OPTIMISATION OF AERODYNAMIC PERFORMANCE OF WIG VEHICLE FUSELAGE USING BLOWING FLOW CONTROL TECHNIQUE

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ABSTRACT

Wing in ground effect (WIG) vehicle is a type of vehicle that flies in the vicinity of the ground, taking advantage of the ground effect phenomenon. WIG vehicle can be categorised as a hybrid technology as it can operate close to the water or ground surface besides flying as fast as a conventional aircraft. Although WIG vehicle has superior advantages compared to either aircraft or marine craft, the usage of WIG is still limited because there are still some issue on its design. The stepped hull design of the WIG fuselage contribute to additional drag during flying condition because of flow separation at the stepped location. This aim of the study is to propose the use of active flow control in the form of blowing technique to improve the aerodynamic performance of WIG. The wind tunnel experiment was conducted with the blowing location located upstream from the step location. The distance of the blowing location with respect to the step height, *h* is 1.53*h*. The blowing velocity coefficients which is the ratio of blowing velocity and the free stream velocity used for the experiment are 0.98, 1.63 and 2.29. Six ground clearance which is the distance of the WIG from the ground with respect to the length of the fuselage has been tested. The ground clearance are in the range of 0.05 to 0.30. The results showed that the use of blowing at all ground clearance and blowing velocity coefficients led to the reduction of drag compared to that of the baseline experiment. In terms of overall performance, the best combination was achieved at ground clearance of 0.05 and blowing velocity coefficient of 2.29, which resulted in 5% of drag reduction, 20% increased lift and 26% increase in lift-to-drag ratio. The data from this study indicate that the combination of ground effect and flow control can give a major improvement towards the performance of WIG vehicle.

ABSTRAK

Kenderaan *wing in ground effect* (WIG) adalah sejenis kenderaan yang mendapat manfaat daripada fenomena kesan bumi untuk terbang pada jarak ketinggian yang hampir dengan permukaan. Kenderaan WIG boleh dikategorikan sebagai teknologi hibrid di mana ia boleh beroperasi sangat hampir dengan permukaan laut atau tanah dan ia juga boleh mencapai kelajuan yang sama dengan kapal terbang konvensional. Walaupun kenderaan WIG mempunyai kelebihan berbanding kapal terbang dan kapal laut, ia masih tidak digunakan secara menyeluruh kerana masih terdapat kekangan pada rekaannya yang menghalang ia daripada mencapai potensi maksimum. Rekaan bertangga pada bahagian fiuslaj WIG menyumbang kepada pertambahan daya seret semasa keadaan penerbangan disebabkan oleh pemisahan aliran pada lokasi bertangga tersebut. Kajian ini mencadangkan penggunaan kaedah kawalan aliran dalam bentuk teknik tiupan untuk meningkatkan prestasi aerodinamik kenderaan WIG. Eksperimen terowong angin dijalankan dengan lokasi tiupan berada sebelum lokasi bertangga. Jarak tiupan berdasarkan ketinggian tangga, *h* adalah 1.53*h*. Pekali kelajuan tiupan iaitu nisbah halaju tiupan kepada halaju sekitar yang digunakan untuk eksperimen ini adalah 0.98, 1.63 dan 2.29. Enam jarak permukaan berbeza digunakan iaitu nisbah jarak di antara permukaan dengan WIG kepada panjang fiuslaj. Jarak permukaan adalah dalam lingkungan 0.05 hingga 0.30. Keputusan yang diperoleh menunjukkan penggunaan kaedah tiupan pada setiap jarak permukaan dan pekali kelajuan tiupan telah menyumbang ke arah pengurangan daya seret berbanding dengan keputusan ujian yang tidak menggunakan teknik tiupan. Untuk prestasi keseluruhan, kombinasi terbaik dapat dicapai dengan jarak permukaan 0.05 dan pekali kelajuan tiupan pada kadar 2.29 yang menunjukkan pengurangan daya seret sebanyak 5%, peningkatan daya angkat sebanyak 20% dan peningkatan nisbah daya angkat kepada daya seret sebanyak 26%. Data daripada kajian ini menunjukkan kombinasi kesan bumi dan kawalan aliran berjaya menghasikan peningkatan yang besar terhadap prestasi kenderaan WIG.

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APPROVAL

The Examination Committee has met on **6^{th} January 2021** to conduct the final examination of **Noor Azman bin Dollah** on his degree thesis entitled **'Optimisation of Aerodynamic Performance of WIG Vehicle Fuselage Using Blowing Flow Control Technique'**.

The committee recommends that the student be awarded the Master of Science (Mechanical Engineering).

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APPROVAL

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Student's full name : Noor Azman bin Dollah

Date of birth : 15th December 1985

Title : Optimisation of Aerodynamic Performance of WIG Vehicle Fuselage Using Blowing Flow Control Technique

Academic session : 2020/2021

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LIST OF ABBREVIATIONS

UPNM	Universiti Pertahanan Nasional Malaysia
WIG	Wing in ground effect
FC	Flow Control
GE	Ground Effect
BFS	Backward Facing Step
UAV	Unmanned Aerial Vehicle
CG	Centre of Gravity
CFD	Computational Fluid Dynamics
CAD	Computer Aided Drawing
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene
TPE	Thermoplastic Elastomer
TPU	Thermoplastic Polyurethane
STL	Stereolitography
PIV	Particle Image Velocimetry

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wing in ground effect (WIG) vehicle is a type of vehicle that flies in the vicinity of ground taking advantage of the ground effect phenomenon. This phenomenon occurs when a flying vehicle flies very near to the ground. The flow around the wing of an aircraft will be affected, thus resulting in an increase in lift and reduction in induce drag. WIG vehicle can travel over different surfaces such as land, ice and sea, but usually operates above water. Due to the method of operation of WIG vehicle where there is a need for take-off and landing on the water, WIG vehicle is designed with both aircraft and marine craft technology based on aerodynamic and hydrodynamic principles. WIG vehicle is a unique vehicle that has the characteristics of aircraft and marine craft, but has more advantages such as higher speed compared to speed boat and wider flight range and higher lift-to-drag ratio than the equivalent sized aircraft [1]. An example of a WIG vehicle is the Airfish model developed by Wigetworks as shown in Figure 1.

In any moving vehicle, the part that produces the highest drag is the part that carries the load. It is called fuselage in an aircraft or a hull for a marine craft. For a WIG vehicle that usually operate above water, the initial stage in its operation requires the WIG vehicle to take off from water, which means that part of the fuselage needs to be water resistant before it can take off. Therefore, the design of the fuselage must be done based on a hull of a marine craft. The usual design of WIG vehicle fuselage is the stepped hull design [2]. The design of the stepped hull involves the Backward Facing Step (BFS) geometry.

Figure 1.1: WIG vehicle [3]

For a BFS geometry, the flow of fluid is separated at the step edge. The separation of flow often results in reduced vehicle performance as a result of increased drag on the vehicle [4]. This condition is not good to the WIG vehicle as it experiences more drag, requiring more power and much fuel to fly to the destination. Reduction of induced drag of the fuselage plays a vital role to make the flight safe, smooth, and effective at a lower cost. One of the methods that can overcome this problem is through flow control, which is the method created to control the boundary layer.

Flow control has been long used in an aircraft to improve lift or pressure distribution characteristics. Flow control is used to prevent or delay the separation of flow by energising the boundary layer, which is a very important concern in the design of an aircraft. Flow control can be categorised as passive flow control or active flow control based on its characteristics. There are many types of flow control being developed over the years and proven to be capable to control flow separation. One of the techniques is known as blowing technique in which air is injected from the fuselage into the free stream of air.

1.2 Problem Statement

WIG vehicle can be categorised as a hybrid technology as it can operate close to the water or ground surface and fly as fast as a conventional aircraft. With the advantage of being the fastest vehicle among the marine crafts, WIG vehicle has the potential to be commercialised as a transport vehicle. It has a bright and encouraging prospect as a vehicle to carry more passengers or cargos and for special purposes such as for armed force missions and rescue operations.

Although WIG vehicle has been practically shown able to be used as a transport vehicle and technically as a vehicle that has superior advantages compared to either aircraft or marine craft, the usage of WIG vehicle is still limited. One of the obstacles is the limitation on the design of the WIG vehicle. Due to the stepped hull design, the WIG vehicle hull fuselage contributes large drag to the WIG vehicle during flying condition because of flow separation at the step location.

Therefore, this study proposed the use of active flow control in the form of blowing technique to improve the aerodynamic performance of the WIG vehicle. The application of active flow control on WIG vehicle has been rarely explored by researchers. In fact, as far as the author is concerned, there is no study being done on the effects of flow control on WIG vehicle fuselage to improve aerodynamic performance. Blowing was done at a location upstream into the flow with different velocity coefficients at various ground clearance and the effects on the aerodynamic characteristics of the WIG fuselage were studied. The effects of this variation of blowing parameter at different ground clearance was investigated in terms of whether or not it will increase the performance of the WIG vehicle in drag coefficient (C_D), lift coefficient (C_L) and lift-to-drag ratio (C_L/C_D). These data were acquired through wind tunnel experiment on the WIG vehicle fuselage.

1.3 Objectives

The objectives of this study are:

- To determine the correlation between the blowing velocity coefficient (C_υ), lift coefficient (C_L) and drag coefficient (C_D) of WIG vehicle fuselage.
- To investigate the correlation between the ground clearance, lift coefficient (C_L) and drag coefficient (C_D) of WIG vehicle fuselage.

1.4 Scopes and Limitations

The scope of this study is focused on the aerodynamic performance of the WIG vehicle fuselage. The wind tunnel test only use the WIG vehicle fuselage and even though the wing-fuselage interaction also contributes to the performance of WIG vehicle, it was not discussed in this study. This study only covers the parameters involving the blowing technique and ground clearance. The ground clearance studied is limited to the size of the wind tunnel test section only. This study is carried out in the subsonic flow region.

1.5 Thesis Outline

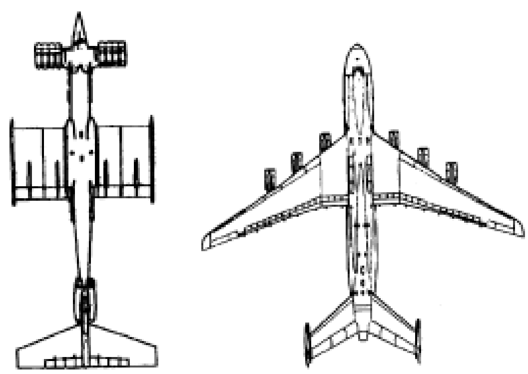
This thesis is divided into five chapter. Chapter 1 covers the introductory topic where the problem statement and objective of study are explained. Literature review on the relevant topic to this study is presented comprehensively in Chapter 2. Chapter 3 explains the methodology of the study. Here, the fabrication of the WIG vehicle fuselage model and setup of the blowing flow control technique as well as the procedure to conduct the wind tunnel testing are presented in detail. The results of the wind tunnel testing are analysed and discussed in Chapter 4. Finally, Chapter 5 presents the summary of this study where the conclusion and recommendations for future work are given.

CHAPTER 2

LITERATURE REVIEW

2.1 Wing in Ground Effect (WIG) Vehicle

WIG vehicle can be defined as a heavier than air vehicle with an engine and designed to operate very near to the ground surface to fully utilise the ground effect [1]. In terms of design, the WIG vehicle can be compared to conventional aircraft and marine craft. Although the basic design of the WIG vehicle is similar to the conventional aircraft, there are some differences in the overall design such as small aspect ratio of the main wing and inclusion of endplates. The design of the fuselage of WIG vehicle is also similar to the hull of a marine craft. Figure 2.1 shows the comparison between WIG vehicle and an aircraft.



(a) (b)

Figure 2.1: Comparison between (a) WIG vehicle and (b) aircraft [1]

In terms of operation, there are other types of vehicle that are often compared to the WIG vehicle such as the seaplane and hovercraft. Conventional seaplane as shown in Figure 2.2 is similar to WIG vehicle where both of them use the aircraft concept in their design and can take off and land on water. However, the main difference between WIG vehicle and seaplane is that the seaplane does not utilise the advantages of ground effect (GE) for its operation. The seaplane also has much larger wing aspect ratio with its wing positioned very high with respect to the hull [5], [6].

Figure 2.2: Seaplane [7]

Meanwhile, hovercraft (Figure 2.3) is very similar to WIG vehicle as they both typically operate over water and use the concept of ground effect. However, WIG vehicle is different from hovercraft in term of design as the hovercraft design is more similar to a marine craft. WIG vehicle is also supported by a dynamic air cushion formed under the lifting wings at large speeds and by enhanced wing-generated lift due to the reduction of the down wash near the ground, while hovercraft depends on static air cushion. This static air cushion from the hovercraft originates from the propeller or air jets that continuously blow up air that are directed between the airfoil and water surface when the vehicle stay still or move slowly over the ground surface and is sufficient to lift the vehicle [8].

Figure 2.3: Hovercraft [9]

Theoretically, by flying in ground effect, there should be an improvement in efficiency due to the increased lift-to-drag ratio. Therefore, based on the theory, WIG vehicle should be more efficient than equivalent aircraft and quicker than equivalent marine craft. Despite some setbacks encountered regarding the operation of WIG vehicle, the potential offered by the WIG vehicle is very promising.

2.1.1 Principle of Ground Effect

When aircraft fly through the air, the movement produces greater static pressure on the lower surface of the wing than on the upper surface. The difference in the lower surface pressure and the upper surface pressure results in an upward force that produces lift allowing the aircraft to fly. Most of the time, aircraft flies at a high altitude and in a free stream where the air around the wing is not bounded to anything as shown in Figure 2.4.

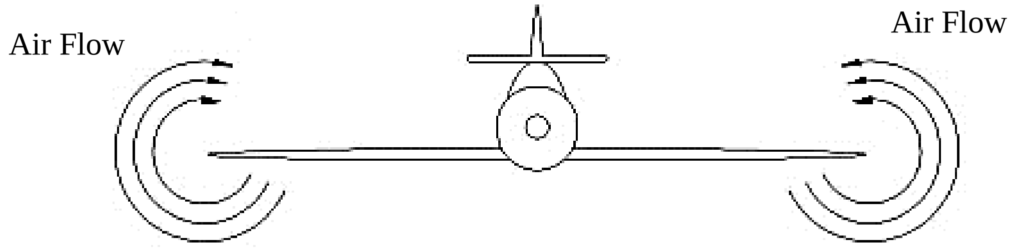


Figure 2.4: Flow of air in free stream [10]

However, in certain stages of flight such as take-off and landing, the aircraft can be flown very near to the ground surface. In this case, the air surrounding the aircraft is not in a free stream anymore. When aircraft fly in the ground effect zone, the ground surface does not allow the flow under the wing to expand as it would in free air. The air flow is subdued in the region between the wing and ground surface, causing the flow of the air to be altered as shown in Figure 2.5. This phenomenon is called ground effect (GE), which contributes to additional lift to the aircraft [11]. The effects of GE become more pronounced as the distance between the wing and the ground is reduced [12]. Different aircraft experience the ground effect at different distance from the ground. From the study conducted by Fink and Lastinger [13], the general distance from the ground where the ground effect can be experienced is at a distance of one chord length above the ground. However, Balow et al. [14] stated that the effects are not usually significant until a height of less than half of the wing span.

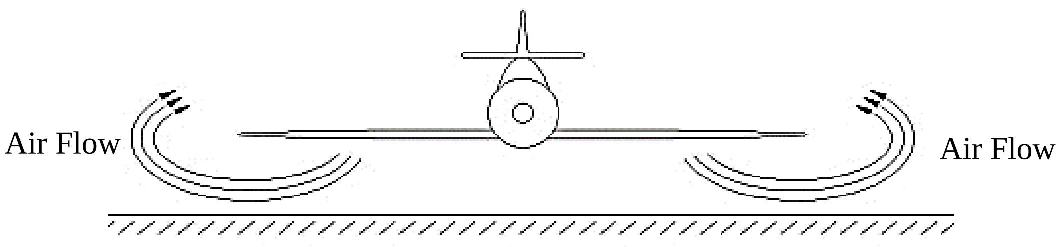


Figure 2.5: Flow of air in ground effect [10]

The ground effect phenomenon was first discovered unintentionally by the Wright brothers. They noticed that when their aircraft approached the ground during landing, there was a significant increase in lift on the wing. However, they thought of it as a cushioning effect during landing [1]. It was in the early 1920s that the theoretical understanding of ground effect was achieved. Since then, a number of early aircrafts used the additional lift from ground effect to increase their efficiency. The ground effect has been also used by the bomber pilots in the World War II who had lost an engine to enable them to fly low over the water, which allowed them to achieve the required range to return safely.

The general finding concerning the effects of GE to the aerodynamic characteristics of an aircraft has been found from the study by many researchers [10], [15]–[20]. It was found that GE can increase the lift of the wing and reduce induced drag of the wing, which result in the increases of the lift-to-drag ratio of the aircraft.

Since the discovery of GE in the 1920s until today, extensive studies have been carried out over the past 100 years to understand and predict the effects of ground effect on the aerodynamic characteristics of the wing. There are many theoretical, experimental and numerical investigations of the ground effect phenomenon. One of the earliest studies has been done by Wieselsberger [21] where he developed an analytical method that determines the drag polar curve of an aircraft at short distances from the ground. According to Wieselsberger's method, the induced drag near the ground must be smaller than out of ground. Despite another developed analytical methods, Wieselsberger's method still remains the most popular.