Investigation on 3-D Wing of commercial Aeroplane with Aerofoil NACA 2415 Using CFD Fluent

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ABSTRACT: *An aerofoil is a cross-section of wing* that *plays an important role in any aeroplane or aircraft for designing the wings because of wings, lift is generated that holds the aircraft in the air. The design of wing with desired aerodynamic characteristics are most important for aircraft like fighter plane, commercial plane, UAV and MAV . The National Advisory Committee for Aeronautics (NACA) has given a proper definition for aerofoils which help us to select aerofoil for designing the wings of aeroplanes. In this work, NACA 2415 aerofoil has been chosen for designing the 3-D wing of commercial aeroplane because of its high lift to drag ratio at low Reynolds number and Mach number. The 3-D wing has chord length 100mm at root & 18mm at tip and span length 177 mm with 6^0 dihedral angle. Other wings also drawn with change in design of wing with profile (root) and dihedral angle. Spalart-Allamaras turbulence model is used for better accuracy around boundary wall of wing. Investigation on commercial aeroplane 3-D wing designs are investigated to study the Drag coefficient (C_D), Lift coefficient (C_L) and Lift-to-Drag ratio (L/D) at various angle of attack. The investigation aims to produce better aerodynamic performance for wing designs to reduce the induced drag formed on wing during the flight operation at take-off; in-turn it will improve the efficiency of the aircraft. The geometry of wing models and meshing are carried out by ANSYS 15 software. The computational simulation is carried out by ANSYS FLUENT at low Mach number (0.23). Flow parameters are measured for different design configurations and compared for efficient design.*

Keywords- NACA 2415 Aerofoil, Angle of Attack, Low Mach number condition, Lift and Drag coefficient, CFD

1.INTRODUCTION

The wing is the most important part of the aircraft due to its shapes that lift and sustain the whole weight of aircraft in the air. All the lifting and tilting movement of the aircraft is done by using the control surfaces on the wings. In flight, a lower pressure is to be found on top surface and higher pressure on bottom surface because of Bernoulli's principle which in turn sucks the aeroplane into the air [1]. The wings of an aeroplane are made from aluminium alloys and carbon fiber etc and designed specifically to bend move up and down.

An aerofoil is a cross-section of any wing [2]. It's main job is to provide lift to an aeroplane during take-off and in-attaining height. To cope up with the Drag (which opposes the motion of the aeroplane) Lift is needed. Aerofoil selection is depend on aircraft's varieties like commercial, fighter, low subsonic, high subsonic, super sonic etc.

1.1 Aerofoil : Terminology and Definitions

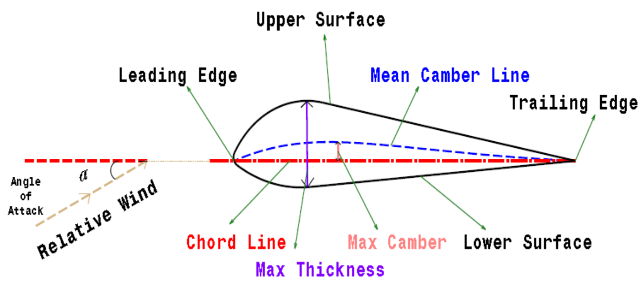

Fig. 1 : Aerofoil Terminology

Aerofoil sketch is shown in Fig.1, which illustrates terminology;

- **Mean camber line-** A line drawn halfway between the upper and lower surfaces of the aerofoil.
- **Leading edge-** It is front edge of aerofoil where maximum curvature can be found.
- **Trailing edge-** It is the rearmost edge of an aerofoil.
- **Chord line-** It is the connecting line between leading and trailing edge and it is straight.
- **Chord length-** It is the length of the chord line.

- **Camber-** It is maximum perpendicular distance between mean camber line to chord line.
- **Thickness-** It is measured either perpendicular to the camber line or perpendicular to the chord line.
- **Angle of attack-** It is defined as the angle between the chord line and the relative wind or flight path.[2,3]

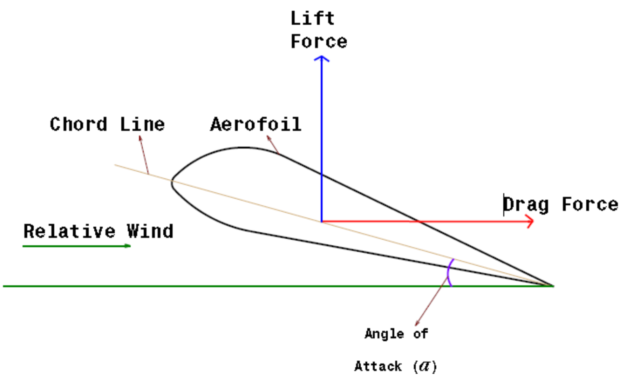

Fig. 2 : Lift and Drag Force

- **Lift coefficient (C_L)-** It is a dimensionless coefficient that relates the lifting force on the body to its velocity, surface area and the density of the fluid in which it is lifting.

- **Lift force -** It is a force which is perpendicular to the relative wind.

$$Lift\ force = 0.5 \times C_L \times \rho \times A \times v^2$$

- **Drag coefficient (C_D)-** It is a dimensionless coefficient that relates the dragging force on the body to its velocity, surface area and the density of the fluid in which it is moving.

- **Drag force -** It is a force which is parallel to the relative wind.

$$Drag\ force = 0.5 \times C_D \times \rho \times A \times v^2$$

- **Dihedral Angle-** It is a upwards inclination of wing from root to tip [3,4].

1.2 NACA Profile Generation

The National Advisory Committee for Aeronautics (NACA) tested 78 aerofoil shapes in wind tunnel and data published in Technical report with the characteristics of all were these sections; tests were conducted in **Variable-Density Wind Tunnel in 1933** [5]. This report resulted in the creation of the four-digit scheme for defining the basic geometry of the aerofoil. This nomenclature was used to define the other aerofoil families, such as the five-digit aerofoils.

The NACA four-digit aerofoil sections define the profile by;

First digit provides maximum camber which is in percentage of the total chord length.
Second digit provides the distance of maximum camber from leading edge in tens of percentage of the total chord length.
Last two digits describe maximum thickness of the aerofoil as percentage of the total chord length [5].

For example, **NACA 2415** aerofoil has total chord length 100 mm. So aerofoil has maximum camber 2mm which is 40mm far from leading edge with 15mm thickness.

1.3 Wing Design Dimensions

In this paper, Boeing 737-700 aeroplane wing is selected and scaled model is drawn with aerofoil NACA 2415. Other wings with modified root profile as well as dihedral angle are also drawn with scaled dimensions. True and scaled dimensions are shown in table. 1.

Table. 1 : Boeing 737-700 aeroplane wing Dimensions

Sr. No.	Wing's terminology	True Dimensions	Scaled Dimensions
1	Wing Root Length	6.98 m	100mm
2	Wing Tip Length	1.25m	18mm
3	Span length	12.35m	177mm
4	Dihedral Angle	6^0	6^0
5	Sweep angle	25^0	25^0

2.METHODOLOGY

CFD investigation consists of three stages. Starting from pre-processing stage where 3-D geometry of wings model were drawn using ANSYS Design Modular and the grids were generated by ANSYS ICEM-CFD. The second stage was simulation by FLUENT solver using Finite Volume Approach [6]. Finally, third step was the post-processing stage; in which the aerodynamic characteristics like Drag coefficient (C_D), Lift coefficient (C_L) and Lift-to-Drag ratio (L/D) were defined at the various angle of attack for wings.

2.1 Pre-Processing

Geometry and Meshing of wings are created in pre-processing.

2.1.1 Geometry

3-D geometry of wing of Boeing commercial aeroplane 737-700 were drawn with scaled in ANSYS Design Modular [7,8] with aerofoil NACA 2415. The chord length of aerofoil used 100mm for profile (root) and 18 mm for wing-tip. Total span length was 177mm with dihedral angle 6^0. Other wings were drawn with Wing with Modified Profile (root), Wing with Modified Dihedral angle(5^0) and Wing with Modified Profile & Dihedral Angle. These were also drawn in ANSYS Design Modular.

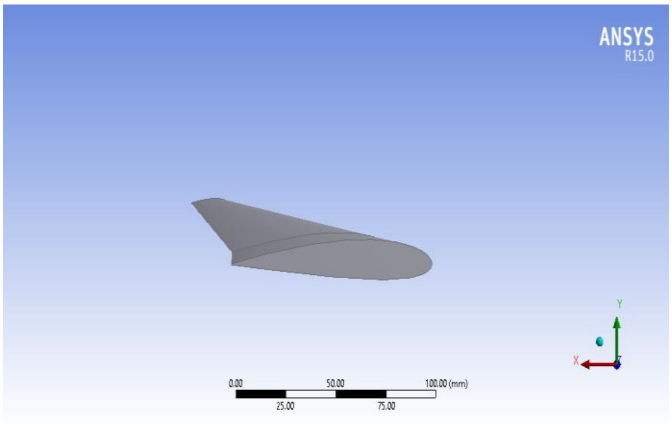

Fig.3 : Wing with NACA 2415

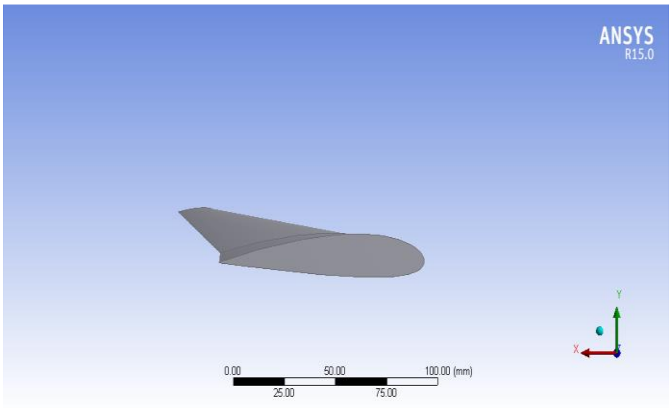

Fig.4 : Wing with Modified Profile & Dihedral Angle

2.1.2 Meshing

The 3-D unstructured tetrahedral mesh was utilized for the flow around the model. Unstructured mesh is appropriate because of the complexity of the model. The advantages of the unstructured mesh are shorter time consumption in grid generation for any geometries and the potential to adapt the grid to improve the accuracy of the computation [8].The Maximum face size, Maximum size and Growth Rate were set to 10mm, 15mm and 1.2 respectively. Inflation was used by selecting edges of wing so that mesh will be more fine around wing surface with first layer thickness (0.1 mm).

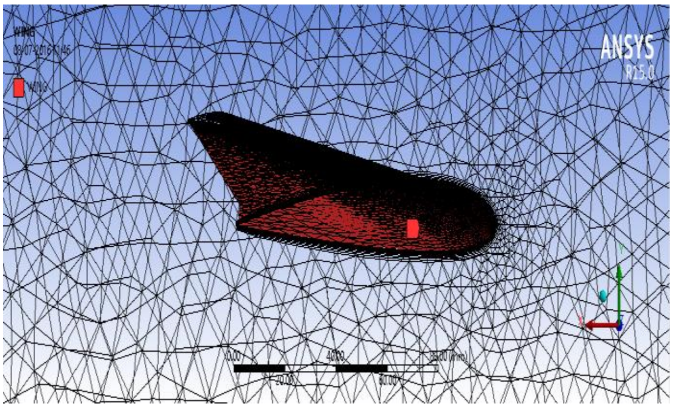

Fig.5 : 3-D Model of Wing with Meshing

2.2 Solver

The numerical simulation by the solver was done after the completion of the mesh generation on fluid flow and wing. The solver formulation using as turbulence model Spalart-Allmaras was used because of low Mach number (0.23) with one-equation turbulence model that provide superior accuracy around boundary wall [8]. After selecting turbulence model; boundary condition, solution control parameters and material properties were defined. All the parameters were specified for various angle of attack, then the model was initialized with inlet values then Run the calculation for some iterations for flow parameters.

Parameters taken for calculations : Constants

- **Properties of Air:**
  Density: ρ = 1.1768 kg/m3
  Viscosity: μ = 1.716e-05 kg/m-s
  Pressure: p = 101325 pa

- **Mach number** = 0.23
  (Lift and Drag force for all wings were find out at low Mach number for take-off condition for efficient design)

- **Mathematical models:** Spalart-Allmaras (Provide accurate results for turbulence model near boundary wall and unstructured mesh with lesser time taken for iterations)

- **Force Monitors**: Lift and Drag with various angle of attacks

- **Reference values:** Far field inlet value are imported.

2.3 Post Processing

After simulation, The aerodynamic characteristics were found for all wings. The details are given in subsequent heading of with Tables 2 to 4 and Figure 8 to 10.

3.RESULTS AND DISCUSSIONS

The aerodynamic characteristics of 3-D wings models likes wing NACA 2415, wing with Modified profile (root), wing with Modified dihedral angle and wing with Modified profile (root) and dihedral angle were found in post processing with various angle of attack like 3^0,5^0,8^0,10^0 and 12^0.

3.1 Lift Coefficient (C_L) : Analysis for Wings

Lift coefficient for Wing NACA 2415, Wing with Modified Profile (root), Wing with Modified Dihedral angle and Wing with Modified Profile & Dihedral Angle were found in post process at various angle of attack. It is observed that the Lift coefficient (C_L) increases with the increases of angle of attack (AOA) as shown in Figure 6.

Table. 2 Lift coefficient C_L : Comparison with all wings

Sr no.	Type	Lift coefficient (C_L)				
		AOA 3^0	AOA 5^0	AOA 8^0	AOA 10^0	AOA 12^0
1	Wing NACA 2415	0.2026	0.2802	0.3838	0.4645	0.5263
2	Wing Modified Profile (root)	0.2066	0.2835	0.3971	0.4680	0.5340
3	Wing Modified Dihedral Angle	0.2057	0.2840	0.3983	0.4710	0.5370
4	Wing Modified Profile & Dihedral Angle	0.2133	0.2929	0.4098	0.4826	0.5439

Table.2-Shows that Lift coefficient is the highest in **Wing with Modified Profile & Dihedral Angle** with comparison with NACA 2415, wing modified profile and Wing with modified dihedral angle. The highest lift coefficient is 0.5439.

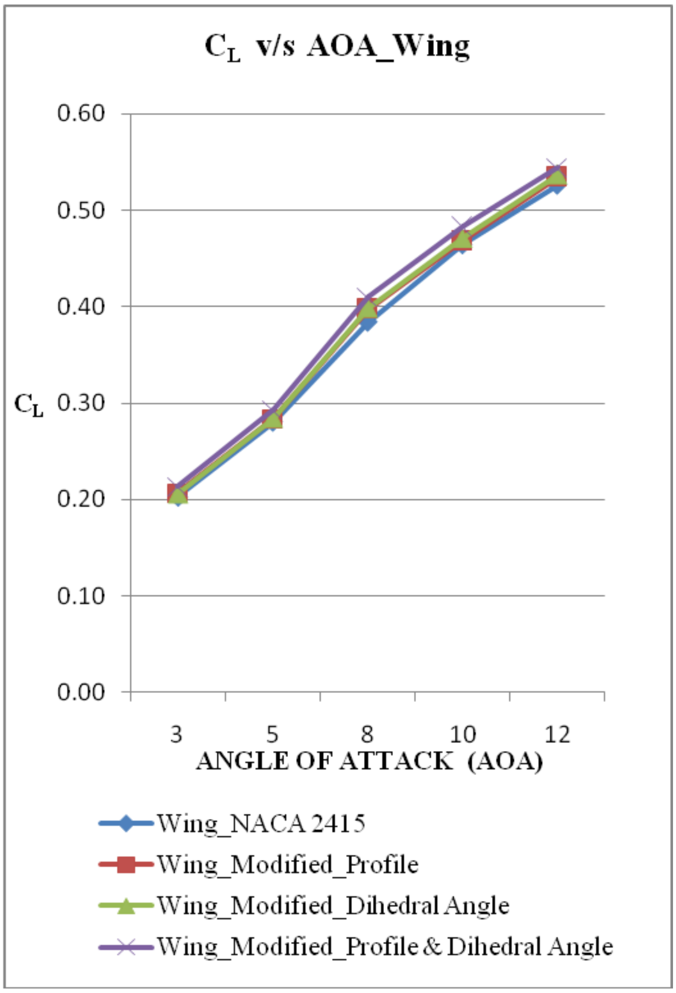

Fig.6 : Lift Coefficient (C_L) at various angle attack

3.2 Drag Coefficient C_D : Analysis for Wings

Drag coefficient for wing NACA 2415, wing with Modified profile (root), wing with Modified dihedral angle and wing with modified profile (root) & dihedral angle were found in post process at various angle of attack. It is observed that the Drag coefficient (C_D) increases with the increases of angle of attack (AOA) as shown in Figure 7.

Table. 3 Drag coefficient C_D : Comparison with all wings

Table.3-Shows that Drag coefficient is increasing with increasing angle of attack.

Sr no.	Type	Drag coefficient (C_D)				
		AOA 3^0	AOA 5^0	AOA 8^0	AOA 10^0	AOA 12^0
1	Wing NACA 2415	0.0134	0.0173	.0252	0.0339	0.0447
2	Wing Modified Profile (root)	0.0137	0.0176	0.0264	0.0344	0.0460
3	Wing Modified Dihedral Angle	0.0137	0.0177	0.0263	0.0344	0.0455
4	Wing Modified Profile & Dihedral Angle	0.0140	0.0180	0.0266	0.0343	0.0445

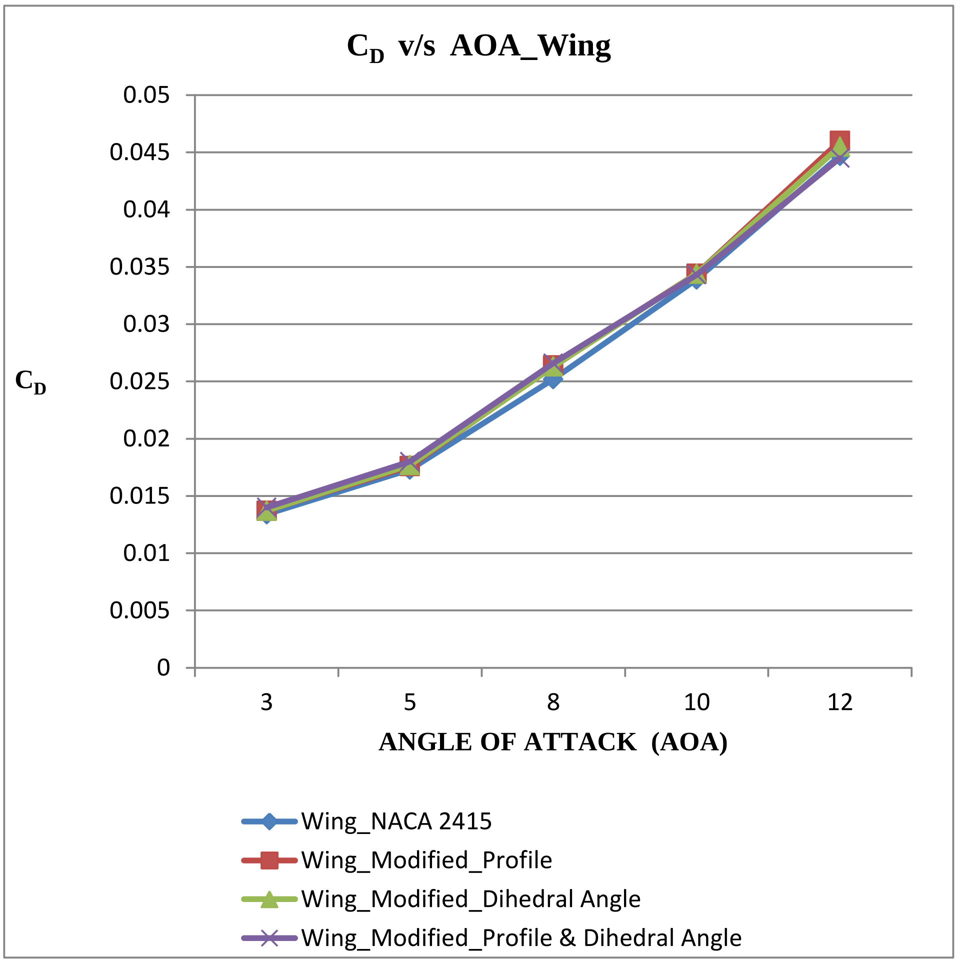

Fig.7 : Drag Coefficient (C_D) at various angle attack

3.3 Lift to Drag ratio (L/D) : Analysis for Wings

Getting all Lift coefficient and Drag coefficient of all wings at various angle of attack, is found that L/D is increasing with increasing angle of attack up to 5^0 and after 5^0, L/D ratio is decreasing with increasing angle of attack. Highest value of L/D ratio is found in **Wing with Modified root & Dihedral angle** (16.31) at 5^0 angle of attack as shown in Figure 8.

Table. 4 Lift to Drag Ratio : Comparison with all wings

Sr no.	Type	Lift to Drag Ratio (L/D)				
		AOA 3^0	AOA 5^0	AOA 8^0	AOA 10^0	AOA 12^0
1	Wing NACA 2415	15.13	16.19	15.25	13.69	11.77
2	Wing Modified Profile (root)	15.05	16.07	15.07	13.62	11.61
3	Wing Modified Dihedral Angle	15.00	16.00	15.14	13.70	11.80
4	Wing Modified Profile & Dihedral Angle	15.19	16.31	15.41	14.06	12.00

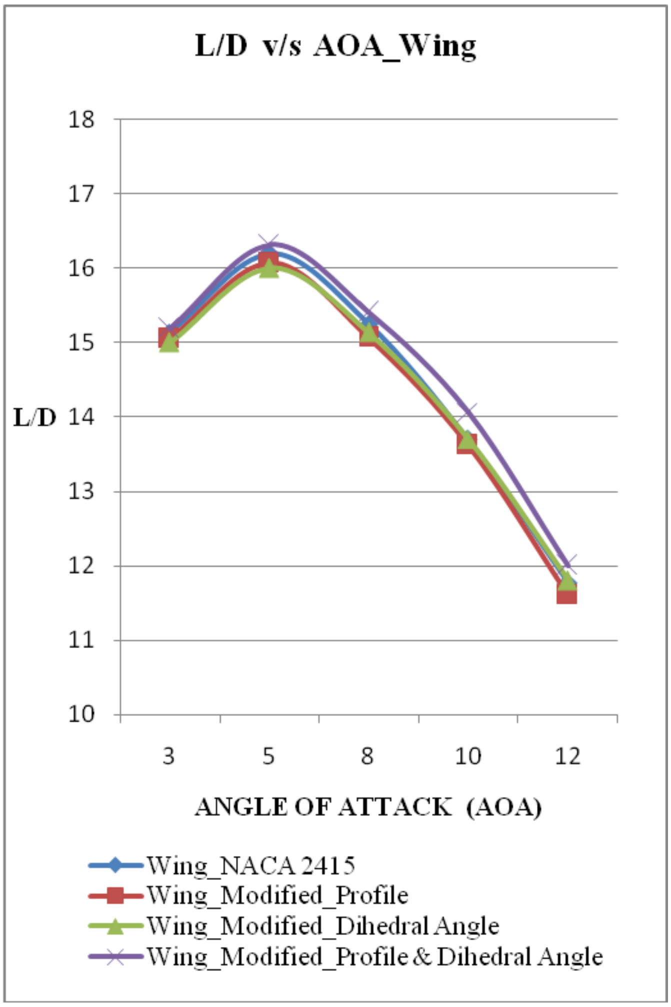

Fig.8 : L/D Ratio at various angle attack

4.CONCLUSION

The results that were obtained after the simulation on each configurations showed that **Wing Modified Profile (root) & Dihedral angle** has the highest value of Lift coefficient and Lift-to-Drag ratio (L/D) as compared to other wings. It proves that the **Wing Modified Profile (root) & Dihedral angle** will be serve the purpose of a wing for aeroplane Boeing 737-700. Hence, if **Wing Modified Profile (root) & Dihedral angle** would be attached to the aeroplane Boeing 737-800 wing it would have good aerodynamic characteristics that would be result in lesser time and lesser fuel consumption.

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