EFFECT OF LENGTH AND DIAMETER OF AIRCRAFT FUSELAGE ON DRAG AND LIFT COEFFICIENT BY CFD

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ABSTRACT

Present work aimed to analysis the aerodynamic drag and lift coefficient of large turbo propeller aircraft fuselage through Computational Fluid Dynamics (CFD) analysis (ANSYS FLUENT). Five different configurations of fuselage without wing attachment by varying length (Lf) and diameter (d_f) were considered for this study. All five models were analysed by varying angle of attack 8 ^{o} and 10 ^{o}. This numerical study indicated that lowest drag coefficient (CD) 0.0045 obtained for the model 5 (Lf = 28 m; d_f = 3.17 m) at angle of attack 10 ^{o}. Maximum lift coefficient (CL) 0.0021 reported for model 4 (Lf = 26 m; d_f = 2.92 m). It is 58% improvement than other models. The variation of coefficient of drag and lift showed similar trend irrespective of angle of attack. In addition the ratio of CL/CD was calculated for all the five models and outcome indicated that maximum CL/CD ratio 0.4112 obtained for the model 4, which is 4.52 times higher than model 2 (Lf = 22 m; d_f = 2.26 m). From this present study it is concluded that model 4 fuselage exhibited better aerodynamic characteristics when compared to other four configurations for both angle of attack.

Keywords: Coefficient of drag; coefficient of lift; fuselage; angle of attack; CL/CD ratio

1. INTRODUCTION

Presently investigation on fuselage to obtain better aerodynamic characteristics such as drag and lift coefficient is gaining attention to the researcher [1 - 3]. Fuselage is the main body of the aircraft and houses of the pilots, passengers, and cargo. Stepanov et al., 2016 [2] studied drag reduction study on helicopter fuselage in the wind tunnel and outcome of this study indicated that 16% reduction of drag for pitch angle varies between −10 ° to 10 ° and 9 % reduction for Yaw angle varies between −18 ° to 12 ° of mode l1 (original fuselage) and model 2 (extended rear ramp).

Garre and Sudheer, 2018 [3] analysed fuselage by numerical method and indicated that at 5 ° angle of attack (AoA) drag is reduced and aerodynamic efficiency enhanced by 65 %.

Angelo et al., 2019 [4] reviewed previous literature related to theoretical, experimental and numerical analysis of aircraft fuselage. From the previous literature it could be understood that the elliptical shape of fuselage exhibits better overall stability of aircraft than other fuselage geometry. And further research also needed to refine the fuselage design to enhance the performance of aircraft performance. Potty et al., 2019 [5] also indicated that the design of fuselage is attracted from body of bird or a fish. Tadakuma et al. 2016 [6] was performed the experimental works of aircraft fuselage with cross section of circular, square and triangular section with subsonic and transonic and flow conditions. This study about cross section of Reusable Launch vehicle fuselage resulted triangular cross section with fins possessed higher lift coefficient among other geometry section in the sub sonic and transonic flow.

Chavan and Pawar, 2017 [7], studied about minimization of power consumption by the aircraft due to the varying external design. 75% of fuel consumption is based on the drag force induced in aircraft. Application of bunches of pipe results reduction of drag as well as accelerate the aircraft. And the outcome indicated that drag force of aeroplane is greatly reduced by the reduction of diameter of fuselage. Similarly, Lai and Kamaruddin, 2018 [8] performed experimental and numerical study about wing-body structure. This research work carried for the effect of diameter in the drag force in aircraft. Prandtl's Lifting theory and Helmbold's theory used to compute the drag and lift force. Both computational and experimental study agreed for wing-body combination for reduction of drag force in air craft.

Aye et al., 2008 [9] analysed the aluminium alloys and ageing heat treatment effect for weight reduction of air craft fuselage. And concluded that age hardened alloy possessed improved strength than natural aluminium alloys for aircraft fuselage material. Mukhopadhyay and Sorokach, 2015 [10] analysed the weight reduction by composite structure airframe technology. The outcome showed the hybrid wing body composite structure fuselage having significant enhancement in strength than conventional aluminium alloy.

Bhatt et al., 2012 [11] reported the drag coefficient and lift coefficient of aircraft fuselage under three different Reynolds number (Re = 3×10^{6}; Re = 6×10^{6} and Re = 9×10^{6}. The outcome depicts when the angle of attack increases the CL and CD were increased. However, experiment results indicated similar CD and CL for all three Reynolds number. The optimum design for fuselage buckling analysis also carried by Vankan et al. 2014 [12] using FEM. Results implied in order to ensure zero failure, constraints of fuselage also to be evaluated.

Tooren and Krakers, 2007 [13] have performed experimental and Finite Element analysis about acoustic behaviour of fuselage structure. In addition, multi disciplinary Design Optimization was studied on aircraft fuselage structure. Similar multi-disciplinary analysis on drag coefficient has been carried by Gur et al., 2010 [14].

Cheng et al., 2015 [15] reported about the method of variation in design and modelling for the aircraft fuselage assembly process, particularly, the elastic behaviour of beam element in the structure model. Nicolosi, 2015 [16] demonstrated the aircraft fuselage geometry for aerodynamic drag and lift coefficient prediction. In this paper presented preliminary method for CFD analysis. Same author Nicolosi, 2015 [17] reported for aerodynamic parameters prediction methods for aircraft fuselage.

Ansari et al., 2022 [18] analysed aerodynamic behaviour of NACA 4412 aerofoil using CFD. And clearly indicated the experimental and numerical analysis are close similar results for aircraft fuselage analysis. In addition that, the results showed drag coefficient is higher than coefficient of lift of fuselage. And similar CFD analysis carried and for different angle of attack and varying velocity by Hiremath and Malipatil 2014 [19].

Sutrisno et al., 2020 [20] analysed fighter jet fuselage design straight body geometry for vortex dynamic analysis. The angle of attack considered for this study 30 ^{o}, 40 ^{o} and 50 ^{o}. The results indicated that modifications of blended wing body design, altered to double engines, to obtain more power.

From this literature review indicated that many researcher have been performed on the performance improvement of aircraft fuselage. The overall performance of fuselage depends upon its cross section geometry, material design. In addition the performance have been analysed through experimental, theoretical and numerical study and indicated that the results are closely agreed with experimental results. However limited researches have been observed related to varying length and diameter of fuselage design. Hence from the identified research gap, it is understood that still researches are needed to enhance the aerodynamic performance of aircraft fuselage. Hence the present study performed a numerical study on the effect of fuselage length and diameter by varying of angle of attack 8 ^{o} and 10 ^{o}.

2. METHODOLOGY

2.1 Experimental parameters

In this present numerical experiment, a standard model of 80 seater fuselage of a turboprop aircraft was considered for aerodynamic analysis. Figure 1 represents the fuselage model with nomenclature. Totally five different configurations of fuselage models were considered for this study to compare the drag coefficient and lift coefficient. The length of fuselage (L_f) varying between 20 m to 28 m and diameter of fuselage (d_f) 2.26 m to 3.17 m. The geometry of all the models is provided in Table 1. In addition, all the models were analysed with two different angle of attack 8 ^{o} and 10 ^{o} respectively (Table 2). Fuselage fineness ratio (F_R) is the ratio of L_f /d_f . Similarly, fuselage fineness ratio of nose (FR_n) is the ratio of L_n / d_f. The elliptical shape geometry was selected for this analysis. Figure 2 illustrates the actual modeling of aircraft fuselages without wing attachment.

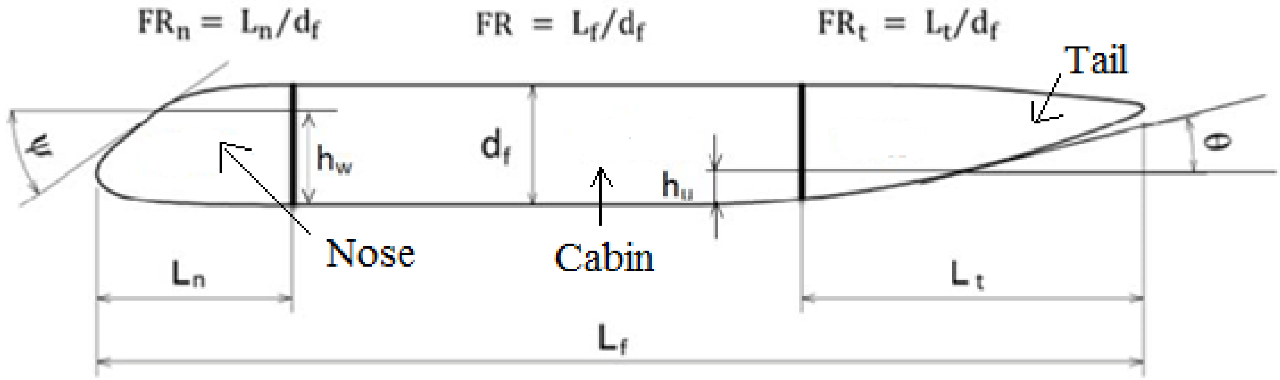

Fig. 1 Aircraft Fuselage and its nomenclauture

Table1 Fuselage geometrical parameters

MODEL	Lf	df	Ln	Lc	Lt	FR	FRn	FRt	hw/df	hu/df	ψ	θ
MODEL 1	20	2.26	3.8	8.6	7.5	8.7	1.6	2.8	0.75	0.26	38˚	12˚
MODEL 2	22	2.4	4.17	9.4	8.2	8.7	1.6	2.8	0.75	0.26	39˚	16˚
MODEL 3	24	2.72	4.56	10.4	9.0	8.7	1.6	2.8	0.75	0.26	37˚	13˚
MODEL 4	26	2.92	4.93	11.2	9.7	8.7	1.6	2.8	0.75	0.26	35˚	15˚
MODEL 5	28	3.17	5.31	12.1	10.5	8.7	1.6	2.8	0.75	0.26	42˚	11˚

Table 2 Angle of Attack (AOA) considered for present experiment

MODEL OF FUSELAGE	AOA	AOA
MODEL 1	8°	10°
MODEL 2	8°	10°
MODEL 3	8°	10°
MODEL 4	8°	10°
MODEL 5	8°	10°

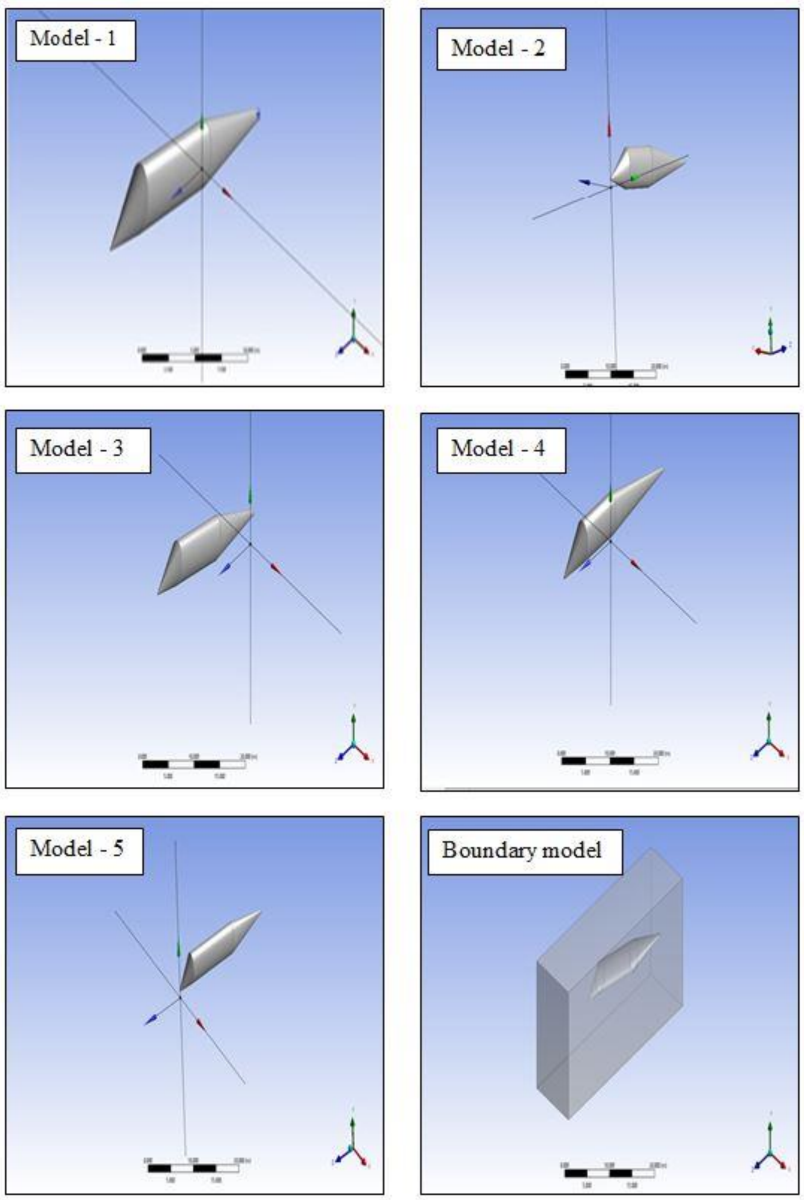

Fig. 2 Modelling of Fuselage

2.2 Computational Fluid Dynamics (ANSYS FLUENT)

The numerical simulation work predicts the consequences of a mathematical model, the solution is obtained for variables at discrete grid points in the computational domain. Five models along two angles of attack (8 ^{o} and 10 ^{o}) were developed to compare the drag coefficient (CD) and lift coefficient (CL). The angle of attack (AOA) is the angle at which the chord of an aircraft's wing meets the relative wind. Each model changes the wind shield angle (ψ) and the upsweep angle (θ) of the fuselage.

2.3 Meshing Model and Experimental Parameter

The mesh model and mesh parameters are indicated in Figure 3 and Table 3 respectively.

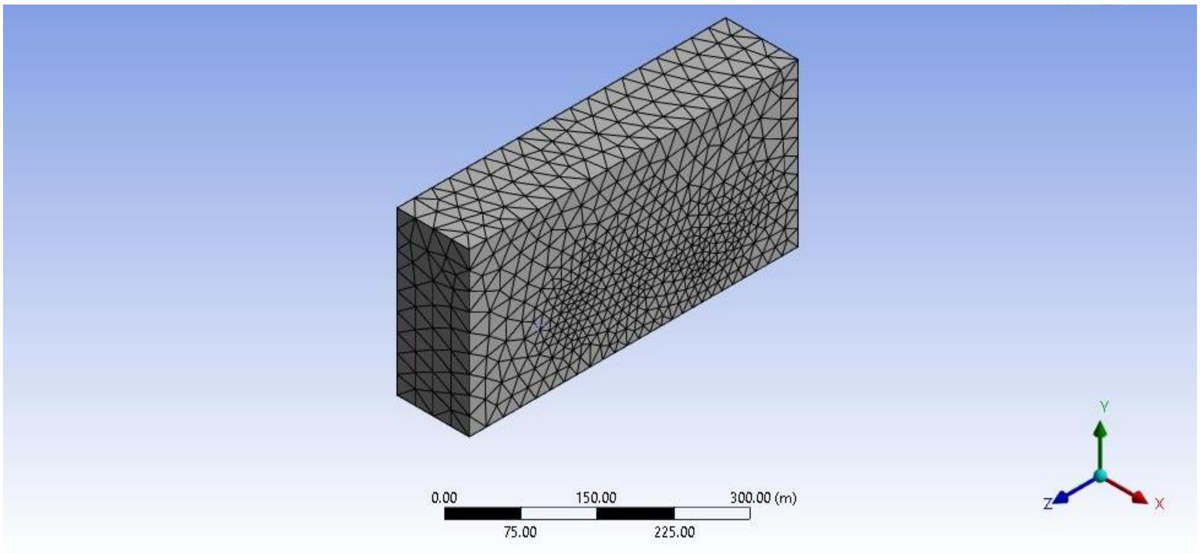

Fig. 3 Modelling of Fuselage

Table 3 Mesh parameters

Physical reference	CFD
Solver reference	Fluent
element order	Linear
element size	24.0m
Inflation maximum layers	6

The setup details include models, materials, cell zone conditions, boundary conditions, initialization and iterations are mainly used are indicated in Table 4.

Table 4 Experimental setup

Models	Viscous (SSTk - Omega)
Materials	Fluid (Air)
Cell Zone Conditions	Fluid (Air)
Boundary Condition	Velocity-Inlet (48m/S)
Initialization	Standard (Compute from inlet)
Number of Iterations	150

2.4 Drag coefficient and Lift coefficient calculation

The coefficient of drag and lift are calculated by the following equations 1 and 2. The drag and lift force, flow velocity and reference area are taken from ANSYS Fluent results.

Drag coefficient (CD) = $\frac{D_f}{(0.5 \times \rho \times u^2 \times A)}$ ⟶ (1)

Lift Coefficient (CL) = $\frac{\boldsymbol{L_f}}{(\boldsymbol{0.5} \times \boldsymbol{\rho} \times \boldsymbol{u^2} \times \boldsymbol{A})}$ ⟶ (2)

Where,

D_f	=	Drag force	(N)
L_f	=	Lift Force	(N)
ρ	=	Density of air	(kg/m^3)
u	=	Flow velocity	(m/s)
A	=	Reference area	(m^2)

2.5 Energy equation iterations

Figure 4 represents the iterations of energy equations. There is continuity equation, X-velocity, Y - velocity, Z - velocity, and omega are solved by numerical analysis.

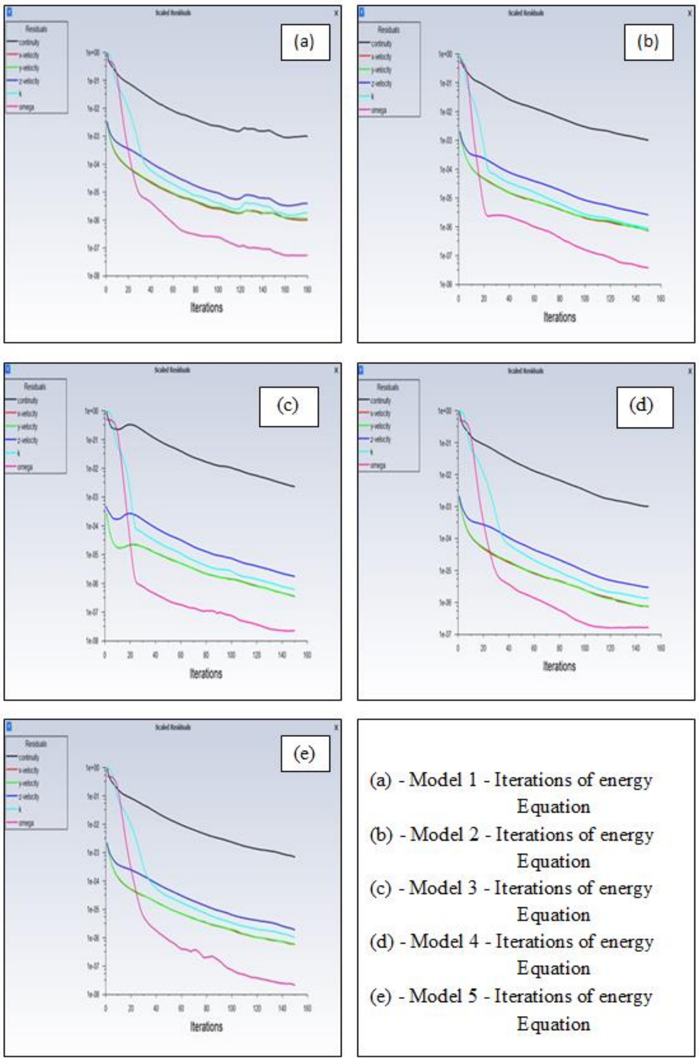

Fig. 4 Iterations of energy equation

3. REUSLTS AND DISCUSSION

3.1 Coefficient of Drag (CD) and Coeffcient of Lift (CL)

Table 5 indicates the analytical parameters such as aircraft fuselage area, flow velocity, pressure maintained inside the aircraft fuselage and induced drag force and lift force for all the five different configurations of fuselage. All these data are arrived from numerical simulation results. Reference area fuselage is slightly reduced when angle of attack increases from 8 ^{o} to 10 ^{o}. But the flow velocity of all models showed slight increasing nature when the angle of increases from 8 ^{o} to 10 ^{o}. Drag force for the model 1 to 4 showed improved when angle of attack increases from 8 ^{o} to 10 ^{o}. But the model 5 drag force and lift force are slightly reduced when angle increases. Among all the models when length of fuselage is 26 m and diameter 2.92 m possess maximum drag force and maximum lift force.

Table 5 Numerical Simulation Results

Angle of Attack (AoA)	Models	Area (m^2)	Velocity (m/s)	Pressure (Pa)	Drag Force (N)	Lift Force (N)
8	1	162.743	57.595	706.292	2281.10	320.079
	2	197.314	55.557	717.656	2393.74	187.741
	3	209.117	57.102	587.774	1931.80	472.699
	4	295.020	58.741	633.304	3166.13	1146.76
	5	304.500	57.356	673.197	2978.61	371.741
10	1	162.704	57.938	660.926	2331.61	548.48
	2	194.890	55.719	717.039	2515.17	188.602
	3	208.293	55.962	650.357	1954.32	444.451
	4	294.195	59.844	613.163	3331.05	1344.82
	5	304.680	58.735	675.141	2932.48	713.287

Table 6 Coefficient of drag (CD) and coefficient of lift (CL)

Fuselage Model	Angle of Attack (8 ^{o})		Angle of Attack (10 ^{o})	
	Coefficient of Drag (CD)	Coefficient of Lift (CL)	Coefficient of Drag (CD)	Coefficient of Lift (CL)
1	0.0068	0.0010	0.0069	0.0008
2	0.0064	0.0005	0.0067	0.0005
3	0.0046	0.0011	0.0048	0.0011
4	0.0050	0.0018	0.0051	0.0021
5	0.0048	0.0006	0.0045	0.0011

The numerical simulation results of drag coefficient and lift coefficient are represented in the Table 6. All the models exhibit lesser lift coefficient compared to drag coefficient. In this present work analysed fuselage without considering wing attachment only considered this could be the possible reason for obtaining lesser lift coefficient than drag coefficient. Similar study was report by Nicolosi, 2015 [16]. And Bhatt et al., 2012 [11] also obtained higher CD value than CL for aircraft fuselage for varying angle of attack (o ^{o} to 4 ^{o}) and varying Reynolds number. Among the entire models lowest drag coefficient is 0.0045 reported for model 5 fuselage at 10 ^{o} angle of attack. Similarly lowest lift coefficient 0.0005 is reported for model 2 for both 8 ^{o} and 10 ^{o} angle of attack.

Figure 5 and figure 6 demonstartes the obtained coefficient of drag (CD) and coefficient of lift (CL) for the proposed five models of aircraft fuselage when the angle of attack is 8 ^{o} and 10 ^{o} respectively. Model 3, 4 and 5 exhibites lesser CD and CL values compared to models 1 and 2. The area of fuselage of the model 3, 4 and 5 increases from 209.12 m^2 to 304.5 m^2 and pressure incraeses from 587.77 Pa to 673.197 Pa and obtained lesser CD value than model 1 and 2 having area 162.7 m^2 and 197.3 m^2 . The numerical analysis results states that when the length of fuselage (Lf) more than 22 m, diameter (df) more than 2.4 m and area more than 197.314 m^2 the aircraft exhibits lesser drag coefficient and lift coefficient compared to model 1 (1622.74 m^2) and model 2 (197.31 m^2). Eventhough minimum variations of air velocity was observed betwen model 1 and model 3 is 0.48 m/s, the drag coefficient CD for model 3 is very less than model 1. Similarly model 4 have less CD value for 1.15 m/s more velocity than model 1.

The coefficient of lift (CL) for model 4 showed improved CL value than all other four models. The nature of CL and CD are not similar for all five models. Eventhough the Lf and df value gradually increases from model 1 to 5, the lift coefficient of model 1 to 2 and model 4 to 5 indicates decreasing nature, but model 2 to 3 and model 3 to 4 showed increasing nature. This behaviour could be the possible reason of lift coefficient is depend upon other parameters.

Similar trend was observed for 10 ^{o} angle of attack in the proposed fuselage. Except model 4 all other models exhibits lesser lift coefficient. In addition compared to model 1 and 2 all other three models possessed lesser cofficient of drag.

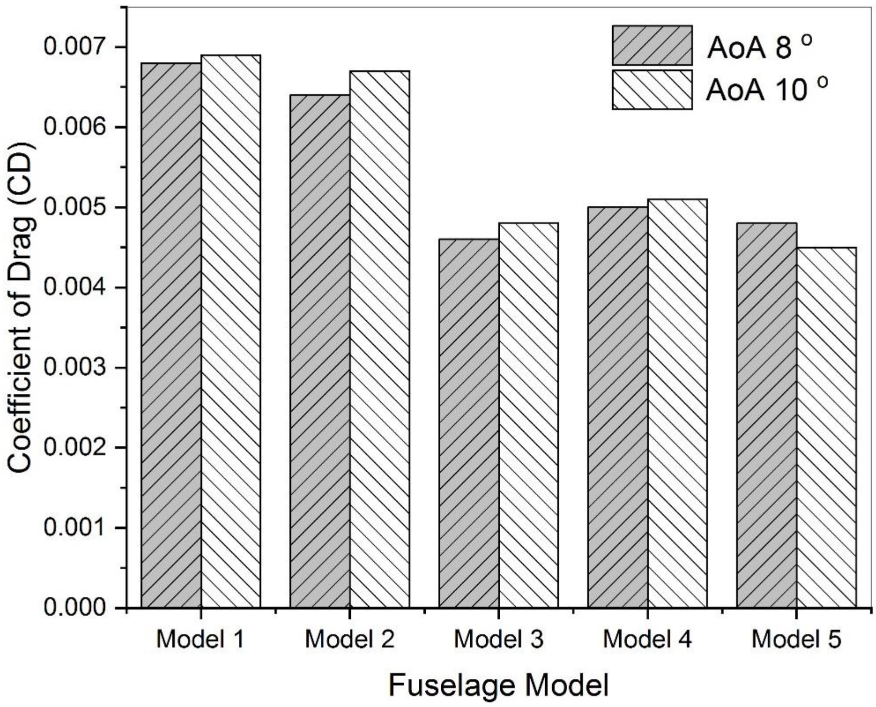

Fig. 5 Coefficient of Drag (CD)

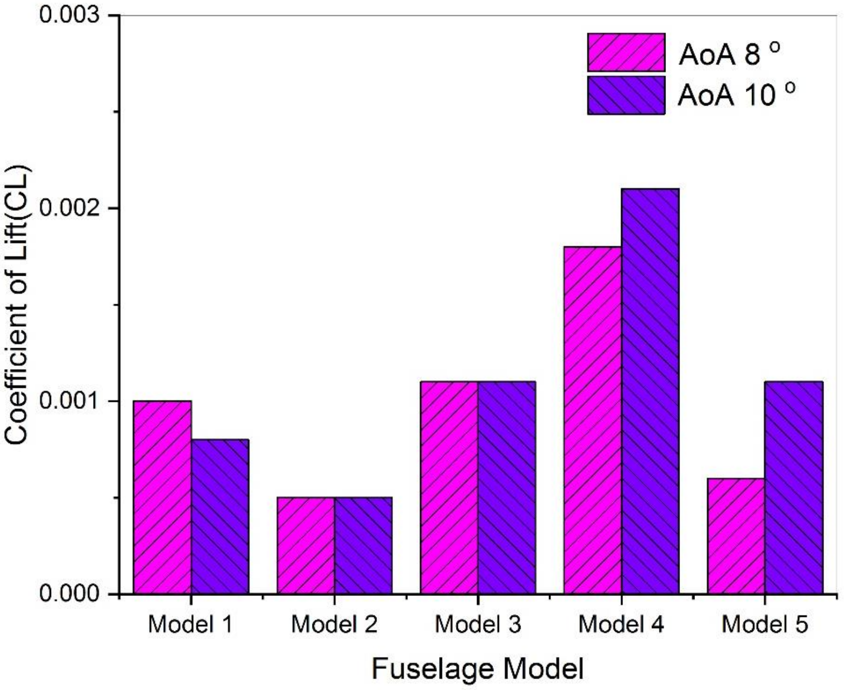

Fig. 6 Coefficient of Lift (CL)

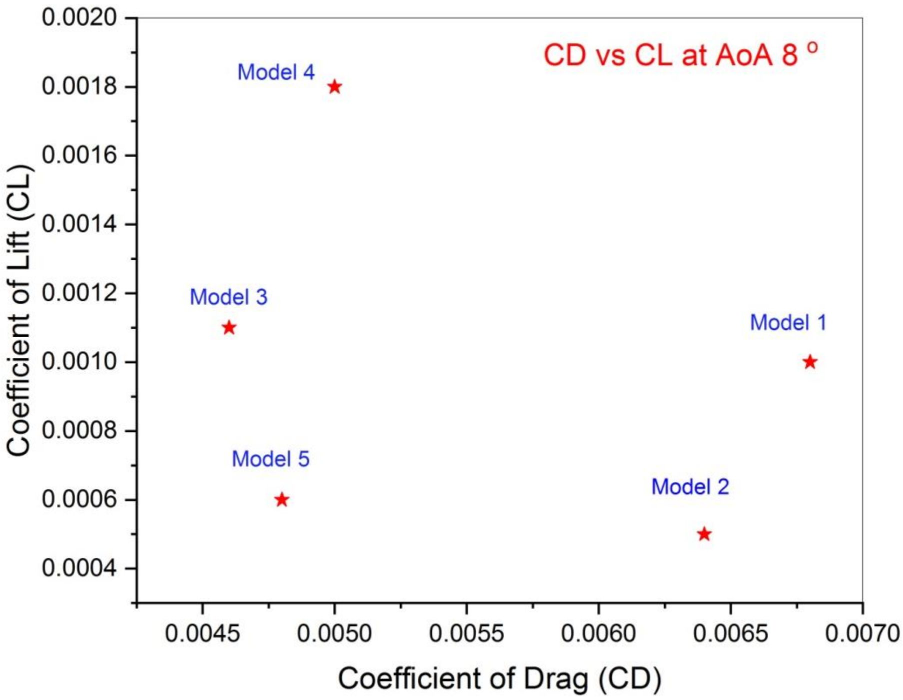

Fig. 7 Comparison of CL and CD for fuselage models (AoA 8 °)

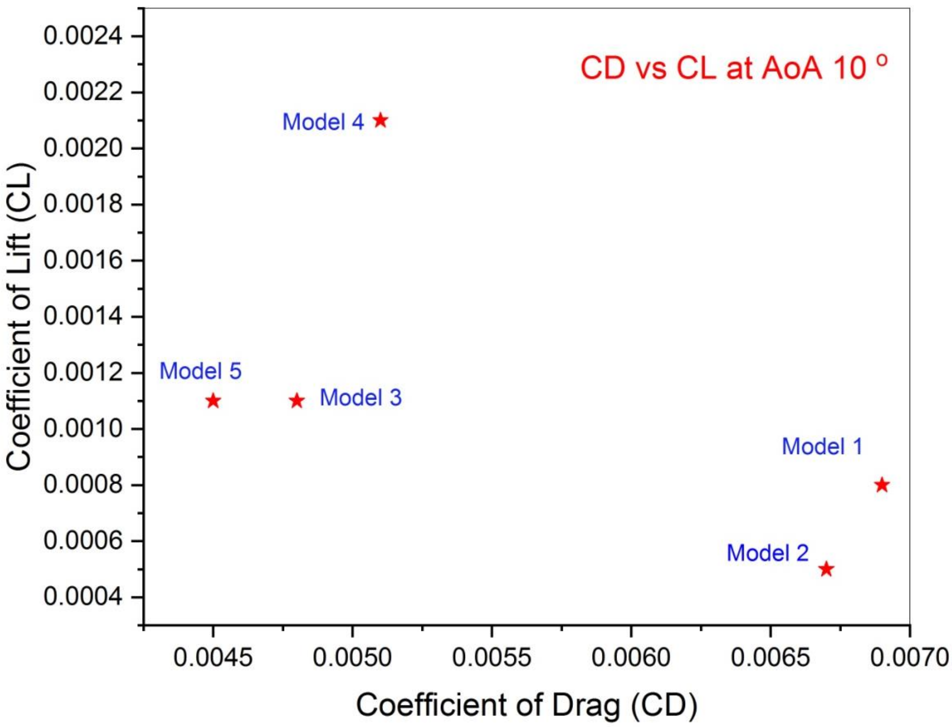

Fig. 8 Comparison of CL and CD for fuselage models (AoA 10 ^{o})

Figure 7 and Figure 8 represents the comparison of CD and CL for the proposed aircraft fuselage model for angle of attack 8 o and 10 o respectively. From the obtained results it is clearly indicated that model 4 (Lf = 26 m; df = 2.92 m) exhibits better aerodynamic drag and lift coefficient than other four models of fuselage. The outcome of numerical study indicated that lowest drag coefficient (CD) 0.0045 obtained for the model 5 (Lf = 28 m; df = 3.17 m) at angle of attack 10 o. Similarly maximum lift coefficient (CL) 0.0021 reported for model 4 (Lf = 26 m; df = 2.92 m). It is 58% improvement than minimum CL/CD ratio of model 2 (Lf = 22 m; df = 2.26 m).

3.2 Ratio of Coefficient of Lift to Coeffcient of Drag

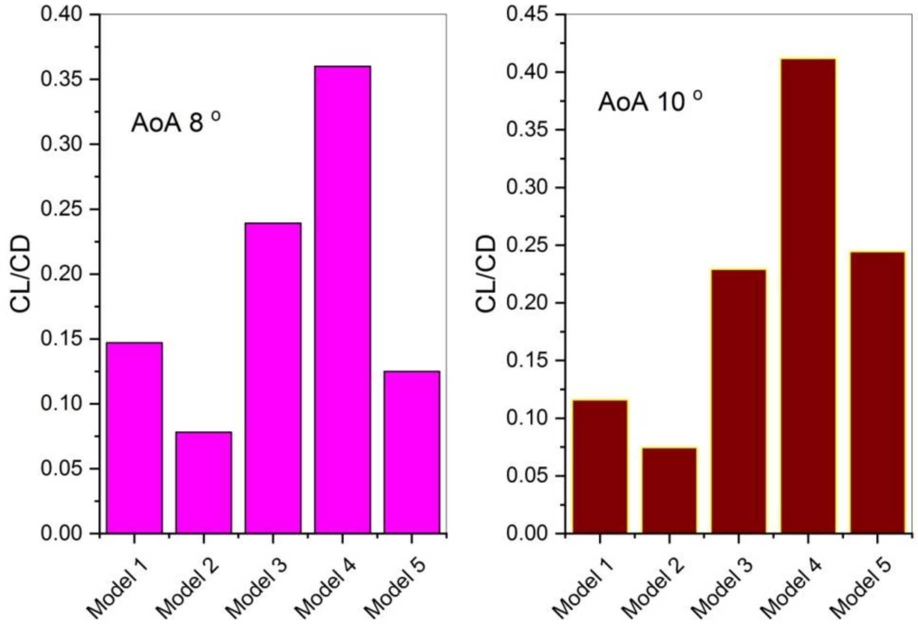

Fig. 9 Ratio of CL and CD for AoA 8 ^{o} and 10 ^{o}

Figure 9 represents the comparison of ratio of lift coefficient to drag coefficient for all the proposed models of fuselage. It clearly indicates model 4 have highest CL/CD ratio amoung all other models. Thus the aircraft fuselage having the geometry Lf 26 m and df 2.92 m has maximum CL/CD ratio of 0.36 at 8 ^{o} angle of attack and 0.412 at 10 ^{o} respectively. In the same time model 2 having the geometry Lf 22 m and df 2.4 m has lowest CL/CD ratio of 0.078 at 8 ^{o} angle of attack and 0.074 at 10 ^{o} repectively.

Hence the maximum improvement obtained for model 4 aircraft fuselage, which showed 3.61 times improved CL/CD ratio than lowest CL/CD ratio of model 2, at angle of attack 8 o. Similarly for angle of attack 10 o model 4 aircraft fuselage indicated that maximum improvement of 4.52 times than the lowest CL/CD ratio of the model 2 aircraft fuselage. Hence this numerical study clearly indicated that if the fuselage designed with the parameters Lf = 26 m; df = 2.92 m at angle of attack 10 o possessed better aerodynamic drag and lift coefficient.

4. Conclusion

The present study analyzed the drag coefficient and lift coefficient for five models of aircraft fuselage varying L_f 20 m to 28 m with two different angle of attack 8 ^{o} and 10 ^{o} respectively. Numerical simulation and analysis were carried using ANSYS software. The drag coefficient and lift coefficient were predicted through CFD aerodynamic calculations. The following results were obtained.

- The outcome indicated the lift coefficient is lesser than drag coefficient for all the proposed models of aircraft fuselages without considering wing attachment.
- The lowest drag coefficient 0.0046 was obtained for model 3 (Lf = 24 m df = 2.72 m and ψ = 37 ^{o}; Θ = 13 ^{o}) at angle of attack 8 ^{o}. And 0.0045 was obtained model 5 (Lf = 28 m df = 3.17 m and ψ = 42 ^{o}; Θ = 11 ^{o}) at angle of attack 10 ^{o}.
- Maximum Lift coefficient 0.0018 was obtained for model 4 (Lf = 26 m df = 2.92 m and ψ = 35 ^{o}; Θ = 15 ^{o}) at angle of attack 8 ^{o} and 10 ^{o}.
- The ratio of CL/CD are calculated, maximum CL/CD 0.412 was obtained for model 4 for 10 ^{o} angle of attack. This is 4.52 times improvement than model 2.
- From this study it was concluded that model 4 (Lf = 26 m; d_f = 2.92 m) exhibits better aerodynamic characteristics as well as CL/CD ratio for both angle of attack 8 ^{o} and 10 ^{o}.

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