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Investigation of Lifting Force Affected by the Velocity and Angle of Attack (AoA) In Wing-in-Ground (WiG) Craft

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ABSTRACT

The Wing-in-Ground (WIG) craft represents a pioneering vehicular innovation that exploits aerodynamic lift via a cushioning mechanism, enabling it to remain suspended above the water's surface. A notable concern encountered during the navigational manoeuvres of the WIG craft over the uneven sea terrain pertains to its potential impact on fuel efficiency during flight durations. This research objective is focused on the pivotal of ascertaining the optimal lifting force prerequisites for a prototype WIG craft. This comprehensive study entails an exploration of diverse combinations of velocities and angles of attack (AoA) to identify the most suitable configuration capable of attaining the requisite lift force levels. The study's methodology revolves around the adaptation of the actual WIG concept, encompassing a focus on the aerofoil profile and leveraging insights garnered from a design concept pertaining to WIG craft. To emulate real-world scenarios with precision, computational simulations employing the flow simulation capabilities of SolidWorks software are executed concurrently with the validation of a fabricated prototype. Parameters encompassing, angle of attack, and velocity are meticulously configured, adhering to the commonly employed parameters within the realm of WIG craft operations. The resulting outcomes are rigorously validated and subsequently compared against a lift coefficient of 1.25 at an angle of attack set at 16°, consistent with outcomes from prior research activities. This established angle of attack serves as a foundational reference for the present study's empirical conclusions. The culmination of these simulations yields the identification of an optimal arrangement characterized by a velocity of 120 km/h coupled with an angle of attack measuring 20°. This particular configuration consistently stimulates the requisite magnitude of lift force, thereby demonstrating the feasibility of elevating the WIG craft prototype without compromising stability or safety.

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1. Introduction

In the world of fast maritime transportation, WIG (Wing-In-Ground) craft is proving to be a promising technology. Multiple studies have been conducted to determine the aerodynamic characteristics of WIG craft [1-3]. The utilization of WIG (Wing-In-Ground) craft presents a compelling strategic option for countries endowed with expansive maritime territories seeking to fortify their national defence capabilities. In comparison to conventional waterborne vessels, WIG craft offer distinctive advantages. These craft function at minimal altitudes above the sea surface, a configuration that optimizes their operational efficiency in contrast to standard boats. This is attributed to the cushioning effect that diminishes hydrodynamic resistance, resulting in reduced fuel consumption that remains unclear in scientific understanding. The quality of the WIG structure's fabrication component was affected by a certain machining process involved in the manufacturing [4]. The material used to manufacture and fabricate the WIG craft is the main element of its development, and it should be appropriate for the structure of the craft, including all parts such as the wing, tail, cockpit, and joined part for a fully assembled WIG craft structure. Material selection is crucial in the manufacturing industry to ensure that the designated product development meets the international standard requirement and produces the desired functions. Recent studies explored the application of natural fibres such as kenaf and banana fibre composite to enhance progress toward sustainability goals [5]. Precision drilling is equally important for the structural integrity and performance of WIG craft as it is for conventional aircraft components. WIG vehicles operate close to the water surface, where aerodynamic and hydrodynamic forces exert a significant influence on structural integrity [6].

Recent advancements in Wing-In-Ground (WIG) effect vehicles have demonstrated the critical relationship between lift coefficient and angle of attack. Optimizing wing design to increase lift efficiency at low altitudes is one of the key priorities. The angle of attack has a significant impact on the lift coefficient, which measures the lift generated by a wing. Changing the angle of attack able improve the lift coefficient and enhance the craft's performance and stability. Researchers are developing models to accurately predict lift behaviour in various conditions, using advanced simulations and wind tunnel tests. For WIG craft to be effective in commercial and defence applications, precise calibration of angle of attack and lift coefficient is crucial.

The WIG prototype faces significant challenges in achieving the required lift force for sustained elevation, as previous studies have revealed a discrepancy between the calculated lift force and the craft's actual weight [7]. This necessitates a reassessment of lift force calculations through both simulation and empirical data. Various factors influencing WIG craft lift force, including wing design, angle of attack, and craft velocity [8,9], have been explored in prior research. However, existing methods for calculating lift force often fail to accurately predict real-world performance, leading to insufficient lift and subsequent operational limitations.

Upon comparing the performance metrics of WIG craft and traditional boats, the former emerges as a superior contender in both swiftness and fuel economy [10]. Ensuring an adequate lift force is pivotal for enabling WIG craft operations at low altitudes [11]. Key determinants such as wing dimensions, angle of attack, and craft velocity play crucial roles in the seamless functioning of WIG craft [12]. An exploration of these factors, as illustrated in Figure 1, is imperative for the advancement of lift force capabilities in the WIG craft prototype.

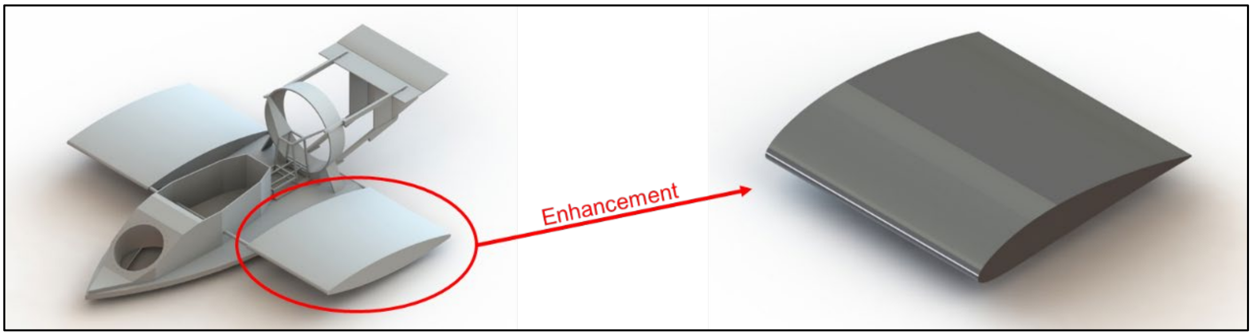


Fig. 1. WIG craft prototype

To ensure optimal operational performance, the Wing-in-Ground (WIG) prototype encountered several issues that required precise computation of the lift force. The lift force calculated in a previous investigation exhibited inadequacy in sustaining the WIG craft's elevation and the lifting force is assessed by comparing the simulation results with weight data, as indicated by previous research [13]. An essential aspect under scrutiny involves the angle of attack, a factor crucial in ensuring the proficient operation of the WIG craft prototype. Furthermore, an in-depth analysis of the craft's velocity assumes significance, given its direct influence on generating the lift force through the principles of aerodynamic lift at the aerofoil, as delineated in [14].

The research endeavour focuses on evaluating the requisite lift force essential for the effective elevation of the WIG craft prototype. The quantification of the lift force hinges on the interplay between velocity and the angle of attack [15]. Thus, this investigation strives to identify the optimal velocity and angle of attack conducive to achieving the desired lift force for the WIG craft prototype.

2. Analysis of WIG Craft Prototype

The comprehensive grasp of the interplay between velocity and angle of attack in relation to lift force paves the way for the engineering of more proficient and robust WIG craft. Such advancements are anticipated to culminate in diminished fuel consumption and augmented performance across diverse operational scenarios. The integration of sophisticated simulation methodologies and cutting-edge material technologies stands to further elevate the utility of WIG craft, positioning them as assets of considerable value in both civilian transportation and defense sectors. Moreover, the findings lay a robust groundwork for ensuing scholarly inquiries within the spheres of aerodynamics and fluid dynamics

An aerofoil is a profile that may generate aerodynamic forces as a result of fluid flow. The aerofoil is critical in creating aerodynamic lift in aviation settings [16]. The shape of an aerofoil is determined by the prototype's intended use and operating situation. Notably, lift force is generated mostly in the bottom area of the aerofoil's surface. The balance of lift force and gravity force determines the possibility of prototype flight. When the lift force exceeds the weight of the prototype, successful flight is possible [17]. The chord line delineates different upper and lower chambers in the design of the aerofoil. The aerofoil's orientation or angle of attack produces different results in terms of aerodynamic lift. This research involves critical comprehensive by simulating the full scale of WIG wings affected to the various important parameters above 1 meter approximately the sea level. The simulation emphasized the straight–line cruise with 5 parameter speeds and 5 different angles using the SolidWorks software.

The angle of attack denotes the angular disposition between the chord line and the relative wind in relation to the aerofoil configuration. Increasing the angle of attack results in a progressive increase in lift force and a corresponding increase in drag [18]. The threshold beyond which the angle of attack must not exceed is termed the critical angle, marking the onset of a stall phenomenon. Due to this stall occurrence, the lift coefficient decreases, resulting in a decline in aerodynamic lift [19]. An unfavorable situation for seamless operation of the prototype results from this situation. Hence, the determination of the angle of attack holds paramount significance. The optimal value of the angle of attack must be ascertained meticulously to ensure the prototype functions proficiently [20].

2.1 Lifting force and Flow Direction

The generation of lift force transpires as a solid entity known as an aerofoil traverse swiftly through a fluid medium. The resultant force acts perpendicular to the prevailing flow direction. The occurrence of lift force is contingent upon the interaction between the airflow and the aerofoil's surface at a specific orientation termed the angle of attack [21]. Within the upper chamber of the aerofoil, the airflow attains elevated velocity, resulting in a concomitant reduction in absolute pressure [22]. This phenomenon gives rise to the manifestation of lift force due to the inherent dissimilarity between the characteristics of the upper and lower chambers. The velocity of the airflow displays an inversely proportional relationship with the absolute pressure.

The wing's configuration takes its cues from the NACA-4412 aerofoil shape. To seamlessly align with the prevailing conditions and weight specifics of the WIG craft prototype, adjustments were implemented in the wingspan dimensions. In a similar vein, alterations were applied to the length of the chord line, carefully tailored to procure the requisite lift force magnitude [23]. Worth noting is the considerable discrepancy in dimensions compared to a prior study [24], which demonstrated its inability to fulfill the prerequisite for generating an adequate lift force. In practical operational scenarios, the WIG prototype bears an estimated weight of approximately 36000N. This comprehensive figure envelops the entirety of the structural components, inclusive of the operator and the gamut of equipment integral to seamless operational functionality.

3. Methodology

3.1 Simulation Condition

WIG craft lifting force able to be calculated by taking into account key parameters such as the weight, the speed, and the engine power of the craft. A precise calculation of these forces will help us determine whether the WIG craft able to operate effectively or whether modifications are necessary. Following the establishment of the necessary parameters, simulations are conducted to determine the required lifting force. These simulations focus on the lift needed for the WIG craft to operate. The resulting data are analysed to determine the optimal values and calculations for the WIG craft to fly above sea level.

The investigative approach adopted for this study on Wing-In-Ground (WIG) craft is a composite of theoretical simulations and practical experimentation. This methodology is designed to refine the aerodynamic parameters essential for the craft's operation. Through the utilization of SolidWorks for Computational Fluid Dynamics (CFD) simulations, the research anticipates the effects of varying velocities on the generated lift force. Subsequent empirical testing is conducted to substantiate the simulated outcomes, ensuring the models' fidelity to actual performance. Emphasizing the use of eco-conscious materials, the research aligns with the imperative of sustainable development. The primary aim is to pinpoint the precise operational conditions—specifically, the velocity and angle of attack—that optimize lift force, thereby elevating the WIG craft's functionality and ecological compatibility.

This study involved simulating several conditions, as detailed in Table 1. The parameters discussed in this table are aligned with the study's objectives and were sourced from relevant external references. These parameters are essential for calculating the lift and thrust forces acting on the WIG craft. The values from Table 1 were also utilized to run simulations, particularly focusing on the wing of the WIG craft. The table provides a comprehensive overview of the parameters pertinent to this study. The speed and the angle of attack is observed for making research about aerodynamic flow that change the value of lifting force and pressure act on the wing. The parameter has been setting in general setting at flow simulation for choosing the condition of the simulation.

Table 1
Parameters

No	Parameter	Value	Unit
1	Velocity	60 90 120 150 180	kmh^{-1}
2	Air density	1.293	kg/m^3
3	Altitude	3	m
4	Temperature (Malaysia Seas)	30.98	$^{\circ}C$
5	Gravity	9.81	ms^{-2}
6	Pressure	101288.97	Pa
7	Angle of attack (AOA)	0 5 10 15 20	°
8	Weight (Whole body of WIG Craft)	36000	N

The forthcoming study will employ SolidWorks for computational fluid dynamics simulations to investigate the impact of velocity on the lift force exerted upon the Wing-In-Ground (WIG) craft's structure. Adhering to the methodologies established in prior research, the simulation will encompass the entire prototype, correlating the lift force with the craft's overall weight. Notwithstanding, particular attention will be given to the wing, as it is a critical component in lift generation. The design specifications for the wing and other structural elements have been predefined, aligning with the findings of earlier investigations. The simulation parameters are delineated in Table 2, as presented in the subsequent section.

Table 2
Design Parameters

Parameter	Types of wings		Notes
	Previous modified	Latest modified	
Width, mm	1943	4000	Wingspan
Length, mm	3009	4020	Chord lines
Height, mm	375	507	Thickness
Radius, mm	25	16	Trailing edge
Area, m^2	5.89	16.23	Lower wing section
Mass, kg	1048	898	
Thickness, mm	32	10	
Platform	NACA-4412		

3.2 Lifting Force Equation

The concept of lift force is central to the field of aerodynamics, particularly in the context of Wing-In-Ground (WIG) craft. This force is engendered as the craft moves through a fluid medium, such as air, and is quantifiable through a specific aerodynamic equation. The lift force equation is instrumental in ascertaining the lift coefficient, which is a measure of aerodynamic efficiency. To accurately compute the lift force, a comprehensive set of calculations is required, taking into account various factors including the craft's geometry and the viscosity of the air. However, for practical purposes, researchers often employ a simplified equation to facilitate these calculations, as depicted in the below equation:

$$L = \frac{1}{2}\rho V^2 A C_L \tag{1}$$

Where:
$L = Lift\ force$
$V = Velocity\ of\ aircraft\ in\ m/s$
$\rho = Air\ density\ folllowed\ by\ the\ altitude$
$A = Reference\ area\ of\ wing\ area\ of\ aircraft\ in\ m^2$
$C_L = Coefficient\ of\ lift$

The velocity V, which refers to the speed of the aircraft in flight, along with the other variables, affects the value of the lifting force. In this equation, $\frac{1}{2}v^2$ represents the dynamic pressure, resulting from the aircraft's movement. The coefficient of lift C_L is dimensionless and varies with the angle of attack. The angle of attack is the angle between the oncoming air and the chord line of the aerofoil. Adjusting the wing surface area A will also impact the lifting force. Therefore, the lifting force is influenced by several factors, including the aircraft's weight and the wing's surface area necessary to achieve lift. This study focuses on quantifying the lifting force acting on the WIG craft based on these parameters.

3.3 Lifting Equation

The performance of aerofoils and wings are compared using the lift coefficient, commonly abbreviated as C_L. The lift equation includes the lift coefficient as one of the variables. The equation was defined as:

$$C_L = \frac{L}{A\frac{\rho V^2}{2}} \tag{1}$$

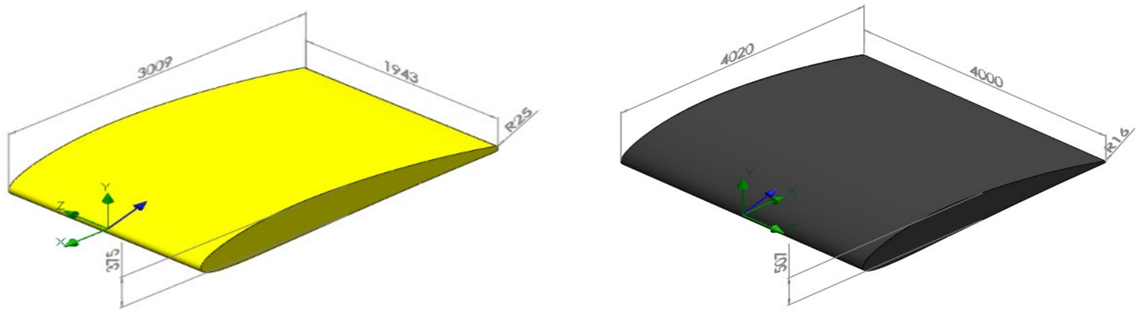
Where:
$C_L = Lift\ coefficient$
$L = Lift$
$A = Wing\ area$
$\rho = Air\ density\ folllowed\ by\ the\ altitude$
$V = Velocity\ of\ aircraft\ in\ m/s$

The lift coefficient (C_L)is a critical parameter in evaluating the performance of aerofoils and wings, as it quantifies the lift generated relative to the wing area, air density, and the square of the aircraft's velocity. The lift equation, expressed as $C_L = \frac{L}{A\frac{\rho V^2}{2}}$ where L represents lift force, A denotes wing area, ρ is the air density, and V is the velocity of the aircraft, allows for the comparison of different aerofoil and wing designs under varying conditions. This equation underscores the interdependence of these variables and facilitates the accurate prediction and optimization of lift performance, essential for the effective design and operation of Wing-In-Ground (WIG) craft and other aerodynamic structures.

4. Results

4.1 Result Comparison between Previous and Recent Modified Wing

These findings were obtained through a rigorous comparison between a previously adapted wing model and its latest version. As depicted in Figure 2(a), the wing model under scrutiny underwent certain alterations as outlined in the referenced work. In contrast, Figure 2(b) portrays the refined rendition of the wing model, which has undergone further enhancements during the ongoing investigation. The simulation parameters were standardized to maintain a velocity of 120 km/h and an angle of attack of 20° for both simulation scenarios. Upon evaluating the outcomes, it becomes evident that the mean upper wing pressure for the previously modified wing stands at 100,935 Pa, whereas the corresponding lower pressure measures 101,727 Pa. The notable divergence in absolute pressure values indicates that dynamic lift forces are exerting their influence beneath the designated wing segment.



(a) (b)

Fig. 2. Previous (a) and recent (b) modified wing model

Subsequently, the pressure magnitudes at the upper and lower wing surfaces for the recently modified configuration are measured at 100,800 and 102,341 respectively as shown in Table 3. The recently modified design exhibits greater disparities between upper and lower wing sections compared to the previously modified design based on analysing the results. Stronger lifting force is expected as the pressure disparity between upper and lower regions increases [25].

Table 3
Summary of comparison between recent and previous modified wing model

Wing section	Modified wing pressure, Pa		Pressure percentage different, %
	Recent	Previous	
Upper wing section	100,800	100,935	0.13
Lower wing section	102,341	101,727	0.6

Based on the present investigation, the latest wing modification heightened the lifting force observed as shown in Figure 3. Through meticulous simulation, a substantial enhancement of approximately 129.42% is evidenced when comparing the most recent wing modification with its predecessor. This notable advancement unequivocally signifies the adequacy of the resultant lifting force for application in the realm of WIG (Wing-in-Ground) craft under the newly stipulated parameter and dimension. The quantification of the lifting force attributed to the beforehand modified wing stands at 4,286 N, whereas the contemporarily altered wing commands a lifting force of 20,005 N. It should be noted that for configurations involving a double-wing arrangement, the lifting force of a singular wing is duly multiplied by a factor of two.

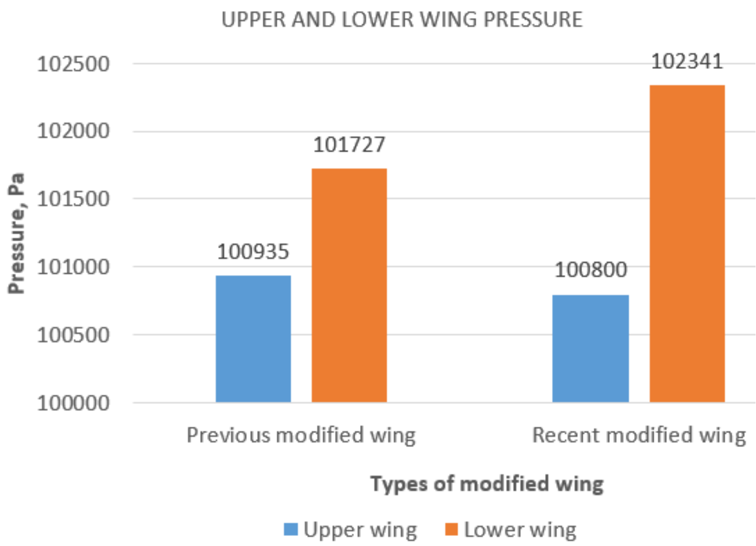


Fig. 3. Upper and lower wing pressure

3.2 Results Summary for Pressure at Upper and Lower Wing Section

The achievement of an appropriate lifting force is imperative for the optimal functionality of the WIG craft. This research delves into several critical parameters pertinent to this endeavour. The simulations in this investigation encompass varying velocities: 60km/h, 90km/h, 120km/h, 150km/h, and 180km/h. These velocity settings were established through probing the upper and lower wing sections, with each segment equipped with three distinct probes. The ensuing values represent the averages derived from these probes. Additionally, an array of angle of attack configurations, namely 0°, 5°, 10°, 15°, and 20°, were employed to comprehensively explore their influence. These distinct angle of attack values subsequently engender diverse pressure and velocity distributions across the aerofoil's surface. The graphical representation in Figure 4 visually portrays the pressure variations across the upper and lower wing sections concerning velocity.

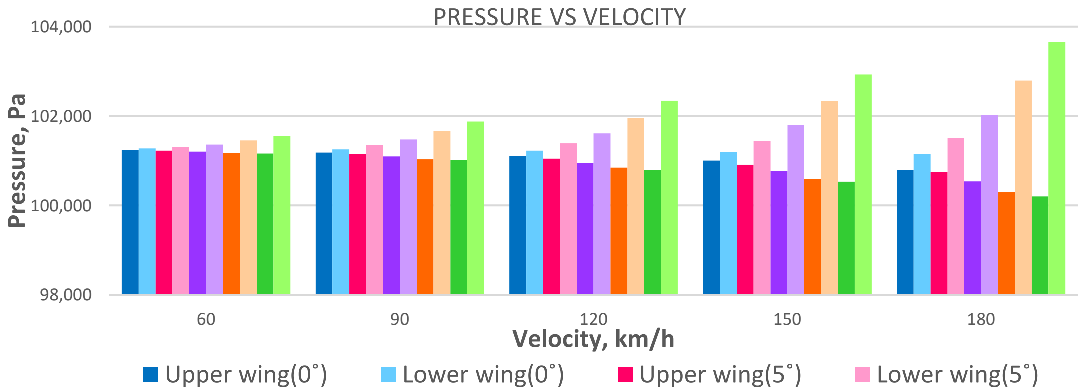


Fig. 4. Graph of pressure vs velocity for upper and lower wing with various velocity

According to the graph in Figure 4, the largest amount of pressure is acting at the lower wing section at a velocity of 180km/h, with a value of 103,657 Pa. The lowest pressure reading, which is 100,203, is again at 180 km/h but acting at the upper wing area. 20° angle of attack is used in both configurations. The pressure differential between the top and lower wing sections is 3,454 Pa, with the lowest pressure difference being 35 Pa at 60km/h and 0° angle of attack. At the lowest pressure differential, the upper wing section pressure value is 101,240 Pa, though the lower wing section pressure value is 101,275 Pa. The relationship between pressure and velocity is inverse. Aerodynamic lift occurs on the aerofoil form once the airflow acts at the leading edge, usually refers to the front segment of the aerofoil [26].

Figure 5 depicts the greatest pressure acting at the lower wing with a velocity of 180 km/h and an attack angle of 20°. The pressure value for the upper wing part decreases as the angle of attack increases at each velocity [27]. The highest-pressure variation acts at 180 km/h with a 20° angle of attack. A lifting force is generated at the wing model by the highest value at the lower wing section. For each velocity, the pressure applied on the lower wing portion increases as the angle of attack increases. Velocity and pressure are inversely related, consequently, the difference in velocity acting at the higher and lower wing sections is caused by the form of the aerofoil. Compared to the top wing segment, the lower wing section travels more slowly. Therefore, although having a different velocity and angle of attack, the lower wing part is under more pressure than the top wing section. However, when a stall occurs, the lift force will decrease, and the aerofoil idea is not applicable [28].

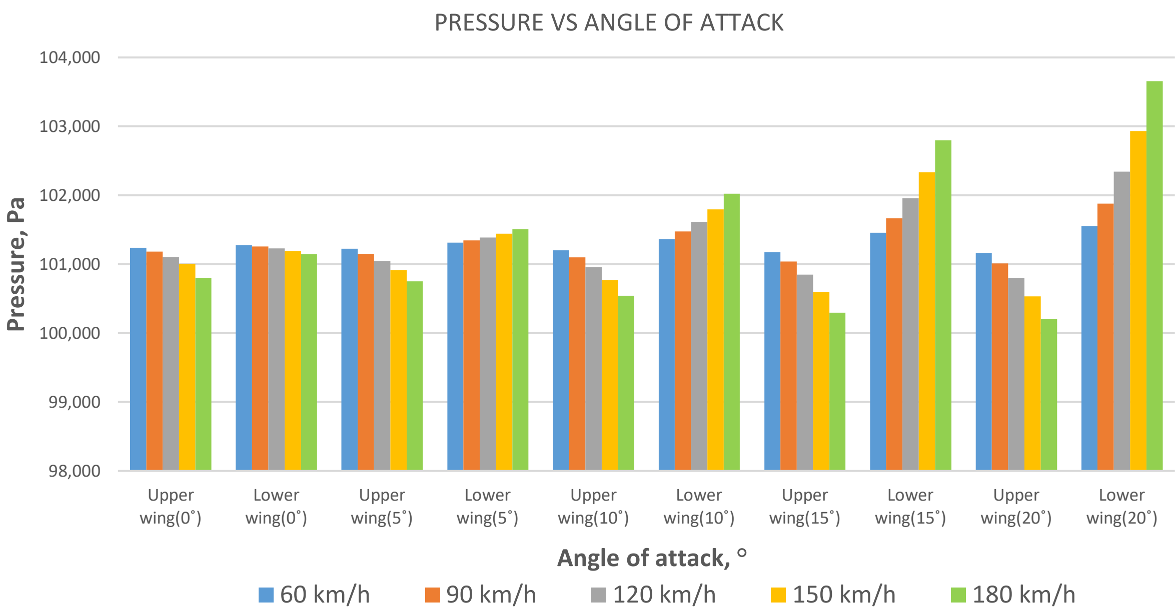


Fig. 5. Graph of pressure vs velocity for upper and lower wing with various velocity

3.3 Results Summary for Lifting Force Acting on Double Wing WIG Craft

The lifting power must be calculated based on the target to guarantee that the WIG craft operates without a hitch. The value of the lifting force is significantly impacted by the angle of attack [29]. The amount of lifting force is determined by the interaction of pressure, velocity, and angle of attack [30]. Figure 6 depicts a graph of lift force versus velocity operating on a double wing at various angles of attack.

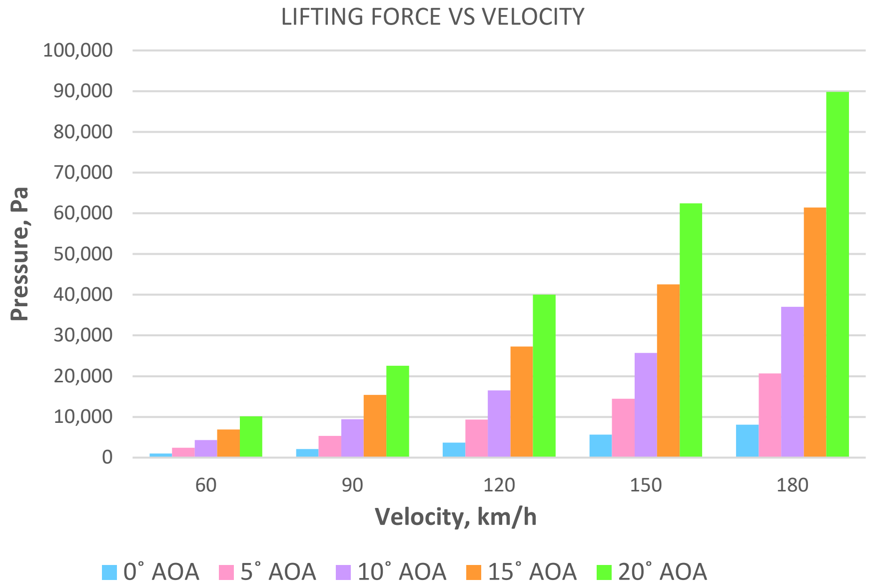
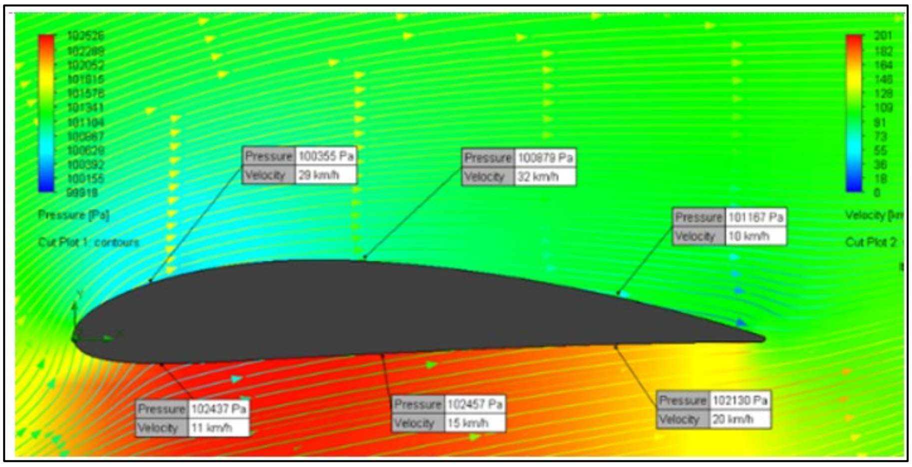


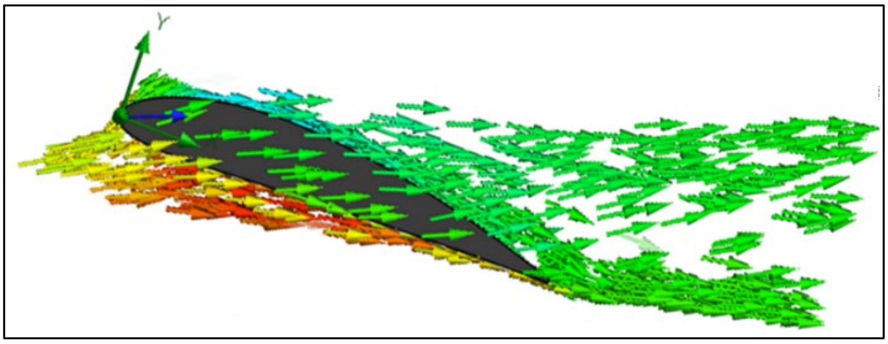
Fig. 6. Graph of lifting force vs velocity with various angles of attack for double-wing

The greatest value of lifting force applied on a double wing occurs at a speed of 180km/h and an angle of attack of 20°. Measured maximum lifting force is 89,862 Newtons. The lowest value of lifting force is at 60km/h with a 0° angle of attack and with 1,026 N lift force value. This study's median speed is 120 km/h. At a 20° angle of attack, the lifting force has a maximum value of 40,011 N and a minimum value of 3,664 N. Given the same setup of angle of attack, the amount of lift force acting increases as velocity rises [31]. Additionally, the lift force value rises as the angle of attack changes. This implies that the lift force is an exact reflection of the angle of attack and the speed. The greatest angle that an aerofoil may attain before experiencing a condition known as stall is referred to as the critical angle of attack [32]. Stalls occur when the upper air flow and upper chamber surface separate, which result in a reduction in lift [33]. The precise orientation angle of attack is therefore crucial to the success of the WIG craft.

The air pressure and flow direction behind the aerofoil form are shown in Figure 7(a). In the simulation, the pressure is represented by colour. The pressure in the lower wing part is high, indicating that the lifting force occurs there. The same information is shown in Figure 7(b) but with values for pressure and velocity.



(a)



(b)

Fig. 7. (a) Visual of pressure and (b) flow direction acting at 120km/h with 20° angle of attack

3.4 Validation of Simulation

Incorporating an alternate set of parameters involving a velocity of 60 km/h coupled with an angle of attack of 16°, the process of validation has been conducted through simulation. To establish the credibility of the simulation data, a comprehensive validation procedure is imperative. The referenced article stipulates a lift coefficient of 1.25. Correspondingly, within the confines of this present study's simulation, the lift coefficient was intentionally adjusted to match the aforementioned value of 1.25, employing identical parameter configurations. In the scenario where an angle of attack of 16° is applied, the exact lift coefficient value was employed during the computational analysis. The resultant computed magnitude, quantified at 3804.33 N, deviates from the initial computed value of 3794.95 N. This discrepancy amounts to a marginal disparity of 0.25% when considering these comparative values.

4. Conclusions

According to the findings, the objective has been effectively achieved. Employing the SolidWorks software, a comprehensive flow simulation was conducted to analyse the parameters of velocity, angle of attack, and lifting force pertinent to the Wing-in-Ground (WIG) craft. When compared to previous iterations of wing modifications, the latest configuration exhibits the highest lifting force, effectively capable of sustaining the WIG craft's weight. The findings from this study have significant implications for the field of mechanical engineering, particularly in the design and optimization of Wing-In-Ground (WIG) craft. The findings from this study have significant implications particularly in the design and optimization of Wing-In-Ground (WIG) craft. The close alignment between the computed lift force and the referenced lift coefficient, with only a 0.25% discrepancy, validates the robustness of our simulation model. This precision suggests that our model can reliably predict WIG craft's aerodynamic performance, reinforcing the utility of computational simulations in lift force calculations. These results align with existing aerodynamic principles and validate the use of tools like SolidWorks for both academic research and practical engineering. Furthermore, this study underscores the critical roles of velocity and angle of attack in determining lifting force, highlighting the necessity for careful parameter selection in WIG craft design. By achieving such precise results, this research supports efforts to improve WIG vehicle efficiency and performance, which is vital for advancing their commercial and defence applications.

Ordinarily, the WIG craft attains speeds exceeding 150 km/h while traversing water. Given the current velocity range characterized by an average condition, the most favourable speed range for generating lift force lies between 90 and 120 km/h. Below the threshold of 90 km/h, the velocity becomes insufficient to provide the WIG craft with the dynamic lift it requires. Despite its elevation of merely 3 meters above sea level, the WIG craft remains constrained to this altitude direction. The simulation conducted at 120 km/h revealed that an angle of attack of 20° resulted in the highest recorded lift force value of 40011 N. Configuring the WIG craft to maintain a velocity of 120 km/h while employing a 20° angle of attack yields sufficient lift force to elevate the craft, which bears an approximate weight of 36000 N. It is noteworthy that the generation of lift force during operational scenarios is contingent upon environmental factors and the cumulative weight of the craft. In conclusion, the highest operational speed required to facilitate the necessary lift force [34] is determined to be 120 km/h, marking the definitive endpoint of this study. Future research should investigate an expanded spectrum of velocities and angles of attack to further refine the understanding of lift force dynamics. Examining the influence of environmental factors and variations in craft weight under operational conditions will yield more comprehensive insights. Moreover, the advancement of materials science and the creation of innovative wing designs promise to enhance efficiency and performance significantly. Broadening the scope of simulations to incorporate real-world testing will be essential for validating these findings and advancing the practical application of Wing-In-Ground (WIG) craft across diverse industries.

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