Study Of Unmanned Aerial Vehicle With Variation Of Dihedral Angle And Configuration Of Empennage Using Computational Fluid Dynamics Methods

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Abstract: Unmanned Aerial Vehicle is a type of aircraft that has a very wide application. In this study, numerical calculations were performed using ANSYS Fluent software to find the configuration and dihedral angles that were considered to provide the best lift, drag, and moment pitch values. The study was conducted by varying two-tail configurations with high and low specifications with each having three variations in the dihedral angle values. Each variation has the same stabilizer surface area value. The study was conducted using the k-omega SST turbulence model (k-ω SST) with the mission profile having a distance of 200 km, a height of 500 m, and a speed of 20.83 m/s. Mesh is made of polyhedral with quality skewness and mesh orthogonal very good. The results of this study indicate that unmanned aircraft with a low tail configuration with the smallest dihedral angle produces the biggest lift and pitch moment value. The drag value produced by each variation has a very small difference that can be ignored.

Index Terms: Aerodynamics, Dihedral Angle, High Low Tail, Unmanned Aerial Vehicle.

1. INTRODUCTION

In this paper, we provide the setting and result of an empennage variation using CFD simulation. Some of the tail parameter will be discussed briefly. At the end of the chapter a fully solved example will be displayed to illustrate the phenomenon that caused by the variation. The primary reason why tail was selected as the main topic for research is its function. The major difference between wing design and tail design originates from the primary function of tail that is different from wing. Primary function of the wing to generate maximum amount of lift, while tail is supposed to use a fraction of its ability to generate lift. If at any instance of a flight mission, tail nears its maximum angle of attack (i.e. Tail stall angle); it indicates that there was a mistake in the tail design process.The empennage provides stability and control to aircraft and it has the ability to restore the aircraft from perturbation in pitch, yaw, and roll. It is vital that aircraft is stable in handling the moments created from various disturbances while maintaining the body under control [1]. Many unconventional tail has been designed including v-tail configuration which removed the vertical tail. Basically, it used to remove the drag produced by wetted area better than the conventional configuration [2]. Meanwhile, the aerodynamicist believes that dihedral angle of tail affect the stability of the aircraft in form of yaw and roll. The result shows that when the angle is too big, it produces less yaw moment. However when the angle is too small, aircraft will lose control as directional stability went enormous [3]. The V-tail design was introduced first by aircraft Beech Model 35 Bonanza which was first produced in 1947 but was grounded due to safety reason. At this moment, lots of unmanned aerial vehicle not only use V-tail as configuration, but also V-inverted tail as they provides fascinating features. As the list of tail configuration is so many, lots of study conducted to see how is the performance from each tail configuration. In comparison, when it comes to T-tail, conventional, and V-tail, the most efficient configuration starts from conventional, T-tail, then V-tail. Efficient here defined as lift divided by drag coefficient [4]. Today, the application of various types of unmanned aircraft is openly very wide. Many configurations were developed in order to fulfill their specific operations and mission requirement. The required flight performance of an UAV is the ability to fly for a very long endurance. The important criteria needed to satisfy this requirement is to design UAV which have high lift, low drag, and sufficient amount of moment for each rotational axis. When the aircraft did not able to produce a certain amount of moment in lateral axis, phenomenon such as nosedive and spiral could happen. The problems may even be worse if the aircraft is flying under gusty conditions.

2. PERFORMANCE PARAMETER

The simulation was put on the cruise flight conditions (Velocity=20.83m/s, Altitude=500m, Target distance=200 km). The computation results were then used to compare quantitatively lift and drag characteristics as well as pitching moment produced. Furthermore, flow phenomena were evaluated qualitatively around the aircraft, wing, and also tail. As the more phenomenological analysis did not reveal any surprising effects, the part of the work presented here will focus on the quantitative results due to space limitations.

3. AIRFOIL

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. Subsonic airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with a symmetric curvature of upper and lower surfaces. Foils of similar function designed with water as the working fluid are called hydrofoils. Airfoil used in this paper is NACA 0012 for tail, and NACA 4412 for wing.

4. AERODYNAMIC AND STABILITY PARAMETER

Aerodynamic parameter in this paper refer to lift and drag coefficient which collected from lift and drag result from simulation. Meanwhile, stability parameter refer to pitching moment and static margin value.

5. PRE-PROCESSING : DESIGNING OF AIRCRAFT

5.1 Design

Dimensions of the aircraft are obtained from calculation respected to the mission profile. Designing and Meshing is carried out in ANSYS Fluent CFD module for two tail configurations with six dihedral angles. The configurations are represent the high and low tail configuration which are V-tail and V-Inverted tail. The value of dihedral angles in this project are 50, 60, and 70 degree.

TABLE 1
DIMENSION SED IN RESEARCH

Aircraft Dimensions	
Width	2.5 m
Length	4.8 m
Fluid Domain Dimension	
Height	4 m
Width	3 m
Length	11 m
Tail Dimensions	
Area	0.3864 m^2
Aspect Ratio	3
Taper Ratio	0.6
Length	1.07 m
Root Chord	0.448 m
Tip Chord	0.269 m

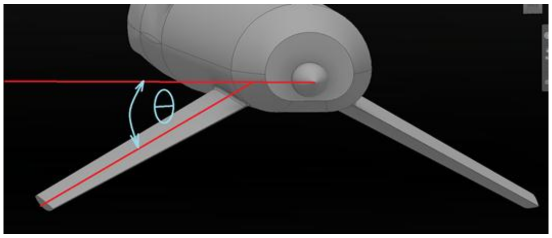

Fig. 1. *Dihedral angle showed by the blue line and symbol.*

Fig. 2. *Aircraft with high (V-Tail) configuration*

Fig. 3. *Aircraft with low (V-Inverted tail) configuration*

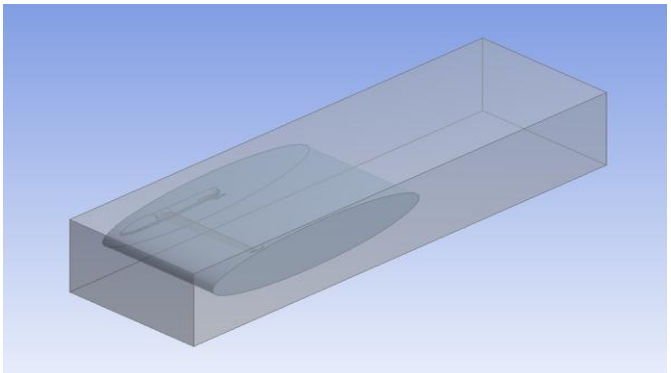

Fig. 4. *Aircraft with body influence in fluid domain*

5.2 Meshing

Unstructured mesh is created for the problem with total 8.59 millions elements were created for each configuration. The quality of the mesh is indicated by value of skewness 0.26 and mesh orthogonal 0.73. Body sizing use body of influence type and Face sizing divided as 3 main parts for wing, fuselage, and tail. Inflation also used with 5 maximum layer and first layer height has value for 5.7×10^{-4} m.

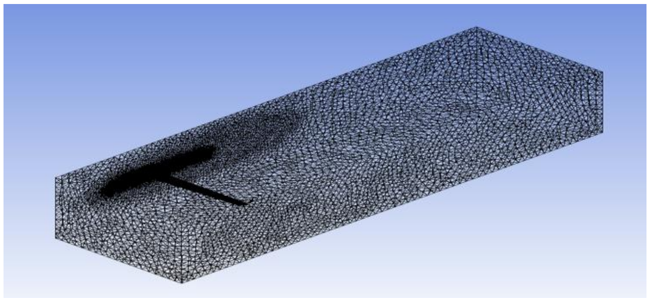

Fig. 5. *Aircraft and fluid domain mesh*

5. SOLVING

The mission of the aircraft is to cover 200 km maximum distance using 20.83m/s velocity, cruising on 500 m altitude. The air density, temperature, and viscosity obtained from the cruising condition. Solution has been converged for 90 until 100 iterations at 10^{-3} residual as shown in above figure. The below figure shows residuals of continuity, x.y.z force and momentum equations for every iteration. Turbulance model used here is k-omega SST.

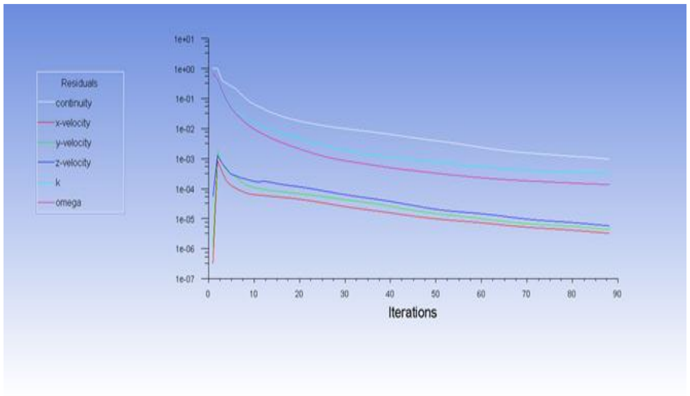

Fig. 6. *Running calculation of the project in ANSYS Fluent to reach residual criteria*

6 POST PROCESSING

To gather the result after solving stage, open ANSYS Post Processing. The result we collect is not only the value of performance parameter, but also the pressure and velocity contour. The countour is shown below.

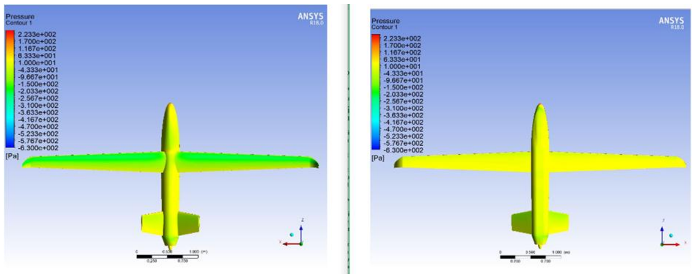

Fig. 7. *Pressure on a) top and b) bottom aircraft*

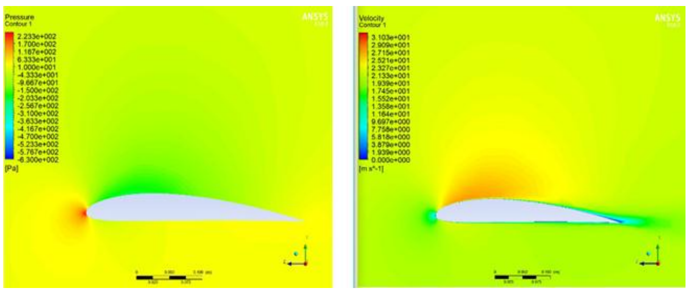

Fig. 8. *a) Pressure and b) Velocity on Wing*

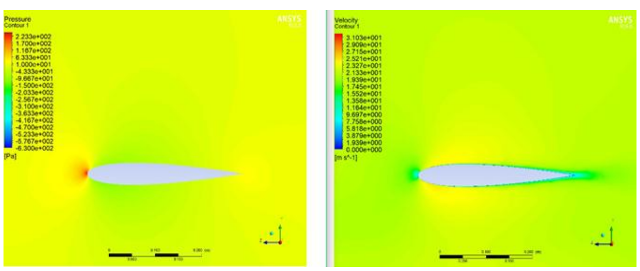

***Fig. 9**. a) Pressure and b) Velocity on Tail*

7 MESH INDEPENDENCY TEST

To check the effect of number of mesh to the result deviation, mesh independency test was taken. Figure 10 and 11 tells what happened when the numbers are varies from small to large. However, as the number of mesh given by the set up is around 8.59 million, it can be safe assume that number of mesh will not interfere the result of this study.

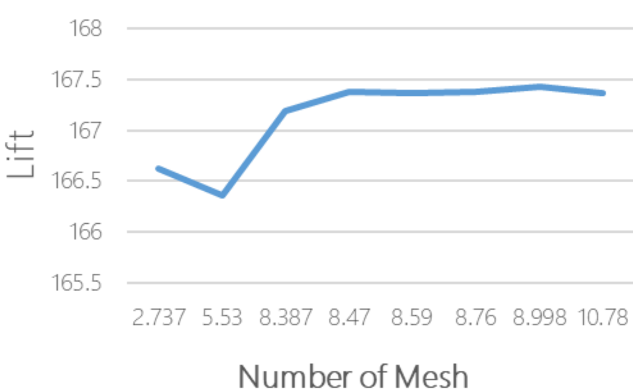

Fig. 10. *Lift vs Number of Mesh*

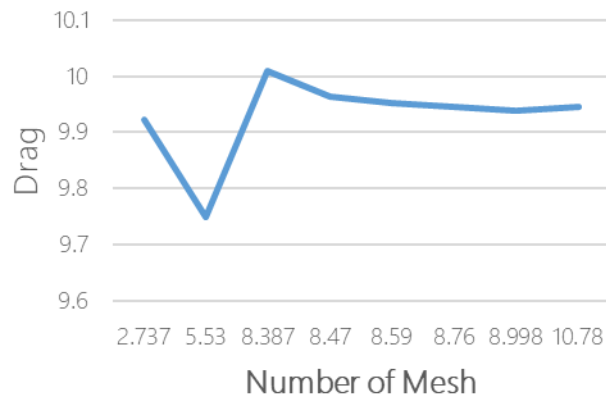

Fig. 11. *Drag vs Number of Mesh.*

8 RESULT AND DISCUSSION

Lift and drag characteristics are first compared and evaluated, followed by a section with special emphasis on the analysis of the stability in pitching moment followed by static margin value are investigated and all the variations and configurations performance at cruise flight condition will be compared. By following the above procedure for all the cases, the performance values are calculated and plotted as shown below by figure 12 until 15.

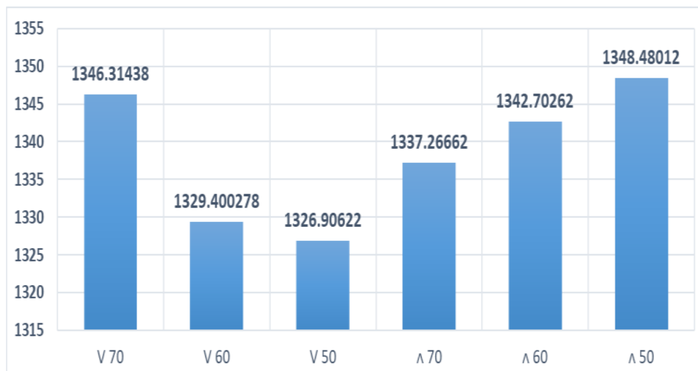

***Fig. 12**. Lift force produced by every angle and configuration.*

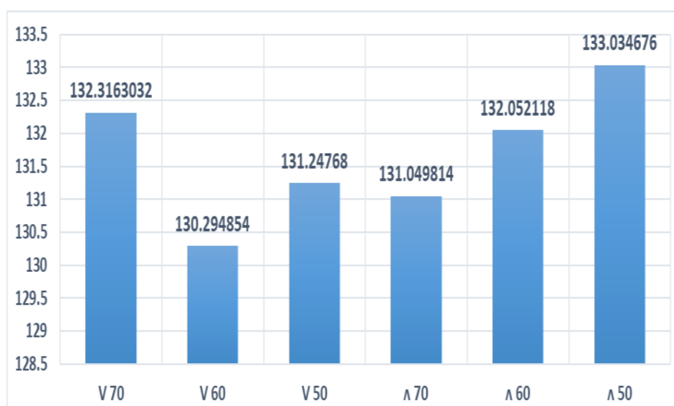

***Fig. 13**. Drag force produced by every angle and configuration.*

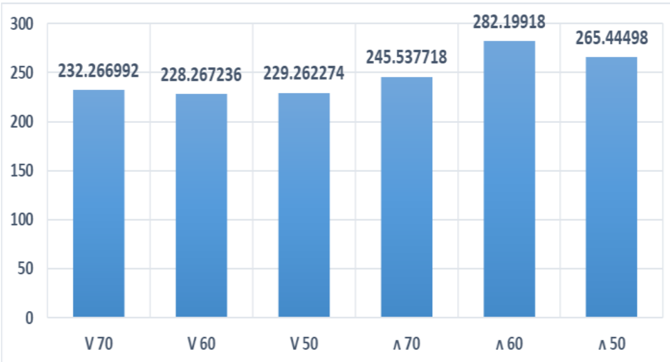

***Fig. 14**. Pitching moment at center gravity produced by every angle and configuration.*

Each data showed by the charts above is the total value from four angle of attack datas putted into one. By comparing one variation to another, we can take a better comprehensive conclusion. V stands for V-Tail and ∧ stands for V-Inverted followed by dihedral angle value.

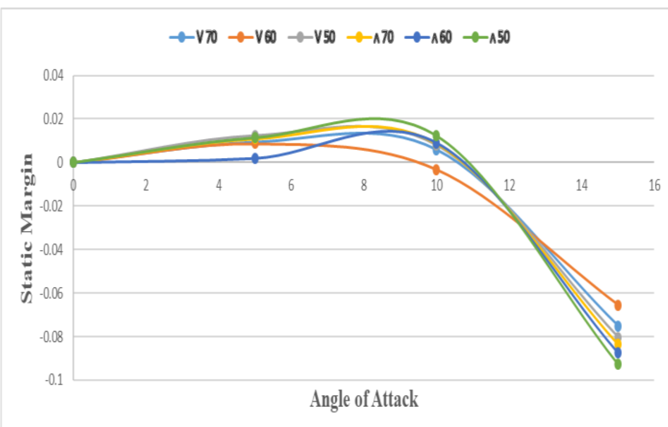

***Fig. 15.** Static margin for every angle and configuration vs angle of attack.*

9 CONCLUSION

Configuration who perform and produce more lift and pitching moment is V-Inverted tail. This can avoid the aircraft from phenomenon such as nosedive and spiral by having better control. However, configuration and value changing of dihedral angle did not make a great impact to drag produced. Interferance drag created by the aircraft did not contribute huge enough compared to other aspect.As we can see from the result above, the dihedral angle value addition works different for each configuration. For V-Tail example, the best set up is using the biggest one, 70 degree. However, V-Inverted tail has 60 degree dihedral angle as the best set up. Therefore aircraft will have better stability and control with the result of this simulation.

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