PARAMETRIC STUDY ON AERODYNAMIC PERFORMANCE OF UAV WINGLET DESIGN

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by

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ENDORSEMENT

I, Haripresath a/l Harikumar hereby declare that all corrections and comments made by the supervisorand examiner have been taken consideration and rectified accordingly.

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ABSTRACT

This work describes the aerodynamic performance of an aircraft model wing with RGV winglet. Ruppell's Griffon Vulture (RGV), which is the highest-flying bird in the world, (with confirmed evidence of a flight at an altitude of 11,300 m (37,000 ft) above sea level) has been taken as the main consideration in designing for this research. The aerodynamic structure of the RGV wing and its wingtip is the main cause of its high-flying ability. Modifying wingtip is much easier and cheaper in aircraft industries compared to change of the whole wing. Thus, a Computational Fluid Dynamics (CFD) study using ANSYS 2019 R3 is conducted to study the effect of the RGV winglet on a tapered wing with doubled number of splits. The wing consists of 660 mm span and 121 mm chord length where the aspect ratio is 5.45. The NACA 65(3)-218 aerofoil is used in this work. The tapered wing with different configuration of winglets have been designed using CATIA V5-R2020 software. The design has been analyzed with Mach 0.06 [Reynolds Number = $1.7\ x\ 10^5$] at various angle of attacks (AOA) using unstructured triangular grids with the growing prism inflation. A 20-layer option has been implemented with first cell above the wall set at y is 0.1 mm. The turbulence model is based on Transition SST [4 eqn] with wall functions. A parametric study is done on aerodynamic performance such as lift coefficient [CL] and lift/drag ratio [CL] /[CD] to get the best result of the RGV winglet design. The CFD result shows 18% increase in [CL] / [CD] ratio, 68% increase in lift coefficient and 32% reduction in drag coefficient by using an RGV winglet with doubled number of splits on a tapered wing.

KAJIAN PARAMETRIK PADA PRESTASI AERODINAMIK REKABENTUK SAYAP UAV

ABSTRAK

Karya ini menerangkan prestasi aerodinamik sayap model pesawat dengan sayap sayap RGV. Ruppell's Griffon Vulture (RGV), yang merupakan burung terbang tertinggi di dunia, (dengan bukti yang disahkan mengenai penerbangan pada ketinggian 11.300 m (37.000 kaki) di atas permukaan laut), telah diambil sebagai pertimbangan utama dalam merancang penyelidikan ini. Struktur aerodinamik sayap RGV dan hujung sayapnya adalah penyebab utama kemampuan terbang tinggi. Mengubah hujung sayap jauh lebih mudah dan lebih murah dalam industri pesawat terbang berbanding perubahan keseluruhan sayap. Oleh itu, kajian pengiraan dinamik bendalir yang menggunakan ANSYS 2019 R3 dilakukan untuk mengkaji kesan sayap RGV pada sayap tirus dengan bilangan perpecahan dua kali ganda. Sayap terdiri daripada rentang 660 mm dan panjang kord 121 mm di mana nisbah aspek adalah 5.45. Aerofoil NACA 65 (3) -218 digunakan dalam karya ini. Sayap tirus dengan konfigurasi sayap yang berbeza telah dirancang menggunakan perisian CATIA V5-R2020. Reka bentuknya telah dianalisis dengan Mach 0.06 [Reynolds Number = 1.7 x 10 ^ 5] pada pelbagai sudut serangan (AOA) menggunakan grid segitiga tidak berstruktur dengan inflasi prisma yang semakin meningkat. Pilihan 20 lapisan telah dilaksanakan dengan sel pertama di atas set dinding pada y ialah 0.1 mm. Model pergolakan berdasarkan Transition SST [4 eqn] dengan fungsi dinding. Kajian parametrik dilakukan pada prestasi aerodinamik seperti pekali angkat [CL] dan nisbah angkat / seret [CL] / [CD] untuk mendapatkan hasil terbaik dari reka bentuk sayap RGV. Hasil CFD menunjukkan peningkatan 18% dalam nisbah [CL] / [CD], peningkatan koefisien angkat 68% dan

pengurangan pekali seretan 32% dengan menggunakan sayap RGV dengan bilangan perpecahan dua kali ganda pada sayap tirus.

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DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date : 05/07/2021

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LIST OF ABBREVIATIONS

USM	: Universiti Sains Malaysia
CFD	: Computational Fluid Dynamics
RGV	: Ruppells Griffon Vulture
AOA	: Angle of Attack
CL	: Lift Coefficient
CD	: Drag Coefficient
BL	: Boundary Layer
AR	: Aspect Ratio
SST	: Shear-Stress Transport

LIST OF SYMBOLS

lim	: Limit
ρ	: Density [kg/m^3]
θ	: Angle in degree [°]
μ	: Viscosity [kg/m.s]
t	: Time [s]
$\rightarrow v$	: Flow velocity vector field
p	: Static Pressure [Pa]
τ	: Stress sensor
$\rho \rightarrow g$	: Gravitational body

CHAPTER 1

INTRODUCTION

This chapter provides general introduction on research background, problem statement, research objectives and the thesis outline.

1.1 Research Background and Problem Statement

The drag produced from an aircraft is one of the primary obstacles that limits the performance of an aircraft. The local relative wind downward (an effect known as downward) and generated a component of the local lift force in the direction of the free stream caused by the drag stems from the vortices shed by an aircraft's wings. The spacing and radii of these vortices are proportional to the strength of this induced drag (Anderson, 2005).

Winglet is the most used device in aircraft industry because of its benefit and one of the promising drag reduction devices. The possible benefits of modifying wing-tip flow have been proven for several years with many investigations. Most popular technique to increase the aerodynamic performances of lifting wings is by modifying tip devices (McCormick (1967)). Winglet is a device which lower the lift-induced drag caused by wingtip vortices and improves the efficiency of an aircraft. The addition of the wing tip surfaces, or winglet can reduce and diffuse the strength of these vortices, thus reducing the overall vortex drag of the aircraft.

Ruppell's Griffon Vulture (RGV), which is the highest-flying bird in the world, (with confirmed evidence of a flight at an altitude of 11,300 m (37,000 ft) above sea level) (Laybourne (1974a)), has been taken as the main consideration in designing for this research. The aerodynamic structure of the RGV wing and its wingtip is the main cause of its high-flying ability. Modifying wingtip is much easier and cheaper in aircraft industries compared to change the whole wing.

RGV bird studies in terms of its aerodynamic performances is not available in open literature, even though RGV bird has extraordinary features of its wing and wingtip design. Since there is limitation in RGV bird literature, this research methodology (RGV winglet design) is based on real RGV bird picture. Aircraft manufacturers are considering in reduction of development cost as well as the fuel consumption. Based on literature review, it is proven that using winglet will give improvement in engine efficiency, increment in cruise operating range and improvement in take-off performance where it reduces span wise flow (wake vortex formation) and reduces induced drag without any major changes in other part of an aircraft. It is believed that RGV winglet will reduce induce drag which is one of the major contributions of the total drag and reduce wake vortex formation. Although most of current winglets give same or better benefit than RGV winglet, this unique idea whereby designing RGV winglet using RGV real bird will bloom the aircraft industry near future. This research can be considered as the first step to design the best nature flyer (RGV bird) and implement it in manmade flyer. Design optimization of RGV winglet will be the best winglet configuration which will benefits aircraft industries. Aircraft model wing with RGV winglet will be designed in CATIA V5 R2020 software and simulates using ANSYS 2019 R3 software in Aerodynamics Laboratory of Aerospace Engineering Department, Universiti Sains Malaysia.

The competition in the global aircraft market forces airlines to reduce the operating cost of the aircraft. This in turn requires from the manufacturer a reduction in development cost as well as the fuel consumption of civil transport airplanes. These fuel savings are linked with two main ways such as: enhance engine performance and improve aerodynamic performance. Aerodynamic performances level can be enhanced by reducing overall drag that aircraft produces. This drag will be reduced significantly if well designed wing, winglet and by increasing aspect ratio of an aircraft used. A perfect winglet design will prevent secondary flow and reduce vortex formation meanwhile if aspect ratio increased, it will increase skin friction drag due to excessive wetted area. Although adding winglet means more weight to be flown and more bending stresses at the root of the wing, so more fuel consumption, but it is proven winglet device will reduce induced drag. The span wise induced velocities from the winglet opposed and thereby canceled those generated by the main wing. Winglet is a complex design where optimization of winglet configuration to reduce induced drag and amount of vortex formation has already been analyzed and researched by previous researcher as discussed in literature review. The studies have been concentrated on RGV winglet design and analysis in ANSYS to increase L/D ratio. Although most of current winglets give same or better benefit than RGV winglet, this unique idea whereby designing best nature flyer RGV wing tip to aircraft winglet will benefit aircraft industry near future.

1.2 Objectives

The objectives of this study are:

1. To study the improvement of L/D ratio with the variation of number of splits of the RGV winglet.
2. To study the effect of the RGV winglet on a tapered wing's lift coefficient (CL) and drag coefficient (CD).

1.3 Thesis Outline

This thesis contains 5 chapters:

- First chapter includes the research background and problem statement of the study. The objectives of the study and the thesis outline are explained and presented in the chapter.
- Second chapter is the literature review of the study. Research, simulation, and experiments done by previous researchers on this topic are discussed.
- Chapter three will be focusing on the methodology which is basically on the setup of the simulation. Description and explanation about co CFD modelling, set up of boundary conditions, solution and validation will be further discussed in this chapter.
- In chapter 4, results will be analyzed and discussed according to the data obtained from ANSYS Fluent simulation. Simulation results will be shown, and graph related will be plotted. Discussion will be done on the results and compared to others' work or research.
- Finally, in chapter 5, it will be discussed on the conclusion of the findings. Recommendations will be stated and proposed so that others that do similar research can improve the simulation. Lastly, future work will be discussed based on the understanding of the whole project.

CHAPTER 2

LITERATURE REVIEW

This chapter provides state-of-art on previous research conducted on aerodynamic performances of wings and winglets. This research used an aircraft model wing with RGV winglet as the main case study which involves more aerodynamic concepts. Aerodynamic concepts relate more to the environment study. The aerodynamic force exerted by the airflow on the surface of a wing is found by integrating the distribution of (Anderson (2005)):

1. Surface pressure, and
2. Shear stress (friction) on the surface (Mc Cormick (1967))

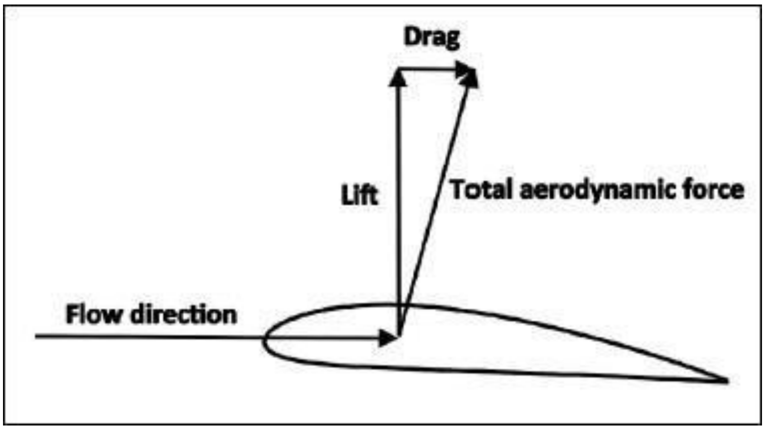

Figure 2.1: Lift Force (Marc Medale (2016))

Lift is defined as the component of total aerodynamic force perpendicular to the relative wind as shown in figure 2.1. Drag is the component of total aerodynamic force parallel to the relative wind. When the flow dividing streamline is below the wing's leading edge, then the velocity on the upper wing surface is higher than on its lower surface causing a pressure difference, calculated using the aerodynamic equations of continuity, momentum, and energy plus the equation of state. As the velocity increases, the streamlines become closer together in subsonic flow and the static pressure drops in that region to obey the conservation of momentum. The Bernoulli equation states that when velocity increases, the pressure decreases. Therefore, if the velocity over the top surface of a wing increases, then the pressure decreases. The greater the wing's angle of attack, the more lift is generated causing the upstream stagnation point to move below the wing's leading edge and up-flow ahead of the leading edge. Simultaneously, the flow aft of the trailing edge will be deflected downwards. The down-flow momentum aft of the trailing edge contributes to the wing lift. When creating lift, the average pressure force on the wing's lower surface will be higher than that on its upper surface.

The wing planform area is the logical choice for a higher life because most of the lift is generated by the wings, and lift is the force perpendicular to the flight direction. The area of the wing along the lift direction is the planform area. The total surface area is proportional to the wing plan form area. Therefore, experimentally the lift coefficient is determined, by measuring the lift and measuring the area and performing the necessary math to produce the coefficient.

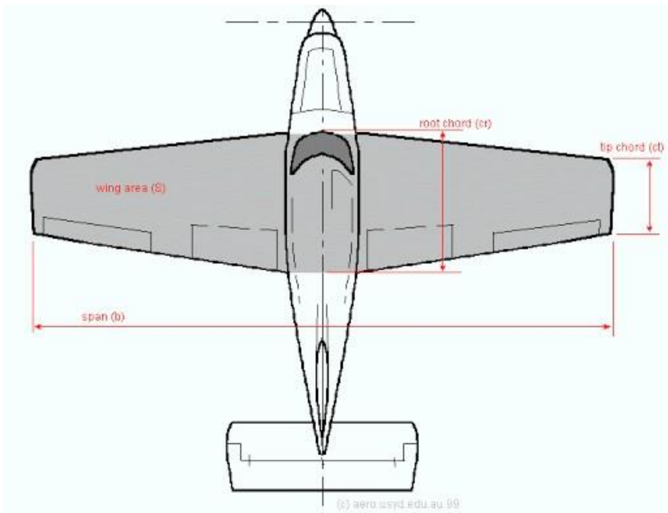

Figure 2.2: The wing plan form area design. (K.Srinivas (2006)).

2.1 Airfoil and Vortices

In aircrafts, the flow around a wing generates mainly an inviscid flow region. It is separated from the airfoil by a thin viscous region called the boundary layer (BL). Due to the lack of shear stress in the inviscid region, the fluid elements there have no angular velocity, and their motion is purely irrotational (Anderson (2007)). Contrarily, the velocity gradient inside the boundary layer generates vorticity or rotational flow of the fluid elements. In an irrotational flow field, the vorticity must be zero at every point within the flow.

There is an opportunity for the pressures acting on the upper and lower surfaces to interact near the wing tip as shown in Figure 2.3.

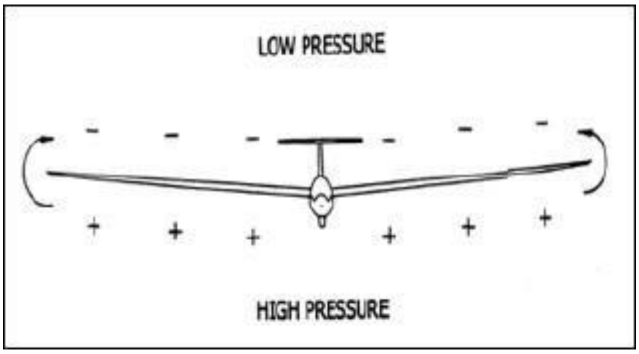

Figure 2.3: Pressure difference (Anderson, (2007))

The high-pressure air below the wing accelerates around the wing tips toward the low pressure region above the wing, resulting in the initiation of two wing tip vortices. This span wise pressure gradient causes inboard flow along the upper wing surface and out flow along the lower surface of the wing. The resulting span wise flow component at the trailing edge prevents the boundary layer vorticities from canceling one another at the trailing edge. As a result, the spanwise pressure distribution decreases towards each tip, and likewise the lift. When the two airfoils, from the upper and bottom surface meet at the trailing edge they are flowing at an angle to each other. This causes vortices rotating clockwise from the left wing and anti-clockwise from the right wing shown in Figure 2.4.

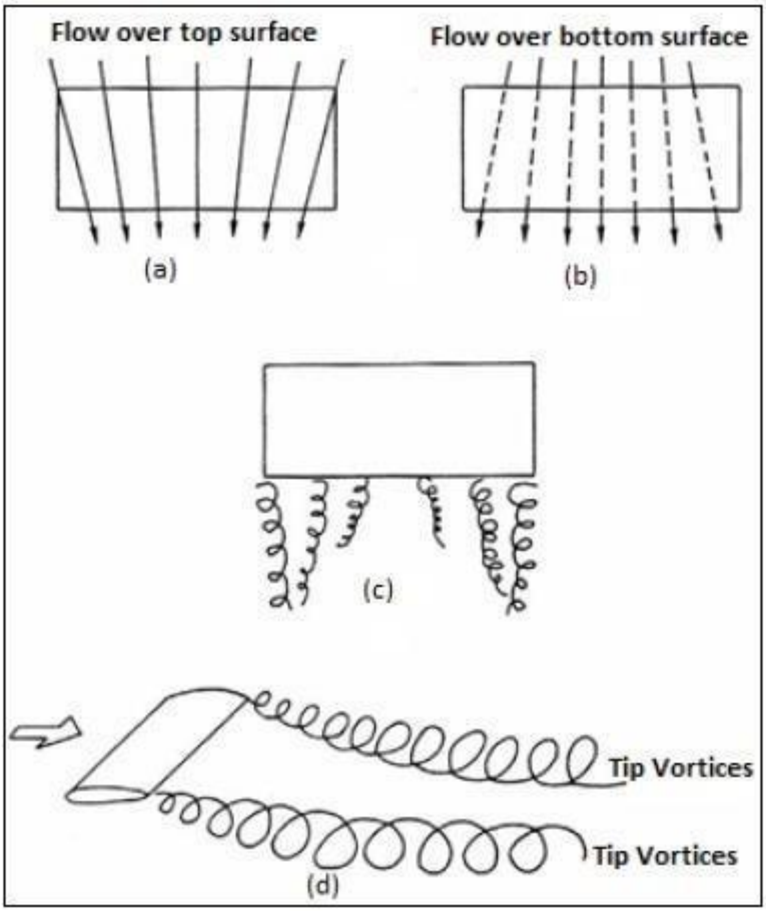

Figure 2.4: Formation of wingtip vortices according to a,b,c,d (Anderson (2007)).

This is further downstream entailed into vorticity shed at the wingtips. The larger the downwash velocity and the induced drag will be if shorter the distance between the tip trailing wing tip vortices (Stinton (2003)).

2.2 Induced Drag

In the large aircrafts, lift-induced drag contributes for approximately 40% of the drag produced (A.S.W. (1985)). The strength of the vortex in the tip region and its interaction with the flow around the wing is related to the drag. Downwash is the filaments of vortex in the wake of the wing induce a downward velocity component on the flow along the wing. The effective incidence of the wing is reduced by downward component of the velocity at the trailing edge. When the lift produced by a wing is perpendicular to the local flow direction, it creates a force, called lift induced drag, which opposes the wing motion as shown in Figure 2.5. To decrease induced drag, one of the fundamental way is by increasing the wing's aspect ratio.

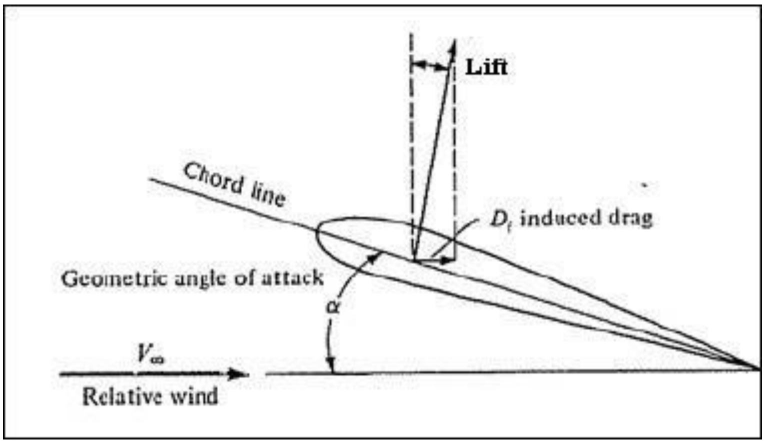

Figure 2.5: Induced Drag on airfoil (Anderson (2007))

2.3 Winglets

Winglet is one of the most used devices to reduce induced drag acting on a wing. It is a non-planar tip device with an aero foil section that interacts with the tip vortex to reduce its influence. The first effect of the winglet is by reducing the strength of the tip vortex. Indeed, as a fence, it prevents the flow from the wing lower surface to roll up. Besides that, it uses the distorted flow in the tip region to produce a force acting in the flight direction. The cross flow and the tip vortex distort the flow at the tip inducing on the winglet an effective incidence. When the winglet is correctly designed, it produces a lift force resulting from this incident flow with a component in the direction of flight. Winglet must have same chord wise position on the tip of the wing and same aerodynamic characteristics as a wing.

Spanned the last 27 years, winglets for modern aircraft were first proposed by Whitcomb at NASA Langley in the mid-1970. He proved that adding winglet at wingtip could increase an aircraft's range or distance as much as 7%. NASA confirmed adding winglet could improve drag coefficient due to the lift efficiency by 10% to 15%. Proper winglet design is very important to obtain the best performance proposed by Posada (Posada et al. (2007)). The winglet should be tapered and swept aft for good supercritical performance. By mounting it behind the lowest pressure point on the wing and by canting it outward, the interference effects are minimized.

Drag reduction increases with winglet span. Jacob and Weierman is the team who investigated the methods for designing winglets to get optimized winglet geometry design at Reynolds numbers near 10^6. Two types of winglet configuration have been analyzed where configuration 1 improved lift over drag ratio up to 10.6% where else configuration 2 is 28.1%.

Figure 2.6: Blended winglet for Airbus A320 (Blended winglet in airbus (2015))

2.4 Wing with multiple winglets

Tucker and Vance (Tucker (1993)) investigate on soaring birds with spitted wingtips. They proved Clark Y tip increased the base wing drag by 25% while the feathered tip reduced the drag by 6%. Smith et al. (Smith, Komerath, Ames, and Wong (2001)) examined multi-winglets. They proved L/D ratio increased by 15-30% as compared with the baseline NACA 0012 wing. Miklosovic and Bookey (Miklosovic et al. (2005)) did experimental analysis to prove efficiency of three winglets mounted chordwise to the rectangular wingtip as shown in Figure 2.7. They come out with the results which showed that the winglets could be placed in various optimum orientations to increase the lift coefficient as much as 65% at the same angle of attack, decrease the drag coefficient as much as 63% at the same lift coefficient, or improve the maximum L/D by up to 71% where the highest L/D measured was 40.1 on the 50/45/40 dihedral configuration as shown in Figure 2.8.

Figure 2.7: Multiple winglets (Miklosovic et al. (2005))

Hossain et al. (2011) investigated with aircraft model with bird feather like winglet as shown in Figure 2.8. Experimental result shows by using this type of winglet, 25-30 % reduction in drag coefficient and 10-20 % increase in lift coefficient.