Case Study on Aerodynamics Stability of Bixel Wing-In-Ground Effect Craft

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Abstract. Wing-in-ground effect (WIG) crafts fly efficiently by exploiting the ground effect i.e. generating a notable rise in the lift-over-drag ratio when a three-dimensional wing approaches a large flat plane either water or ground surface. A successful WIG craft will create another mode of transportation categorise in between commercial airplanes and marine vessels. Hence, this paper presents a case study of Bixel Wing-In-Ground-Effect aerodynamic (Bixel WIG). The initial task is to simulate Bixel WIG aerodynamic using XFLR5 software. The craft configuration is a double wing flat aerofoil wave rider design with aspect ratio variation from 0.25 to 0.5 as in USA PATENT #5105898 C.BIXEL. Based on the result of the simulation, the design of the six seater double wing Bixel WIG is proposed. The design is benchmarked against Lippisch RHB X-114 and UH-18 SPW.

Keywords: wing-in-ground-effect, WIGE craft, Aerodynamics, Bixel, hoverwing

1. Introduction

A phenomenon known as ground effect occurs, when a three-dimensional wing flies closes to a large flat plane either water or ground surface. This result is in a notable rise in lift-to-drag ratio. In this paper, the authors would like to introduce a patented Double wing flat aerofoil design from Charles G. Bixel known as BIXEL WIG craft.

BIXEL WIG craft is a sea going vessel that exploits the wing-in-ground effect phenomenon by flying at low altitude relative to the water surface. The low aspect ratio and highly elongated flat wing provides a travelling capability within the ground effect region at a safe distance over the water [1]. BIXEL WIG craft has a high Reynold number although it operates at low cruising speed (max 150 km/h). The construction cost of BIXEL WIG craft is expected to be less than that of an airplane of the same load capacity. BIXEL WIG crafts are categorised as a ship and operates under the International Maritime Organization (IMO), hence the design requirements and regulations for BIXEL WIG crafts are not as rigorous as those governing aircraft industry. The thick wing and low aspect
ratio of BIXEL WIG craft are simple to assemble because it is operating at a very low altitude as compared to the aircraft or seaplanes.

Although there are various types of WIG crafts that have been designed and developed globally, they have not been successfully commercialised. One major reason is the uncertainty of the performance of the vessel in the open sea and the service operation costs. The operating cost of the vessel increase as it operates on the sea during take-off which requires higher power to overcome the hydrodynamic drags. After take-off and during cruising, less power is required hence an inefficient engine capacity usage. Reducing the power requirement during take-off is the key to successful development of a BIXEL WIG craft. Therefore, the authors have been studying the BIXEL configuration that has shown potential solution to the commercial viability.

Section 2 of this paper reports the aerodynamic characteristic of Bixel WIG craft. Section 3 focuses the XFLR5 simulation method used to obtain the preliminary data is described. Section 4 analyses the aerodynamic data obtain based on the double wing flat aerofoil wave rider design with aspect ratio variation from 0.25 to 0.5 as in USA PATENT #5105898 C.BIXEL. Section 5 proposes six seater hoverwing configurations, and finally concluding remarks are in Section 6.

2. Aerodynamic characteristics of Bixel Wing-In-Ground effect craft

For a start, an explanation of a generic WIG craft need to be described before further elaboration on the specific Bixel WIG craft. Generally, a WIG craft is an aircraft operating in close proximity of the ground or any level surfaces [2]. Under the International Maritime Organization (IMO), it is classified as a marine vessel [3]. The technology was develop by the Russian military for transporting heavy military equipment. The iconic WIG known to the west is ‘Caspian Sea Monster’ [4]. Later the German develop a smaller WIG for commercial purposes [5]. Currently, beside the above two countries China and Korea are actively pursuing the development of passenger WIG [6-7]. China (DXF100-Tianyi-1), Korea (C&S AMT Aron7), Iran (Bavar 2) and Singapore (AF8 001-Airfish) are working from small to large capacity WIG crafts. The major difficulties encountered is due to the vessel operating in three different environment; on land or water, ground effect zone and outside ground effect (free stream) [8]. Each of this environment require different vehicle characteristic for stability and efficiency. Improving the aerodynamic performances of WIG is a challenge. This is due to the limited published information on the performance and the commercial viability. Most of the limited information are based on simulations or performance of remote control (RC) model.

The Bixel WIG configuration is different from the current design by the Russian and the German. This type of WIG craft has a double wing configurations augmented by the hover craft capabilities for acceleration to take-off speed. It is claimed that the Bixel WIG craft has is more efficient than modern aircraft by 250%, faster than cargo ships by 15 folds and able to fly over various terrains (land and sea) [1]. Theoretically, the integration of wing and fuselage will increase lift-to-drag ratio since the lift area increases due to fuselage turning into wing. Furthermore the rectangular shape wing also contributes to the lift.

In this paper, a first order analysis of aerodynamic simulation on Bixel WIG craft is done by using XFLR5 software [9]. Aerodynamic characteristic such as lift, drag, pitching moment and aerodynamic centre are obtained to guide the design process.

3. Bixel WIG craft: Aerodynamic Investigation

In order to justify that WIG craft is totally different from standard aircraft, it is important to first outline a few aerodynamic concepts. Theoretically, the raise of lift to drag ratio represents the raise of body efficiency [10]. As a wing moves through air a resultant force is generated. This resultant force can be express into lift and induced drag component. Another type of drag is referred to as parasitic drag. This type of drag is the result of friction as the aircraft moves through the air. The combination of parasitic drag and induced drag is called total drag, as shown in Fig. 1.
Another important point to highlight is the ground effect. This effect occurs by the presence of a physical boundary at short distances under the wing. The effect is inversely proportional to the distance between the boundary and the wing. Since the lift to drag ratio is the wing efficiency, the ground effect contributed significant increase to the wing efficiency.

For flow over a smooth flat plate, the transition from laminar to turbulent starts roughly at about $Re \approx 1 \times 10^5$. The flow becomes fully turbulent when Reynolds number reaches around $3 \times 10^6$ [12]. Generally, an accepted value for low Reynolds number is below $3 \times 10^6$. The equation (1) for Reynold number is as stated below:

$$Re = \frac{\rho V x}{\mu} = \frac{V x}{v}$$

where $V$ is the upstream velocity, $\rho$ is the density of the fluid, $\mu$ is the dynamic viscosity of the fluid, $v$ is the kinematic viscosity of the fluid and $x$ is the characteristic length of the geometry, which, for a flat plate, is the length of the plate in the flow direction.

The Bixel configuration model as stated in [1] is a double wing flat aerofoil wave rider design with aspect ratio variation from 0.25 to 0.5 as in USA PATENT #5105898 C.BIXEL was simulated and its' aerodynamic characteristic such as coefficient of lift ($C_l$), coefficient of drag ($C_d$), angle of attack ($\alpha$), and coefficient of moment ($C_m$) are being drawn as first order analysis. Noted that the ground effect is also applied in the analysis with the height from ground to underbody surface is set to be maximum of 500 mm. (Fig. 2 illustrates an artist view of the conceptual Bixel WIG craft). The Bixel WIG craft model dimension is about 332 mm x 500 mm with wing and body act as one big wing. The investigation is done to define the aerodynamic capability of this type of configuration.

Fig. 1: Lift and drag of an aerofoil [11]

Fig. 2: Bixel WIG craft model illustrated in XFLR5 (ISO)
4. Analysis

4.1. Analysis software and result
The chosen software analysis to produce preliminary aerodynamic result on this Bixel WIG craft model is XFLR5, is a free aerofoil, wing and aircraft analysis instrument that operates at low Reynolds numbers. Fig. 3 to Fig. 4 shows the illustrated Bixel WIG craft configuration based on the previous scale model in (3). The several test was simulated for dimensional variation as the percentage of vertical height (H) divided by wing span (WS) which is 20%WS (0.1m), 40%WS (0.2m), 60%WS (0.3m), 80%WS (0.4), and 100%WS (0.5m). The velocities variation applied is 10 m/s and 25 m/s. The analysis uses the Vortex lattice method (VLM) and the maximum height above the surface applied is 500mm. Fig. 5 to Fig. 7 shows the various aerodynamic properties as the final output.

![Bixel WIG craft model height variations in XFLR5](Fig. 3)

![Bixel WIG craft model illustrated in XFLR5 (ISO)](Fig. 4)
4.1.1. Lift and drag

Fig. 7 shows that the highest $C_l$ achieved is 0.456, $\alpha = 9.822$ with 20% WS at both 10 m/s and 25 m/s velocities. This indicates that as the angle of attack ($\alpha$) increases, the coefficient of lift ($C_l$) also increased. The amount of lift is increase proportionally to model $\alpha$. Fig. 8 shows that at 10 m/s, $C_d = 0.018$, $\alpha = 0.011$, and at 25 m/s, $C_d = 0.014$, $\alpha = 0.022$. The amount of drag is existed even when the model $\alpha$ is at 0. Fig. 8 also showed that less drag is achieved as the model gain higher velocity. Fig. 9 shows the $C_l - C_d$ variation for all vertical height (H) at both speeds. The amount of $C_l$ increases as the $C_d$ increase.

4.1.2. Aerodynamic efficiency

The amount of efficiency $C_l/C_d$ is increasing proportionally with the rises of the model $\alpha$ in all velocities as illustrated in Fig. 9.
Fig. 7: Bixel WIG craft model result in XFLR5 (C_D vs \( \alpha \))

Fig. 8: Bixel WIG craft model result in XFLR5 (C_L vs C_D)
4.1.3. Pitching moment
Pitching moments $C_m$ against the angle of attack $\alpha$ for the Bixel WIG craft model is illustrated in Fig. 10. From the $C_m - \alpha$ curve, the model has longitudinal static stability for all vertical height (H) and both speed. Normally, most of the WIG craft's operational cruise condition is within the main plane attack angle of 2° to 4° [13] and in this graph, the negative slope for positive $\alpha$ indicates stability in pitching moment. The graph indicates positive pitching moments in this range. By making an assumption of setting $\alpha = 4^\circ$ for cruising condition, increasing the aerodynamic efficiency will potentially rise 40% of its overall lift for the current type of WIG. A continuous trimming on the elevators’ pitching moments need to be done in order for Bixel WIG crafts to operate in this condition. Continuous flight control can be used to reduce the workload of the flying crew as well as to automate and manage many related tasks [14]. Stability and control understanding becomes important because it is hard to master load and vertical controls [15].

4.1.4. Pressure centre line variant
Besides the aerodynamic features of a full model, the experiments also went on the determination of the pressure center line pattern acting below the model wing and body surfaces. [16]. By using XFLR5, the pressure centre line pattern is as shown in Fig. 11 to Fig. 14.
Fig. 11: Bixel WIG craft model result in XFLR5 ($\alpha = 0^\circ$)

Fig. 12: Bixel WIG craft model result in XFLR5 ($\alpha = 1^\circ$)

Fig. 13: Bixel WIG craft model result in XFLR5 ($\alpha = 3^\circ$)
Fig. 10 to Fig. 13 indicates that higher lift force acting on the model middle surfaces. This is due to the increases of lift area compare to both left and right wing [17]. As angle of attack increases more than $\alpha = 3$ degree, the lift line acts on the wing and body surfaces is almost in the same location. The graph also showed a significant rises of pressure centre line location on the body surfaces from $\alpha = 0^\circ$ to $\alpha = 1^\circ$ [18].

From result showed in section 3.1.4, Bixel type of wing shows a significant location different in lift pattern from $\alpha = 0^\circ$ to $\alpha = 1^\circ$ degree. Whereas the lift pattern showed a steady location different starting from $\alpha = 1^\circ$. Fig. 15, Fig. 16 and Fig. 17 show the different of $\alpha$ change as stated before.
Based on tests and calculation, it is necessary to validate all aerodynamic analysis assumptions [19]. For that reason the authors proposed to initiate flight testing with a remote control of a small scale Bixel WIG craft.

5. Proposed six seater Hovering Configuration
The X-112, one of the first WIG craft was developed by Alexander Lippisch, in 1963. The X-112 planform was a reverse delta wing with low aspect ratio, anhedral and forward sweep [20]. This configuration is now referred to as the Lippisch planform. The reversed delta planform of Lippisch is said [21] to have a lower movement of the centre of pressure while obtaining a high lift to drag ratio [22]. The planform results in a lesser change in pitch stability and thus has a reduced tail area when comparing with ram wing craft [23]. Due to the configuration of the planform, it is less significant for the change in pitching moment with height above ground plan. This decreases the control power needed for height transition and thus decreases the area of the tail plane.
The subsequent development of X-112 is the X-114 Hoverwing as shown in Fig. 18. It is designed as a high-performance hovercraft capable of flying at speeds exceeding 75 mph over rough water. Cruise altitude is 2 to 6 feet from ground level and the WIG craft can climb up to 20 feet to clear large obstacles. Even though WIG craft operates in the ground effect region, it is categorised as a boat and thus does not require a pilot's license. This in turn brings a wide range of new opportunities to the commercial and tourism industry. Recent development by Universal Hovercraft is the UH18SPW as showed in Fig. 19 and further develops into UH19XRW.
The research is based on the UH18SPW platform which is modified to incorporate the Bixel platform configuration to accommodate six passengers as in X-114 [25]. The proposed Bixel WIG craft mock up model platform is as shown in Fig. 20.

![Small scale Bixel WIG craft model (Side ISO)](image)

**Fig. 21**: Small scale Bixel WIG craft model (Side ISO)

![Small scale Bixel WIG craft model (Front ISO)](image)

**Fig. 22**: Small scale Bixel WIG craft model (Front ISO)

As a final result the authors concluded that the proposed Bixel type of WIG craft is able to produce good lift and it has longitudinal static stability.

6. **Conclusion**

Based on the analysis, the proposed Bixel type wing configurations are able to achieved higher lift for a given wingspan [26]. For this type of configurations, it is shown that the longitudinal static stability can be achieve due to its’ negative slope of the pitching moment plot.

The performance analysis described in the previous section has not been validated. In addition, further analysis will be carry out on the modified basic rectangular wing configuration used in UH18SPW by incorporating endplate and later the addition winglet [27].

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