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FLOW ANALYSIS OF AIRFOIL WITH MECHANICAL SLAT AND FLAP USING CFD

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Abstract— The usage of slats and flaps in airfoils may reduce the fuel consumption of airplanes and improve their performance as well. In terms of performance, it will increase the lift coefficient of the airfoil. Therefore, in this study, simulation works have been carried out to investigate the effect of various angles of flap and slat to the lift coefficient of the airfoil. The mechanical slats and flaps are designed to improve the lift coefficient of the airfoil model NACA 0015 at the high angle of attack, $\alpha = 17°$. While, the angles of flap, β and slat, δ were set at 3 cases, namely ($\delta = 15°$, $\beta = 25°$), ($\delta = 20°$, $\beta = 30°$) and ($\delta = 25°$, $\beta = 35°$). The simulation was performed using Ansys Fluent software. The simulation results of lift coefficient and velocity distribution around the airfoil have been compared between base case and mechanical slat and flap cases. There were about 49% to 110% improvement of lift coefficient by using mechanical slat and flap. In addition, the airfoil with a mechanical slat and flap for the case (δ = 20°, β = 30°) indicates the maximum lift coefficient at 0.3107. The result of the lift coefficient is supported by the result of velocity distribution.

I. Introduction

The aerodynamic performance of an airfoil becomes a crucial issue in devising an airplane. In terms of the mechanical aspect, the lift generated by the airfoil depends on its shape, area, speed and position. A larger wing area is required for aircraft taking off and landing. A slat is an additional part or element that is installed in front of the leading edge while the component behind the trailing edge is called a flap. The slats and flaps move along the chord to increase the area of the wing by changing the angle or adjusting the distance. Several types of flaps can be used depending on the type of aircraft, weight and runway conditions. These include plain flap, fowler flap, slotted flap, split flap, zap flap, double slotted flap, Junkers flap, Gouge flap and Krueger flap [1-5].

The field of computational fluid dynamics has become a commonly used tool for generating fluid flow solutions with or without solid interactions [2-4]. For analysis problems involves in fluid flow, computers are used to execute the calculations to simulate the free-stream flow of the fluid or air, and the interplay of the fluid (liquids and gases) with surfaces defined by boundary conditions. From that, it can use the governing equation for discretization and iteratively solve each control variable to get the approximate value of each variable in the computational domain. A good configuration of slat and flap angle may improve lift coefficient which will reduce fuel consumption [1,5,7,9,10].

However, there was a lack of research to investigate the effect of various slat and flap to lift coefficient in a high angle of attack. In this study, Ansys Fluent software was chosen due to the reason that this software can solve the most sophisticated models for multiphase flows, reacting flow, fluid-structure interaction and even complicated viscous and turbulent, internal and external flows. It will save the fabrication cost and the result of lift coefficient, drag coefficient and velocity distribution can be determined due to the various input properties. Therefore, in this study, simulation works have been carried out to investigate the effect of various angles of flap and slat on the lift coefficient of an airfoil.

II. Methodology

A. Airfoil model

Figure 1 shows the model of NACA 0015 with added mechanical slat and flap. NACA 0015 was chosen due to the availability of the previous experiment result of this model [11,12]. The angles of flap, β and slat, δ were set at 3 cases, namely (δ = 15°, β = 25°), (δ = 20°, β = 30°) and (δ = 25°, β = 35°). The setting angles of flap, β and slat, δ were based on the model airfoil [1] as shown in Figure 2. Those 3 cases were chosen based on the combination of angles of flap, β and slat, δ which stated in Table 1 and Table 2. Table 1 shows that the C_L is higher in the range of 15°, 20° and 25°. While Table 2 indicates the highest C_L at 25°, 30° and 35°.

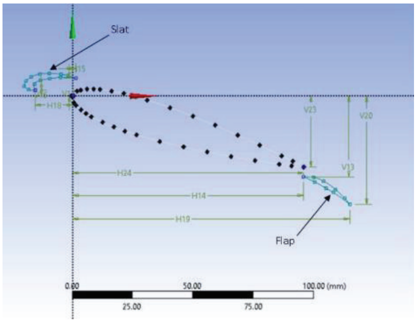

Figure 1: NACA 0015 with added mechanical slat and flap coordinate

Table 1: Lift coefficient of NACA 0015 with mechanical slat

NACA 0015 with added mechanical slat	
Angle of slat, δ (°)	Lift coefficient
0	0.2603
5	0.2606
10	0.2611
15	0.2671
20	0.2685
25	0.2690
30	0.2654
35	0.2607

Table 2: Lift coefficient of NACA 0015 with mechanical flap

NACA 0015 with added mechanical flap	
Angle of Flap, β (°)	lift coefficient
0	0.2603
5	0.2794
10	0.2800
15	0.2990
20	0.3008
25	0.3029
30	0.3089
35	0.3040

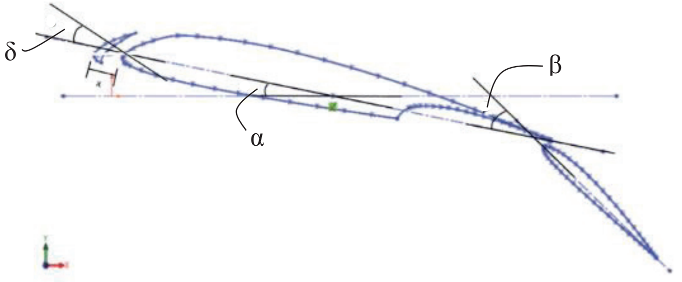

Figure 2: The ideal model design for this project simulations [1]

B. Simulation using ANSYS Fluent software

In this study, the model of standard K-epsilon was chosen. Next, the materials were set to be air around the airfoil. Other than that, the boundary conditions are the priority setting in this project. Boundary conditions include the inlets and exit flow boundaries, wall and pole boundaries and internal face boundaries. The inlet velocity was set to be 10 m/s and the air flowing around the airfoil is turbulent.

In the meshing process, the computational domain is divided into simple elements by using the meshing process.

The mesh influences the convergence, accuracy and simulation precision. It is essential to have an excellent strategy to meshing in to obtain faster and more accurate solutions. In this domain, the tetrahedral mesh cells are formed by using different types of meshing. Figure 3 shows the edge sizing around the base case airfoil after the meshing process. Similar mesh method and sizing were used for airfoil with slat and flap with number of element of 79852.

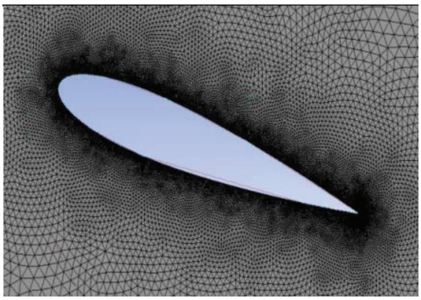

Figure 3: Edge sizing around the airfoil

This grid independence test was performed to reduce the impact of mesh size on computational results while maintaining simulation accuracy. Generally, this test is executed in order to identify a sufficient number of mesh elements for simulation analysis. Table 3 shows the results of the grid independence test for different types of grid resolution from extra coarse to extra fine. There is a significant drop in the value of lift coefficient during the initial grid independence test, while the mesh cells number achieved from 8×10^4 to 8.2×10^4, the value of lift coefficient achieved a stable state which the fluctuation is not significant. Besides, the optimum mesh resolution has the low discretization error and also need a time cost effective computational time. Figure 4 shows the optimum mesh size used in this study is the fine mesh with number of cells is 79852. The reason of this mesh grid is chosen is due to the short discretization error and low execution time for computational results. The average skewness obtained was in the range of 0.0485 to 0.0582.

Table 3: A grid independence test

Mesh Model	Grid Resolution	Number of Cells	oefficient of Lift	Percentage Error (%)
1	Extra Coarse	73152	0.1525	1.77
2	Coarse	74493	0.1498	1.07
3	Medium	76437	0.1482	1.56
4	Fine	79852	0.1478	0.00
5	Extra Fine	81963	0.1478	0.00

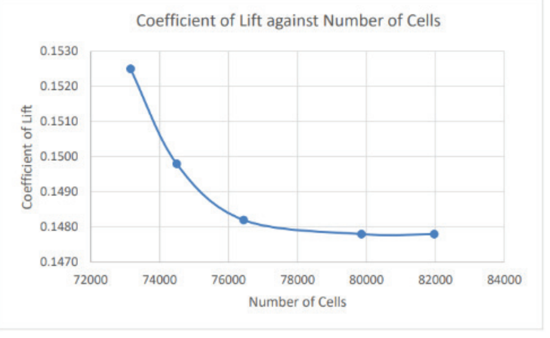

Figure 4: The coefficient of lift against number of cell

III. Result

A. Lift coefficient of airfoil with different angle of slat and flap

The lift coefficient of NACA 0015 with mechanical slat and flap obtained was higher than the NACA 0015 base case (Figure 5). This shows that extending the wing slat and flap will increase the wing's camber or curvature, which could obtain a higher lift coefficient than NACA 0015 base case. From the graph, it shows that the slat at 20° and the flap at 30° obtained the maximum lift coefficient of 0.3107. This is because the suitable angle of slat and flap will prevent separation from occurring near the leading edge. Therefore, the air will flow near the upper surface of the airfoil which will increase the lift coefficient.

B. Velocity distribution

For NACA 0015 base case, it can be observed that there was a large flow separation that occurred at the entire upper surface from leading edge to the trailing edge of the airfoil (Figure 6). On the other hand, the separation of airflow near the leading edge for the mechanical slat and flap case can be prevented by using slat. The presence of the slat may divide the incoming airflow into the low velocity region (blue color region) and the high velocity region (near airfoil upper surface). When air passes through the slots, the airflow over the airfoil on the upper surface increases its speed which causing a reduction in pressure. Indirectly, lift force will be increased due to the pressure different changed between the upper and lower surface on the airfoil.

The presence of flap will maintain the airflow at a high velocity near the trailing edge. Therefore, the combination of slat and flap will increase the airflow velocity from the leading edge to the trailing edge. As a result, the airfoil with the slat at 20° and the flap at 30° which have the highest velocity of airflow (Figure 6) among other cases will also indicate the highest lift coefficient as shown in Figure 5.

From a closer look, the wake region on the NACA 0015 base case decelerated air arises behind the body around which the fluid flows and extends for some distances. However, the stagnation point was changed when applied the mechanical slat and flap on it. It allows the airflow remain attached on the upper surface of the airfoil which may produce lift force in the pressure changes.

Figure 5: Comparison lift coefficient between NACA 0015 with combination of mechanical slat flap and base case

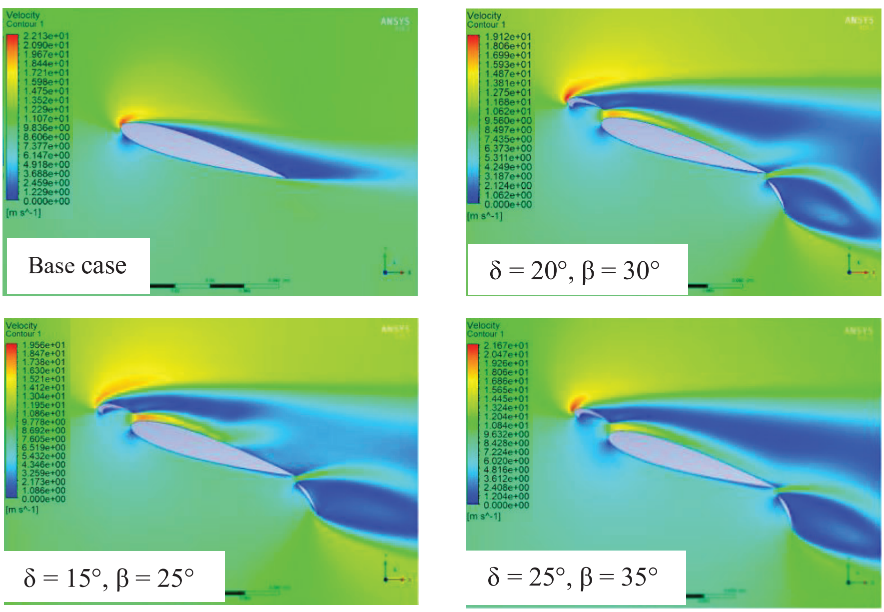

Figure 6: Velocity distribution around NACA 0015 for base case and combination of mechanical slat and flap

IV. Conclusion

In conclusion, the simulations for NACA 0015 base case and NACA 0015 with mechanical slat and flap were done by using the model of K-epsilon in Ansys Fluent software.

The setting of (slat angle, δ = 20°, flap angle, β = 30°) shows the highest lift coefficient compared to other sets of slat and flap angle including base case. It approved that optimisation of the slat and flap angle was essential to obtain the greater lift force with the acceptable drag coefficient. By using the mechanical slat and flap, airflow could remain attached to the upper surface of the airfoil. As a result, there was an increase in lift force from 62% to 110%.

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VI. References

[1] N. Sarjito, Aklis and T. Hartanto, "An optimization of flap and slat angle airfoil NACA2410 using CFD", *AIP Conference Proceeding, 1831,* 2017. https://doi.org/10.1063/1.4981179

[2] S. Wang, Y. Zhou, M. M. Alam, and H. Yang, "Turbulent intensity and Reynolds number effects on an airfoil at low Reynolds numbers", *Physics of Fluids*, vol. 26, no. 11, 2014. https://doi.org/10.1063/1.4901969

[3] Andrew Stacey, *Fluid Flows and Infinite Dimensional Manifolds. The Azimuth Project*, 2000. [Online] Available: http://www.azimuthproject.org/azimuth/show/Blog+-+fluid+flows+and+infinite+dimensional+manifolds+(part+3)

[4] L.E. Olson, P.R Mcgowan, C. Guest, "Leading-edge slat optimization for maximum airfoil lift", *Nasa Technical Memorandum*, vol. 26, 1979. https://ntrs.nasa.gov/api/citations/19790018929/downloads/19790018929.pdf

[5] R. Balaji, F. Bramkamp, M. Hesse and J. Ballmann, "Effect of flap and slat riggings on 2-D high-lift aerodynamics", *Journal of Aircraft*, vol. 43, no. 5, pp. 1259–1271, 2006. https://doi.org/10.2514/1.19391

[6] W. D. P. Fonseca, M. W. Frasão Reis, P. F. Lavra Dias, and L. M. De Sousa Filho, "CFD Analysis of airfoils with flaps for low Reynolds number," *Revista de*

Engenharia e Pesquisa Aplicada, vol. 4, no. 4, pp. 93–101, 2019. https://doi.org/10.25286/repa.v4i4.1240

[7] R. Thejaraju, D. Jose, V. R. Niveditha, V. Suresh and A. Sumanthran, "A study of airfoil flap deflection angle using cfd simulation techniques". *International Journal of Mechanical and Production Engineering Research and Development*, 9 (Special Issue), pp. 125–132, 2019. https://doi.org/10.24247/ijmperdjun201913

[8] V. B. Gawande, A. S. Dhoble, D. B. Zodpe and S. Chamoli, "A review of CFD methodology used in literature for predicting thermo-hydraulic performance of a roughened solar air heater", *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 550–605, 2016. https://doi.org/10.1016/j.rser.2015.10.025

[9] Chuan He, Thomas C. Corke, and Mehul P. Patel, "Plasma Flaps and Slats: An Application of Weakly Ionized Plasma Actuators", *Journal of Aircraft*, vol. 46, no. 3, pp. 864-873, 2009.

[10] Bart A. Singer, David P. Lockard, Kenneth S. Brentner, "Computational Aeroacoustic Analysis of Slat TrailingEdge Flow", *5th AIAA/CEAS Aeroacoustics Conference* 10-12 May, Greater Seattle, Washington, 1999.

[11] F. A. Zainuddin, N. M. Daud, A. F. A. Ghani, "Experimental study of flow around airfoil at high angle of attack by using DBD plasma actuator", *Proceedings of Mechanical Engineering Research Day*, 2018.

[12] F. A. Zainuddin, N. M. Daud, S. Mat, Z. Buntat , "Experimental study on flow around airfoil by using dielectric barrier discharge (DBD) plasma actuator", *ARPN Journal of Engineering and Applied Sciences*, vol. 13, no. 7, pp. 2400-2407, 2018.