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Analysing Hydro– Aerodynamic Characteristics of Three– Seat Wing in Ground Effect Craft

TRAN TIEN ANH, TRAN LE TRUONG HIEP
Department of Aerospace Engineering, Ho Chi Minh City University of Technology, Vietnam
Email: tienanh@hcmut.edu.vn; tien_anhjp@yahoo.co.jp

Abstract: Flying boat design is the topic that the Aerospace Engineering Department has concerned and studied since 2004. Previous students and researchers had researched and analysed about the characteristics of various configurations with the purpose of making an effective model of flying boat or Wing in Ground effect Vehicle (WIG). The model needs to adapt stability and safety during operation, which sets the first stage for commercialization in Vietnam market. Following previous studies, we improve, analyse and design a small flying boat with the new configuration which is similar to hovercraft. This flying boat (or WIG) differs from the traditional seaplane and simple WIG because it has an additional air cushion system to provide supplemental lift during take-off stage. In consequence, the aerodynamic and hydrodynamic drag will be reduced so that the required power from the engine is also reduced. The research purpose is to analyse the hydro- aerodynamic characteristics of the flying boat, then comparing the difference between a traditional WIG and the new one using air cushion system. In addition, proving for the effectiveness when using an air cushion system and calculating the required power is presented. Finally, propulsion system is intergraded with suitable engine for our Wing in Ground effect Vehicle.

Keywords: *Aerodynamic Lift, Hydrodynamic Lift, Drag, Additional Lift, Wing in Ground (WIG) Effect Vehicle, Air Cushion.*

Introduction:

Wing in Ground (WIG) effect vehicle is designed to attain sustained flight over a level surface (usually over the sea), by making use of ground effect, the aerodynamic interaction between the wings and the surface. These transportation vehicles are known with the other names like Ekranoplans, ground effect vehicle (GEV), Sea skimmer, Flare- craft or wing in surface effect ship (WISE).WIG operates at height which is near to the clearance ground (water, ground…), it uses an interaction between the wing's surface and the ground- called ground effect. In order to operate in a good condition, the aero- hydrodynamic characteristics, structure, stability of WIG while operating must be consider carefully.Our aim is making a design and constructing a model of WIG for three persons (including pilot) with an additional lifting system in take- off stage. The traditional Ground effect vehicles need a large power to take off because of the total drag. We decide to use the lifting system to supply more lift. In consequence, the hydrodynamic drag reduces so the magnitude of required power in take- off stage is smaller.The Aerospace Engineering Department of the Ho Chi Minh city University of Technology has been interested in GEV design for years. Our professors and students have studied the published documents and done many experiences to understand the characteristics and different configurations in order to build an effective model of WIG. Now, we continue to develop the model by analysing previous results by research team of of Dr. Tran Tien Anh. This configuration is different from the previous WIG by the additional air cushion system, which provides supplemental lift during take-off stage. In consequence, the aerodynamic and hydrodynamic drag will be reduced so that the required power used in take- off stage is also reduced. In the first step, understanding the definition and the influence of ground effect on WIG's operation is necessary. While this vehicle is operating near the ground, using the advantages of the ground effect, we need to remember two important factors in this stage are: height clearance and chord length, because these quantities determine the height where WIG can be sustained. Secondly, we make a preliminary design and choose size, weight and figure base on Roskam's documents. After comparing many options, we give our final configuration. Then establishing the aerodynamic and hydrodynamic equations of the forces that affect the WIG and using algebraic method to calculate the these forces while the WIG is working. Finally, calculating the quantity of power needed in the take- off stage, make a comparison with the traditional WIG, then make a final conclusion.

Figure 1: Hoverwing 2 for two persons

Materials and Methods:

Analysing hydro- aerodynamic characteristics of WIG

WIG is a combination of airplane and ship, so it has both characteristics of them. A designer must pay attention to this because these features determine which velocity needs to be attained to take off. In addition, calculating the forces acting on WIG during operation helps to specify a suitable structure, stability, engine…

In the beginning, we need to understand ground effect. When an aircraft flies at a ground level approximately at or below the length of the aircraft's wingspan, there occurs, depending on air foil and aircraft design, an often noticeable ground effect. This is caused primarily by the ground interrupting the wingtip vortices and downwash behind the wing. When a wing is flown very close to the ground, wingtip vortices are unable to form effectively due to the obstruction of the ground. The result is lower induced drag, which increases the speed and lift of the aircraft.In this research, an experimental method in Roskam's document is used to attain the change of C_L in ground effect zone. Following these steps:

+ For each air foil, it is possible to have the value of $C_{L\alpha}$ and angle of attack α when C_L = 0. From $C_{L\alpha}$ and α, equation $C_{L2D} = C_{L\alpha}(\alpha-\alpha_0)$ can be written.
+ At a specific height, calculate a decrement $\Delta\alpha_g$ (when WIG is in GE zone) and value of C_{L2D} (when WIG is out of GE zone).
+ With new angle of attack and old C_{L2D}, it is able to draw a graph of C_{Lg} and α at one specific height. From one graph, we use interpolating method to find out an approximate function of (C_{L2D}, α) at that height.
+ Repeat these steps at different height to calculate the value of C_L with different angle of attack.

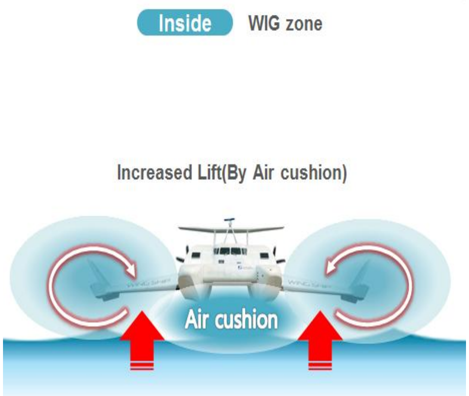

Figure 2: WIG in ground effect zone

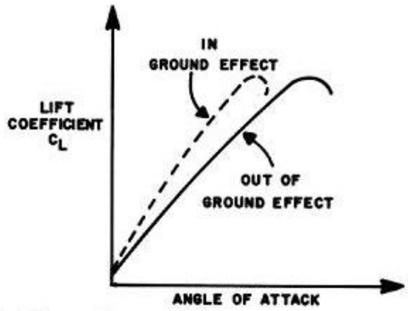

Figure 3: Lift coefficient increases in GE zone

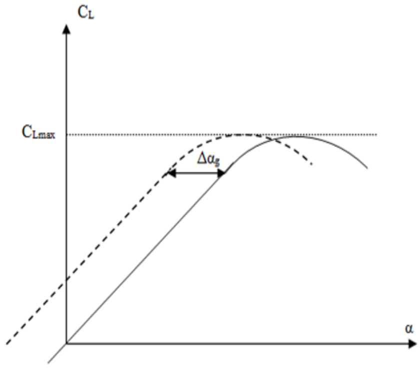

Figure 4: Decrement of angle of attack in GE zone

Forces in take- off stage: aerodynamic lift (main wing, horizontal tail,…), aerodynamic drag (main wing, fuselage, tail, nacelle,…), hydrodynamic lift, Archimedes Lift, hydrodynamic drag, wave drag. Aerodynamic forces can be established by using Roskam's documents [1]:

$$L_W = \frac{1}{2}\rho_k V^2 S C_{L_w}$$

$$L_h = \frac{1}{2}\rho_k V^2 S_h C_{L_h}$$

$$D = \frac{1}{2}\rho_k V^2 S C_D$$

In these formulas, ρ is air density (kg/m^3), V is velocity of WIG (m/s), S is wing area (m^2), S_h is horizontal tail area (m^2), C_L is lift coefficient, C_D is drag coefficient.When WIG stands still on water surface, its behaviour is like a normal ship. WIG can be started and operated on the water surface, but it needs enough power to take off. Because of large total drag, includes both aerodynamic and hydrodynamic drags, a required power must be larger than a small plane.In take–off stage, hydrodynamic lift includes two components: reactive force on the bottom and Archimedes buoyancy. At low speed high proportion buoyancy, as the velocity increases, the buoyancy is mainly derived from the dynamics, formula of lift coefficient can be written as below:

$$C_{L_o} = \tau^{1.1}\left(0.012\sqrt{\lambda} + \frac{0.0055\sqrt{\lambda}}{C_V^2}\right)$$

If the bottom of WIG is V type, which means the bottom angle β ≠ 0, C_{L0} need to be corrected:

$$C_L = C_{L_o} - 0.0065.\beta.C_{L_o}^{0.6}$$

Hydrodynamic lift:

$$L_h = \frac{1}{2}\rho V^2 S_{wet} C_L$$

It is impossible to have an exact formula to calculate a value of drags that acting when WIG is moving on the water. It depends on the demand of a design so it is necessary to choose appropriate formulas.
Hydrodynamic drag:

$$D_h = \frac{1}{2}\rho_n V^2 S_{wet} C_F$$

Drag coefficient is calculated follow ITTC 57 standard:

$$C_F = \frac{0.075}{(log_{10}Re - 2)^2}$$

Determining wet area of WIG's body:
To simplify WIG's body immerse in the water, consider it shapes as a prism (Combination of triangular prism and cube). As soon as WIG is floating, as soon as the immerse decreases, so we have some conditions:

$$0.1\,m \le T \le 0.24\,m \rightarrow \begin{cases} d = T - h \\ h = 0.1\,m \end{cases}$$

$$0.1\,m > T \rightarrow \begin{cases} d = 0 \\ h = T \end{cases}$$

So the wet area can be calculated as:

$$S_{wet} = 17.6d + 32.8h$$
$$V = 3.2d + 1.6h$$

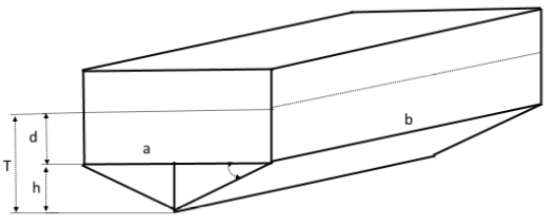

Figure 5: Simple body of WIG in water

Now we can build the equations of movement.
Equilibrium equation for WIG in take- off stage can be built as:

$$L_w + L_h + L_{hydro} + L_{acsimet} + Tsin\theta = W$$
$$Tcos\theta - (D_{aero} + D_{hydro} + D_{wave}) = m.a$$

When adding an air lifting system, rewritten these equations:

$$F_N + L_w + L_h + L_{hydro} + L_{acsimet} + Tsin\theta = W$$
$$Tcos\theta - (D_{aero} + D_{hydro} + D_{wave}) = m.a$$

Like seaplane, WIG in takeoff stage wishes to have a minimum of hump drag, because when velocity increases, drag increases. To decrease required power on take- off stage, reducing the total drag is needed. The angle of attack and the immerse change when velocity changes. So we need to find the value of angle of attack and the immerse suitable with each velocity to obtain the smallest magnitude of drag. There are steps of the progress:

+ At each velocity, put in one value of angle of attack.

+ Change the immerse part of WIG in water. Each value of immerse determines value of wet area and volume.

+ Calculate value of aerodynamic and hydrodynamic forces.

+ With every angle of attack and immerse is true for the equations above, choose their value which can obtain the smallest drag.

+ Repeat these steps for the next velocity.

With the final value of forces acting when WIG is operating, we can calculate the value of power.

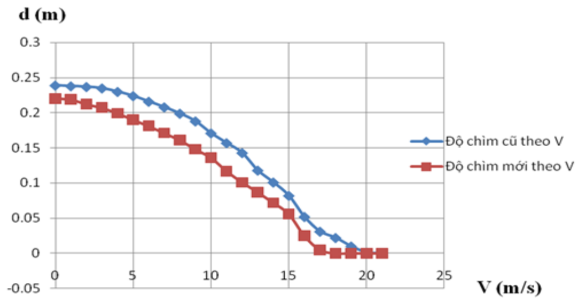

Figure 6: Submersible level changes according to the speed before and after installing an air cushion system.

From the comparative diagram also shows that the sinking height is decreased quickly when using the lift system. Therefore, a total drag will be also reduced faster.

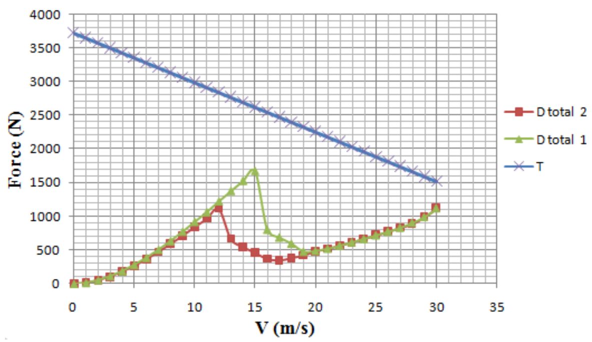

Figure 7. Resistance before and after the air cushion system

For the lift, at the velocity 21 m / s, the magnitude value is sufficient aerodynamic, lift is greater than the weight so that the flying boat will be taken off. When not using an air cushion system, the biggest drag in this case is D_{max}= 1647.5 N at speeds of 15 m / s .
When fitted with air cushion system, additional lift due to air holes will maintain the flying boat moves forward until it reaches the speed of 21 m / s, then it will take off. The maximum drag D_{max}=1111.2 N at V = 12 m / s.

Results and Discussion:

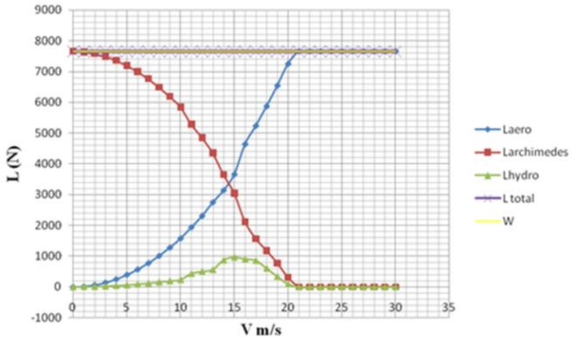

Figure 8: Lift changes with V chart for a traditional WIG

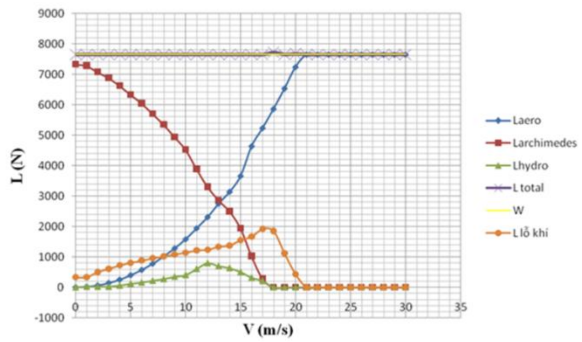

Figure 9: Lift changes with V chart for a new WIG

From two charts above, we can see:

- At V = 21 m/s, value of lift force is enough for taking off from the water.
- For traditional WIG, maximum value of total drag is 1648N at V= 15 m/s. Otherwise, when using an additional air cushion system, WIG has maximum of drag is 1111 N at V= 12 m/s.
- The immerse part of WIG in water is decreases faster when activating the air system. That is the reason why total drag is not large as the old types.

Conclusion:

In this research, we completed the configuration design and analysed the aero- hydrodynamic characteristics of this Wing in Ground effect Vehicle. For main wing, the chosen air foil is NACA4412, with area of 23 m^2 for trapezium shape, span of 9 m, wing tip of 1.46 m and wing root of 3.65m length. Dihedral angle is -3^0 and sweep angle is 7^0. The wing weights 130 kg and is made of aluminium. For fuselage, width is 1.8 m, length in 8 m, maximum height is about 1.32 m. Streamline shape for overall body. Material is aluminium. For horizontal tail, air foil is NACA 0015, area is 4.7 m^2 for rectangle shape, span is 4 nm chord is 1.14 m. Elevator's area is 1.88 m^2. For two vertical tails, they have trapezium shape, with airfoil of NACA 0012, area of 1.25m^2, height of 1.8 m, average chord length of 0.7 m and taper ratio of 0.58. Rudder on each vertical tail has the height of 0.9 m and average chord length of 0.28 m. Buoys have length of 4 m, width of 0.4 m and height of 0.3 m. They are made from aluminium material.The results of analysing the characteristics of WIG are similar to seaplane on the market. If WIG operates traditionally, it will float on the water surface at 21 m/s and can take off at this velocity. If using an additional air cushion system, WIG is able to float completely on surface water at 18 m/s and continue to reach 21 m/s to take off. When applying the air lifting system, we can reduce a significant value of total drag, therefore, reduce time for take-off stage.

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