4] Lift pressures are lower pressures on upper surfaces and higher pressures on lower surfaces, the issue is how those pressures are generated. The concise "Guidelines" for how air flow creates aerodynamic lift is: 1) impacting flow causes higher pressures, 2) diverging flow causes lower pressures, and 3) air flows from higher to lower pressures at the speed of sound. Also, toward lift-drag ratio ("L/D") efficiency, a pressure on a surface creates form drag and lift on the surface where: 4) the L/D of a section of an airplane surface is approximately equal to 57° divided by the pitch of the surface in degrees for lower surfaces and -57° divided by the pitch for upper surfaces at low pitch angles. These four guidelines are substantiated at both the continuum and discrete mechanics levels in the papers of provisional patent application 63/649,487; the papers include the foundation for system analysis to identify and minimize lost work. In all instances, provisional patent applications were filed before publication of the papers.

[5] The highest L/D efficiencies are created by lifting bodies where leading sections of aircraft surfaces have negative form drag, which is referred to as induced thrust in this Document. A fan propulsor can create both induced thrust and induced lift when the lower-pressures afore the fan's intake act on an upper surface possessing a negative pitch.

[6] Attaining high L/D efficiency requires both generating lift pressures and blocking the dissipation of lift pressures. Instant inventions include ground-effect flight aircraft which fly close to the ground or water and use the ground to block the loss of lift pressures. Using the ground to block lift pressures allows aircraft to attain higher lift and higher L/D than flight without the ground partially blocking loss of lift pressures.

[7] Whereas previous art is influenced by erroneous theories like "turning air theory" and "Bernoulli's theory of lift"; instant inventions are guided by Guidelines 1-4. Previous art correlated increases in L/D efficiency of ground effect aircraft with decreasing ratios of: [air gap between the lifting body and the ground]:[chord length]. Instant inventions use trailing-edge upper surface propulsion to transform the performance trend of increasing L/D efficiency with decreasing ratios of: [clearance of the fence with the ground]:[thickness of the lifting body].

[8] The embodiments of instant invention bring forth the following unexpected results: a) practical applications of thin airfoils at cambers greater than 2 and L/D efficiencies greater than 15, b) aerial vehicles having cavities resembling hovercraft cavities but with efficiencies greater than 15, c) ground effect flight over railway tracks having L/D efficiencies greater than 20, and d) reduced lost work from downwash during flight resulting in higher L/D efficiencies.

SUMMARY OF THE INVENTION

[9] Instant invention consists of a base case lifting body which is enhanced to a high-performance aircraft with: a) lift-span technology as coupled with distributed propulsion and b) cross-over propulsor as coupled with towed platform technology.

[10] Base Case Lifting Body – The base case lifting body is especially effective in ground-effect flight. A ground-effect flight **vehicle** consists of a *lower surface cavity* configured to contain pressure, an upper-surface propulsor, and a forward upper surface configured to generate induced thrust. The lower surface cavity is comprised of a port fence, a starboard fence, and a trailing edge flap said trailing edge flap having a trailing flap edge. The ground-effect aircraft is configured to operate with the chord connecting the forward stagnation point to the trailing flap

edge at a pitch between 0° and 3°. The base case lifting body (**Fig. 1**) is the base case vehicle absent the propulsor.

[11] Lift-Span Technology – Lift-span technology is designed to stop the lower pressures of a propulsor intake from generating form drag when cruising, which translates to a surface afore the intake with a zero to slightly negative pitch. However, that same surface may optimally have a higher slope when gliding. The invention (**Fig. 11**, Fig. 2) is an aircraft comprising a variable pitch lift span afore an upper surface propulsor where the variable pitch lift span is an upper surface are configured to operate at decreasing average surface pitch with increasing thrust of the upper surface propulsor.

[12] Crossover Propulsor – A crossover propulsor is designed to top off the dynamic pressure of oncoming air to provide adequate lift pressures in the chamber formed by a concave downward thin plate lifting body. The invention (**Fig. 4**) is a lifting body comprising a propulsor, an upper surface afore the propulsor, and a panel aft the propulsor where the propulsor intake is above the upper surface and the discharge is below the panel.

FIGURES

[13] **Fig. 1** illustrates: a) a piecewise flat lifting body, b) its mid-board airfoil, and c) the airfoil's calculated pressure profile.

[14] **Fig. 2** illustrates a ground effect aircraft with fences and mid-chord flap.

[15] **Fig. 3** illustrates the planform of the Fig.2 aircraft.

[16] **Fig. 4** illustrates the stagnation point at the front of an airfoil.

[17] **Fig. 5** illustrates an aircraft with a lower-surface cambered chamber.

[18] **Fig. 6** illustrates a thin cambered airfoil with a crossover propulsor.

[19] **Fig. 7** illustrates a towed platform aircraft with crossover propulsor and bifacial solar panels.

[20] **Fig. 8** illustrates aircraft with alternative lateral wings locations.

[21] **Fig. 9** illustrates fence additions to the Fig. 7 aircraft.

[22] **Fig. 10** illustrates vehicle with center fuselage and lateral wings with slats: a) extended and b) retracted.

[23] **Fig. 11** illustrates an aerial tail on the Fig. 2 aircraft.

[24] **Fig. 12** illustrates a hydrofoil tail on the Fig. 2 aircraft.

[25] **Fig. 13** illustrates sequential fence and flap sections on an aircraft.

[26] **Fig. 14** illustrates fences that pivot back and up as configured: a) on an aircraft, b) with a wheel, c) as a ski, and d) with a wheel on a rail.

[27] **Fig. 15** illustrates a catamaran boat designed for ground-effect flight with extendable slats and flaps where: a) is slat extended and b) is slat retracted.

[28] **Fig. 16** illustrates a passively-adjusting lift span.

[29] **Fig. 17** illustrates a lead aircraft option for towing a platform. CG is center of gravity, CP is center of pressure, CT is center of tow force, and S is propulsion thrust.

[30] **Fig. 18** illustrates an alternative pivot connection of a lead aircraft.

[31] **Fig. 19** illustrates distributed propulsion for forming jet discharges.

[32] **Fig. 20** illustrates a thin cambered lifting body aircraft with "a)" and without "b)" wings.

[33] **Fig. 21** illustrates a ground-effect flight railcar.

[34] **Fig. 22** illustrates railway side walls to enhance railcar L/D efficiency.

[35] **Fig. 23** illustrates a ground-effect aircraft in a tunnel with overhead LIM.

[36] **Fig. 24** illustrates a towed glider aircraft with crossover propulsors.

[37] **Fig. 25** illustrates Bernoulli loops using vehicle traffic to reduce tunnel pressure.

[38] **Fig. 26** shows pressure profiles in a sequence of Bernoulli loops.

[39] **Fig. 27** shows pressure profile for the airfoil of the Fig. 2 airfoil.

[40] **Fig. 28** shows the pressure profile for the Fig. 5 airfoil.

[41] **Fig. 29** shows correlations of performance parameters.

[42] **Fig. 30** shows trends in L/D efficiency versus clearance ratio.

[43] **Fig. 31** shows trends in cavity pressure versus clearance ratio.

[44] **Fig. 32** shows an algorithm for controlling vertical fence actuation.

DEFINITIONS

[45] The definitions are written to allow direct substation of the following into a claim of patent: Wherein the {insert term} is {insert definition}.

[46] Abbreviations: t – thickness, c – chord, D – drag, L – Lift, L/D – lift-to-drag ratio.

[47] Aerodynamically-Streamlined – A surface absent leading edges that form forward stagnation points.

[48] Air Ski – A water ski designed to have air flow between at least part of the lower surface and water below the surface.

[49] '#'c – is used to express distance from leading edge back as a fraction of chord length (e.g., 0.4c) or a length as a percent of total chord length (e.g., 10%c).

[50] Chamber - The higher-camber concave downward space below the lower surface of a cambered airfoil. NOTE: this definition does not apply to the copies of papers in this provisional application.

[51] Clearance Ratio - Where the airfoil thickness (i.e., centerline of a lifting body) is defined based on the airfoil exclusive of a trailing edge flap, fences, or deployed slats. Clearance Ratio is the distance between the closest object to the ground (e.g. the bottom of the fence, flap, or slats) divided by the airfoil thickness. In the absence of further clarification, clearance is the air gap between an object and the ground, where the ground may be water, ice, dirt, vegetation, roads, tracks, and other objects on earth's surface.

[52] Cavity [Lower Surface] - The air/fluid volume below the lower surface of a vehicle, between port and starboard fences, and in front of a trailing-edge flap.

[53] Crossover Propulsor - – A ducted fan where the intake air is from an upper surface and at least part of the discharge air is to a lower surface. Preferably, the average air flow through the duct is within 2° of horizontal.

[54] Fence, Fence Sections - Laterally extending vertical surface on a lifting body having a length (chord) typically greater than three times the height. For instant invention, the fence extends downward from the vehicle.

[55] Gap Ratio - Where the airfoil does not include a trailing edge flap, slats, or fences, Gap Ratio is the distance between the ground and bottom of the airfoil divided by the airfoil thickness.

[56] Ground – Refers to Earth's surface with may be dirt, water, ice, asphalt, the upper surface of a rail, vegetation, or other objects that set the height of what is below a lifting body.

[57] Induced Lift, Induced Lift Surface, Lift Span Surface – A lift force generated on a lifting body surface by the lower pressure intake of a propulsor.

[58] Induced Thrust, Induced Thrust Surface – A forward force on a lifting body surface such as a lower pressure on an upper frontal section.

[59] Leading Section – Whereas a leading edge is about the forward 1% of a lifting body, the leading section is the forward 25% [preferably 15%]. A frontal section is implicitly the surface of the frontal section.

[60] Lifting Body – A lifting body refers to an object that generates lift, and herein, does not include flaps, slats, and fences unless otherwise indicated.

[61] Lift-Span [Variable Pitch], Lift Span Surface, Passively-Adjusting Lift Span– The lift-generating upper surface afore an upper-surface propulsor having an average surface pitch between -2° and 5°, more-preferably between -1° and 3°. A "variable pitch" lift span is configured to have decreasing average pitches with increasing propulsor power.

[62] LIM – Linear induction motor.

[63] Mid-Chord Flap – A flap or morphing surface in a cavity between 0.2C and 0.8C configured to change the pressure center of the cavity and L/D by a change in the setting/shape of the surface.

[64] Pitch – Angle relative to horizontal where positive is leading edge up. Pitch may be a vehicle chord line pitch, a vehicle average pitch, or a local surface pitch.

[65] Panel – A pre-fabricated section of a lifting body installed with an average pitch between -5° and 5° that is installed to form lift pressures on both upper and lower surfaces, typically having a t/C less than 0.05.

[66] Propulsor, Fan – A blade-based device that generates thrust by accelerating air.

[67] Pressure – Pressure is reported in Pa divided by density at 1.2 kg/m^3.

[68] Slat – Forward extending surface of a lifting body.

[69] Stagnation point [Forward] – A point afore an aircraft's or lifting body's leading edge having no vertical or longitudinal air flow. It is a point of on the stagnation line which separates upward flowing air from downward flowing air.

[70] Streamlined Upper Surface – a surface void of leading edges that generates stagnation points except for: a) leading edges of a fan duct and b) leading edges of tail section.

[71] Piecewise flat Ground-Effect Aircraft – A ground-effect aircraft comprised of upper flat surfaces rather than curved surfaces.

[72] Towed Platform – A trailing lifting body pulled by a leading lifting body through a pivot capable contiguous connection.

[73] Trailing Flap Edge – The trailing edge of a flap attached to the trailing edge of a lifting body.

[74] Trailing Section- Whereas a trailing edge is about the aft 1% of a lifting body, the trailing section is up to the aft 25% [preferably 15%]. A trailing section is implicitly the surface of the trailing section.

[75] Trailing Taper – The upper surface of a lifting body between a trailing-section propulsor discharge and the trailing edge, said Trailing Taper has an average pitch between 3° and 20° and preferably between 4° and 8°.

DETAILED EMBODIMENT

[76] The instant invention is a ground-effect flight vehicle (e.g., Fig. 1) having a lower surface extending lengthwise along an underside of the vehicle from a forward stagnation point to a trailing edge flap, the lower surface bounded on a portside by a portside fence, and the lower surface bounded on a starboard side by a starboard side fence. The portside fence extends downward from the lower surface along the portside of the lower surface and abuts against a portside edge of the trailing edge, and the starboard fence extends downward from the lower surface along the starboard side of the lower surface and abuts against a starboard edge of the trailing edge. The lower surfaces, the portside fence, the starboard fence, and the trailing edge flap are configured to form a cavity underneath the vehicle and contain pressure during flight.

[77] The ground effect vehicle has an upper surface extending lengthwise along an upper side of the vehicle from the forward stagnation point to the trailing edge flap and further comprising an upper-surface propulsor operably connected to the upper surface. The upper surface has a forward upper surface portion proximal the stagnation point, wherein the forward upper surface is configured to generate induced thrust.

[78] Figs. 1-2, 6-15, and 21-24 illustrate example lifting bodies of this invention.

[79] The ground effect vehicle's lower surface can be substantially flat surface with a pitch of 0° to 3°, relative to a horizontal pitch of 0°. A key feature to maximize L/D is a trailing edge flap having a lower surface than the vehicle's lower surface.

[80] In an alternative sequence of limitations, the instant invention includes a ground-effect flight vehicle having a lower surface 8 cavity 1 configured to contain pressure, an upper-surface propulsor 2, and a forward upper surface 3 configured to generate induced thrust. The lower

surface 8 cavity 1 comprises a starboard side fence 4, a portside fence 5, and a trailing edge flap 6; the trailing edge flap 6 has a trailing flap edge 7. To achieve higher efficiencies, the vehicle is designed to operate with a lower surface 8 having an average surface pitch between 0° and 3°.

[81] An approximate design criterion is for the pitch angle of the straight line 9 (or chord) connecting the leading edge of the vehicle to the trailing flap edge 7 at an angle between 0° and 3°. A more-rigorous design criterion is a flap and leading section designed with a straight line 9 of pitch between 0° and 3° connecting the forward stagnation point 10 to the trailing flap edge 7.

[82] Preferred fence 4 5 positions are on the port and starboard sides of the cavity 1 at a height between 5% and 100% of the thickness of the lifting body, more preferably 10% to 50% of the lifting body thickness. The fences are preferably a vertical longitudinally-extending surface which may be augmented by vertical structures extending from the ground, such as railway tracks 11. Fences may deviate from vertical such as at an angle, curved, or formed as spaced from vertical surface extensions.

[83] Preferably, the longitudinally extending fence 4 5 is a sequence of fence sections 12 with each section configured to move vertically as a control surface. At a given sequence of vertical heights of fences, the vehicle will assume a steady-state flight position including a vehicle pitch and an angle in the roll dimension. When a fence section is moved upward, more lift pressures disperse laterally at a greater rate at that position, resulting in lower lift and a lowering of the vehicle at that position and any positions having lift pressure indirectly impacted. The vehicle will lower at the positions of lower lift leading to a new steady state vehicle pitch and roll angle; hence, the fence is preferably a vertically moving control surface.

[84] Preferably, the trailing flap 6 pivots or extends from a position on the lifting body by methods known in the art. The flap extends between a pair of fences. A lowering of the trailing flap edge 7 creates higher pressures in the cavity 1 and more lift. In the absence of vertical ground structures 11 augmenting fence functionality (e.g., a railway track), a good operating position is the trailing flap edge 7 at 70% of the vertical distance between the lifting body's trailing edge and the fence at that chord position. The trailing flap position is a results'-driven parameter of vehicle operation. The trailing flap may be a laterally extending sequence of flap sections 12 between a pair of fences 4 5.

[85] Any fence or flap section may optionally have independent control actuation 27 and independent shock-absorbing function by moving in response to contact with an outside surface.

Fig. 14a illustrates a fence with sections 12 in sequence in vertical and longitudinal dimensions with boards connecting vertical sequences with pivoting contact 14 to allow the fence sections 12 to pivot back and up in control actuation 27 or shock absorbing action. Wheels (Fig. 14b) or ski configurations (Fig. 14c) may be used to assist in absorbing the shock or to sustain contact with a surface in close clearance. The fence is configured to move up and back while blocking loss of lift pressures. For example, adjacent faces of fences in close proximity can move while providing resistance to air flow.

[86] A key factor to achieve higher L/D efficiency is induced thrust on a frontal surface 3; lower pressures and respective induced thrust are created by expansion of higher pressure along the stagnation line 9 upward. Lower pressure forms when air flow diverges from a surface such as a curved surface (Fig. 2) or when a transition occurs from a lower pitch surface (i.e., more negative) to a higher pitch surface as illustrated by the frontal section lower surface 8 regions of Fig. 1c. Induced thrust 3 subtracts from drag in L/D performance; hence, as drag decreases from small values of induced thrust 3 there can be large increases in L/D.

[87] The frontal section 3 induced thrust may be enhanced by an upper-surface propulsor 2 where the propulsor intake 15 creates a lower pressure on the upper surface which increases the rate of expansion from the stagnation line 9 which causes greater velocities of divergence from frontal surfaces having shapes to enhance this propensity.

[88] Devices that enhance the performance of the base case ground-effect lifting body include: a) Trailing-edge flap comprising a sequence of laterally-extending flap sections, b) an upper surface comprised of a sequence of flat surfaces 16, c) a variable-pitch lift-span 17, d) a crossover propulsor 18, e) a panel surface 19 extending at least half the vehicle chord and at least one third the vehicle width, f) a towed platform 20, g) a trailing taper 21, h) laterally-extending wings 22 with optional ailerons 23, i) slats 24 configured to increase the camber of a lifting body when extended, j) a mid-chord cavity flap 25, k) a mid-chord cavity morphing surface 26, l) vertical control actuation 27 of fence sections 12, m) forward-extending fences 28, n) a second pair of fences 29, o) an aerial tail 30, p) a hydrofoil tail 31, q) a fence hydrofoil 32, r) the fence comprised of a plurality of sequential fence sections 12, s) a fence air or water ski 33, t) a fence wheeled ski 34, u) a ductless focusing fan 35, v) an inboard chambered panel 36 comprising an inboard cambered panel between two outboard lifting body fuselage 37, w) shock-absorbing fence sections 38, slats 39, and flaps which optionally include shock-absorbing embodiments in

retraction/extension track assemblies 44 45. Here, the chamber 53 is a space below a concave downward panel which has sides that may or may not be fences.

[89] Vehicle categories of this invention include but are not limited to: a) A marine aircraft, b) A railway car 40, c) A subway car, d) A roadway vehicle, e) A piecewise flat platform vehicle 41, f) An all-terrain vehicle, g) A ship, h) A boat with boat hulls 42 43, i) and a guideways system (tracks, terraced guideway, overhead electric assembly).

[90] Configured to Generate Induced Thrust – For instant invention, a leading section (i.e., leading 25% of the lifting body) configured to generate induced thrust has a leading edge on the lower 25%, preferably 15% of the surface and a surface that continuously, or stepwise continuously, has decreasing pitch as the surface processes upward and rearward from the leading edge. Preferably, greater than 80% (more preferably, greater than 90%) of oncoming air flows upward from the stagnation surface (i.e., stagnation line in 3D) and over the leading section including diverging flow from the surface which creates lower pressures on some upper surfaces having pitches less than 0° (more preferably, from 45° to 0°).

[91] Shock-Absorbing Extendable Slats – Slats, fences, and flaps are downward extensions of a lifting body; they offer the following advantages: a) enabling the lifting body, slats, fences, and flaps to operate at different clearances; b) enabling fast-actuating vertical movement of fences, slats, and flaps to avoid hitting the ground (i.e., the use the momentum of the lifting body to counter the momentum of fast actuation), c) reducing shear at low clearance relative to the entire lower surface of the lifting body being at that clearance, d) enabling shock-absorbing mechanisms to allow contact with the surface as a mode of operation or as a minor versus major perturbation, and e) enabling the vehicle to change aerodynamics for free flight versus ground-effect flight.

[92] An advantageous change in surfaces to change aerodynamics is to increase the camber of a wing, fuselage, or other lifting body for ground-effect flight. Highly concave (e.g., a camber greater than 0.03) lower surfaces rely on the expansion of higher pressures from the lower surfaces of the trailing section to the lower surfaces of the leading section to create lift throughout the entire lower surface. In free flight, those lift pressures dissipate before reaching the lower surfaces of the leading section with resulting low L/D efficiency. In ground effect flight with fences and ground block losses of lower surface lift pressure and higher L/D are attainable. The general description of this embodiment is a vehicle having surfaces configured to

operate at high-camber lower surface concave-downward surfaces when close to the ground and a lower-camber lower surfaces when flying distant from the ground. Flaps and slats can be used to increase the lower surface camber.

[93] Preferred embodiments have slats that extend or pivot to increase camber of lower surfaces from less than 0.02 (concave downward) to greater than 0.03 (concave downward. Figure 15 illustrates a curved track assembly 44 with two roller connections that allow the slat 24 to provide an extended configuration (Fig. 15a) with increased camber for ground-effect flight and a retracted position (Fig. 15b) with lower camber for free flight. Methods known in the art can provide shock-absorbing capabilities along the track travel path or at the connection between the track assembly 44 and the hull 42 43.

[94] Fence Control Actuation – Efficiency of ground effect vehicles increases as the clearance ratio (CR) decreases. The preferred actuation is active fast vertical movement of fence sections with an algorithm consisting of the steps: a) detection on oncoming bump/wave, b) calculation of timing to move fence section upward to avoid the bump/wave, c) return of fence section, and d) repeat of process for subsequent fence sections encountering the wave/bump. Preferably, superimposed over this algorithm is a control algorithm adjusting other control surfaces (e.g. ailerons, other fence sections) to maintain a smooth ride.

[95] A preferred fence includes a lower surface characterized as a ski with upward force provided by wheels, air, or water on the lower surface of the ski. Wheels, air, or water on the lower surface of the ski, which are attached to the fence, sustain from 0% to 20% (preferably 0.5% to 4%) of the vehicle weight with most of the vehicle weight supported by lift pressures (from aerodynamic forces) on the vehicle. The advantage being that the close clearance ratios are maintained with a low Ski drag due to the low weight supported by the Ski. Methods known in the art may be used to design fences with wheels, skis on snow, skis on water, and skis on water with air injection. Fences are designed to restrict air from flowing through the fence and the fence-vehicle interfaces. The ski may have a narrow long cavity 1 to create aerodynamic lift below the ski to buffer impact and reduce drag.

[96] Fences with lower ski surfaces may be designed for a preferred state with the ski engaging the surface or with the ski as an approach to better absorb inadvertent contact with the surface; in either case, performance can be improved with high-speed controlled actuation of the extent of vertical extension of fence sections. A fence control inner algorithm is comprised of

the following sequence: a) detection of on-coming ground level, b) calculation of timing for raising or lowering fence sections to maintain a set point clearance above the ground level, and c) movement of fence sections to match ground level. Superimposed over this inner algorithm is a second-tier algorithm to move the lifting body up and down in the case of severe changes in ground level. Superimposed over both of these algorithms is a third algorithm that inputs available input into an AI calculation algorithm designed with the objective function of creating a smooth ride. The second and third algorithms use additional control surfaces of flaps, slats, and ailerons to move the lifting body up or down per Fig. 33.

[97] Lift Span Tech - Upper-surface propulsor 2 intakes 15 create low pressures on upper surfaces which create lift; those same lower pressures can create form drag or induced thrust 3. For a trailing section propulsor, at about 0.75c, higher pitches are preferred at low propulsor power to reduce boundary layer separation when gliding. At higher propulsor power, the propulsor dominates boundary layer phenomena and a lower pitch surface at the intake (e.g., -0.1°) is preferred. The lower pitch surface at the intake reduces or eliminates form drag and reduces the amount of resistance the surface has on air flow into the propulsor. Preferred is an intake surface that exhibits decreasing pitch with increasing propulsor power. The term "Lift Span" 17 is used to refer to the surface afore an upper surface trailing section propulsor intake 15 which experiences lower pressures due to the propulsor, and the term "Lift Span Tech" is used to refer to embodiments that reduce the pitch of the surfaces afore propulsor intakes 15 with increasing propulsor power.

[98] The related invention embodiment is an aircraft comprising a variable pitch Lift Span 17 afore an upper-surface propulsor 2 where the variable pitch Lift Span 17 is an upper surface configured to operate at decreasing average surface pitch with increasing thrust of the upper-surface propulsor 2. It is not uncommon for the pitch of the entire aircraft to decrease with increasing speed. The preferred aircraft is configured for the average surface pitch of the variable pitch Lift Span 17 to decrease relative to the aircraft chord pitch with increasing thrust of the upper-surface propulsor 2.

[99] A passively-adjusting Lift Span 17 device is illustrated by Fig. 16 and is comprised of a contiguous connected sequence of a) a forward connection to the aircraft 46, b) a Lift Span surface 47, c) an upper-surface propulsor 2, d) a pivotable connection 48, e) a trailing taper panel 49, and f) a contiguous sliding contact 50 with the trailing section of the aircraft. The passively

adjusting Lift Span 17 device includes a spring or similar elastic device 51 connecting the passively-adjusting Lift Span surface 47 device to the aircraft. For active control, the spring may be replaced with active control actuators. Also, the elastic aspect of the device may be incorporated into the Lift Span 17 surface such that lower pressures stretch the surface upward toward overall lower pitch; such elastic surfaces may be referred to as morphing surfaces.

[100] Cross-Over Propulsor – Air may be forced into the cavity 1 to increase pressure beyond that expressed by oncoming air's dynamic pressure. This can be achieved with a cross-over propulsor 18, where a lifting body comprising a propulsor, an upper surface afore the propulsor, and a panel 19 aft the propulsor is configured with the propulsor intake 15 above the upper surface and the discharge is below the panel 19 as illustrated by Fig. 5. The preferred propulsor is a ducted fan and the panel 19 is a rearward extension of the upper surface of the ducted fan.

[101] Preferably, the panel 19 is a convex upward cambered panel 19 having a thickness to chord ratio less than 0.1 [preferably between 0.005 and 0.02] and a camber between 0.02 and 0.12 [more preferably between 0.04 and 0.08]; this is referred to as a high-cambered span 52. Preferably, the high-cambered span is an inboard panel 19 span between two outboard fuselage spans 37.

[102] The cross-over propulsor 18 is an effective method to extend a platform surface of an aircraft. Fig. 7 illustrates a lead aircraft 56 and a towed platform 20 connected through a pivotable connection 55 where a cross-over propulsor 18 is part of the transition from the lead aircraft to a towed platform 20. The lead aircraft comprises of the propulsor and the towed platform 20 comprises of the panel 19. Said panel 19 has a camber greater than 0.02. The towed platform 20 is configured to operate with a balance of lift and panel 19 center of gravity coupled with the leading lifting body by a pulling force acting through the pivotable connection. When the panel is a bifacial solar panel 57, the towed platform 20 may be configured to collect considerably more energy than is needed to sustain the flight of the towed platform 20.

[103] Railcar Embodiment – The ground-effect railcar embodiment has particularly good performance due to the ability to travel at low clearance gap ratios resulting in high L/D efficiency. At locations where traffic is high, additional blocking of lateral losses, from upper and lower surfaces, can be achieved with railway side walls 58 along the sides of the tracks positioned for preferred lateral vehicle clearances of 0.3 to 1.5 feet. An overhead LIM 59 may

be used as a safeguard against derailment and may be part of a guideway separate from the tracks.

[104] Typically, a clearance is a vertical distance, however, over rails the fence may extend over the side of the rail. Fig. 21a illustrates a fence 5 beside a rail 11 with a horizontal clearance ratio. Fig. 21b illustrates a fence curved in the vertical dimension.

[105] Transit in tunnels enables enhanced blocking of vertical and lateral losses of lift pressures. For operation in tunnels, the preferred vehicle is powered by fans and a non-aerodynamic method such as wheel traction or LIM propulsion. Preferred operating conditions are with enough non-aerodynamic propulsion so as to create a slightly higher pressure afore the vehicle which pushes air through the tunnel in the direction of vehicle travel and enhances system efficiency with the created “tailwind”. Preferably, the non-aerodynamic propulsion is 5% to 30% of the vehicle’s propulsion needs.

[106] A LIM is able to provide non-contact propulsion with the preferred LIM 59 being overhead a vehicle and also providing: a) energy transfer, b) partial suspension, and c) tractor-type guidance along a LIM cable. More preferably, an overhead electrical assembly consists of an upper LIM cable and a lower contact cable; the contact cable configured to transfer electrical power to conventional trains which may operate on the same tracks.

[107] Bernoulli loops 60 at entrance-exit locations can reduce pressures in tunnels to further reduce drag and increase efficiency. Bernoulli loops are ducts configured (see Fig. 25 and Fig. 26) to convert air’s dynamic pressure into a driving force for the transfer of air from entrance sections to exit sections.

[108] Free Flight – Free flight is away from ground effects. In free flight the fences are typically retracted and with the flap set at a lower setting.

[109] Parametric Ranges – Important design parameters include the following:

a. Trailing taper is important because a higher taper (i.e. pitch) of the upper surface is needed to avoid having large lengths of fuselage of height too low for prime applications and a high taper enables lower lift span pitch angles with related induced thrust. Preferred trailing tapers are between 3° and 20° where higher pressures from propulsor discharge counter lower pressures from air flow diverging from the surface to create pressures near free-stream pressure and resulting near-zero form drag, preventing boundary layer separation and trailing turbulence.

b. The cavity creates most of the lift for embodiments of this invention when operating at low clearance ratios, and the pressure in the cavity is designed to approach oncoming air's dynamic pressure. A typical full suspension speed is 90 mph, but suspension can be augmented with wheels, maglev suspension, buoyancy, and crossover sources the force air into the cavity. At low clearance ratios, the compressed air creates thrust as it exits below the flap; this is an operational advantage of the crossover propulsor.

c. A typical good flap percent is 70% of the gap between the lifting body's trailing edge and the lower part of the fence at the flap location.

d. The flap preferably extends aft and downward from the trailing edge of the lifting body and extends laterally to moving contact with the port and starboard fences that define the cavity under the lifting body. Deployable flaps may be used to transform boats to ground-effect aircraft.

e. Fences extend downwards to define the sides of the cavity; wider is better to create more aerodynamic lift. The lifting body is defined independent of the fences, and the fences typically have a height (from lower fence edge to the lower surface of the lifting body) at average 5% to 100% of the thickness of the lifting body. Preferably the fence extends laterally from at least the leading edge to the flap with a thickness as necessary to sustain pressures in the cavity. The fence may extend forward, typically from 0% to 20% of the lifting body chord.

   On the upper surface, fences are primarily "in the shadow" of surfaces that have frontal projections. By example, a good benefit-loss ratio applies to a fence extending aft and for the outer surface of a ducted fan.

f. Shock-absorbing characteristics are preferred to reduce the force of impact of contact with ground or water. Fences or slats that move aft and up upon contact are examples of shock absorbing structures. Methods known in the art may be used to enable the shock-absorbing motion in the aft and upward directions. Tracks used to extend slats preferably have shock-absorbing characteristics built into the track.

g. The speed at which full aerodynamic suspension is attained is a design degree of freedom. A typical design speed for full aerodynamic lift at maximum L/D and a clearance ratio of 0.2 is 90 mph. The mid-chord flap can be used to adjust the steady-state pitch (at constant fence settings) similar to an elevator flap on contemporary aircraft. Pivoting of flap about a connection to the lower surface is a method to change the flap setting; however, any morphing or morphing surface action that moves the center of pressure forward is a viable design strategy.

h. The mid-chord flap is a flap at a chord location between the leading edge and the trailing flap, but preferably with a mid-chord flap leading edge between 0.3c and 0.8c and chord length between 5%c and 15%c. The greater the lateral cross section blocked by the mid-chord flap the more the center of pressure is moved forward in the lifting body.

[110] Illustrative Examples – The inventors' axiom includes Guidelines 1-4 (¶4) and the use of the ground or water, and fences to block losses of lift. Unless otherwise stated, lifting body speed was 40 m/s in 1 atm air. The following applies to the key design features of the ground effect vehicle: a) The trailing flap and lifting body leading edge are key sources of pressure generation, b) the fence and ground strategically block air flow that would lead to greater losses of lift pressure, and c) induced thrust from the upper surface of the leading section and the lift span (from distributed propulsion) subtract from the denominator of L/D with the result of high values of L/D efficiency. The following are trends in performance consistent with these key design features:

a. A flat plate airfoil (horizontal, extending from x = 0.1 m to 0.90 m and from y = 0.03 m to 0.04 m), a flat plate flap (0.01 m thick, extending from x = 0.9 m to 1.0 m and from y = 0 m to 0.04 m) and a flat plate slat (0.01 m thick, extending from x = 0 m to 0.1 m and from y = 0.016 m to 0.04 m to 0.04 m trailing edge flap) were evaluated at 40 m/s in steady-level flight in air in both free flight and above ground at y = -0.01 m in configurations of: i) the airfoil, ii) the airfoil with the flap, and iii) the airfoil with a flap and slat. The respective free flight L/D were: i) 0.02 and -3.5, ii) 15.3, and 30.4, and iii) 22.7 and 59.4. These 2D simulations illustrate how the flap improves ground effect flight and how a slat that adversely impacts free flight can improve L/D in ground-effect flight. Fig. 32 provides pressure profiles.
b. Figs, 1c. 5, 27, and 28 illustrate induced thrust on upper frontal surfaces,
c. Increasing L/D and L with decreasing gap ratio (Figs. 29a, 29b, and 30) since the ground more-effectively blocks lift pressure losses at closer proximity.

d. Decreasing drag coefficient with decreasing gap ratio (Fig. 29b) due to increased frontal induced thrust with a minimum when shear drag begins to dominate.
e. A peak in L/D at about 70% flap (Fig. 29c) because the lifting body's lower surface is at a constant position and lower flap reduces lift pressure losses but this is only effective when the fence is lower than the flap to stop lateral lift pressure losses.
f. Increasing lift coefficient and cavity pressure with increasing % flap, increasing flap reduces aft lift pressure losses, decreasing effective gap ratio without decreasing the distance between the cabin and the ground surface.
g. The ground effect vehicle with an upper surface wing has a lower lift coefficient (Fig. 30; L/D is Cl/Cd) than without a wing because the non-optimized wing adds proportionately more surface area than lift pressures at low clearance ratios.
h. For the Figs. 30 and 31 lifting bodies, the L/D of the 3D digital prototype does not approach the 2D performance because of significant lateral lift pressure losses on upper surfaces for the 3D prototypes, but the cavity pressures of 3D digital prototypes do approach 2D performance because the ground and fences effectively block lift pressure losses.
i. Fig. 2 illustrates a mid-chord flap with a leading-edge pivot at 0.4c and extending between the pair of side fences. Without the mid-chord flap, the center of pressure was at 0.56c, with a mid-chord flap at 100%gap the center of pressure was 0.44c at 0.2 CR and 0.34c at 0.02 CR.
j. The upper-surface trailing-section propulsor was positioned afore the trailing taper of the lifting body of Figs. 5 and 27. At 0.02 CR, the propulsor power setting was increased from 0 to 1000 to 5000 m^4/s^2 on a 6.4 model with corresponding change in L/D from 41.8 to 50.4 to 62.1.
k. VTOL configurations are possible, the crossover source is configured to provide vertical force useful in vertical takeoff and landing (VTOL). The VTOL force may be supplemented with additional lift-generating propulsors.
l. A series of simulations of the Fig. 2 vehicle at varying pitch (40 m/s in atm air and CR of 0.2 and 0.02) exhibited decreasing coefficients of moment with increasing pitch which identified stable pitch behavior including a steady state at a 0 moment of coefficient.

m. A series of 2D simulations were performed with the Fig. 2 upper section trailing propulsor output increasing from zero to 100 m^4/s^2. As the propulsor power increased, the center of pressure moved forward as increasingly lower pressures formed in front of the propulsor, and the L/D increased from under 50 to over 90.

n. The position of the mid-chord flap of Fig. 2 was increased from 0% to 100% flap with L/D decreasing from 19.6 to 15.3 at a 0.2 CR (decreasing from 43.7 to 24.5 at a 0.02 CR).

[111] Multiple ground-effect embodiments of this invention exhibit the following innovation sequence, some of which are illustrated by the examples of the previous paragraph:

a. Higher pressure generated by a trailing flap (which extends lower than the lifting body) expand throughout the underside of a lifting body in close proximity to the ground. Absent the trailing flap, negative pitch surfaces after the lower surface's lowest point have reduced lower-surface pressures. Absent the ground, much of the higher pressures dissipate downward before reaching the front of the lifting body. See illustrative example "a.". A trailing edge flap is a starting point for realizing improved ground-effect flight.

b. If a flap has too large a vertical projection, the horizontal form drag of the flap diminishes performance where for the overall cavity L/D the run over rise of the progress from the forward stagnation point to the trailing point edge is diminished. The applicable heuristic is that local L/D = 57 / α°, where α° is the pitch (in degrees) of the line extending from the stagnation point to the trailing flap edge; a value of α° < 3° corresponds to local L/D contribution >19.

c. In 3D performance, lateral loss of lift pressures is a problem, fences block lateral losses and allow the lift pressures in the cavity created by the fences to expand/extend forward (approaching 2D performance pressures); see Fig. 31.

d. As higher pressures expand forward on a lower surface to forward slats, slat surfaces are able generate lift from higher pressures on lower surfaces and lower pressures (i.e., induced thrust) on at least part of the upper surfaces; the resulting induced thrust increases L/D. These slat surfaces increase ground-effect flight L/D but can diminish free flight L/D (see Illustrative example "a."); and so, retractable slats on a lifting body are preferred to a fixed lifting body geometry.

e. The lower the clearance ratio of the fences, the lower the lateral losses of lift pressures, and the higher the L/D efficiency; hence, passive, active, and interactive (i.e., skis) control has a high benefit-cost ratio to maintain low clearance ratios. Skis can maintain close tolerances with low drag since most of the vehicle weight is supported by the lift pressures in the cavity created by the fences. When using wheeled skis on rails (Fig. 14d), the bottom of the fence, not the bottom of the wheel, is used to determine the clearance ratio 62.

f. A trailing-section upper-surface propulsor can enhance induced thrust (increasing L/D) and disrupt boundary layer separation of a high-taper (i.e., pitch > 3°) trailing tapers which allows shorter thicker fuselages and transforms correlations of increasing L/D with increasing chord length to correlations of increasing L/D with increasing lifting body thickness. There is a basis for the frontal section to continue to generate increasing amounts of induced thrust with increasing thickness, but there is a doubt that a trailing taper can approach free stream pressure on the upper surface at higher thickness. These results teach toward an optimal thickness to chord ratios (t/c) less than about 0.2. A t/c of 0.06 performs well.

g. The combination of forward slats and a trailing edge flap define total vehicle of higher camber (i.e., lower surface concave downward camber greater than 0.03) where correlations of increasing L/D with decreasing clearance ratios correlate with the height of a cambered panel rather than the thickness of the panel.

h. This path of innovation attains high performances without optimizing upper surface or lateral wing extensions; performances can be further increased by: a) optimizing upper surface and laterally-extending wings where optimized wings vary with application (i.e., percent of time in free flight) and b) optimizing surface curvatures.

i. Smooth curved surfaces, in general, are more efficient than piecewise flat surfaces.

This innovation path applied the Axiom and heuristics developed by the inventors.

[112] A question arises as to the correlation of increasing L/D with increasing chord length. The answer may be that at a constant thickness, increasing chord decreases α°. A more profound answer is that as lost work is eliminated, an optimal airfoil can convert pressures of the stagnation curve to lift and, for the overall lifting body, essentially all unavoidable drag from the forward stagnation region can be converted to lift (i.e., form drag is converted form lift). And

furthermore, by designing and operating upper trailing taper surfaces to operate at free stream pressure, form drag from the trailing section of the vehicle is substantially eliminated. Net induced thrust is primarily an upper-surface phenomenon (induced thrust is coupled with induced drag on lower surfaces); and so, there tends to be a maximum in induced thrust versus lifting body thickness.

[113] A lost work analysis (system's analysis) reveals the following trends:

a. Lower fence clearances reduce lost work from lateral losses of lift pressure.
b. Flow next the ground forces exiting flow without downwash eliminating lost work in the downward velocity of exiting air flow.
c. Flap geometries that streamline discharged air flow to being parallel with the ground eliminate turbulence lost work from the rapid reduction of pressure as air exiting below the flap; this teaches toward a S-shaped flap with the flap trailing edge not being the lowest part of the flap.
d. Locating and operating propulsors to: a) simultaneously use propulsor intake lower pressures to create lift on upper surfaces and avoid choking the intake while b) discharging the propulsion air in a manner that does not create higher pressures on upper surfaces. Propulsor discharge pressures on upper surfaces can be avoided by: i) having the discharge on the trailing edge (which is problematic except for very thin airfoils due to geometric constraints and intake geometry constraints), ii) discharging above a trailing taper that balances higher pressures of propulsor discharges with diverging of air flow from the surface to create a near free-stream pressure above the taper, and iii) using discharge-focusing fans 35 where the fan geometry balances the discharge higher pressures with velocities diverging form a surface.
e. Propulsors can cause air to have an angular discharge velocity component which is ultimately lost work where a solution is to use two fans in sequence (Fig. 19) having opposite angular rotation.

[114] Further details, data, and examples are available in prior art U.S. Prov. Appl. No. 63/649,487 of 20-MAY-2024.

CLAIMS

1. A ground-effect flight vehicle comprising
   a *lower surface* extending lengthwise along an underside of the vehicle from a forward stagnation point to a trailing edge flap, the lower surface bounded on a portside by a portside fence, and the lower surface bounded on a starboard side by a starboard side fence, wherein the portside fence extends downward from the lower surface along the portside of the lower surface and abuts against a portside edge of the trailing edge, wherein the starboard fence extends downward from the lower surface along the starboard side of the lower surface and abuts against a starboard edge of the trailing edge, wherein the lower surfaces, the portside fence, the starboard fence, and the trailing edge flap are configured to form a cavity underneath the vehicle and contain pressure during flight.
2. The ground effect vehicle of claim 1, further comprising an upper surface extending lengthwise along an upper side of the vehicle from the forward stagnation point to the trailing edge flap, and comprising an upper-surface propulsor operably connected to the upper surface.
3. The ground effect vehicle of claim 2, wherein the upper surface comprises a forward upper surface portion proximal the stagnation point, wherein the forward upper surface is configured to generate induced thrust.
4. The ground effect vehicle of claim 1, wherein a line connecting the forward stagnation point to the lowest part of the flap has a pitch of 0° to 3°, relative to a horizonal pitch of 0°.
5. The ground-effect vehicle of claim 1 comprising at least one from a group comprising:
   a. Trailing-edge flap comprising a sequence of laterally-extending flap sections,
   b. An upper surface comprised of a sequence of flat surfaces for piecewise flat cambered surfaces
   c. A Variable-Pitch Lift-Span
   d. A Crossover Propulsor
   e. A panel surface extending at least half the vehicle chord and at least one third the vehicle width
   f. A Towed Platform
   g. A Trailing Taper
   h. Laterally-Extending Wings (see Figs. 2, 6-11, 20-24)

i. Slats configured to increase the camber of a lifting body when extended
j. A Mid-Chord Compartment Flap
k. A Mid-Chord Compartment Morphing Surface
l. Vertical Control Actuation of Fence Sections
m. Forward-Extending Fences
n. A second pair of fences
o. An aerial tail
p. A hydro tail
q. A fence hydrofoil
r. The fence comprised of a plurality of sequential fence sections
s. A fence air or water ski
t. A fence wheeled ski
u. A Ductless focusing fan
v. An inboard chamber comprising an inboard cambered panel between two outboard lifting body fuselages
w. Fence Sections, Slats, and Flaps that "give way" on impact with ground/water (i.e., rotate back and up)

6. The ground-effect vehicle of claim 1 wherein ground-effect vehicle is configured to operate as at least one from a group comprising:
    a. A marine aircraft
    b. A railway car
    c. A subway car
    d. A roadway vehicle
    e. A piecewise flat platform vehicle
    f. An all-terrain vehicle.
    g. A ship
    h. A boat
    i. A guideway system (tracks, terraced guideway, overhead electric assembly)
7. The ground-effect vehicle of claim 1 comprising slats said slats configured to increase the camber of the lifting body when extended.

8. The ground-effect vehicle of claim 1 configured for flight above railway tracks at a clearance ratio less than 0.1.
9. The ground-effect vehicle of claim 1 wherein the ratio of the fence height to the lifting body thickness is greater than 0.2
10. An aircraft comprising a variable pitch lift span afore an upper surface propulsor wherein the variable pitch lift span is an upper surface configured to operate at decreasing average surface pitch with increasing thrust of the upper surface propulsor.
11. The aircraft of claim 10 wherein the average surface pitch of the variable pitch lift span decreases relative to the aircraft chord pitch with increasing thrust of the upper surface propulsor.
12. The aircraft of claim 10 wherein the variable pitch lift span device is a passively-adjusting lift span device, the passively-adjusting lift span device comprising a the contiguous connected sequence of a) a forward connection to the aircraft, b) a lift span surface, c) the upper surface propulsor, d) a pivotable connection, e) a trailing taper surface, and f) a contiguous sliding contact with the trailing section of the aircraft
    the passively adjusting lift span device further comprising a spring or similar elastic device connecting the passively-adjusting lift span device to the aircraft.
13. The aircraft of claim 10 further comprising an elastic lift span surface configured to stretch upward and with lower average pitch as the pressure above the lift span surface decreases.
14. The aircraft of claim 10 further comprising a trailing taper aft the upper surface propulsor where the trailing taper has an upper surface with an average pitch between 4° and 8°.
15. A lifting body comprising a propulsor, an upper surface afore the propulsor, and a panel aft the propulsor wherein the propulsor intake is above the upper surface and the discharge is below the panel.
16. The lifting body of claim 15 wherein the propulsor is a ducted fan and the panel is a rearward extension of the upper surface of the ducted fan.
17. The lifting body of claim 15 wherein the panel is a convex upward cambered panel said cambered panel having a thickness to chord ratio less than 0.1 [preferably from 0.02 to 0.005] and a camber from 0.02 to 0.12 [more preferably from 0.04 to 0.08].
18. The lifting body of claim 15 configured as part of an aircraft to create lift as an inboard panel span between two outboard fuselage spans.

19. The lifting body of claim 15 further comprising a lead aircraft and a towed platform connected through a pivotable connection
wherein and the lead aircraft comprises the propulsor and the towed platform comprises the panel said panel have a camber greater than 0.02.
wherein the towed platform is configured to operate with a balance of lift and panel center of gravity coupled with the leading lifting body by a pulling force through the pivotable connection.
20. The lifting body of claim 15 wherein in panel is a bifacial solar panel.

Fig. 1

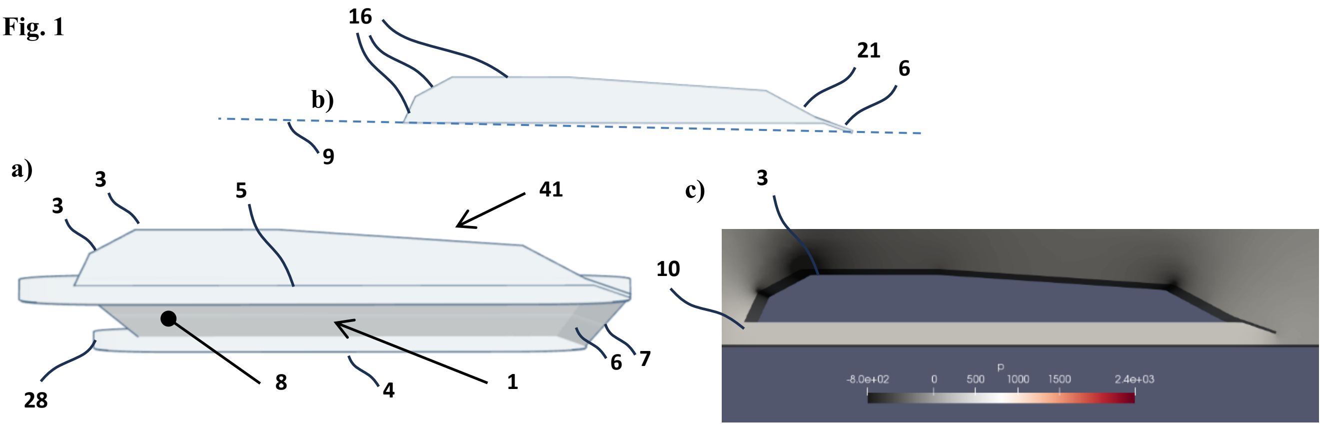


Fig. 2

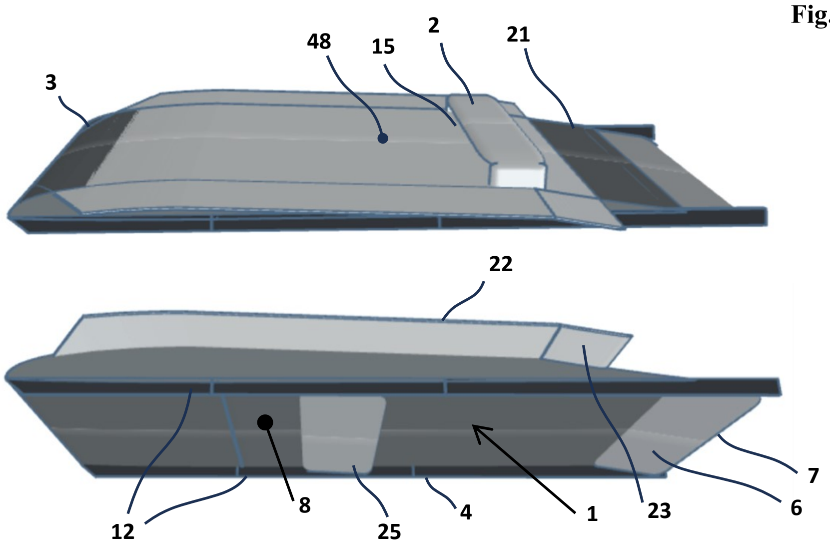


Fig. 3

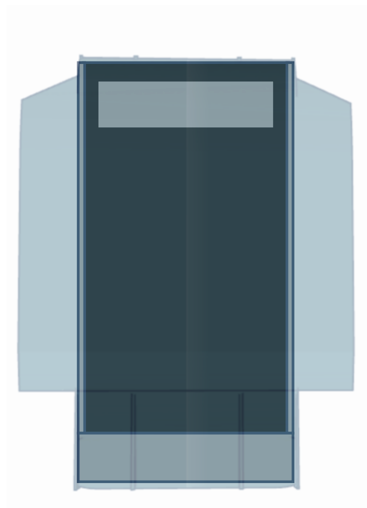


Fig. 4

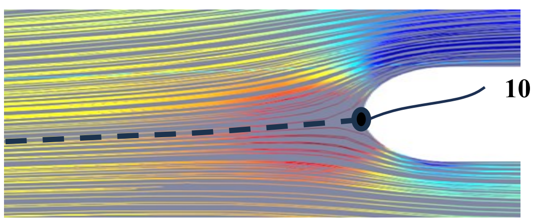


Fig. 6

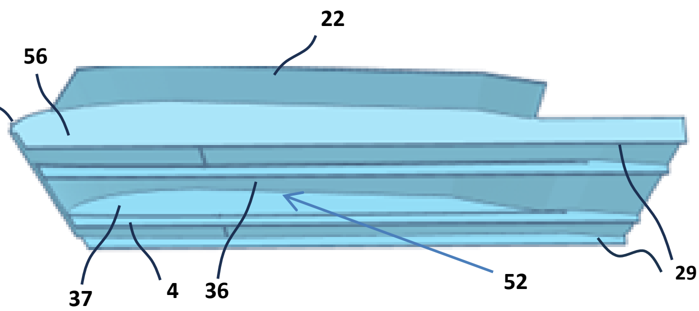


Fig. 5

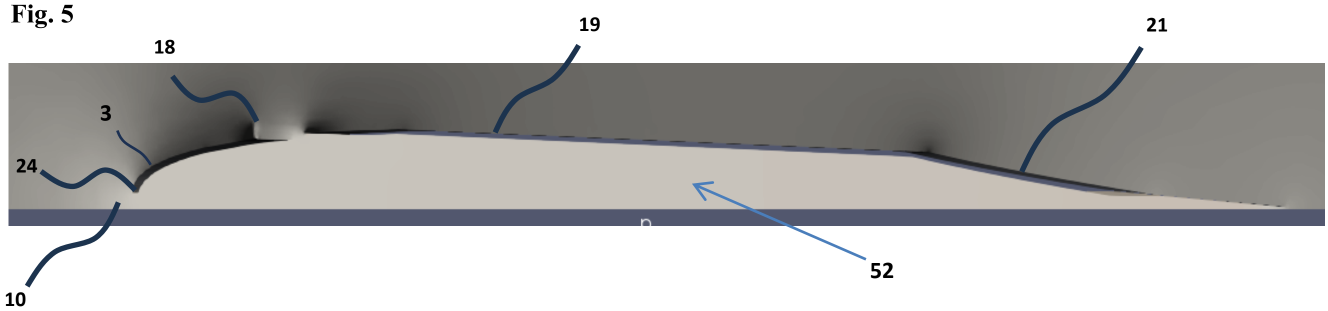


Fig. 7

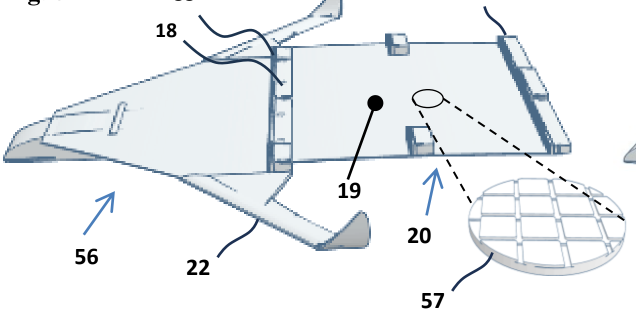


Fig. 8

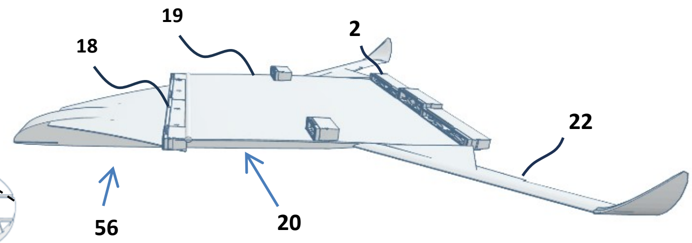


Fig. 9

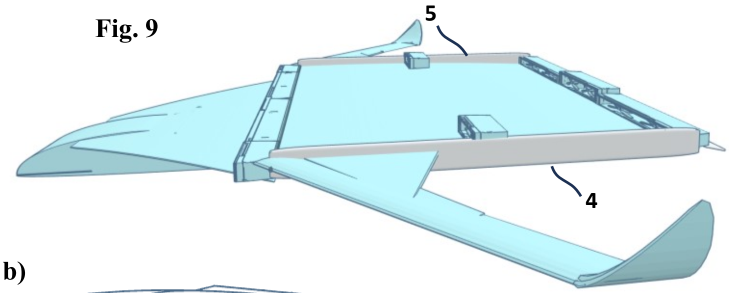


Fig 10

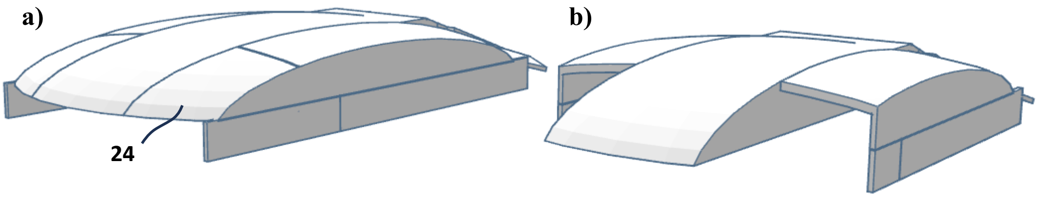


Fig 12

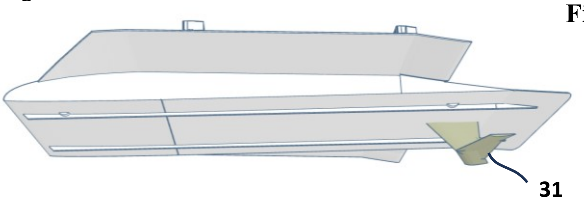


Fig. 13

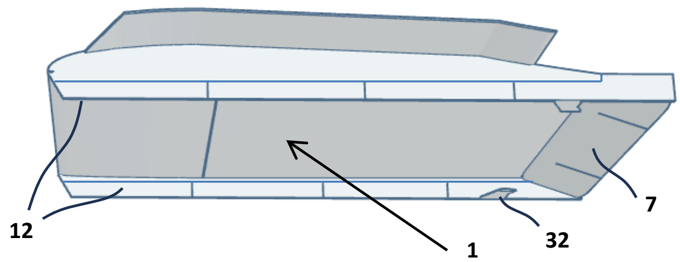


Fig 11

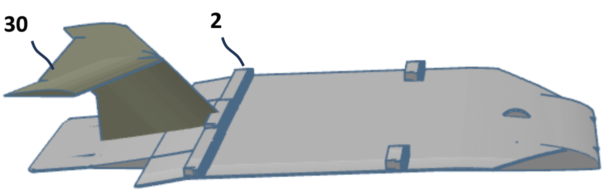


Fig. 14

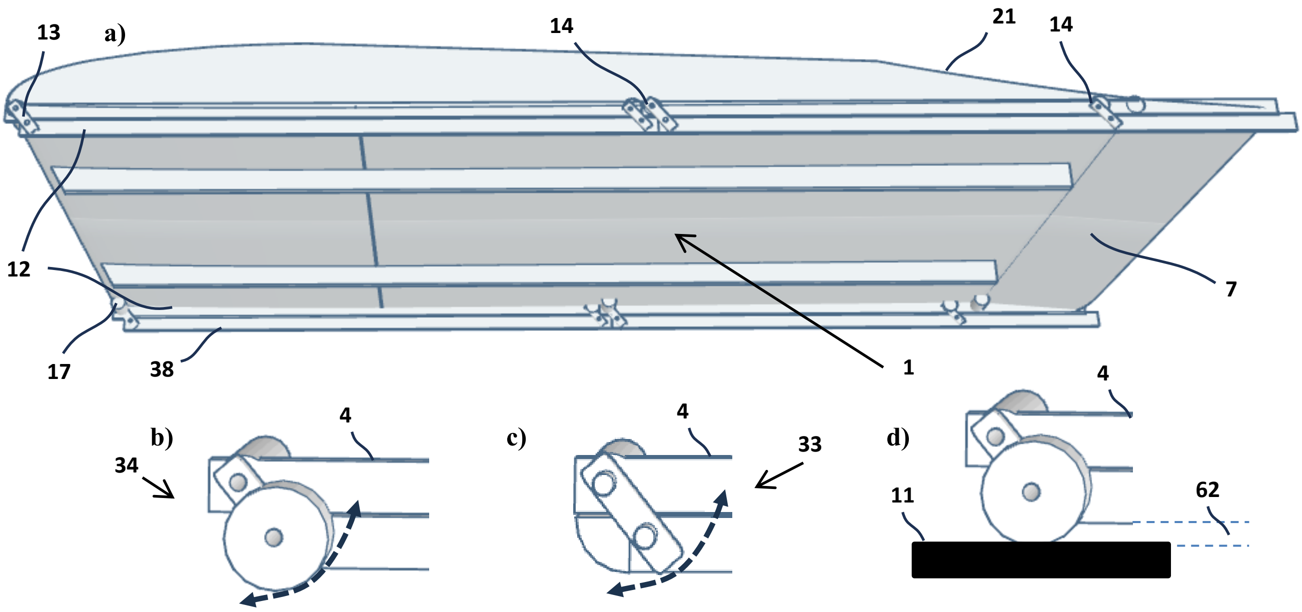


Fig. 15

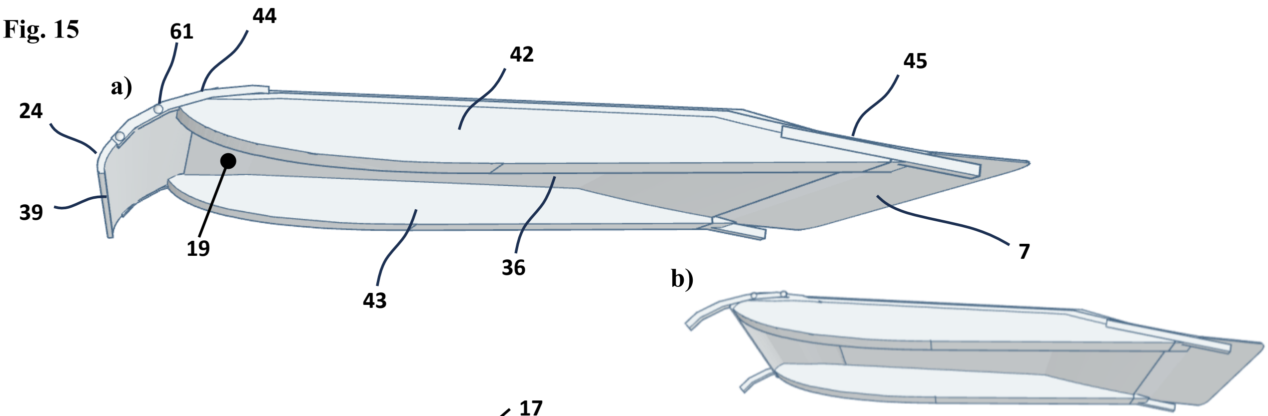


Fig. 16

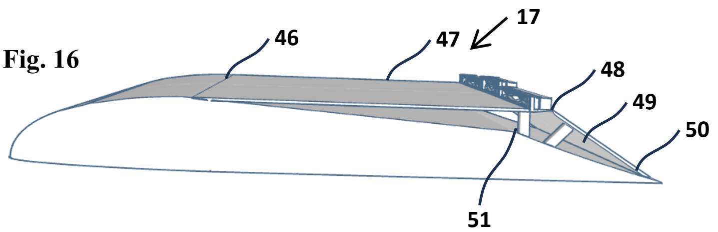


Fig. 17

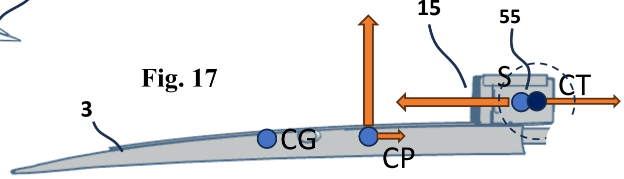


Fig. 18

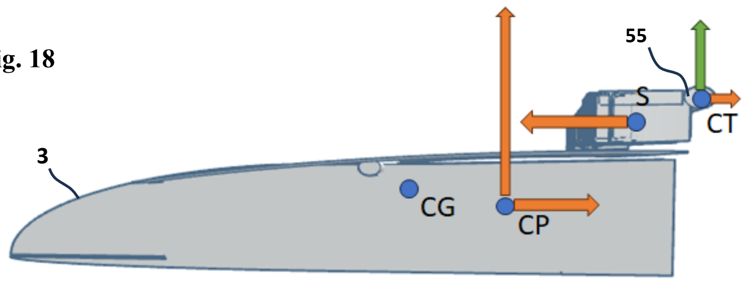


Fig. 19

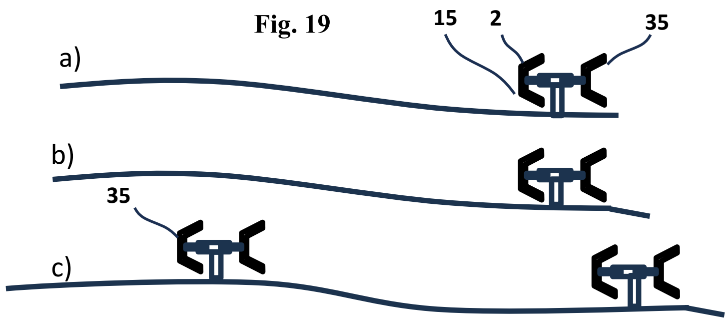


Fig. 20

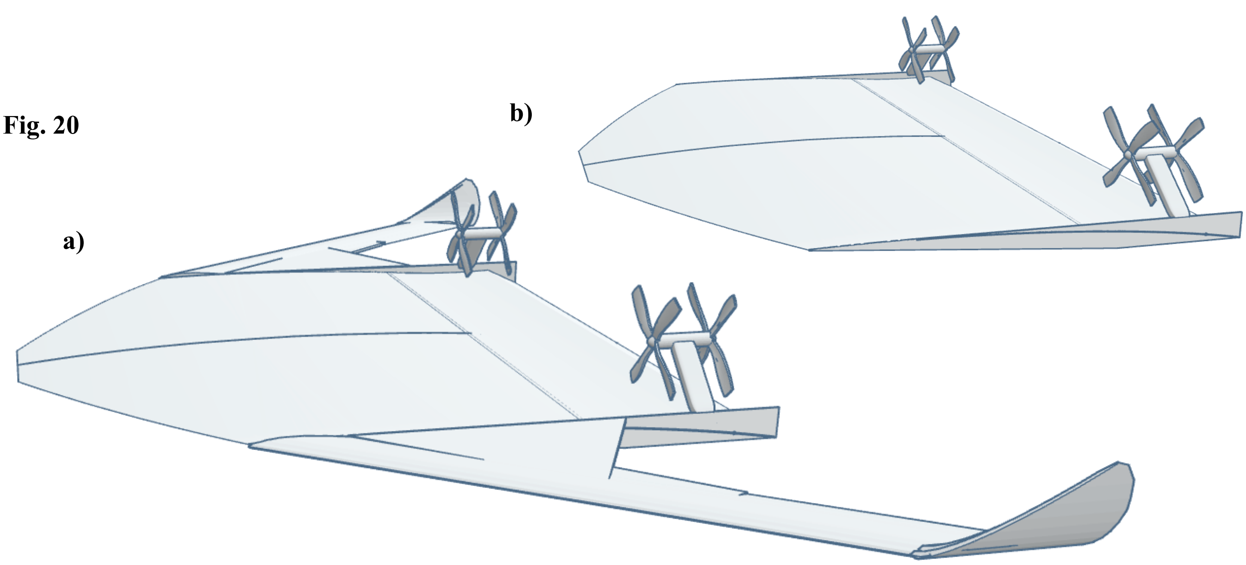
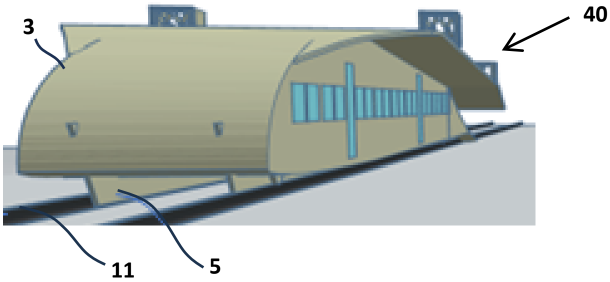


Fig. 21
a)



b)

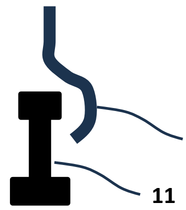


Fig. 22

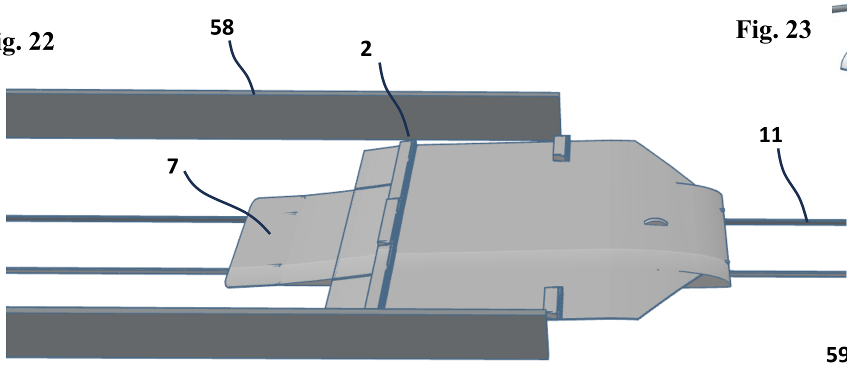


Fig. 23

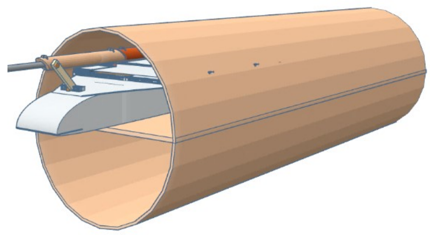


Fig 24

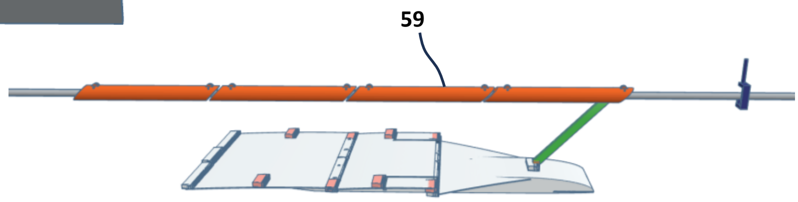


Fig. 25

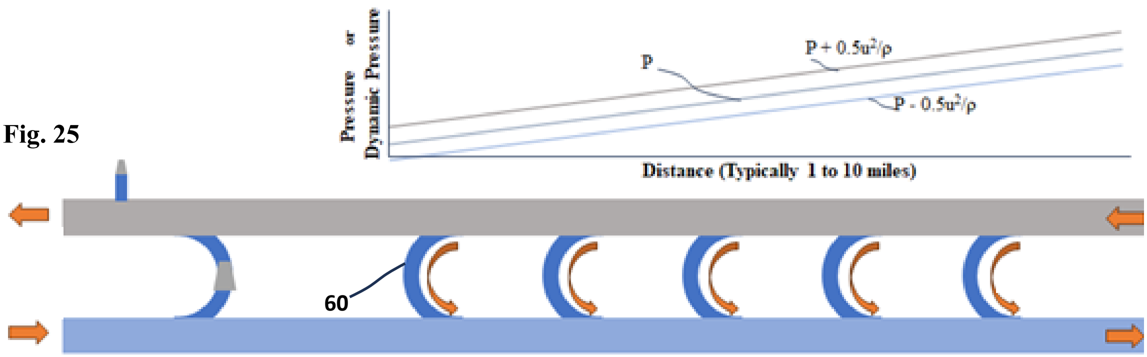


Fig 26

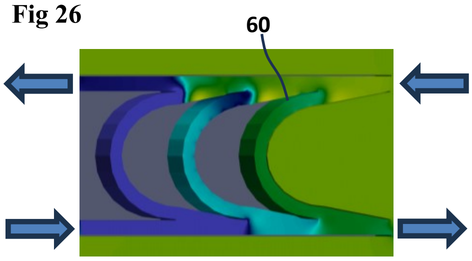


Fig. 27

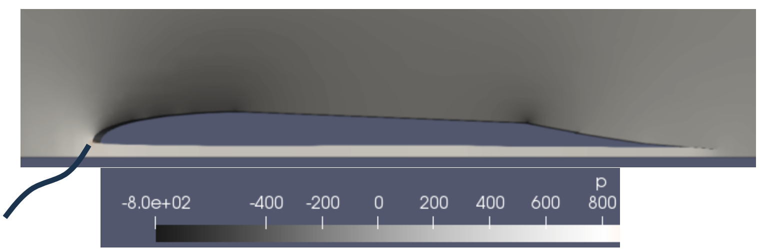


Fig. 28

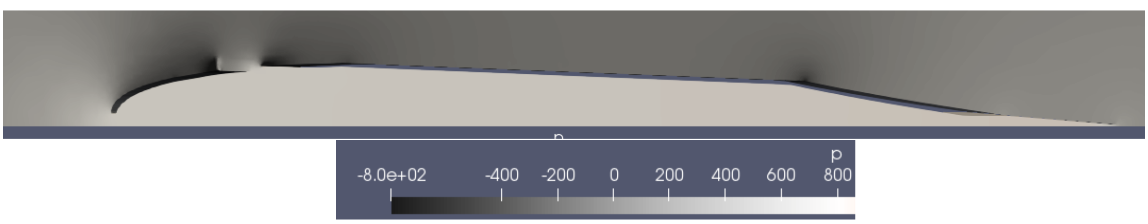


Fig. 29

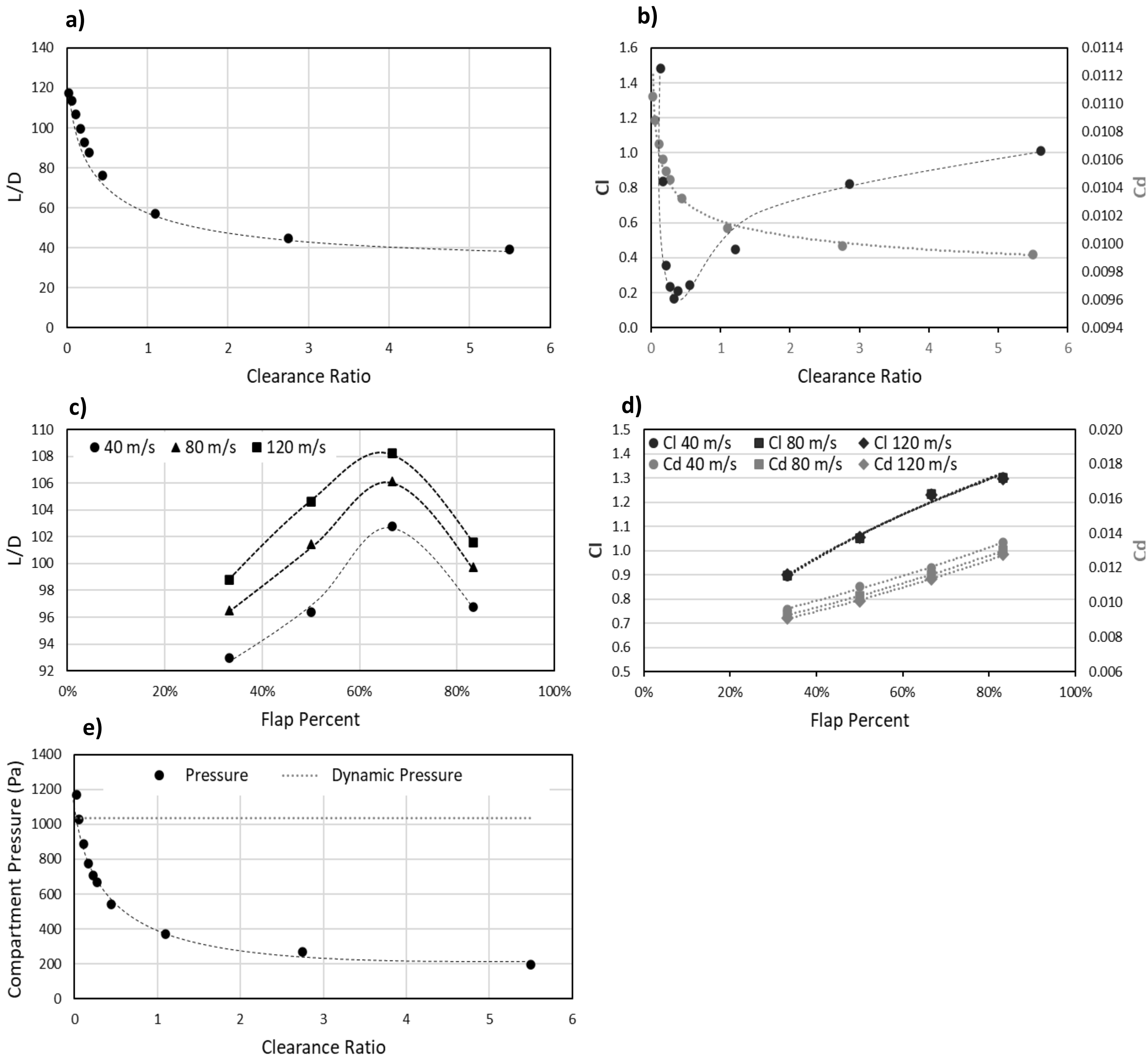

a)
L/D
Clearance Ratio
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
b)
Cl
Cd
Clearance Ratio
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.0094
0.0096
0.0098
0.0100
0.0102
0.0104
0.0106
0.0108
0.0110
0.0112
0.0114
c)
40 m/s
80 m/s
120 m/s
L/D
Flap Percent
92
94
96
98
100
102
104
106
108
110
0%
20%
40%
60%
80%
100%
d)
Cl 40 m/s
Cl 80 m/s
Cl 120 m/s
Cd 40 m/s
Cd 80 m/s
Cd 120 m/s
Cl
Cd
Flap Percent
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
e)
Pressure
Dynamic Pressure
Compartment Pressure (Pa)
Clearance Ratio
0
200
400
600
800
1000
1200
1400

Fig. 30

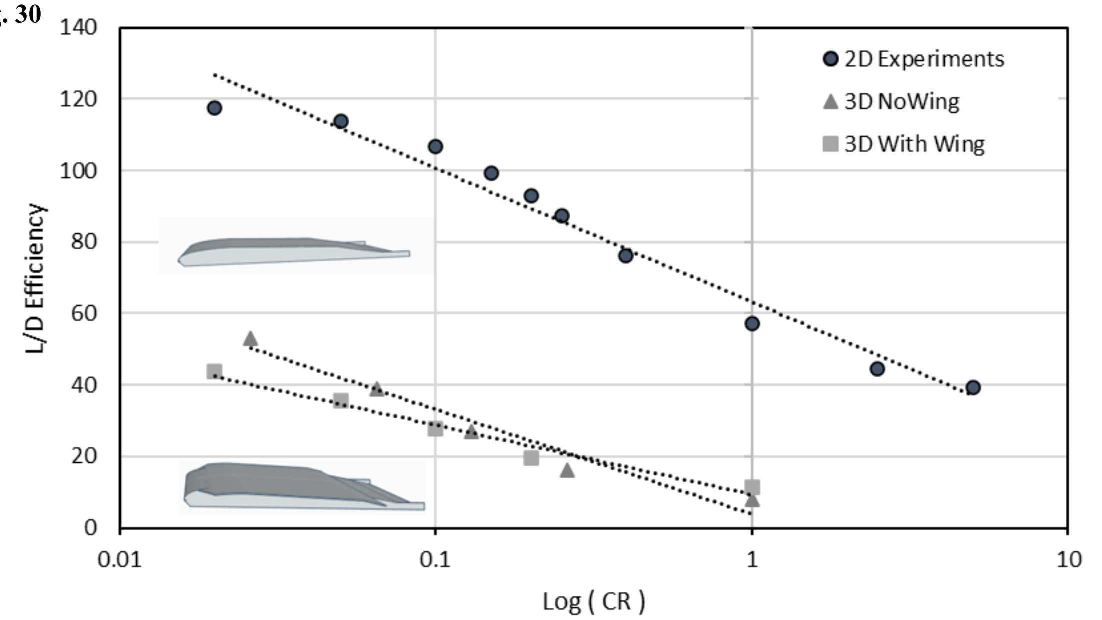

2D Experiments
3D NoWing
3D With Wing
L/D Efficiency
Log (CR)
0
20
40
60
80
100
120
140
0.01
0.1
1
10

Fig. 31

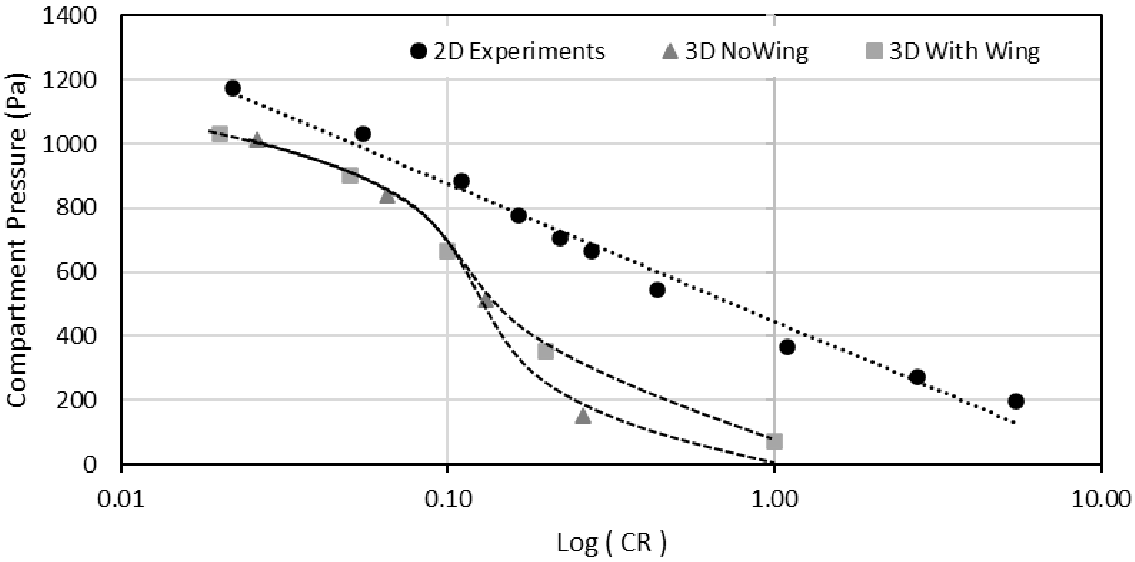


Fig. 33

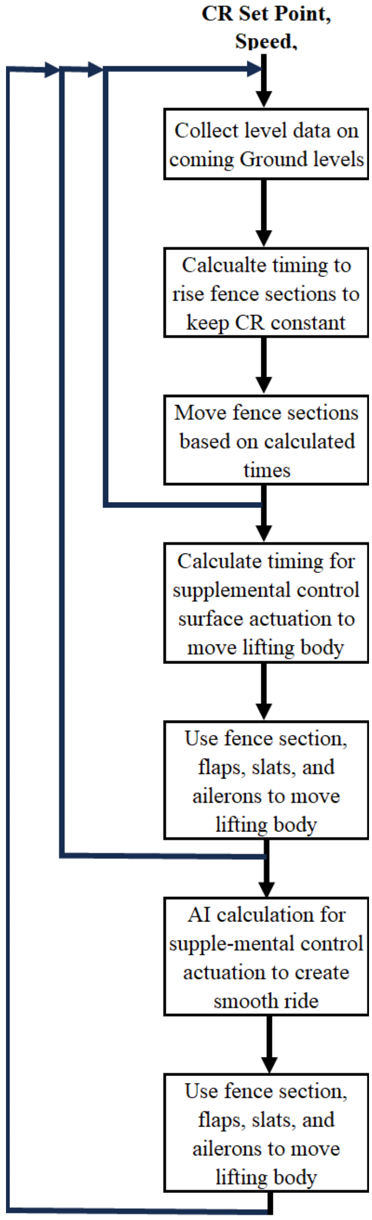


Fig. 32