Numerical Investigation of M21 Aerofoil and Effect of Plain Flapper at Various Angle of Attack

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Abstract. The aerofoil plays an important role in any structure moving in a fluid-like in a passenger plane, jet plane, or helicopter. The aerofoils decide whether the lift force is appropriate to balance the weight of the plane or not and the amount of drag force is required on the vehicle. The purpose of this project is to simulate the M21 Aerofoil with the help of FLUENT and validate it with theory. This Project also includes the study of various Flapper designs and their simulation. Flappers are useful when the Airplane is about to take-off or landing. The Important parameters to be study are Lift Force, Drag Force, lift coefficient, and Drag coefficient. Simulation has been done for the different Angle of Attack which is useful for finding maximum Lift force and Stall Angle. The Work includes simulation of Plain Flapper for the Angle of Attack where \( \frac{C_L}{C_D} \) is maximum. Similar work can be done for different types of Flapper used in Airplane. The stall angle achieved for M21 was 24° and maximum value of \( \frac{C_L}{C_D} \) measured at 7° A.O.A. Investigation also shows that for the 10° plain flap angle highest drag and lift force was possible. It contains the study of the Adverse Yaw effect which rolls the Airplane while taking a turn. since the validity of any theoretical prediction can only be assessed in practice.

1. Introduction

Aerodynamics is an extension of science that is concerned with focusing on the movement of air when dealing with a [1]solid object, such as an aerofoil. An aircraft is a basic machine that is capable of fly in aerospace by gaining support from the air. The relation between [2]aircraft and the air is termed aerodynamics [3] which deals with the effects of forces, moments, and motion of the airplane through space. The wing of an aircraft is one of the critical parts of aerodynamics. Few important terms are required to understand before jumping to the field of aerodynamics. The Figure 1. Explain the few major parameters easily.

Lots of aerodynamics problems are difficult to solve or analyse by analytical method or experimental methods. So, one of the best [4]options to solve these problems are using numerical analysis methods. Ansys is one of the user-friendly software which helps the researcher to investigate [5]complicated cases. Ansys is an alternative method to predict the characteristic of aerodynamics parameters, the effect of the various wings and designs on the performance of aircraft.
It can be seen from Figure 1. that the downward flap gives better performance compare to straight and upward flap positions. As per the survey downward flap has been introduced for the current investigation. The performance of the aerofoil can be checked using non-dimensional numbers like drag & lift coefficient. To convert the drag & lift forces in the non-dimensional term we have lift & drag coefficients [7] which are as follows.

\[
\text{Lift coefficient: } C_L = \frac{2L}{\rho AV^2} \quad \text{Drag coefficient: } C_D = \frac{2D}{\rho AV^2}
\]

Where \( L \) is lift force, \( D \) is the drag force, \( A \) is an area of the aerofoil, \( V \) is fluid velocity and \( \rho \) is the density of the fluid. These non-dimensional[8] coefficients mostly depend on lift, drag force, [9] angle of attack, and Reynold number.

\( C_L, C_D = f (\alpha, \text{Re}, \text{Mach No, Aerofoil Profile}) \)

For low-speed flow Mach numbers do not affect given aerofoils.

For the present investigation Aerofoil was chosen as M21. The current work aims to find the stall angle for a particular aerofoil. Also, the flap angle for the same [10] aerofoil has been found using numerical investigation.

2. Numerical Investigation of M21 Aerofoil

The present investigation is purely based on numerical simulation for the M21 Aerofoil with and without flapper. The numerical simulation[11] helped to find the stall angle for the given aerofoil. The required coordinates for the aerofoil were taken from the NACA tool. These coordinates help to generate a 2D drawing of the aerofoil in design modular. Aerofoil was placed horizontally in the 5m*4m enclosed Domain in AutoCAD. The chord length was taken around 1.0148m.

2.1 Geometry Modelling

Since Selected body as M21 Was in One direction. The cross-sectional area in that direction was constant and there was no significant variation in that [4] direction and the flow was normal to the body, the problem could be completely described in one plane, which made it a two-dimensional model. The bottom-up approach was used to create the model geometry.
The above Figure 2. Shows the domain created in the Ansys geometry modular. The next step in the process of simulation is grid generation.

2.2 Grid Generation
Mesh generation is one of the critical [12] aspects to study the behaviour of the fluid flow. There are lots of types to create a mesh. For the present work triangular [13] type grid had been taken having fine mesh. A grid independence test has also been done for accurate results.

As shown in Figure 3. An inflation layer has been provided to the edge of the aerofoil which gives better results. After the grid independence test around 3,95,846 elements were generated.

2.3 Preprocessing
In the pre-processing procedure inputs of the work have been submitted. The software requires the input parameters in terms of turbulence modeling, Initial & Boundary conditions, various schemes, and numbers of iterations have been [14] applied for the investigation. According to the literature k-omega, the SST turbulence model has been selected having 2,00,006 Reynold number as an initial boundary condition. The investigation has been done for 500-time step by saving it for every 0.01 sec. By keeping Reynold number as a constant value, work was carried out for various angle of attack like -6°,-4°,-
2°, 0°, 3°, 5°, 7°, 9°, 10°, 15°, 20°, 22°, 24°, 25° to 30°. The results have been analyzed and contours for various A.O.A have been generated, which are shown in the next chapter.

3. Results and Contours of Numerical Investigation

The numbers of simulations have been completed for the present analysis. The most important parameter in aerodynamics is lift and drag. The results were explained in terms of lift and drag coefficient. Results are shown in Table 1 as follows.

| A.O.A | $F_D$ (N) | $C_D$ | $F_L$ (N) | $C_L$ | $C_L/C_D$ |
|-------|----------|-------|----------|-------|-----------|
| -6    | 0.49408  | 0.095521 | 2.5897 | 0.500672 | 5.2414862 |
| -4    | 0.32798  | 0.06341  | 0.76009 | 0.146949 | 2.317442  |
| -2    | 0.215381 | 0.041639 | 0.65165 | 0.125984 | 3.025625  |
| 0     | 0.108721 | 0.021029 | 1.80769 | 0.34964  | 29.862629 |
| 3     | 0.11785  | 0.022785 | 3.5194  | 0.68042  | 3.025625  |
| 5     | 0.13357  | 0.02768  | 4.2768  | 0.8674   | 31.336705 |
| 7     | 0.163    | 0.031514 | 5.4442  | 1.0525   | 33.397855 |
| 9     | 0.204703 | 0.039575 | 5.94744 | 1.1498   | 29.053696 |
| 10    | 0.23982  | 0.04636  | 6.7166  | 1.2985   | 28.00906  |
| 15    | 0.49487  | 0.09567  | 7.5132  | 1.45255  | 15.18292  |
| 20    | 1.007971 | 0.19516  | 8.17421 | 1.58033  | 8.0976122 |
| 22    | 2.3557   | 0.45544  | 9.7929  | 1.8809   | 4.1298525 |
| 24    | 5.44682  | 1.05304  | 12.0189 | 2.3264   | 2.2066018 |
| 25    | 4.6822   | 0.90521  | 7.46601 | 1.44341  | 1.5945582 |
| 30    | 4.604    | 0.8796   | 7.01569 | 1.3563   | 1.5419509 |

It is important to observe the stall angle for a particular aerofoil where the ratio of non-dimensional parameter starts decreasing. The stall angle is where we get maximum tilt position for a given aerofoil. As shown in Table 1 the stall angle for M21 aerofoil was achieved 24° where there was a sudden decrease in both lift and drag force achieved to aerofoil. Also, it can be concluded from the analysis that at 7° the ratio of $C_L/C_D$ is 33.397 which was the maximum. This angle improves the aircraft in lifting it. The pressure and velocity contours help to understand the behavior of the fluid flow when it strikes the aerofoil. Here it is shown contours generated for the same investigation. The below contours are only for the few negatives, zero, and positive angles of attack.

![Contour of Static Pressure](image.png)

Figure 4: Pressure Contour of A.O.A -6°.
The above Figure 4 and Figure 5 are for the -6° angle of attack between the chord line and the flow direction. The flow separation region can be easily seen from the pressure contour. A high amount of pressure was generated when fluid strikes the leading and trailing edge of the aerofoil.

**Figure 5.** Velocity Contour of A.O.A -6°.

**Figure 6.** Pressure Contour of A.O.A 0°.

**Figure 7.** Velocity Contour of A.O.A 0°.
Initially, the investigation was performed for the 0° angles of attack of the aerofoil. After the horizontal position of the aerofoil, numbers of analyze have been completed for the different angles of attack. The results in Table 1. also shows the results obtained for all angle where the horizontal position of aerofoil gives moderate output in terms of drag force and lift force.

![Figure 8. Pressure Contour of A.O.A 7°.](image)

![Figure 9. Velocity Contour of A.O.A 7°.](image)

The above Figure 8. And Figure 9. are pressure and velocity contours generated for the 7° angles of attack. As results show that the 7° angles of attack are more preferable for lifting the aircraft compared to other angles. The reason to prefer 7° angles was only because it got the maximum ratio of non-dimensional parameters.
The Figure 10. & Figure 11. are for the 24° angles of attack with the fluid direction. Both contours are for the stall angle of attack achieved by the simulation result. After the increment in angle both drag and lift, the force will start to decrease. The drag force achieved at stall angle was 5.44 N and the lift force measured was 12.01 N. Figure 11. This shows that a large void generates above the wall of the aerofoil which shows the large flow separation.

So, these are the results and contours produced by numerical investigation. The results obtained from the analysis have been used for the graph generation which gives a better idea to understand the behavior of aerofoil. Further investigation has been done on the same M21 aerofoil using few modifications available in the aerofoil design. More research has been explained in the next section of the paper.

4. Analysis of M21 Aerofoil using Plain Flapper

Lots of researchers have worked on the various design of the aerofoils. Many of them worked on the different types of flappers that can be used to improve the performance. In general, there are types of flappers available for the investigation like Plain flapper, Split flapper, Slotted flipper, Fowler flapper,
etc. Further work can be done on the shape of the aerofoil using numerical methods. For this paper flapped[5] aerofoil has been used for the investigation. Research shows that aircraft has more effect on the lift performance while using flappers than without flapper. For current work, analysis has been done by taking 7° angles of attack having maximum performance among all. The change has been made in the aerofoil by providing flapper.

As shown in Figure 12, flapper was used at different angles and analysis was done. Again the meshing was done for the different model of an aerofoil with a flapper attached to it. The remaining pre-processing work was the same as done for the without flapper. The input parameters and turbulence models were set as the same for current work. Again the results generated from the investigation are shown in the form of tabular and contours.

| Plain Flap Angle | F_D (N) | C_D | F_L (N) | C_L | A.O.A |
|------------------|---------|-----|---------|-----|-------|
| 8                | 0.20514 | 0.031259 | 7.1263 | 1.51108 | 7 |
| 9                | 0.21238 | 0.041061 | 7.9384 | 1.5347 | 7 |
| 10               | 0.23404 | 0.04524 | 8.6761 | 1.6773 | 7 |
| 11               | 0.22505 | 0.04351 | 8.2326 | 1.5916 | 7 |
| 12               | 0.19542 | 0.03778 | 8.11085 | 1.568 | 7 |

Above Table 2, explain the results obtained by the numerical investigation for the various plain flap angle for 7° angles. Numbers of investigations have been performed for the various flap angles as shown in Table 2. The maximum drag and lift coefficient was achieved at the 10° angle of attack which helps the aircraft in take-off and landing positions. The drag force produced at the optimized angle was 0.234 N and the maximum lift force generated was 8.676 N. In terms of non-dimensional parameters, the drag coefficient was 0.0452 and the lift coefficient achieved was 1.677.
The above Figure 13. and Figure 14. are the pressure and velocity contours for the 10° plain flap angles provided with 7° angles of attack. The present work is only done for the plain-type flappers and their performance on the M21 aerofoil. The data obtained by the current numerical investigation have been analysed and graphs have been plotted for various non-dimensional parameters.

5. Graphs and Discussion
In this chapter, the results have been shown in a graphical method for an easy understanding of the improvement of the aerofoil. The graphs are for the non-dimensional terms for better comparison of model and prototype.
Figure 15. A.O.A vs C_l/C_D curve of M21 Aerofoil

The above-plotted curve is for the ratio of non-dimensional parameters to the angle of attack. This curve gives the idea about the optimized angle for the better lifting force of the aerofoil when it starts take-off. As shown in Figure 15, the maximum ratio achieved was 33.397 at 70 degrees. The drag force generated at this angle was 0.163 N. The lift was developed around 5.44 N.

The further investigation results on the flapper are also shown in form of plots. More work on the flap angle has been completed for the 70 degrees. The next two plots are flap angles against the drag coefficient and lift coefficient.

Figure 16. Plain Flap Angle vs C_D Graph
The above Figure 16. is a graph of Plain flap angle vs drag coefficient. As it is seen from it that 10\(^\circ\) flap angle has better drag force compared to others. The drag force produced by the modification was achieved as 0.234 N. Second Figure 17. is for lift coefficient to the flap angle. Results show that the maximum lift force developed was 8.676 N for 10\(^\circ\) flap angles in the aerofoil.

The desirable conclusions have been made after analysing the numerical investigation results on M21 aerofoil. The various conclusions are suggested in the next chapter.

6. Conclusions
The following conclusions were made after analysing the M21 aerofoil using the numerical method.
- As the angle of attack increases, the lift force, as well as drag force, will also increase. But after optimized angle, both start to decrease.
- The optimum angle of attack for the present M21 aerofoil was at 7\(^\circ\) where \(\frac{C_l}{C_D}\) was observed maximum.
- The stall angle was found to be at 24\(^\circ\) where a sudden fall in the lift was observed due to the formation of eddies and flow separation.
- Plain Flapper helps to improve the lift force applied on the aerofoil. For M21 aerofoil it was measured as 10\(^\circ\).
- For the low value of the plain flap angle, the lift coefficient value was observed less compare to higher angles.

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