Numerical Analysis of Wings for UAV based on High-Lift Airfoils

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Abstract - The main theme of my project is to design a wing for UAV based on different high lift devices. My work initiated with the modelling of wing alone and after that with flaps and leading edge slat by Using CATIA V5 and the simulation was done using ANSYS CFD with the aim of validating the design. Wing design of UAV requires a different approach comparable to man–operated airplanes. The maximum lift is a primary factor to achieve high endurance factor values and short take-off and landing distances. The main design problem for UAV wings design is compromise between the getting maximum lift, reducing drag. The special feature of main airfoil with either flap or slat is extremely low local Reynolds number on second element (flaps section) providing danger of flow separation, especially for deflected flap. Generally, UAV with low flight speed create design difficulties, and lift increment of plain wing is also limited. This paper describe the use of slat as well as flap for getting high lift and also find advantages and disadvantages of adding slat and flap on plain wing. This paper not only addresses aerofoils design, but also the 3-D wing design with flap and slat for low Reynolds number.

Key Words: airfoil, wing, CATIA V5, ANSYS CFD, CFX Solver, UAV, Aerodynamics, single slotted flap, leading edge slat.

Nomenclature:

C_l	= Airfoil lift coefficient	C_l max.	= Maximum lift coefficient.
C_d	= Airfoil drag coefficient	Re	= Reynolds number
AR	= Aspect Ratio	UAV	= Unmanned Aerial Vehicle
α	= Angle of attack	L/D	= Lift to drag ratio

I. INTRODUCTION

This chapter provides an introduction about the UAV (Unmanned aerial vehicle) and importance of the present project with respect to aerodynamic/wing effect. The motivation of this work is described first, followed by the objective of the present work. The final section of this chapter outlines the entire thesis, with a summary of the chapter.

Since 1917 when the first UAV (Unmanned Air Vehicle) was developed successfully in England, It has been progressing through several stages, which are target drone, reconnaissance aircraft and multi-role UAV. Also, it has been successfully useful for military purpose in four local wars, which has come to the attention of the world.

At present there are various kinds of UAV's for different purposes. Their aerodynamic configurations can be categorized mainly into three kinds: conventional, unconventional and that with rotor. The former two kinds are adopted by most UAV. Wing design for UAV applications requires a special approach which in different from conventional man operated airplane.

The engineering optimum in low Reynolds number Aircraft design is a compromise between the various mentioned parameters.

Obviously UAV have some drawbacks like short endurance, poor flying qualities, fast landings causes damage of equipment, low lift/drag ratio of flight.

For these drawbacks, this paper analyze wings with different types of Flap and also with Leading-edge device at different angles of attack at low Reynolds number to enhance more lift and lift to drag ratio for subsonic aerofoil.

High lift devices used for bearing surfaces are designed to expand the flight envelope by changing the local geometry according to phases of flight of the aircraft. This paper shows the result on NACA 4415.

UAV is used to surveillance or monitoring where human beings can't reach easily to monitor the location. This paper represents to make such type of UAV with the same parameter which is already mentioned above. I took help from some journals and some highly motivated books, which are mentioned below:

II. CONFIGURATIONAL STUDY

This chapter provides geometrical details of the fixed wing UAV configuration and its variants.

PARAMETERS	VALUE
Aspect Ratio	6
Span (m)	6
Chord (m)	1
Wing Area (m^2)	6
Flap Chord (m)	0.332
Slat Chord (m)	0.152
High Lift device Flap Span (m)	1.12

Simulation condition for this project, Re=$1.4x10^6$, Velocity =20.42m/s.

III. MODELLING AND SIMULATION

The computation involved the designing of plain NACA 4415 aerofoils, plain, split, single-slotted, double-slotted flaps and slats and a bullet shaped fluid domain on software CATIA V5.

The surface meshing of the designs for grid generation was done on ICEM CFD ANSYS 14.5. The CFD analysis was carried out using commercial code ANSYS FLUENT 14.5. The post processing of the results was done using ANSYS CFD POST.

The 2D airfoil co-ordinates were exported to part module of CATIA V5 which is software for modelling. The 2D aerofoil co-ordinates sketch was extruded using the pad command [9].

The aerofoil with the single slotted flaps as well as leading edge slats are of NACA 4415 profile (Fig.1.).

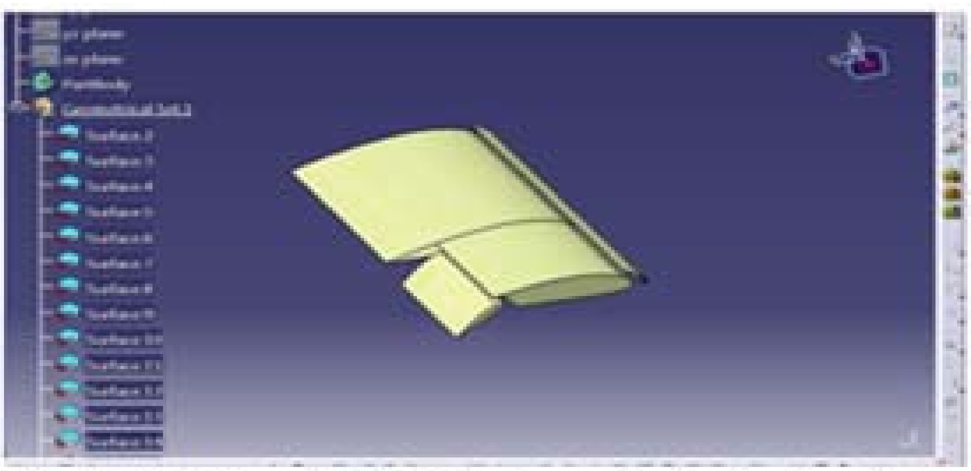

Fig.1. CATIA model of the slat and single slotted flap at 30° with NACA 4415 aerofoil profile.

IV. GRID AND SIMULATION

A bullet shaped fluid domain was created in part design module of CATIA V5and then import in ICEM-CFD ANSYS software for the grid generation study.

Tetrahedral surface meshing was done for generating the grid. Refinement was done on the leading and trailing edges of aerofoil, slats and single slotted flaps. Coarse type sizing was used to generate the mesh.

The mesh quality depends upon the value of smoothness which defines the rate of change of cell size. For a good quality mesh the rate of change of cell size should be smooth. (Fig.2).

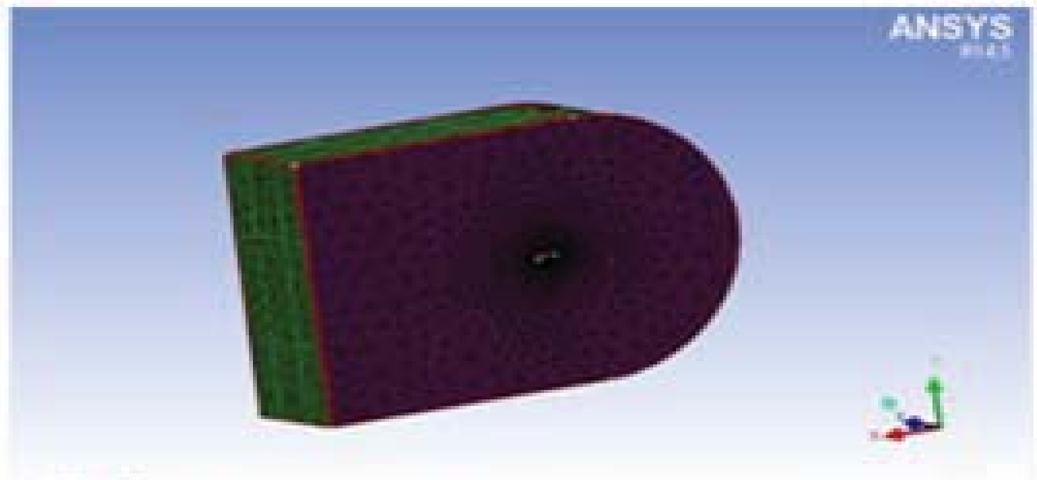

Fig.2. Surface mesh of the domain containing the single slotted with NACA 4415 and slat aerofoil profile.

Lift-coefficient Analysis

Fig. 3, Fig.4, Fig.5, Shows the Graph and Table of C_l and C_d. The description at different AOA is below.

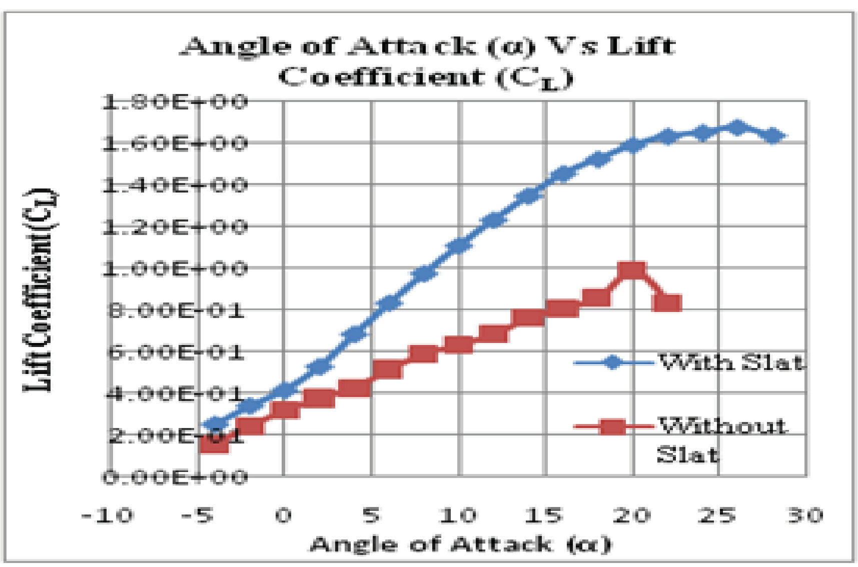

Fig.3. Shows the max.C_l of NACA 4415 wing with and without slat and flap fixed at 30°

Angle of attack at 4°: At 1.4×10^6 Reynolds number the value of C_l for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° was found to be 0.686212 which was the maximum C_l obtained in comparison to the $C_{l\,max}$ value obtained for NACA 4415 wing with only single slotted flap at 30°.

Angle of attack at 8°: At 1.4×10^6 Reynolds number the value of C_l for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° was found to be 0.9779 which was the maximum C_l obtained in comparison to the $C_{l\,max}$ value obtained for NACA 4415 wing with only single slotted flap at 30°.

Angle of attack at 12°: At 1.4×10^6 Reynolds number the value of C_l for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° was found to be 1.234961which was the maximum C_l obtained in comparison to the $C_{l\,max}$ value obtained for NACA 4415 wing with only single slotted flap at 30°.

Angle of attack at 16°: At 1.4×10^6 Reynolds number the value of C_l for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° was found to be 1.456909 which was the maximum C_l obtained in comparison to the $C_{l\,max}$ value obtained for NACA 4415 wing with only single slotted flap at 30°.

V. LIFT TO DRAG (L/D) RATIO ANALYSIS

Angle of attack at 4°: At 1.4×10^6 Reynolds number the value of L/D ratio for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° obtained was 5.737078 which is higher than the NACA 4415 wing with only single slotted flap.

Angle of attack at 8°: At 1.4×10^6 Reynolds number the value of L/D ratio for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20 obtained was 6.870267 which is higher than the NACA 4415 wing with only single slotted flap.

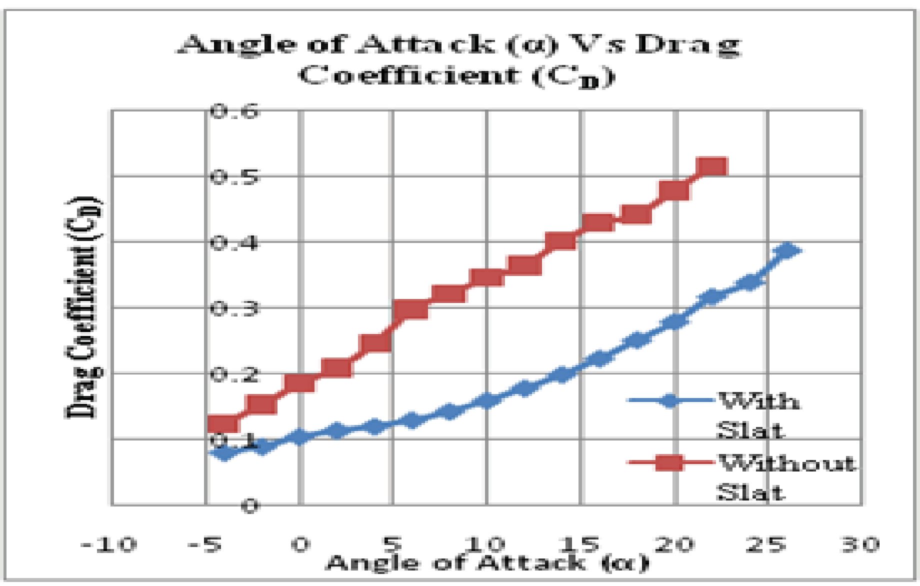

Fig.4. Shows the max. C_d of NACA 4415 wing with and without slat and flap fixed at 30°

Angle of attack at 12°: At 1.4×10^6 Reynolds number the value of L/D ratio for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° obtained was 6.962665 which is higher than the NACA 4415 wing with only single slotted flap.

Angle of attack at 16°: At 1.4×10^6 Reynolds number the value of L/D ratio for NACA 4415 wing with a single slotted flap at an angle 30° and leading edge slat at 20° obtained was 6.553266 which is higher than the NACA 4415 wing with only single slotted flap.

Wing Configuration		AOA 4°	AOA 8°	AOA 12°	AOA 16°
NACA 4415 Aerofoil with single slotted flap fixed at 30°	C_l	0.426842	0.589296	0.683874	0.809674
	C_d	0.244879	0.320694	0.363401	0.427614
	L/D	1.743073	1.837565	1.881872	1.893469
NACA 4415 Aerofoil with single slotted flap fixed at 30° and leading edge slat at 20°	C_l	0.686212	0.9779	1.234961	1.456909
	C_d	0.11961	0.142338	0.177365	0.222318
	L/D	5.737078	6.870267	6.962665	6.553266

Fig.5. Table Shows C_l and L/D ratio of NACA 4415 Aerofoil with and Without Slat and flap at 30°

VI. Contours of Coefficient of pressure

The Coefficient of pressure (C_p) for a NACA 4415 wing with single slotted flap and leading edge slat attached to it as shown in figure 6.

The figure suggests that with increasing angle of attack from 4 to 16 degrees, the low pressure coefficient area tends to shift towards the leading edge on the upper surface. The magnitude of C_p of NACA 4415 wing with single slotted flap and leading edge slat is lesser than the C_p on the NACA 4415 wing with only single slotted flap. Thus, causing higher lift generation.

Fig.6. The coefficient of pressure contours on NACA 4415 wing with slat and flap fixed at 30°

VII. VELOCITY STREAMLINES ANALYSIS

Velocity streamlines Analysis are used to study the path of a fluid as it moves over a structure or interacts with it.

Velocity line generated during post processing of CFD result, individually define the flow path of a fluid on the design.

In figure 7, clearly shows that the turbulent flow gets shifted towards the trailing edge of the aerofoil and on the single slotted flap. Therefore, the flow over the upper surface of wing is almost laminar flow and gives higher C_l.

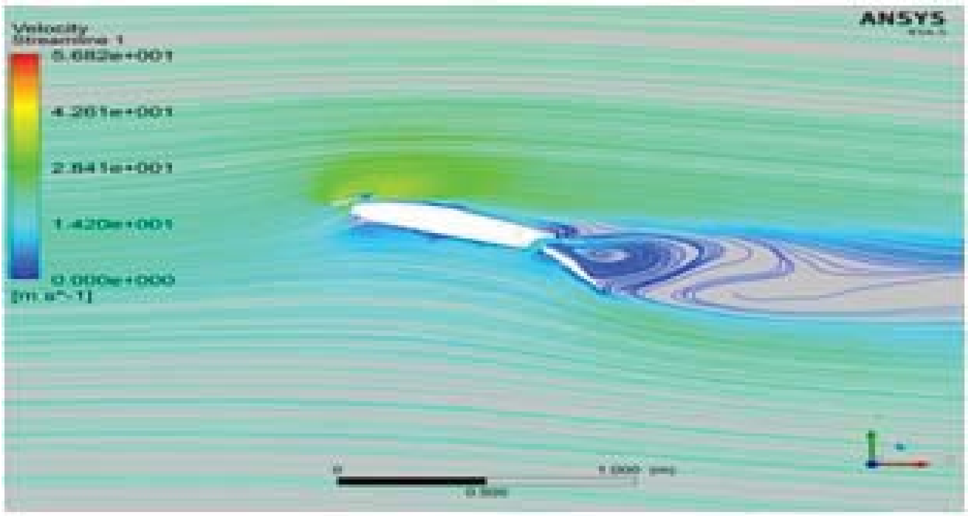

Fig.7. Streamlines of velocity magnitude on NACA 4415 aerofoil with slat and flap at 30° , also showing turbulent flow at trailing edge.

VIII. CONCLUSION

The results obtained from the CFD analysis of single-slotted flaps fixed at 30 degree and Leading- edge slats at 20 degrees was the ideal for getting maximum lift coefficient ($C_{lmax.}$) and Lift to Drag ratio for UAV.

Compare with fixed plain wing these values rectify the problem face at the time of take-off and landing time

With the modelling and analysis part completes, finally an optimum design of wing of UAV (with single-slotted flaps and leading-edge slats), which is giving more $C_{lmax.}$ And lift to drag ratio compare to others.

Finally, I conclude that this wing design can be incorporated as a part of UAV without any problem and even more modification can be done to improve C_l and lift to drag ratio for getting high performance while monitoring.

In future, we will use full wing as a movable like leading edge slats because UAV is small aircraft and its wing configuration is also small compare to other aircraft.

With this, we change the geometry of wing and increase or decrease angle of attack as our requirements.

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