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CFD Simulation and Analysis of a UAV

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Abstract

This paper consists of analyzing the lift and drag coefficient of a UAV and also observing the pressure distribution, velocity vector, velocity contour, path-line around the separated parts of the UAV at different angle of attack using CFD Fluent software. To fulfill the purpose the airfoil of wing, airfoil of tail and fuselage are simulated separately. In case of wing and tail the 2-D airfoil is simulated in Fluent and lift and drag coefficient is found at different AOA. Then using 2-D to 3-D conversion formula wing (3-D) and tail (3-D) lift coefficient is calculated. The total Lift coefficient (C_{LT}) of the UAV is calculated by adding wing, tail and fuselage lift-coefficient. It is seen from the analysis that at about 8 degree angle of attack the UAV reaches at its maximum lift coefficient. After 8 degree AOA the lift coefficients of the UAV starts to decrease. The start of transition period (flow separation) as a percentage of chord length is also determined using X-foil software. And it is seen that at an increased AOA flow separation occurs more quickly.

Keywords: Lift co-efficient, velocity vector, Angle of attack (AOA), flow separation, path-line.

1. Introduction

For A good UAV design, aerodynamic efficiency of the UAV model is needed to be studied. Aerodynamic efficiency depends on the fluid flow distribution around the model. From it, certain parameters are calculated e.g. lift co-efficient, drag co-efficient, pressure co-efficient, moment co-efficient etc. are used to describe the aerodynamic behavior like boundary layer separation, downwash effect, vortices etc. These parameters are mainly determined by wind tunnel testing and CFD simulation. But to test the UAV model, the available wind tunnel in the laboratory does not provide accurate data for certain limitations e.g. calibration problem, unavailability of full scale wind tunnel etc. For this reason, CFD simulation of the UAV model is performed to determine these parameters.

CFD is based on Navier-Stokes equations, nonlinear PDEs, which are used to express the relationship among the velocity, pressure, temperature, and density of any fluid flow. In this paper the simulation of fluid flow around the airfoil and fuselage that is used for Unmanned Aerial Vehicle (UAV) model is illustrated and to calculate total lift coefficient. Any aerial vehicle which is used or intended for flight without on board pilot is called Unmanned Aerial Vehicle. As its name implies, it is capable of sustained flight in the atmosphere without the traditional pilot, it is controlled either remotely or automatically. It is used for various purposes. UAV includes airplanes, helicopters, airships, and powered–lift aircraft without an onboard pilot. Traditional balloons, rockets, tethered aircraft and un-powered gliders are not included in UAV.

For the CFD simulation of our UAV model, two airfoils are used-

a) NACA-4412 for wing.
b) NACA-0012 as for horizontal and vertical tail.

2. Theory

Lift Equation:

$$L=1/2 * \rho V^2 C_L A \tag{1}$$

Drag Equation:

$$D=1/2 * \rho V^2 C_D A \tag{2}$$

Reynolds Number:

$$Re=\rho VL/\mu \tag{3}$$

The approximate relating equation between wing lift and airfoil lift is-

$$C_L\ (\text{wing}) = 0.9C_{l\ max}(\text{airfoil}) * \cos\text{^}0.25c \qquad (4)$$

As there is no sweep angle in the experimented UAV. So,

$$C_L = 0.9C_{lmax} \qquad (5)$$

Tail Contribution

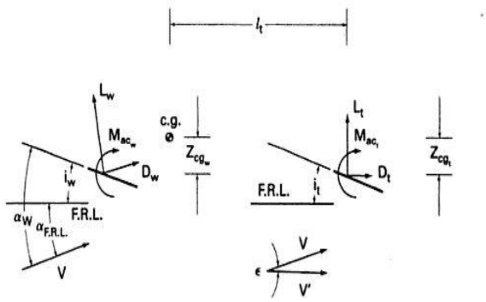

Fig.1. Aft tail contribution to the pitching moment

Now, angle of attack for tail,

$$\alpha_t = \alpha_w - i_w - €+i_t \qquad (6)$$

Here,

$$€ = 2C_{LW}/\ (\pi.\ AR_w) \qquad (7)$$

3. Methodology & Various Steps

3.1 Geometry Setting

The 2-D airfoil (NACA0012 and NACA 4412) setting:

The co-ordinate file of the airfoil is imported into the Design Modeler.

The chord length: NACA 0012 (for tail) = 0.4m and NACA 4412 (for wing) = 1m.

C-domain is drawn around the airfoil and divided into six surfaces. C-domain is taken as it is convenient for the air flow around the airfoil and flow enter into the domain in all direction.

The 3-D fuselage setting:

The 3-D fuselage is drawn in ICEM CFD. The fuselage is cylindrical shape which Diameter = 0.6m and Length = 5m.A rectangular shape domain is drawn around the fuselage. The distance of the front surface and the rear surface of the domain is taken about 3 times greater than the fuselage from the leading and trailing edge of the fuselage. The distance of the upper and lower surface of the domain from the fuselage is taken about 10 times greater than the diameter of the fuselage.

3.2 Mesh Setting

For 2-D airfoil (NACA 0012 and NACA 4412) Structured Grid C-mesh is used. In edge sizing number of divisions is taken as 50.And Bias factor is taken 50.Bias Type is at an increment rate at the leading edge and at a decrement rate from the tailing edge of the airfoil.

For fuselage volume mesh is used in and mesh type is tetrahedral in all domains. Prisms mesh is used surrounding the fuselage.

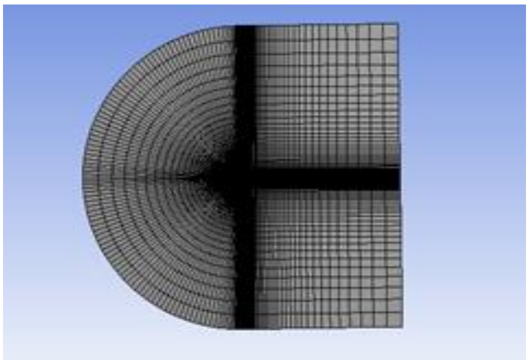

Fig.2. Mesh of 2-D airfoil NACA-0012

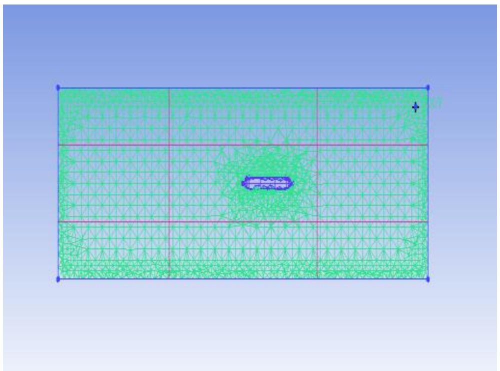

Fig.3. Fuselage mesh with domain (Cut plane)

3.3 Solution Setup

Table 1. Solver settings

CFD Simulation	2-Ddouble precision (3-D double precision)
Solver	Fluent
2d Space	Planar
Velocity Formulation	Absolute
Time	Steady
Type	Pressure-based

Table 2. Viscous model and turbulence model settings

Turbulence model	k-epsilon (2 equation)
k-epsilon Model	Standard
Near-Wall Treatment	Standard wall Function
Operating Conditions	Ambient

Table 3. Boundary condition settings

Velocity Inlet	Velocity specification method	Component
	Reference Frame	Absolute
	Turbulence specification method	Intensity and Viscosity Ratio
	Turbulent Intensity	5 %
	Turbulent Viscosity Ratio	10
Pressure Outlet	Gauge Pressure magnitude	0 Pascal
	Backflow direction specification method	normal to boundary
	Turbulence Specification Method	Intensity and Viscosity Ratio
	Backflow Turbulence Intensity	5 %
	Backflow Turbulent Viscosity Ratio	10
Wall zones	Wall motion	Stationary wall
	Shear condition	No slip
	Wall Roughness height	0
	Wall Roughness constant	0.5
Fluid Properties Air	Fluid Type	Air
	Density Kinematic viscosity	ρ = 1.225 (kg⁄m^3) v =1.7894×10^(-5) (kg⁄(m·s))

Table 4. Solution controls

Equations	Flow and Turbulence
Discretization	a. Pressure: Standard b. Momentum: Second Order Upwind c. Turbulence Kinetic Energy: First Order Upwind d. Turbulence Dissipation Rate: First Order Upwind
Monitor	Residuals & Drag and Lift Coefficient
Convergence Criterion	- Continuity = 0.00001 - X-Velocity = 0.00001 - Y-Velocity = 0.00001 - k = 0.00001

4. Results and Discussion:

Reynolds Number is approximately $2.05*10^6$ (using eqn. 3). So the flow is turbulent.
The C_l and C_d for NACA-4412, NACA- 0012 and fuselage are obtained by simulation in ANSYS Fluent solver. Then the 2-D lift coefficient of the airfoils is converted into 3-D lift coefficient by using equation 5. All three (wing, tail, fuselage) lift coefficient is then added to calculate total lift coefficient for the UAV.
Initial angle of incidence for wing is 1 degree and for tail is 0 degree. Effective AOA is calculated using 6 & 7 equations.

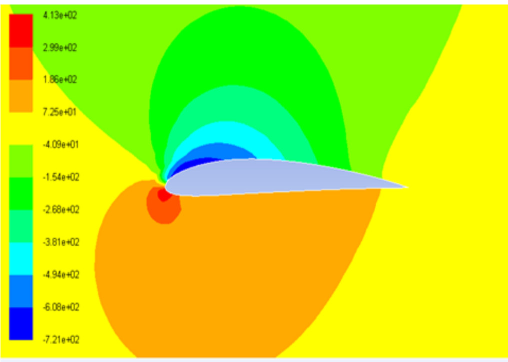

Fig.4. Pressure Contour at 4 degree AOA (Effective AOA 5 degree) (Naca-4412)

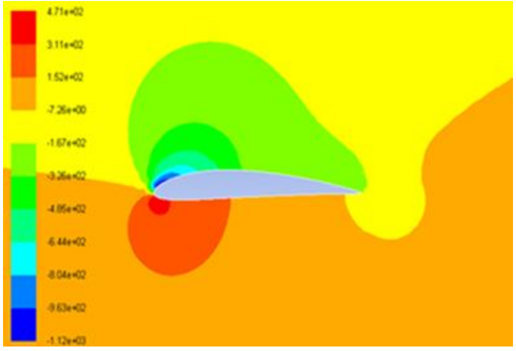

Fig.5. Pressure Contour at 10 degree AOA (Effective AOA 11 degree) (Naca-4412)

From the fig. it is seen that at an increased AOA pressure on the lower surface increases as well as pressure on the upper surface decreases. Here, red color means higher pressure.

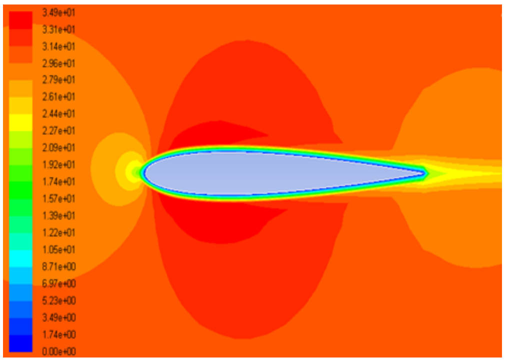

Fig.6. Velocity Contour at 2 degree AOA (Effective AOA -0.412 degree) (Naca-0012)

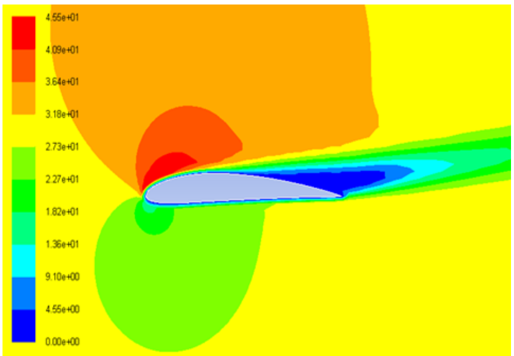

Fig.7. Velocity Contour at 10 degree AOA (Effective AOA 11 degree) (Naca-4412)

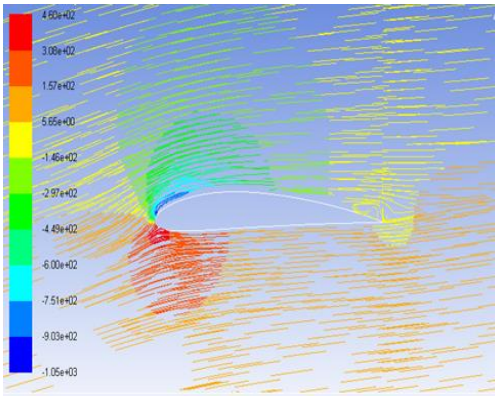

Fig.8. path-line at 8 degree AOA (Effective AOA 9 degree) (Naca-4412)

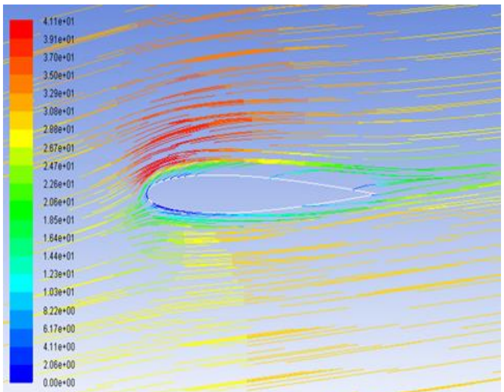

Fig.9. path-line at 10 degree AOA (Effective AOA 7.429 degree) (Naca-0012)

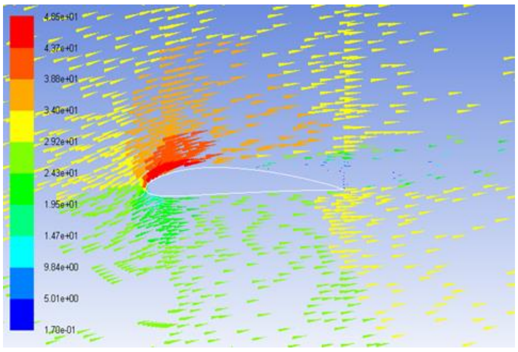

Fig.10. Velocity Vector at 10 degree AOA (Effective AOA 11 degree) (Naca-4412)

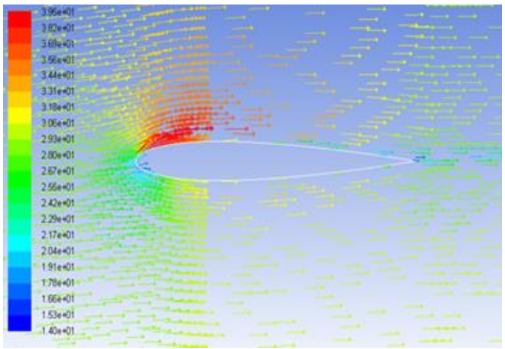

Fig.11. Velocity Vector at 6 degree AOA (Effective AOA 3.439 degree) (Naca-0012)

It is seen from the above figures that at a higher AOA velocity at the upper surface of the airfoil increases and at the lower surface decrease. And from fig. 7 & 10 it is clear that at a higher AOA air flow separates from the surface quickly which gradually causes to stall.
In fig. 8 & 9 air is circulating anti-clockwise which is called vortex Starting vortex is created in the air adjacent to the trailing edge. It leaves the airfoil and remains stationary in the flow. Downwash effect is occurred in the trailing edge which reduces lift and increase drag.

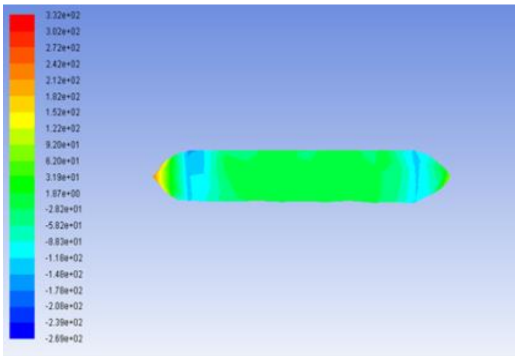

Fig.12. Pr. contour of fuselage at 6 deg. AOA

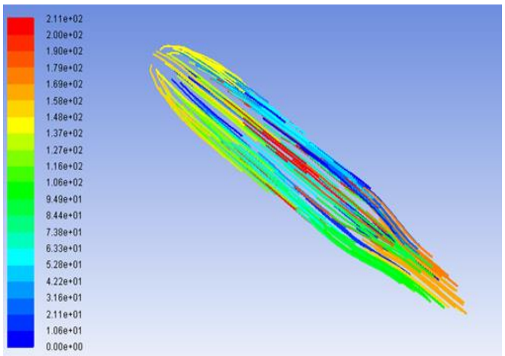

Fig.13. Path line of fuselage at 10 deg. AOA

The incidence AOA of the fuselage is zero. So the change of pressure distribution, velocity distribution, path line around the fuselage does not show too much change. For this reason the lift coefficient of the fuselage is very small. As a result the fuselage has less contribution to the generation of lift force of the UAV.

Table 5. The start of Transition period for NACA-4412 determined by X-foil

AOA	Transition period starts (% of chord length)
0	44.12%
2	41.22%
4	33.84%
6	12.92%
8	6.7%
10	2.45%

Table 6. The start of Transition period for NACA-0012 determined by X-foil

AOA	Transition period starts (% of chord length)
0	75.79%
2	59.15%
4	39.57%
6	19.91%
8	5.84%
10	2.47%

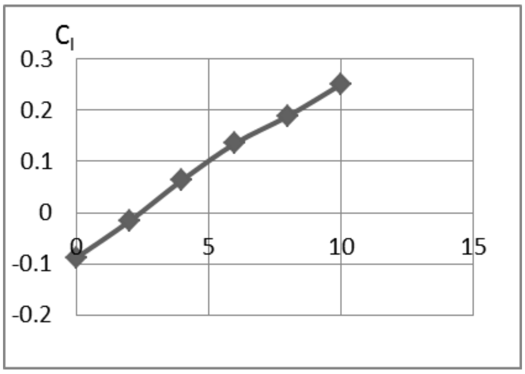

Fig.14. C_l vs. AOA for NACA-0012

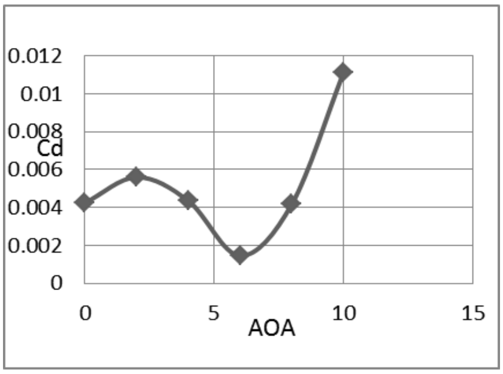

Fig.15. C_d vs. AOA for NACA-0012

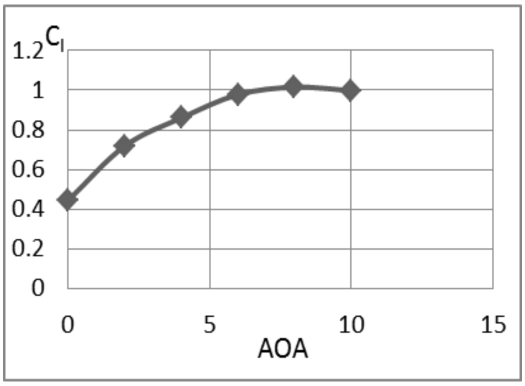

Fig.16. C_l vs. AOA for NACA-4412

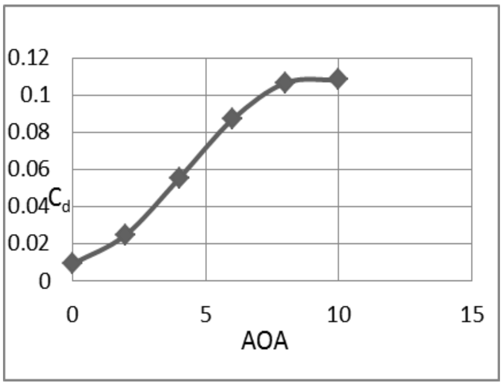

Fig.17. C_d vs. AOA for NACA-4412

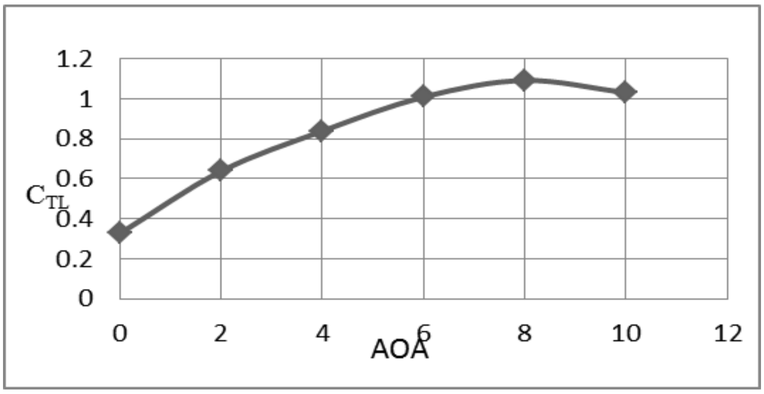

Fig.18. C_{TL} vs. AOA for total UAV

5. Conclusion

Max total calculated Lift-Coefficient of the UAV is 1.0915 at 8 degree AOA. After this the Lift coefficient of the UAV decreases and drag increases. As the speed of the UAV is lower that's why stall happens at a lower AOA.

For the vertical stabilizer of the UAV NACA-0012 airfoil is used. As the contribution of the vertical tail to the lift-coefficient of the UAV is too small, so the lift coefficient of the vertical tail is neglected.

6. References

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