Experimental And Computational Aerodynamic Analysis Of Blended Wing Body

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Abstract: **The present research deals with the experimental and computational aerodynamic Analysis of BWB at lower Mach number using Ansys CFD as a simulation tool and ICEM CFD as modelling tool and wind tunnel for experimental results at different angle of attacks and free stream velocity. The study will focus on the aerodynamic characteristics such as Mach number and pressure variation over the body, from these results we can find the aerodynamic efficiency(lift force to drag force ratio) so that we can compare the CFD results with wind tunnel results with respect to variation in angle of attacks.. These results are used for calculating aerodynamic efficiency of both results.BWB is fuel efficient and environment friendly. Improving fuel efficiency is important for an environment as well as from economical perspective. BWB is fuel efficient and environment friendly. So the study is focused on increasing aerodynamic efficiency which will give fuel efficiency and environment friendly product.**

Keywords — Blended Wing Body (BWB), Aerodynamic, Hexa mesh, Wind tunnel, Angle Of Attack (AOA).

I. INTRODUCTION

The Blended-Wing-Body (BWB) aircraft are being invented and researched with the aim to develop more efficient aircraft configurations [2]. The concept combines the fuselage, wing and the engines into single lifting surface where the body is designed to have a shape of an airfoil and carefully streamlined with the wing to have a desired plan form. According to Liebeck, the blended configuration is significantly lighter, has a higher lift to drag ratio and substantially a lower fuel burn. Improvement in fuel efficiency is important for an environmentally as well as from economically with increasing fuel prices - up by almost 13% from about a year ago- airlines will need more fuel efficient options given the predicted growth in the air traffic[4].Higher greenhouse gas stabilization goals means higher ranges of temperature changes and even worse effects. In this study is done on half BWB which saves required computational time for whole project. Fuel efficiency increases not only the cure of project design improvement is project motive which reduces drag and increases lift and we get higher aerodynamic efficiency. So BWB is studied for increasing aerodynamic efficiency so that it will be more fuel efficient and environment friendly.

In 2011,Zurriati M. Ali, Wahyu Kuntjoro et.al. discusses, blended wing body aircraft is a relatively new concept and has a potential to serve air-craft industry in various backgrounds like domestic, military, cargo etc. This concept was first introduced in 1998 by 'Liebeck R.H' in his research paper entitled **'**Blended Wing Body Subsonic commercial Transport'. As he mentioned in his paper that when engine, fuselage, wing and body are merged into single lifting surface, the aerodynamic efficiency will be improved. In simple words, BWB can be referred as a flying wing. As BWB is having symmetry shape, then only half body is needed to be generated. The advantages using the half model are reduction of computer's memory, saving time in modeling and decreased simulation time.

II. GAP ANALYSIS

In 1903,Wright Flyer designed and first flown aircraft. The swept-wing Boeing B-47 took flight in 1947.In 1980, Blended Wing Body concept introduced. In 1992, Airbus A330 designed appears to be essentially equivalent to B-47.BWB research team in Unversiti Technologi MARA was formed in 2005 with the first design, Baseline-I. In 2009,the new design of BWB has been investigated and called as BWB Baseline-II.

III. EXPERIMENTAL METHODOLOGY

The study carried out primarily using CFD simulations followed by experimental validations at using wind-tunnel testing of the half BWB model.

1. The geometry will be created in CREO software using the coordinates given for NACA2418 and NACA0017 aerofoils whose design is as shown in fig.1.
2. The geometry converted to STEP / IGES format and will be imported to ICEM CFD software for meshing.
3. Meshing done using Hexa meshing method in ICEM.
4. The model will be primarily tested using Euler equations in ANSYS Fluent and later can be solved to detailed analysis using turbulence. Spalart-Allmaras model (one-equation) model used in solving.
5. No-slip boundary conditions imposed to every solid boundary while wind-tunnel will be created to simulate the performance. The Reynolds number will be varied for testing and will be in order of 10^6 with international air atmospheric properties.
6. The geometry simulated for various angles of attack. The Mach number will be typically 0.1 (approx. 34 m/s air velocity).
7. The model will be simulated without winglet for reasonable analysis and available computational power limitations.
8. Then experiment on half BWB model (fig.2) performed and by getting readings of lift and drag, aerodynamic efficiency is calculated. Lift and drag coefficients are calculated by using following equations.

$$C_L = \frac{2F_L}{\frac{1}{2}\rho V^2 S_{ref}}$$

$$C_D = \frac{2F_D}{\frac{1}{2}\rho V^2 S_{ref}}$$

9. Then CFD results are compared with the Wind Tunnel results for validation purpose.

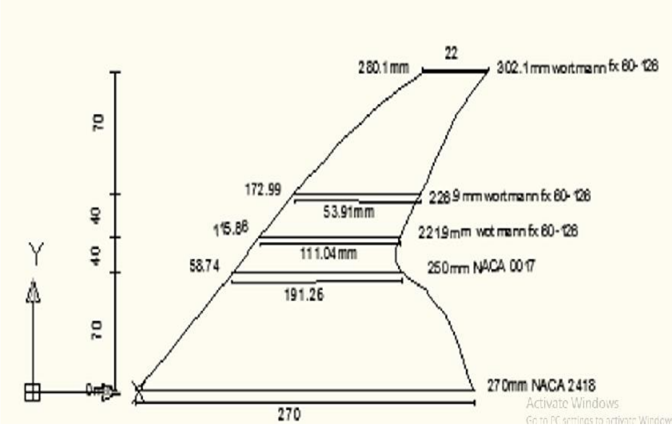

Fig.1 Design of Blended Wing Body

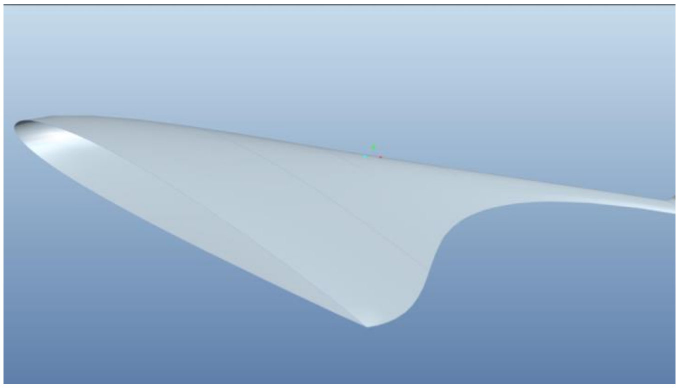

Fig.2 Model of Blended Wing Body

IV. EXPERIMENTAL SETUP

The tests were conducted using subsonic wind tunnel (Fig. 3). This wind tunnel has a test section area of 300mm X 300mm x 1000 mm. The tunnel is of simplest tube section open type along which air is propelled. Wind tunnel is made up of FRP material in a single mould, which gives inside smooth surface and less leakages, capable of measuring lift force and drag force. Hence, a half model of BWB is used for the tests. The BWB planform was obtained. The half model of this BWB has been manufactured using carpentry .Fig.1 shows the dimension of the half model of NACA 2418 and NACA 0017.Fig. 2 shows the manufactured wooden model. The tests are conducted at 3 different angle of attacks, i.e. -3^0, 0^0 and $+3^0$ as per the requirement of project for higher aerodynamic efficiency [5].

Fig.3 Model of half Blended Wing Body

Fig.4 Wind Tunnel

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V. MODELLING AND MESHING IN ICEM CFD

Select the front plane (YZ plane) as the reference plane. FILE-IMPORT GEOMETRY-FORMATED POINT DATA as shown in fig.4, then create curves as shown in fig.5

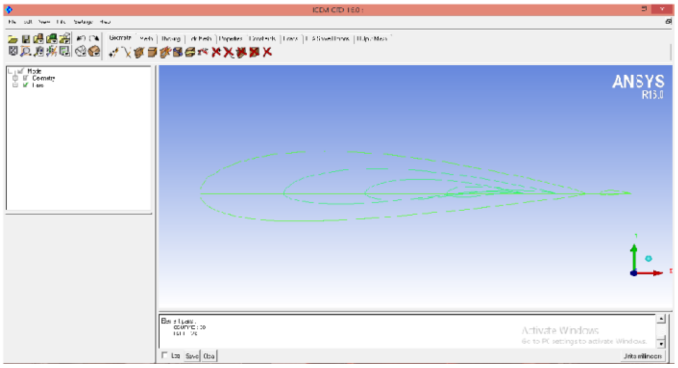


Fig.5 Aerofoils curve import for BWB

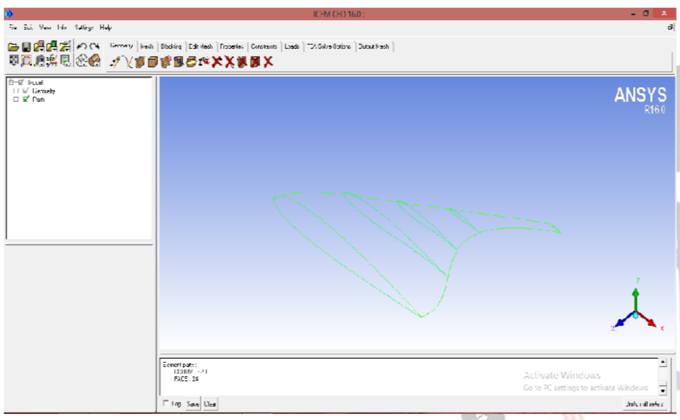


Fig.6 Create curves required

A. Create/Modify Surface Options

The From Curves option allows you to create surfaces from curves by selecting surfaces of airfoil.

Fig.7 Half BWB

B. Mesh

This involves conversion from three dimensional CREO model into CFD element to create the meshing element. Then, the succeeded meshing models were exported to FLUENT for the analysis. The result presented is the simulation for subsonic flow at Mach number equals to 0.1. Boundary conditions and airflow are simulated in this stage purposely-executed for two reasons; first is determination of pressure distribution on the surface of the BWB that later on leads to calculations of aerodynamics characteristics of BWB such as C_L and C_D at various angle of attack, second is the visualization of the air flow around the BWB using Post Processing. In this study hexa meshing is preferred as per the requirement of project for improved results. The analytical of aerodynamics characteristics for various angles of attacks using CFD simulation will be conducted in this final stage.[5]

Compute Mesh (The Compute Mesh option allows you to generate the mesh specified by the mesher and various parameters as shown in fig.8.)[2]

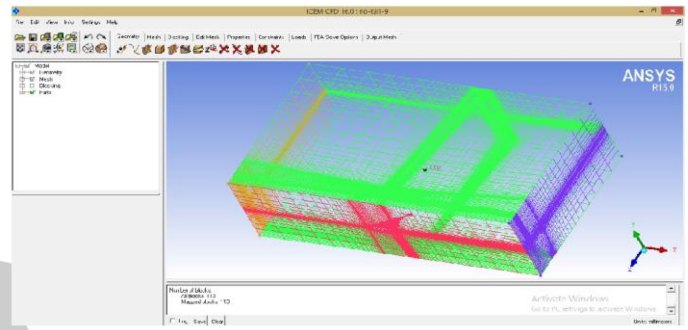


Fig.8 Meshing of BWB

C. Boundary Conditions

As per the estimate on the capital as well as operating cost required for the CFD analysis and experimental validation of the results, the scaled model has been selected for testing. A scaled model is used for CFD analysis while the same scale is used for wind-tunnel testing of the model. The surface of the BWB is set to no-slip. A wind-tunnel will be created to simulate the performance. The inlet and outlet of the wind tunnel is considered as free air stream. The Reynolds number will be varied for testing and will be in order of 10^6 with international air atmospheric properties**.** The Mach number will be typically 0.1 (approx. 34 m/s air velocity). The model will be simulated without winglet for reasonable analysis and available computational power limitations. The model is set for symmetric boundary condition to further reduce the computational cost.

VI. RESULT ANALYSIS AND DISCUSSION

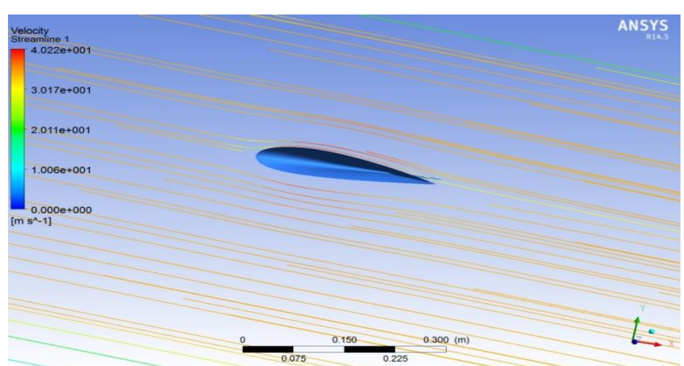


Fig.9 Streamlines for Mach 0.1, AOA +3^0

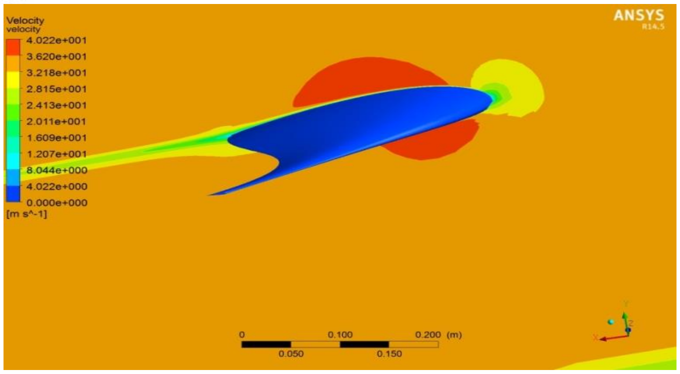
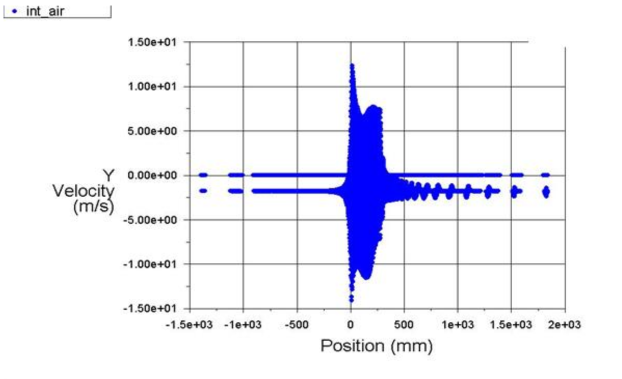


Fig.10 Pressure contours for Mach 0.1, AOA +3⁰



Graph.1 Velocity variation along body Mach 0.1, AOA +3⁰

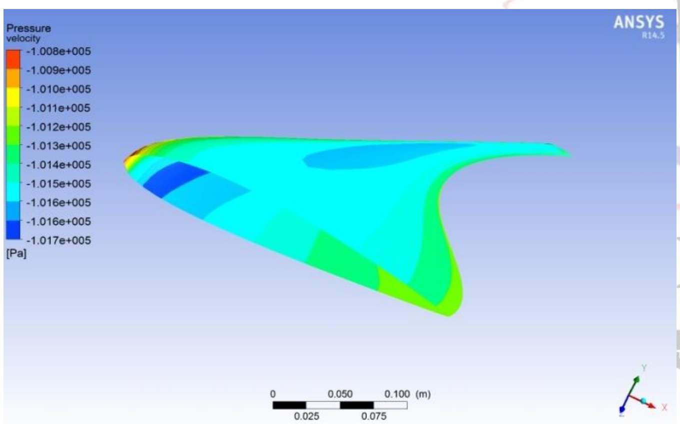
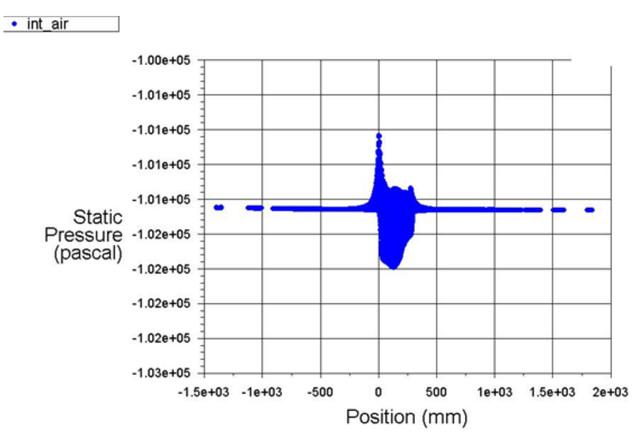


Fig.11 Pressure contours for Mach 0.1, AOA +3⁰



Graph.2 Pressure variation along body for Mach 0.1, AOA +3⁰

Table-1: Analysis report Mach 0.1, AOA +3⁰

Variable	Units	Inlet	Outlet	Symmetry	Body
Velocity	M/s	34	34	30.69	33.91
Static Pressure	Pa	-101310	-101331	-101315	-101444
Area	M^2	1.28	1.28	2.45	0.984
Mach no	--	0.098	0.098	0.088	0.098
Force-X ("total" drag)	N	--	--	--	0.000391
Force-Y (total)	N	--	--	--	0.010329
Mass-Flow	Kg/s	53.31	53.31	0	NA
Average Static Temp	K	300.01	300.02	300.06	300.58

Drag force calculated by CFD is 0.000391N and by experimentally is 0.000368N and lift force calculated by CFD is 0.010329N and by experimentally is 0.010704N for +3⁰angle of attack. Which are approximately equal.

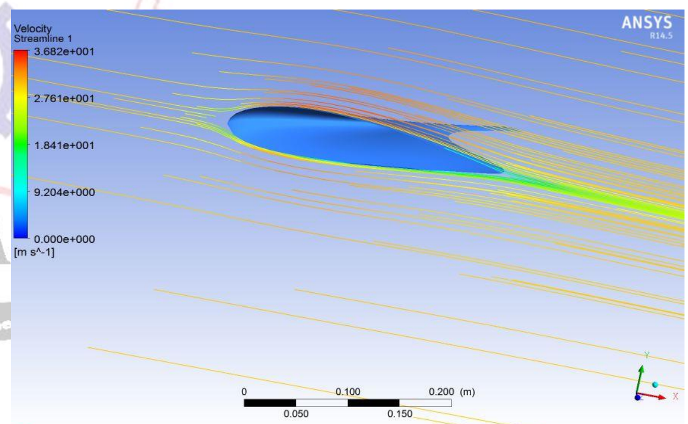


Fig.12 Streamlines for Mach 0.1, AOA 0⁰

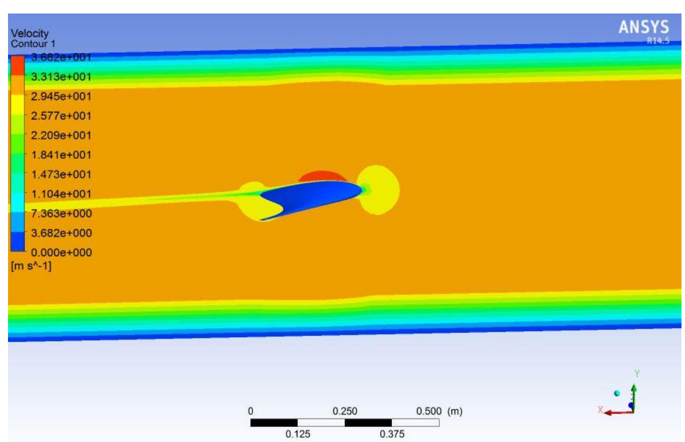
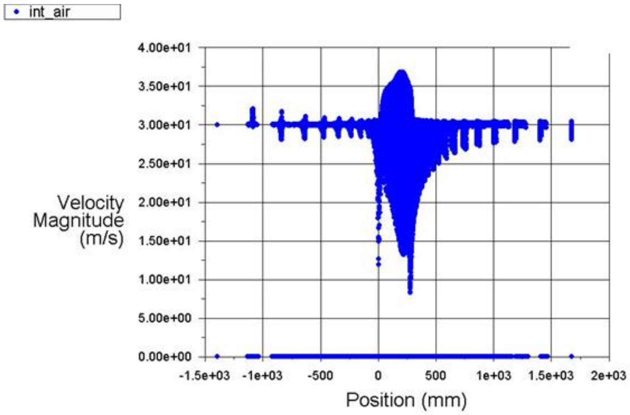


Fig.13 Velocity contours Mach 0.1, AOA 0⁰



Graph.3 Velocity variation along body Mach 0.1, AOA +0^0

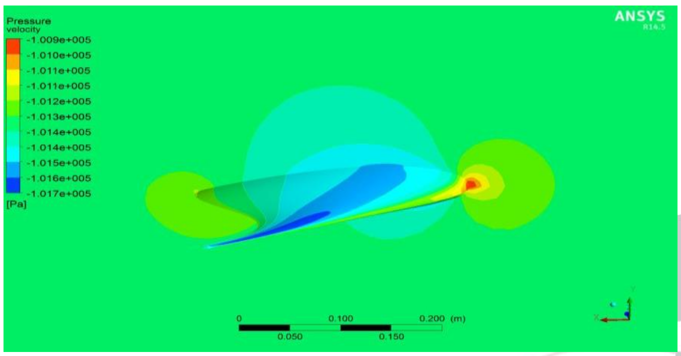
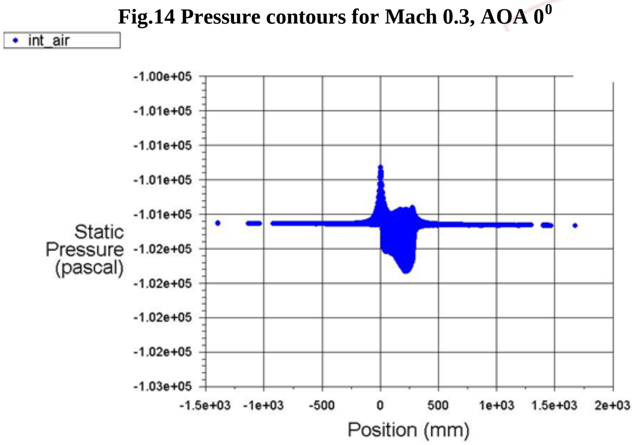


Fig.14 Pressure contours for Mach 0.3, AOA 0^0



Graph.4 Pressure variation along body for Mach 0.1, AOA 0^0

Table-2: Analysis report Mach 0.1, AOA +0^0

Variable	Units	Inlet	Outlet	Symmetry	Body
Velocity	M/s	30	30	26.94	30.78
Static Pressure	Pa	-101318	-101332	-101336	-101387
Area	M^2	1.28	1.28	2.45	0.984
Mach no	--	0.086	0.086	0.078	0.089
Force-X ("total" drag)	N	--	--	--	0.000713
Force-Y (total)	N	--	--	--	0.006059
Mass-Flow	Kg/s	47.04	47.04	0	NA
Average Static Temp	K	300.01	300.01	300.03	300

Drag force calculated by CFD is 0.000713N and by experimentally is 0.00073N and lift force calculated by CFD is 0.00605N and by experimentally is 0.00592N for 0^0angle of attack. Which are approximately equal to experimental results are calculated by using Wind tunnel which gives directly readings of drag force and lift force for all three angle of attacks(+3^0, 0^0 and -3^0).

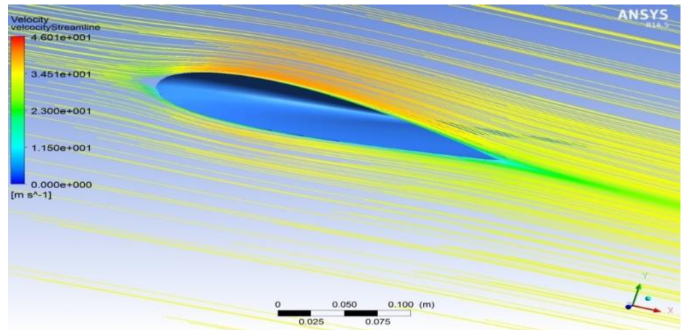
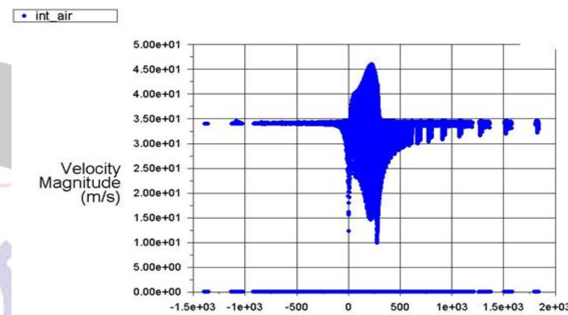


Fig.15 Streamlines for Mach 0.1, AOA -3^0



Graph.5 Velocity variation along body Mach 0.1, AOA -3^0

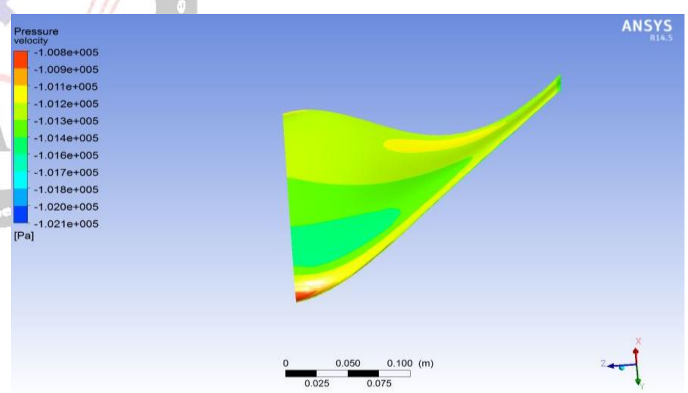
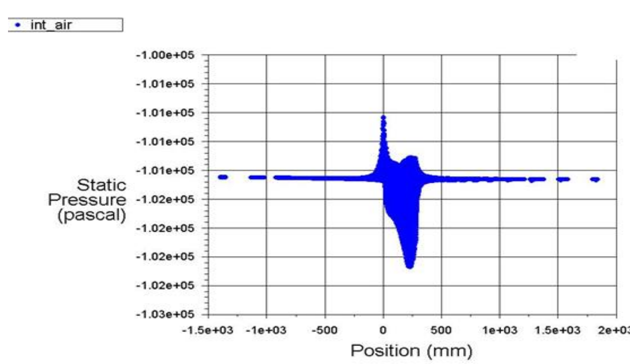


Fig.16 Pressure contours for Mach 0.1, AOA -3^0



Graph.6 Pressure variation along body for Mach 0.1,AOA-3^0

Table-3: Analysis report Mach 0.1, AOA -3^0

Variable	Units	Inlet	Outlet	Sym metry	Body
Velocity	M/s	34	34	30.49	33.78
Static Pressure	Pa	-101312	-101329	-101316	-101388
Area	M^2	1.28	1.28	2.45	0.984
Mach no	--	0.098	0.098	0.088	0.097
Force-X ("total" drag)	N	--	--	--	0.000713
Force-Y (total)	N	--	--	--	0.00169
Mass-Flow	Kg/s	53.31	53.31	0	NA
Average Static Temp	K	300.01	300.01	300.06	300.54

Drag force calculated by CFD is 0.000713N and by experimentally is 0.000661N and lift force calculated by CFD is 0.00169N and by experimentally is 0.00161N for 0^0 angle of attack. Which are approximately equal.

The 'x' and the 'y' component of forces are obtained from the fluent software. As we know that the force exerted by the fluid on a body, in flow direction is called as drag. We also know that the component of the pressure and wall shear forces in the direction normal to the flow tend to move the body in that direction, their sum is called a lift.

F_y and F_x obtained from the CFD simulations represents the axial and normal force respectively. At zero angle of attack, F_y and F_x are equivalent to the lift (F_L) and drag force (F_D) respectively.

$F_D = F_x \cos\alpha + F_y \sin\alpha$
$F_L = F_y \cos\alpha - F_x \sin\alpha$

After obtaining F_y, F_x and the torque with respect to z-axis, the results for C_L and C_D at various angles of attack were derived using below equations we can find

$$C_L = \frac{2F_L}{\frac{1}{2}\rho V^2 S_{ref}}$$

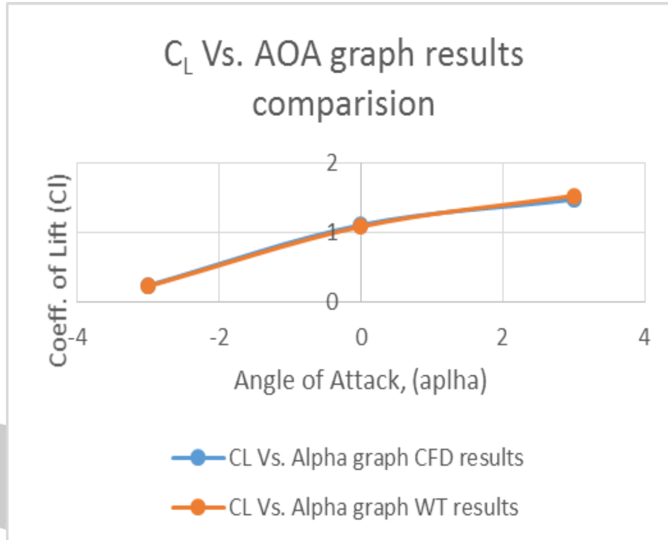
$$C_D = \frac{2F_D}{\frac{1}{2}\rho V^2 S_{ref}}$$

A. Lift Coefficient Analysis

With different angle of attack and Mach number near to 0.1, the lift coefficient tends to increase. The velocity is strictly limited to the operating condition in the wind tunnel.

For angle of attack from -3^0 to +3^0, the coefficient of lift tends to rise and agreeing satisfactorily with the wind tunnel results. However, it is expected that the lift coefficient will fall during continuous rise in angle of attack.

The behaviour of angle of attack has to be tested at higher velocities (hence higher Mach)

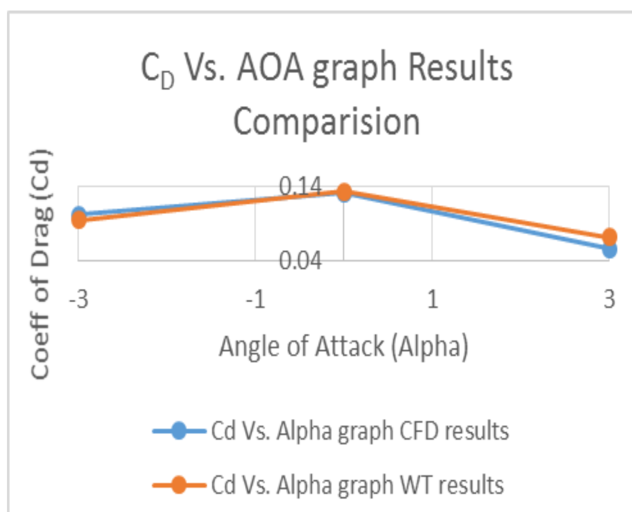


Graph.7 C_L versus Alpha

B. Drag Coefficient Analysis

The drag coefficient behaves very sensitively with the angle of attack for lower match numbers. It is expected to be near constant for higher Mach number flows (M=0.7 and above). From the obtained results, it is concluded that the C_D is sufficiently small and there is no flow separation, also, wakes are also not generated.

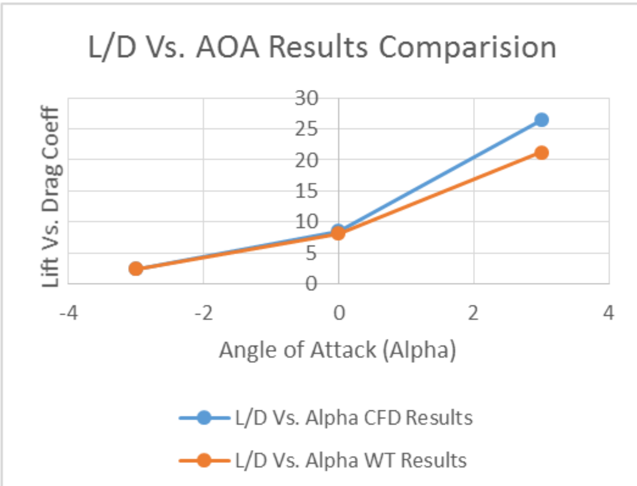
It is also proven practically that at higher speeds the coefficient of drag increases positively.



Graph.8 C_D versus Alpha

C. Lift-to-Drag Ratio Analysis

The L/D ratio tends to increase with angle of attack. However with practical experiences, it is known that the same will increase till the certain value of angle of attack (typically between 8^o to 15^o) and then falls asymptotically to 1. There is a slight variation between the results obtained from CFD and actual WT testing. At alpha = $+3^0$, the highest L/D ratio is achieved. At the above mentioned alpha, CFD give L/D ratio as 26.4 however practically it is little lower to 21.2



Graph.9 L/D ratio versus Angle of attack

Table-4: L/D ratio CFD Results

Angle of attack	C_D (X 10^-5)	C_L (X 10^-5)	C_L/C_D
-3^0	0.102336487	0.242564745	2.37026648
0^0	0.131445532	1.11535129	8.485273492
3^0	0.056120009	1.482515531	26.4168798

Table 5: L/D ratio Wind Tunnel Results

Angle of attack	C_D (X 10^-5)	C_L (X 10^-5)	C_L/C_D
-3^0	0.0948	0.231	2.4357
0^0	0.1345	1.0913	8.1095
3^0	0.0725	1.5363	21.1903

Table 6: Comparison of L/D ratio between CFD Simulation and Wind Tunnel Results

Angle of attack	CFD C_L/C_D	Wind Tunnel C_L/C_D	%Error
-3^0	2.37026648	2.4357	2.69
0^0	8.485273492	8.1095	4.43
3^0	26.4168798	21.1903	19.78

VII. CONCLUSION

In present study the simulation is carried out for sub-sonic flow and scaled model at different angle of attack. The results are shown in various means including velocity streamlines, pressure contours, x-y plots for lift, drag etc. The results of aerodynamic efficiency (lift to drag ratio) obtained from wind-tunnel testing has also be shown and compared. It can be concluded that the CFD results are satisfactorily agreeing to the WT test results. With different angle of attack and Mach number near to 0.1, the lift coefficient tends to increase and with increase in angle of attack drag coefficient first increases then start decreasing. So that increase in lift coefficient and decrease in drag coefficient, we get good aerodynamic efficiency. The present work can be used for making the BWB drones due to small dimensions however, in future this work can also be extended for the higher Mach numbers and bigger models. Optimization testing for BWB can also be done in future.

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