Impact of Variation in Angle of Attack on NACA 7420 Airfoil in Transonic Compressible Flow Using Spalart- Allmaras Turbulence Model

[1]Ovais Gulzar, [2]Saqib Gulzar, [3]Sanjay Bhatele, [4]Neelesh Soni
[1,3,4]Dept. of Mechanical Engineering, SRCEM, RGPV, MP, India
[2]Dept. of Civil Engg., National Institute of Technology, Srinagar

Abstract

The present work deals with the comparative study of variation in the angle of attack over NACA 7420 airfoil. The simulation of Transonic Compressible flow is performed over NACA 7420 for three different angles of attack i.e., 4^0, 5^0 & 6^0 using the Spalart- Allmaras turbulence model. The geometry and meshing is performed in ICEM CFD package of ANSYS 14.5 and the simulation is performed in FLUENT Package of ANSYS 14.5.Various flow and fluid properties are compared for different angle of attacks. As angle of attack is varied, the X- component and Y- component varies over a range which yields a set of results for a particular angle of attack. The numerical and computational analysis is performed to obtain the optimized angle of attack for a definite set of operating conditions.

Keywords

Spalart-Allmaras Turbulence Model, Compressible Flow, Airfoil, ICEM, Fluent, CFD, Pressure-based Coupled Solver, Pseudo Transient Condition, Angle of Attack

I. Introduction

With the developments in technology, computational analysis has emerged as a vital tool used in the analysis of aerodynamic & fluid flow problems. This work is based on the computational study of NACA 7420 airfoil. National Advisory Committee for Aeronautics is a federal agency to undertake, promote, and institutionalize aeronautical research [1]. The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties [2]. The NACA 7420 is under consideration for this case study.

A. Geometry of Airfoil NACA 7420:

The NACA airfoil is already a published airfoil with well-defined coordinates [3]. The geometry of NACA is shown as in fig. 1.

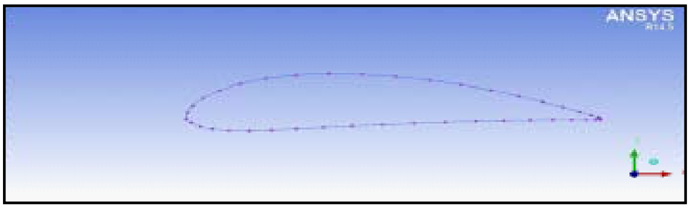


Fig. 1: Geometry of NACA-7420

B. Specifications of NACA-7420

The NACA four-digit wing sections define the profile as per below specifications:
First digit describing maximum camber as percentage of the chord,
Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percent of the chord and Last two digits describing maximum thickness of the airfoil as percent of the chord.
The specifications NACA 7420 are given Table 1.

Table 1: Specifications of NACA 7420

Camber	Maximum camber of 7% located 40% (0.4 chords) from the leading edge
Thickness	Maximum thickness of 20% of the chord
Four-digit series airfoils by default have maximum thickness at 30% of the chord (0.3 chords) from the leading edge.	

II. Angle of Attack

In fluid dynamics, angle of attack (AOA, or (Greek letteralpha)) is the angle between the chord line of an airfoil and the vector representing the relative motion between the body and the fluid through which it is moving [4]. Angle of attack is the angle between the body's chord line of airfoil line and the oncoming flow [5] as shown in fig. 2.

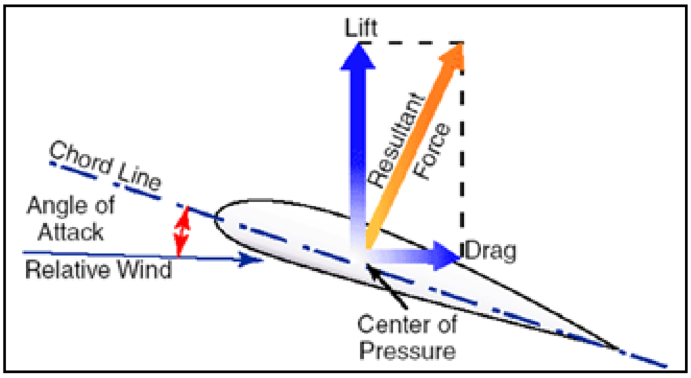


Fig. 2: Angle of Attack

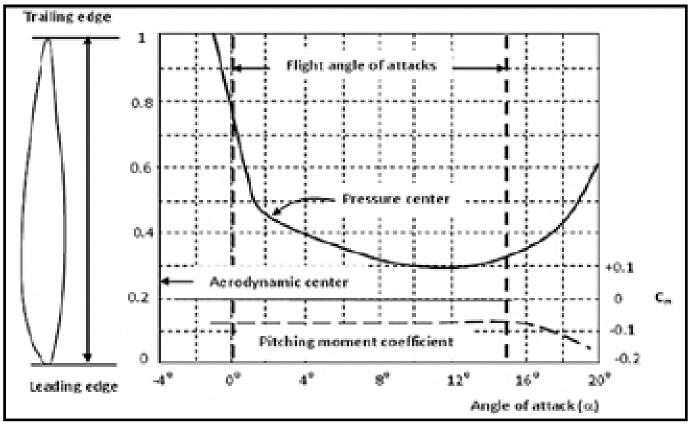


Fig. 3: The Pressure Centre Movement as a Function of Angle of Attack

ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

III. Spalart Allmaras Model

The Spalart-Allmaras model can be written in tensor notation as follows [6]:

$$\frac{\partial \grave{\upsilon}}{\partial t}+\frac{\partial\,(\grave{\upsilon} v j)}{\partial x j}=C_{b1}(1-f_{t2})S\grave{\upsilon}+\frac{1}{\sigma}\{\frac{\partial}{\partial x}[\widetilde{v_L+v\frac{\partial \grave{\upsilon}}{\partial x}}]+C_{b2}\frac{\partial \grave{\upsilon}}{\partial x j}\frac{\partial \grave{\upsilon}}{\partial x j}-[C_{w1}f_w-\frac{Cb1}{K^2}f_{t2}]$$
$$(\frac{\grave{\upsilon}}{d})^2+f_{t1}\|\Delta\grave{\upsilon}\|_2^2$$

The various constants in above equations are defined as [7]

$$C_{b1}=0.1355,\ C_{b2}=0.622,\ C_{v1}=7.1,\ C_{v2}=5,\ \sigma=\frac{2}{3},\quad k=0.41,\ C_{w1}=\frac{C_{b1}}{k^2}+\left(1+\frac{C_{b2}}{\sigma}\right),\ C_{w2}=0.3,\quad C_{w3}=3,\ C_{t1}=1,\ C_{t2}=2,\ C_{t3}=1.3,\quad C_{t1}=0.5$$

IV. Fluent Simulation

The mesh file so obtained is read in FLUENT 14.5. The simulation is done using fluent launcher to start 2D version of ANSYS FLUENT and enabling double precision for accurate results.
The problem set up for Spalart-Allmaras Turbulence model for ANSYS FLUENT is given in Table 2:

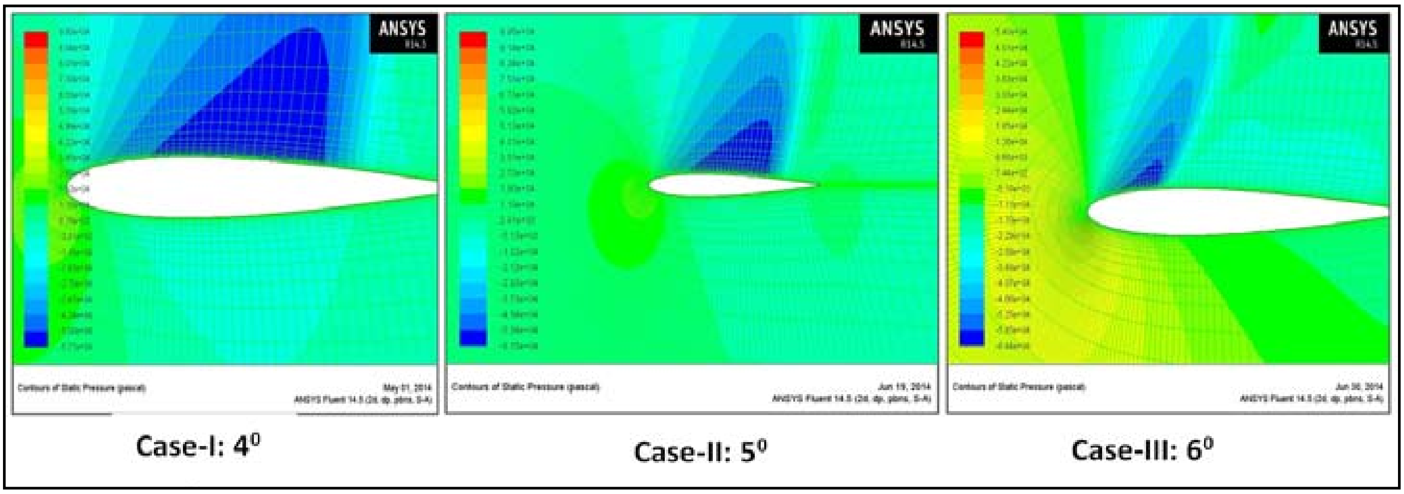
Table 2: Problem Set Up for Spalart-Allmaras Turbulence Model

Problem Set Up for Sparat-Allamaras Turbulence Model	
Solver	Pressure Based
Velocity Formulation	Absolute
Time	Steady
2D Space	Planar
Viscous Models	
Model	Spalart-Allmaras Model
Sparat-Allamaras Production	Strain/Vorticity based
Material Selection	
Air	Density- Ideal Gas Cp = 1006.43 Thermal Conductivity = 0.0242 Viscosity = 1.7894e-05 Molecular Weight = 28.966
Boundary Conditions	
Gauge Pressure	0 Pascal
Mach No.	0.8
X- Component of Flow Direction (at 40)	0.997564
Y- Component of Flow Direction (at 40)	0.069756
Temperature	300 K
Operating Pressure	101325 Pascal
Turbulence	
Specification Method	Turbulent- Viscosity Ratio
Turbulent- Viscosity Ratio	10
SOLUTION METHODS	
Pressure-Velocity Coupling	
Scheme	Coupled
Spatial Discretization	
Gradient	Least Square Cell Based
Pressure	Standard
Density	Second order upwind
Momentum	Second order upwind
Modified Turbulent Viscosity	Second order upwind
Solution Controls- Pseudo Transient Explicit Relaxation Factors	
Pressure	0.5
Momentum	0.5
Density	0.5
Body Forces	1
Modified Turbulent Viscosity	0.5
Turbulent Viscosity	1

The simulation is performed thrice for three different angles of attack, thereby changing the boundary conditions accordingly. In the first case i.e. angle of attack (α)=4^0, the x-component of flow velocity is equal to thecos 4^0 = 0.997564 and y- component of flow velocity is equal tisin 4^0 = 0.069756.
Similarly for other two cases i.e., α= 5^0 & α = 6^0 the x- component and y- Component are changed accordingly.

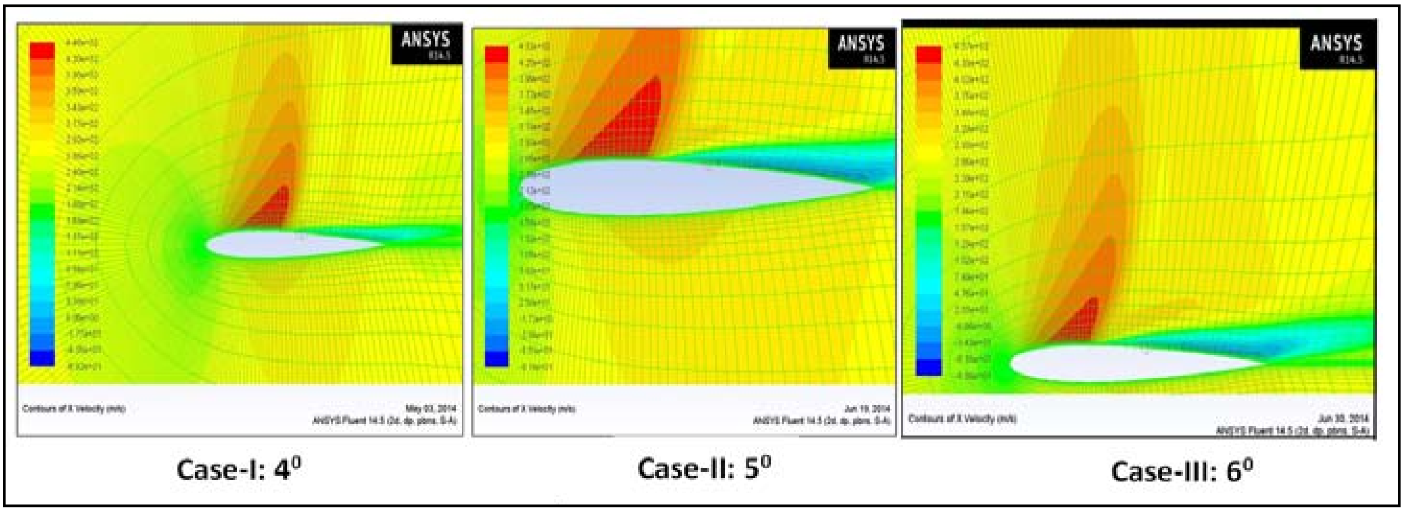
V. Results and Discussions

A. Contours of Static Pressure



Case-I : for 4^0 angle of attack, the maximum and minimum static pressure (Pascal) is of the order of 9.60e+04 and -5.77e+04 respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum static pressure (Pascal) is of the order of 9.95e+04 and -6.15e+04 respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum static pressure (Pascal) is of the order of 5.40e+04 and -6.44e+04 respectively.

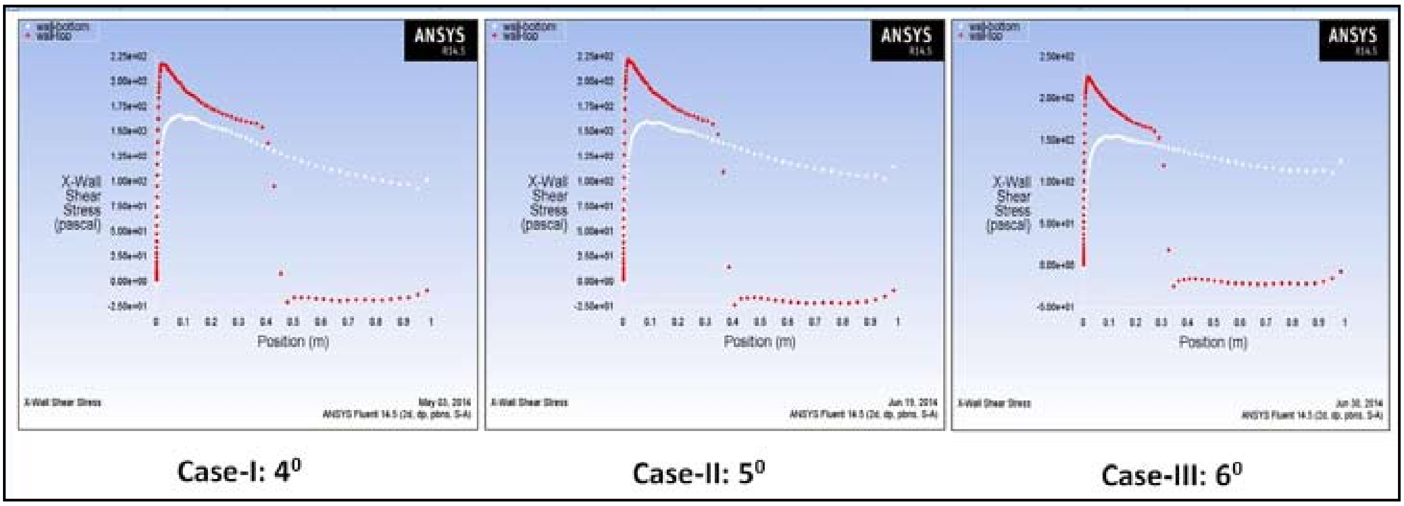
B. Contours of X- Velocity



Case-I : for 4^0 angle of attack, the maximum and minimum X-velocity(m/s) is of the order of 4.46e+02 and -6.92e+01 respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum X-velocity(m/s)is of the order of 4.52e+02 and -8.18e+04 respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum X-velocity(m/s) is of the order of 4.57e+04 and -8.89e+01 respectively.

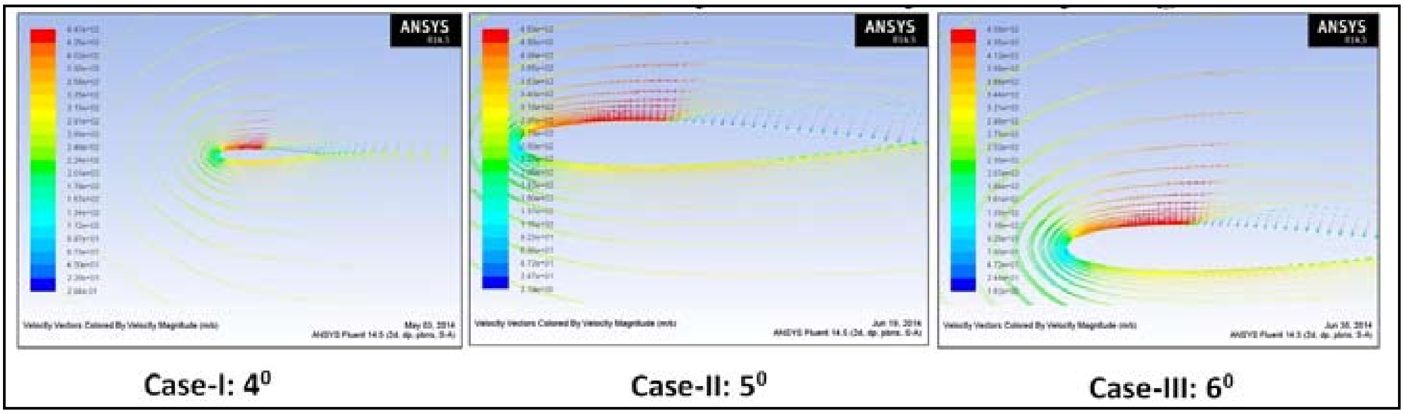
 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

C. Plot of X- wall Shear Stress



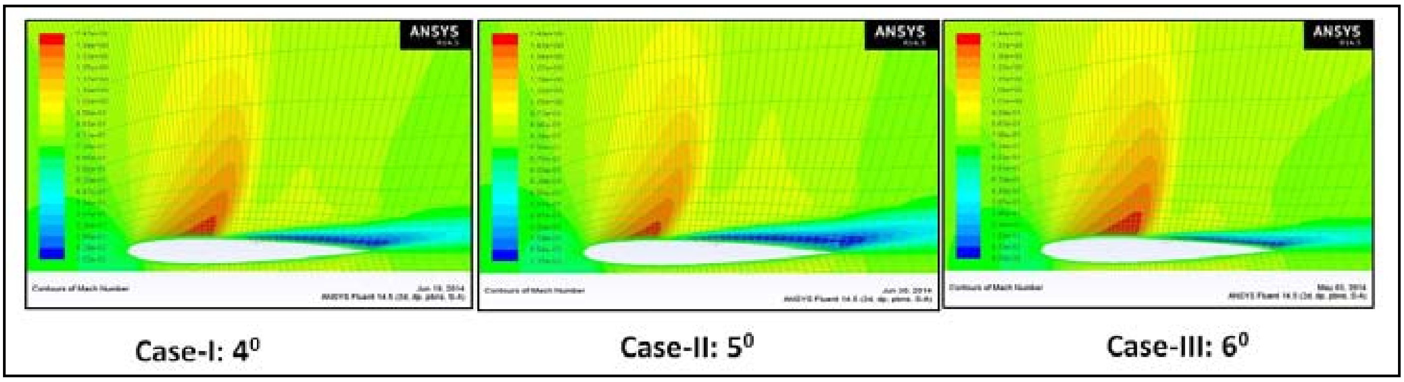
Case-I : for 4^0 angle of attack, the maximum and minimum X-Wall Shear Stress (Pascal) is of the order of 2.25e+02 and -2.50e+01 respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum X-Wall Shear Stress (Pascal) is of the order of 2.25e+02 and -2.50e+01respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum X-Wall Shear Stress (Pascal) is of the order of 2.50e+02 and -5.00e+01 respectively.

D. Contours of Colored Velocity Vectors by Velocity Magnitude



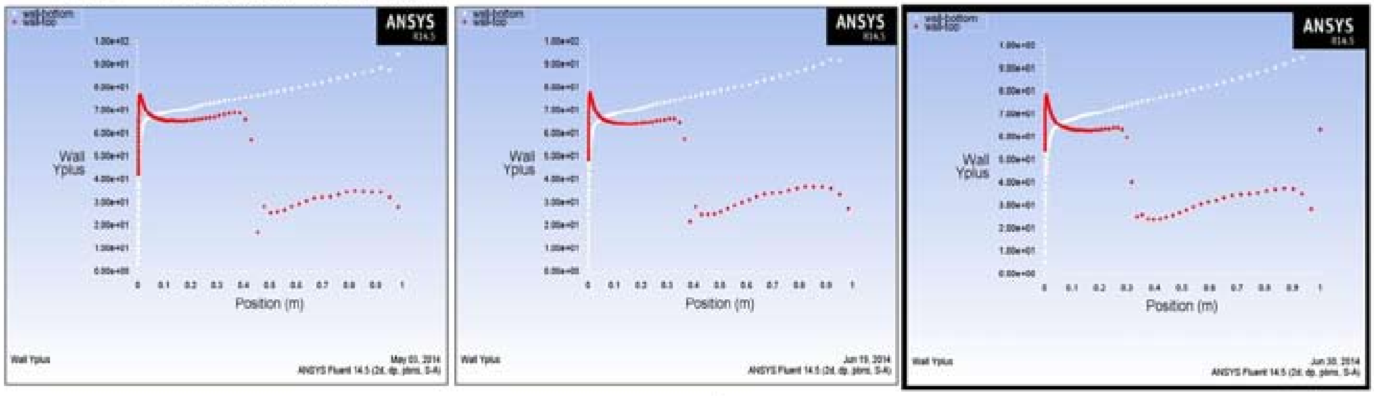
Case-I : for 4^0 angle of attack, the maximum and minimum Velocity magnitude is of the order of 4.47e+02 and 2.94e-01 respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum Velocity magnitude is of the order of 4.53e+02 and 2.19e+00 respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum Velocity magnitude is of the order of 4.58e+02 and 1.62e+00 respectively.

E. Contours of Mach Number



Case-I : for 4^0 angle of attack, the maximum and minimum Mach Number is of the order of 1.44e+00 and 9.85e-03 respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum Mach Number is of the order of 1.47e+00 and 1.02e-02 respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum Mach Number is of the order of 1.49e+00 and 1.15e-02 respectively.

F. Plot of Y Plus



Case-I: 4^0 Case-II: 5^0 Case-III: 6^0

Case-I : for 4^0 angle of attack, the maximum and minimum Wall Y Plus distance is of the order of 1.00e+02 at trailing edge and 0.00e+00 at leading edge respectively.
Case-II : for 5^0 angle of attack, the maximum and minimum Wall Y Plus distance is of the order of 1.00e+02 at trailing edge and 0.00e+00 at leading edge respectively.
Case-III : for 6^0 angle of attack, the maximum and minimum Wall Y Plus distance is of the order of 1.00e+02 at trailing edge and 0.00e+00 at leading edge respectively.

VI. Conclusion

From above it is concluded that with the increase in angle of attack the lift increase, but it also increases drag so that we have to provide more thrust with the aircraft engines. The 4^0 angle of attack has been found suitable as the pressure, Velocity, Mach Numberencountered are within safe limits for an subsonic flow. The 5^0 angle of attack is also an optimum except it increases the Drag component of force which thereby increases engine power which is not economical for subsonic flows. The 6^0 angle of attack has not yielded the optimum results for the subsonic flow as the pressure zones formed are not over the airfoil which causes turbulence and unsatisfactorily flight. Thereby concluding that 4^0 of angle o optimum for NACA 7420 for Transonic Compressible flow as per the Spalart- Allmaras Turbulence Model

Refrences

[1] [Online] Available: http://www.en.wikipedia.org/wiki/National_Advisory_Committee_for_Aeronautics
[2] [Online] Available: http://en.wikipedia.org/wiki/NACA_airfoil
[3] Wing Design by Mohammad Sadraey, Daniel Webster College
[4] Bradshaw, P., Ferris.D.H, Atwell, N.P.,"Calculation of boundary- layer development using the turbulent kinetic energy equation", Journal of Fluid Mechanics V28-3, pp. 593-616, 1967.
[5] Metais, O., Ferziger, J.,"New Tools in Turbulence Modelling", Vol. 1, Springer, 1996.
[6] Jiri Blazek,"Computational Fluid Dynamics: Principles and Applications".
[7] Gatski T.B., Hussaini M.Y., Lumley, J.L.,"Simulation and Modelling of Turbulent Flows, Vol. 1, Oxford Press, 1996.

Mr. Ovais Gulzar received his B.Tech. degree in Mechanical Engineering from University of Kashmir, India in 2011 and M.Tech. degree in Thermal System & Design from Rajiv Gandhi Technological University Madhya Pradesh, India. He was a lecturer with University of Kashmir (North Campus) 2011.He also worked with Mahindra Powerol as Quality Control Manager. His research interests include CFD, Thermal systems, Solar Energy Development, Material Handling And Allied Activities, Pneumatic Systems, Mechanical Processes And Equipment Working, Material And Manpower Management, Industrial Safety, etc. He has published numerous technical research papers in various international journals & conferences.