IOP Conf. Series: Materials Science and Engineering **197** (2017) 012076 doi:10.1088/1757-899X/197/1/012076

# *Aerodynamic Analysis Over Double Wedge Airfoil*

**U S Prasad[1], Ajay V S[2], Rajat R H[3], Samanyu S[4]**

[1]Sr. Assistant Professor, Institute of Aeronautical Engineering, Hyderabad, India.
[2 3 4] UG scholar of Aeronautical Engineering, MIT, Manipal, Manipal University, India.

Email: shivaprasad047@gmail.com

**Abstract.** Aeronautical studies are being focused more towards supersonic flights and methods to attain a better and safer flight with highest possible performance. Aerodynamic analysis is part of the whole procedure, which includes focusing on airfoil shapes which will permit sustained flight of aircraft at these speeds. Airfoil shapes differ based on the applications, hence the airfoil shapes considered for supersonic speeds are different from the ones considered for Subsonic. The present work is based on the effects of change in physical parameter for the Double wedge airfoil. Mach number range taken is for transonic and supersonic. Physical parameters considered for the Double wedge case with wedge angle (ranging from 5 degree to 15 degree.

Available Computational tools are utilized for analysis. Double wedge airfoil is analysed at different Angles of attack (AOA) based on the wedge angle. Analysis is carried out using fluent at standard conditions with specific heat ratio taken as 1.4. Manual calculations for oblique shock properties are calculated with the help of Microsoft excel. MATLAB is used to form a code for obtaining shock angle with Mach number and wedge angle at the given parameters. Results obtained from manual calculations and fluent analysis are cross checked.

## 1. Introduction

Double wedge airfoils (DWA) are very rarely used in physical applications because of its complex geometrical parameter variations. DWA have different types of shocks at higher speeds which make studies interesting to analyse the flow parameters along the body. Supersonic flow over different contours is a leading study in today's aeronautical field. Since any disturbance (either physical or shock related) takes up great deal of importance in supersonic flow, it becomes a necessity to analyse flow over different contours to get higher and efficient performance. Detailed analysis of change in flow properties over airfoils is done with the aid of CAD Modelling and Fluent for analysis.

Supersonic characteristics for a Double wedge airfoil are associated with shocks and expansion waves. This results in increase in Drag. Manual and Fluent analyses over Double wedge airfoil was done to minimize this drag. Oblique shock and expansion waves for Double wedge airfoil were manually calculated for different wedge angles and the same was carried using ANSYS Fluent software. This was

IOP Conf. Series: Materials Science and Engineering **197** (2017) 012076 doi:10.1088/1757-899X/197/1/012076

done at 0, 5, 10, 15degree angle of attack (AOA) for a 5deg half wedge angle. Also another model with 10 degree half wedge angle was analysed at 0 degree AOA.

Using coding software MAT lab shock angles for corresponding Mach number and Wedge angle is found. These angles are used for further calculation of flow properties after oblique shock and expansion wave are found. Modelling of Double wedge airfoil was carried out using CAD Software. Analysis was carried out in Fluent Software, Standard Flow conditions was used with change in Mach number and wedge AOA. Pressure coefficient, drag Coefficient and other important plots are considered for the study. Conclusions based on these plots were made.

Oblique shock and expansion waves theory was studied [1] and the implementation of shock and expansion waves over Double wedge airfoil was carried further. Manual calculations for oblique shock properties and expansion wave are formulated in Excel. Lift and drag are analyzed numerically by solving Navier stokes equations for variable density flow field on double wedged aerofoil by varying the angle of attack and thickness to chord ratio [2].

## 2. Modeling of double wedged airfoils

Modeling is carried out using CAD modeling software. Model varies in physical dimensions, the chosen value for half wedge angle is 5 degree and 10 degree at $0^o$, $5^o$ , $10^o$ and $15^o$ AOA. Model Specifications: Domain Size 22 x 10 m (For $5^o$ half angle model) Faces: 4, Boundary Conditions: Wedge surface = Wall, Walls of Domain: Pressure far field.

Second model specifications: Domain Size 22 x 10 m. (For 10o half angle model) Boundary Conditions: Wedge surface = Wall, Walls of Domain: Pressure far field Meshed model files was imported to FLUENT. Two equation model used for turbulence are K-epsilon model amongst viscous models [4]. Epsilon model is recommended for flows with separation, recirculation and whose scales are smaller than cell size. Two extra transport equations have been used for simulating the turbulent properties of the flow which allow two equation model to account for history effects like convection and diffusion of turbulent energy.

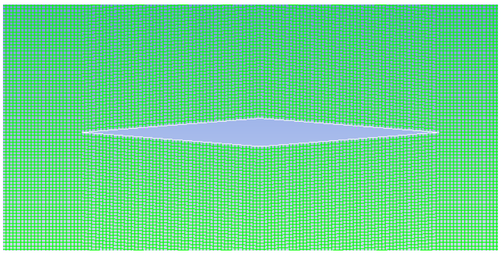

**Figure 1a**. $5^o$ half angled aero foil

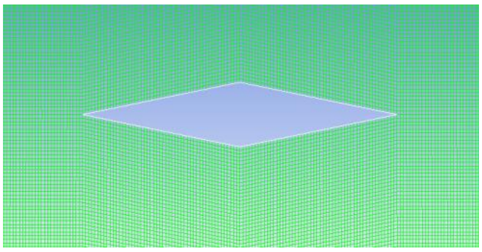

**Figure 1b.** $10^o$ half angled aero foil

## 3. Results and analysis

TheMeshed Model is imported in fluent software for analysis. Analysis is carried out for Mach number range of 1.2-1.8 at $0^o$ and $5^o$ AOA. Solver used is Density based with K-epsilon viscous model. Operating conditions are set to 0. Iterations are carried out until convergence of Standard Equations. Changes in Mach number was made and plots were analyzed. Changes in AOA and half wedge angle was made.

Further changes in the Angle of attack were made in fluent to 5, 10, 15 degree angle of attack and similar analysis was carried out at different Mach number. It was observed that as half wedge angle equals the AOA, No shock was visible at the leading edge. This mainly due to the fact that the upper first half of the plane becomes parallel to free stream direction. Hence no flow tends to turn into itself.

AOA was further increased to 10 degree and 15 degree. When the AOA is increased to value higher than half wedge angle, An Expansion wave is seen at top leading edge as show in Figure 7. For the same Mach number but different AOA it was observed that the expansion wave on top and the shock wave at lower surface got stronger as shown in Figure 8 and Figure 9. This was concluded based on velocity contours and oblique shock relations.

IOP Conf. Series: Materials Science and Engineering **197** (2017) 012076 doi:10.1088/1757-899X/197/1/012076

*3.1 Important plots with respect to change in angle of attack*

Properties Such as dynamic pressure, Mach number, Temperature and turbulence over the surface are compared for study. $C_l$, $C_d$ Lift and Drag Vs Mach number was tabulated manually and plotted using post processing software.

*3.2 Change in wedge angle*

CAD Model made in modeling software to 10° half wedge angle (deflection angle) was read in fluent. Analysis at 0° AOA was carried out with Mach number ranging from 1.2 to 3.5. Contours and plots were studied.

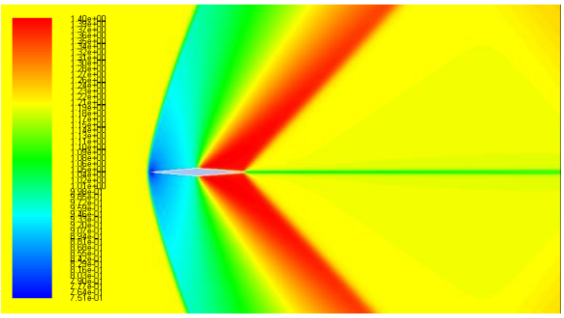

**Figure 2.** Velocity Contour on 5° half wedge angle, 0° AOA at Mach 1.2

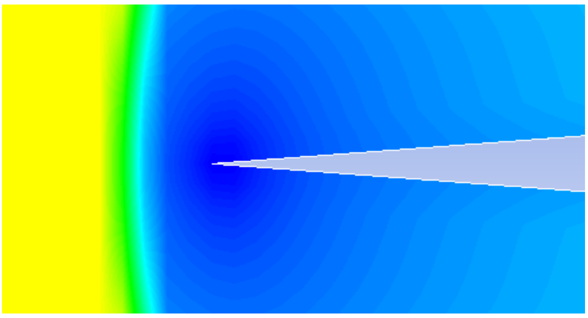

**Figure 3.** Detached shock wave (magnified image) on 5° half wedge angle

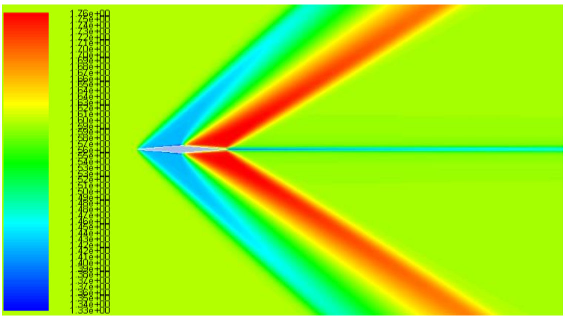

**Figure 4**. Mach 1.6velocity contour over 5° half wedge angle

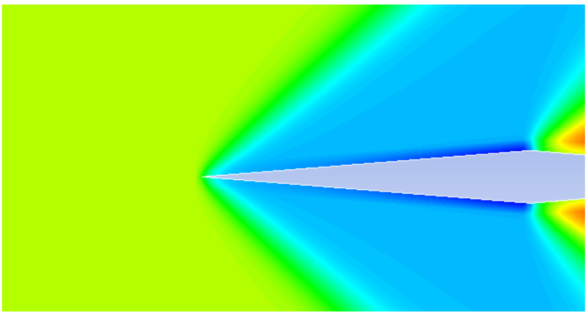

**Figure 5.** Mach 1.6 attached Shock (magnified image)

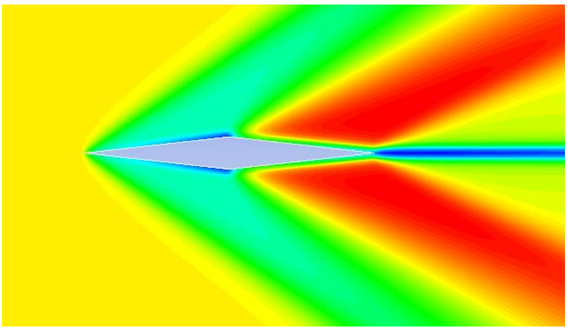

**Figure 6a.** Velocity contours at 0° AOA respectively with 5° half wedge angle at Mach 2 freestream velocity.

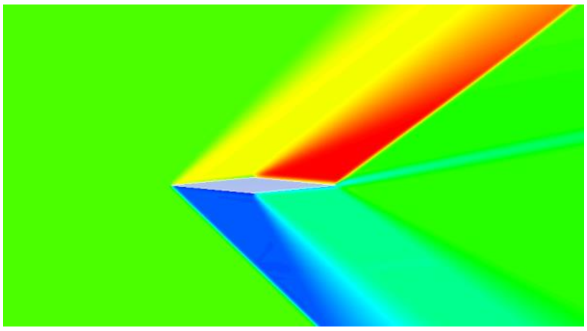

**Figure 6b**. Velocity contours at 5° AOA respectively with 5° half wedge angle at Mach 2 freestream velocity.

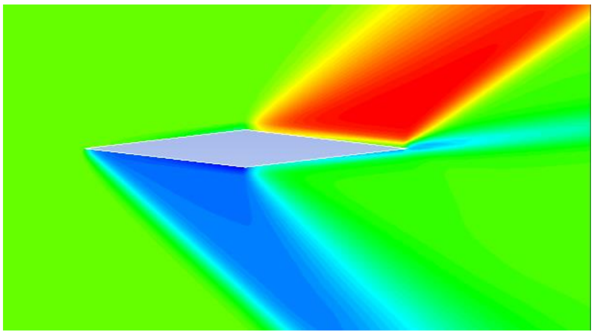

**Figure 7.** Expansion wave observed at top Leading edge when the AOA exceeds the half wedge angle.

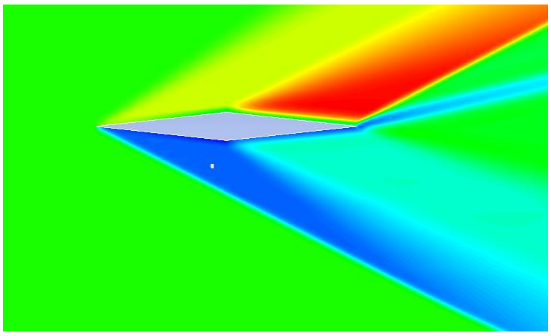

**Figure 8**.Velocity contours at Mach 3, AOA at 10° Angle of attack

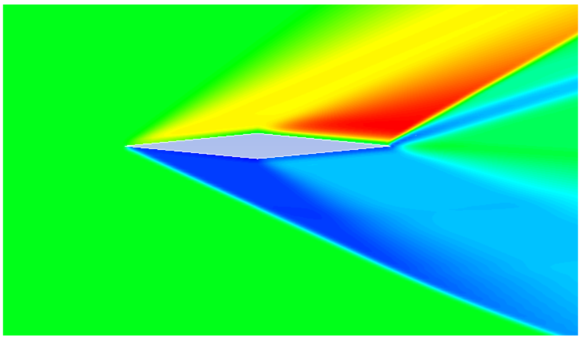

**Figure 9**.Velocity contours at Mach 3, AOA at 15°.

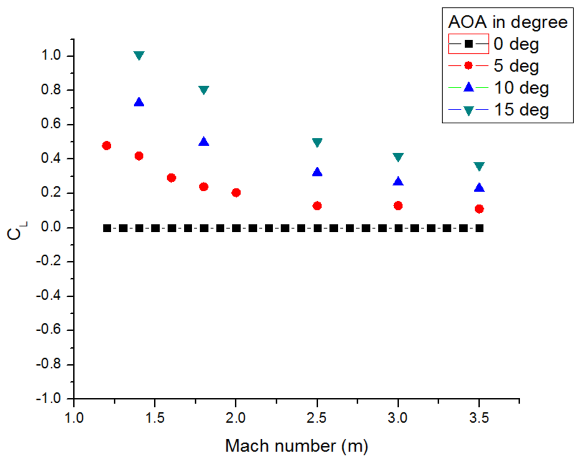


**Figure 10.** Coefficient of lift at different AOA with respect to Mach number.

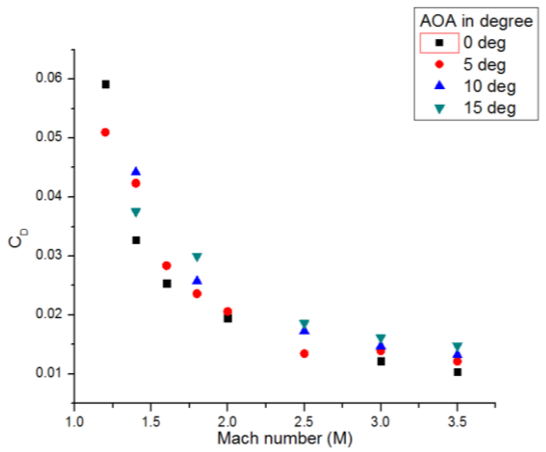


**Figure 11**. Coefficient of drag at different AOA with respect to Mach number.

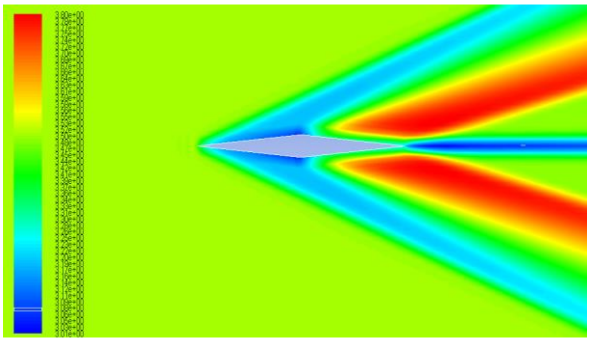

**Figure 12a**. Velocity contours at Mach 3.5 with 5° Half wedge angle

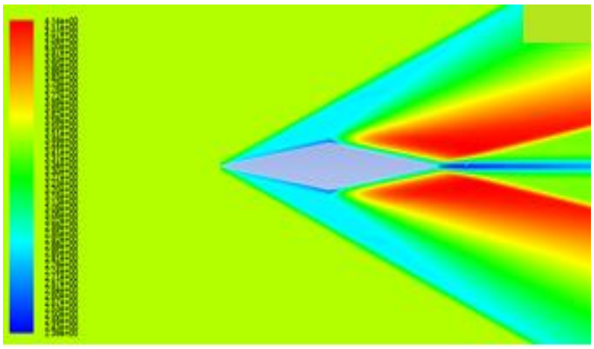

**Figure 12b**. Velocity contours at Mach 3.5 with 10° Half wedge angle

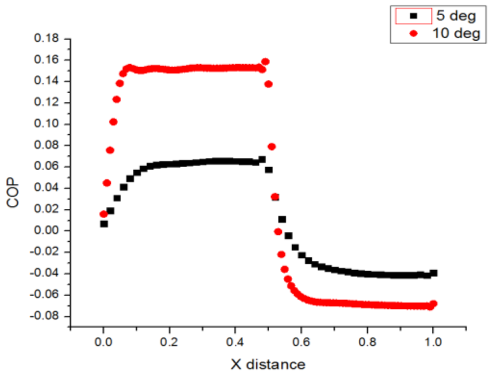


**Figure 13**. Coefficient of pressure Vs length(m) of aerofoil

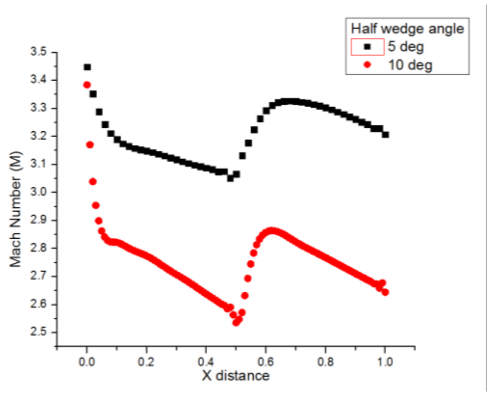


**Figure 14**. Mach number over surface Vs Length of the airfoil (m).

## 4. Conclusions

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

### 4.1 *Double Wedge Airfoil*

4.1.1 *At 0 degree AOA* Manual calculations agrees well with fluent results. The de-attached shock for shock angle above 90° is clearly seen in fluent. Pressure Coefficient is seen to decrease with increase in Mach number after shock. Peak Mach number and turbulent kinetic energy above surface is seen to increase with inlet Mach number. Total temperature gradually decreases along wedge. It is higher at higher inlet Mach.

4.1.2 *At different AOA* No shock observed when half wedge angle equals AOA. An Expansion wave is seen at top leading edge at AOA>half wedge angle. The strength of Expansion wave and Shock wave at top and bottom leading edge increases with AOA provided AOA exceeds the half wedge angle.

### 4.2 *For AOA half wedge angle*

As the AOA increases, Patterns of plots remain same but the Pressure coefficient at the top surface increases and at bottom surface decreases. The same pattern is observed in case of Mach number, Dynamic pressure and turbulent kinetic energy plots.

$C_l$ and $C_d$ (Coefficient of Lift and Drag) seen to decrease with increase in M and decrease in AOA. Lift and Drag increase with increase in M and AOA.

**Table 1**: All calculations are tabulated in an Excel sheet as shown below and the Oblique shock pattern study is carried out.

| γ | Θ | β(Radians) | $M_1$ | $P_1$ | $M_{n1}$ | $M_{n2}$ | $M_2$ | $T_1$ | $P_2$ | $\rho_1$ | $\rho_2$ | $T_2$ | $P_{01}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.4 | 0.0873 | 1.578 | 1.2 | 1 | 1.199969 | 0.84219 | 0.844899 | 288 | 1.513246 | 1.225 | 1.64341 | 324.857 | 2.42497 |
| 1.4 | 0.174 | 1.587 | 1.2 | 1 | 1.199842 | 0.842269 | 0.852865 | 288 | 1.512892 | 1.225 | 1.64314 | 324.834 | 2.42497 |
| 1.4 | 0.261 | 1.587 | 1.2 | 1 | 1.199842 | 0.842269 | 0.868151 | 288 | 1.512892 | 1.225 | 1.64314 | 324.834 | 2.42497 |
| 1.4 | 0.348 | 1.587 | 1.2 | 1 | 1.199842 | 0.842269 | 0.890857 | 288 | 1.512892 | 1.225 | 1.64314 | 324.834 | 2.42497 |
| | | | | | | | | | | | | | |
| 1.4 | 0.087 | 0.92 | 1.4 | 1 | 1.113842 | 0.90117 | 1.217875 | 288 | 1.280752 | 1.225 | 1.46119 | 309.235 | 3.18227 |
| 1.4 | 0.174 | 1.583 | 1.4 | 1 | 1.399896 | 0.739753 | 0.749543 | 288 | 2.119659 | 1.225 | 2.06961 | 361.332 | 3.18227 |
| 1.4 | 0.261 | 1.587 | 1.4 | 1 | 1.399816 | 0.739787 | 0.76252 | 288 | 2.1194 | 1.225 | 2.06944 | 361.318 | 3.18227 |
| 1.4 | 0.348 | 1.587 | 1.4 | 1 | 1.399816 | 0.739787 | 0.782463 | 288 | 2.1194 | 1.225 | 2.06944 | 361.318 | 3.18227 |
| | | | | | | | | | | | | | |
| 1.4 | 0.087 | 0.767 | 1.6 | 1 | 1.110365 | 0.9038 | 1.437357 | 288 | 1.27173 | 1.225 | 1.45388 | 308.6 | 4.25041 |
| 1.4 | 0.174 | 0.889 | 1.6 | 1 | 1.242307 | 0.816984 | 1.246129 | 288 | 1.633881 | 1.225 | 1.73359 | 332.508 | 4.25041 |
| 1.4 | 0.261 | 1.576 | 1.6 | 1 | 1.599978 | 0.668444 | 0.690925 | 288 | 2.819919 | 1.225 | 2.48884 | 399.731 | 4.25041 |
| 1.4 | 0.348 | 1.587 | 1.6 | 1 | 1.59979 | 0.668501 | 0.707065 | 288 | 2.819216 | 1.225 | 2.48846 | 399.693 | 4.25041 |
| | | | | | | | | | | | | | |
| 1.4 | 0.087 | 0.67 | 1.8 | 1 | 1.117775 | 0.89822 | 1.631553 | 288 | 1.290991 | 1.225 | 1.46945 | 309.953 | 5.7458 |
| 1.4 | 0.174 | 0.768 | 1.8 | 1 | 1.250456 | 0.81238 | 1.451508 | 288 | 1.657582 | 1.225 | 1.75097 | 333.983 | 5.7458 |
| 1.4 | 0.261 | 0.889 | 1.8 | 1 | 1.397596 | 0.740724 | 1.260748 | 288 | 2.112152 | 1.225 | 2.06472 | 360.905 | 5.7458 |
| 1.4 | 0.348 | 1.582 | 1.8 | 1 | 1.799887 | 0.616527 | 0.653226 | 288 | 3.612859 | 1.225 | 2.88983 | 441.07 | 5.7458 |
| | | | | | | | | | | | | | |
| 1.4 | 0.087 | 0.598 | 2 | 1 | 1.125981 | 0.89215 | 1.824252 | 288 | 1.312473 | 1.225 | 1.48673 | 311.449 | 7.82445 |
| 1.4 | 0.174 | 0.685 | 2 | 1 | 1.265346 | 1.644338 | 1.644338 | 288 | 1.701284 | 1.225 | 1.78275 | 336.679 | 7.82445 |
| 1.4 | 0.261 | 0.79 | 2 | 1 | 1.420707 | 1.448766 | 1.448766 | 288 | 2.188142 | 1.225 | 2.11377 | 365.213 | 7.82445 |
| 1.4 | 0.348 | 0.929 | 2 | 1 | 1.602043 | 1.216746 | 1.216746 | 288 | 2.827634 | 1.225 | 2.49309 | 400.141 | 7.82445 |

*4.3 Change in Wedge angle*

For same Mach number Increase in half wedge angle increases the strength of shock and expansion waves at 0o AOA. $C_p$ increases in the first half region and decreases in second half region of wedge with increase in wedge angle. Pattern remains similar with respect to Dynamic pressure plots. Mach plots shifts down with increase in wedge angle representing a decrease in value.

Turbulent kinetic energy increases with increase in wedge angle.

**Acknowledgments**

Authors would like to express sincere gratitude to all those who have directly or indirectly contributed to this research work. Authors would like to thank Prof. Dr. Satish Shenoy B. Head of the Department Aeronautical & Automobile Engineering, Research Director (Technical), and MIT-Manipal University, Manipal, for the computational support given.

**References**

[1]. John D Anderson Jr, 2010 Fundamentals of Aerodynamics, 5 Edition.
[2]. Ramesh Kolluru and Vijay Gopal 2012 Proc. Excerpt Comsol p 1.
[3]. Pritam Kumar Patel and M Premchand CD adapco, *CFD basics*, American Agency, Training Document, P 38.
[4]. Colleen D. Scott-Pomerantz 2004 The k-epsilon model in the theory of turbulence. Tech. Rep. Univ. of Pittsburgh. P 10.