International Journal of Engineering Research and General Science Volume 3, Issue 2, March-April, 2015
ISSN 2091-2730

Design of NACA 2412 and its Analysis at Different Angle of Attacks, Reynolds Numbers, and a wind tunnel test

Er. Shivam Saxena[1], Mr. Rahul Kumar[2]

[1]Department of Aeronautical Engineering, Babu Banarsi Das National Institute of Technology and Management, Lucknow, India, Contact No. +91- 8573951317, Email: shivamwork@gmail.com

[2]Department of Mechanical Engineering, Sri Satya Sai Institute of Science & Technology, Sehore, India, Contact no. +91-9680541033, Email: rahul.aero001@gmail.com

Abstract—The purpose of this project is to analyze airfoil at different Reynolds numbers using Gambit and Fluent, and wind tunnel experiment. One model is prepared for wind tunnel analysis and 2D and 3D models are created and drawn in solid work and they were meshed in Gambit using geometry data gathered by Airfoil database available on internet. These models were read into Fluent where flow boundary conditions were applied and the discretized Navier-Stokes equations were solved numerically. Tests also run in wind tunnel to find out the general aerodynamic characteristics of the Airfoil (NACA 2412).

Keywords— airfoil, NACA 2412, analysis of airfoil, design of airfoil, 3D analysis of airfoil, four digit airfoil, angle of attacks

INTRODUCTION

In this project, computational Fluid Mechanist analysis of airfoil has been done to understand the aerodynamic airfoil concepts

Airfoil taken is NACA 2412, this is cambered airfoil belongs to the four digit series of the NACA airfoil classification, the general characteristics of this airfoil are:-

NACA FOUR DIGIT SERIES

The NACA four-digit wing sections define the profile by:

1. First digit describing maximum camber as percentage of the chord.
2. Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord.
3. Last two digits describing maximum thickness of the airfoil as percent of the chord.

NACA 2412 is the airfoil of NACA 4 digit series. From its designation we get the NACA 2412 airfoil has a maximum camber of 2% located 40% (0.4 chords) from the leading edge with a maximum thickness of 12% of the chord. Four-digit series airfoils by default have maximum thickness at 30% of the chord (0.3 chords) from the leading edge. NACA 2412 is slow speed airfoil; this airfoil is used in single engine Cessna 152, 172 and 182 airplanes

SOME PARAMETERS

Reynolds number

The Reynolds number relates the density, viscosity, speed and size of typical flow in a dimensionless equation which is involve in many fluid dynamics problems. This dimensionless numbers or combination appears in many cases related to the fact that laminar flow can be seen or turbulent. From a mathematical point of view the Reynolds number of a problem or situation is defined by the following equation.[3]

$$Re = (\rho \times V \times L)/\mu$$

Table No.1/ Aerodynamic forces

For lift coefficient	For Drag Coefficient	For moment coefficient
$C_L = 2 f(Re, M, \alpha)$	$C_D = 2 f(Re, M, \alpha)$	$C_M = 2 f(Re, M, \alpha)$
$\mathbf{L = C_L \tfrac{1}{2} \rho V^2 c}$	$\mathbf{D = C_D \tfrac{1}{2} \rho V^2 c}$	$\mathbf{M = C_M \tfrac{1}{2} \rho V^2 C^2}$

PROCESS OF AIRFOIL DESIGN

Coordinates of NACA 2412 is taken from Javafoil software and its Reynolds no. characteristics are also taken [11]

Table No. 2/ **Coordinates of NACA 2412**

Upper surface			**lower surface**		
1	**0**	**0**	**0**	**0**	**0**
0.989259	0.002267	0	0.012606	-0.01662	0
0.957222	0.008773	0	0.04613	-0.02921	0
0.905298	0.018704	0	0.098928	-0.03756	0
0.835653	0.030889	0	0.168624	-0.04171	0
0.751234	0.043993	0	0.25226	-0.0421	0
0.655658	0.056642	0	0.346406	-0.03963	0
0.553071	0.067493	0	0.447493	-0.03544	0
0.447978	0.075277	0	0.551457	-0.02982	0
0.344577	0.078639	0	0.653359	-0.02351	0
0.24774	0.076012	0	0.748766	-0.01728	0
0.162245	0.067489	0	0.833478	-0.01161	0
0.092055	0.054036	0	0.903719	-0.00681	0
0.040324	0.037207	0	0.956323	-0.00313	0
0.009246	0.01873	0	0.988889	-0.0008	0
0	0	0	1	0	0

NACA 2412 airfoil is analyzed on JAVA FOIL. JAVAFOIL is the analysis software which gives analysis data of various airfoils its coordinates, parameters for various Reynolds number, coefficient of lift and drag graphs, coefficient of moment and angle of attack graphs etc.

Modeling of airfoil

The airfoil model is easily designed in solid work. In order to do that airfoil coordinates are plotted and the airfoil 3D model is created.

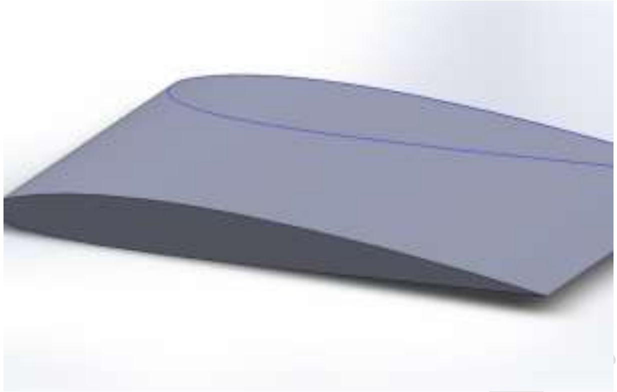


Figure No. 1/ Design of airfoil on solidwork

Gambit is meshing software that is capable of creating meshed geometries that can be read into Fluent and other analysis software. Making a meshed file, it is done in both 2D and 3D these files are imported in fluent.

We have done meshing of Airfoil NACA 2412 and of its domain and then the simulation of flow variables over this control volume is done in case of 2D of Control Line.

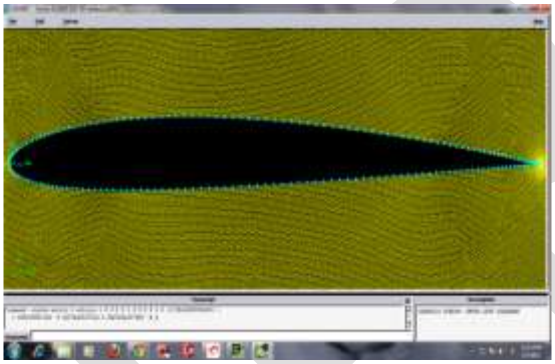


Figure No. 2/ 2D meshing of Airfoil 2412

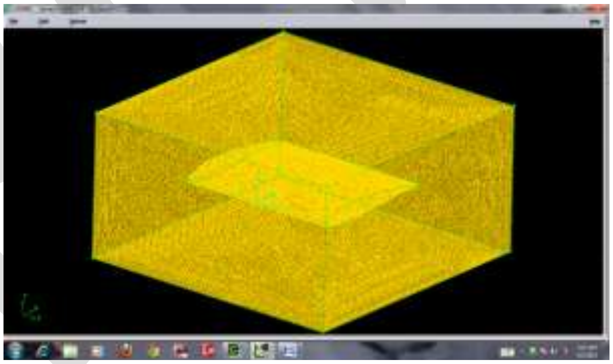


Figure No. 3/ 3D meshing of Airfoil 2412

The desired mesh can now be read into FLUENT which will then run the geometry through the numerical analysis. Different angles of attack will be analyzed in FLUENT 6.3.26. Airfoil and angle of attacks 4, 8, and 12 degrees are analyzed. Fluent gives results.

2D ANALYSIS DATA

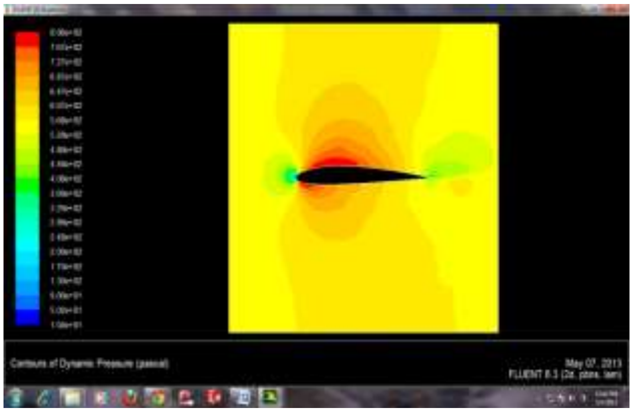


Figure No. 5/Contour of dynamic pressure

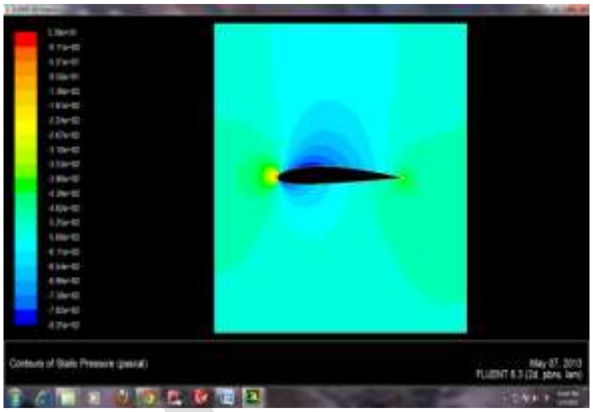


Figure No. 6/ Contour of static pressure

Figure No. 7/ Variation of static pressure

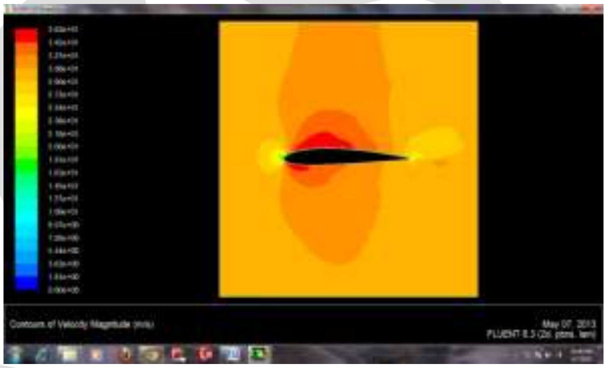


Figure No. 8/ Contours of velocity magnitudes

Figure No. 9/ Variation of Dynamic pressure

Figure No. 10/ Variation of Total pressure

3D ANALYSIS RESULTS

Figure No. 11/ Contour of total pressure

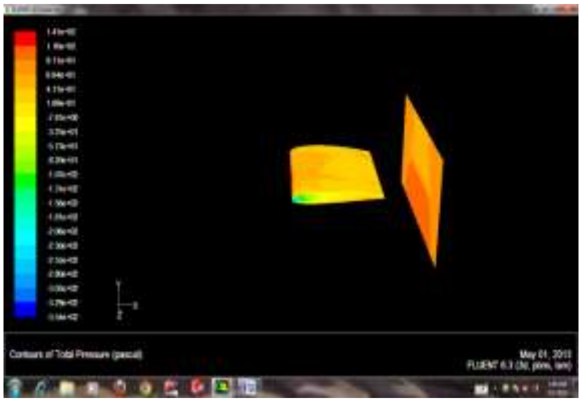


Figure No. 12/ Contour of static pressure

Figure No. 13/ Contour of Total Pressure

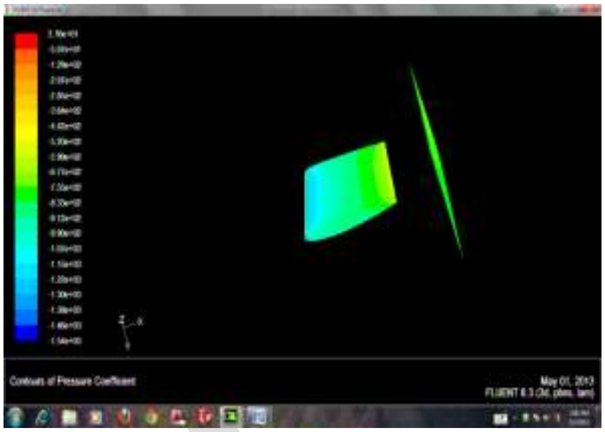


Figure No. 14/ Contour of Pressure Coefficient

Results at different angle of attacks and at different Reynolds numbers For this three Reynolds numbers are chosen 60000, 100000, and 140000 with four different angle of attacks 0, 4, 8, and 12 degrees. (Table No. 4, 5, & 6)

Table No.3/Velocity characteristics

α	Cl	Cd	Cm 0.25	Cp*	M cr.
[°]	[-]	[-]	[-]	[-]	[-]
0	0.261	0.01197	-0.051	-0.572	0.77
4	0.733	0.01483	-0.055	-1.458	0.603
8	1.139	0.02418	-0.059	-3.935	0.418
12	1.144	0.09473	-0.029	-7.403	0.318

Table No. 4/ **Coefficient of lift, drag and moments at different angles of attack, at Reynolds number 60000.**

A	Cl	Cd	Cm 0.25
[°]	[-]	[-]	[-]
0	0.261	0.01532	-0.05
4	0.73	0.01841	-0.055
8	1.128	0.02794	-0.059
12	1.142	0.10236	-0.027

Table No. 5/ **Coefficient of lift, drag and moment at different angles of attack, at Reynolds number 140000.**

A	Cl	Cd	Cm 0.25
[°]	[-]	[-]	[-]
0	0.261	0.01126	-0.051
4	0.734	0.0131	-0.055
8	1.143	0.02226	-0.06
12	1.146	0.0905	-0.031

Table No. 6/ **Coefficient of lift, drag, pressure and moments at different angles of attack, at Reynolds number 100000.**

α	Cl	Cd	Cm 0.25
[°]	[-]	[-]	[-]
0	0.261	0.01197	-0.051
4	0.733	0.01483	-0.055
8	1.139	0.02418	-0.059
12	1.144	0.09473	-0.029

After a century of theoretical research on the subject of airfoil and wing theory, the final word on the performance of an airfoil must still come from wind tunnel testing. The reason for this state of affairs is that the flow field about a wing is extremely complicated. The simplifying assumptions that are frequently introduced in order to treat the problem theoretically are much too severe to fail to influence the final results. Many of these assumptions ignore the effects of viscosity, nonlinearities in the equations of motion, three-dimensional effects, non steady flow, free stream turbulence, and wing surface roughness. Nevertheless the theoretical prediction of lift produced by a wing has been reasonably successful (not quite so true for drag) and serves as an effective basis with which to study the experimental results.

RESULTS OF THE 3D ANALYSIS DATA

1) Static pressure varies form -4.97e+02 to -1.03e+03 Pascal from trailing to leading edge.
2) Dynamic pressure at upper most part and lower most part is of order 8.06e + 02 Pascal while at leading edge it is of order 1.70e+02 and at trailing edge it is of order 4.53e+02.
3) Total pressure is maximum at the leading edge 1.41e+02 Pascal and decreases along the length.
4) Coefficient of pressure is maximum at leading edge and trailing edge while lower at thick surfaces.
5) Absolute pressure is also higher at leading and trailing edge while it has smaller values at thick surfaces of order 1.01e + 05 Pascal.
6) Velocity magnitude is seems to be constant over the whole airfoil surface 1.81e m/s.
7) X-Velocity is constant.
8) Y-Velocity is nearly constant -4.84e+01 m/s.
9) Z-Velocity is also nearly constant with magnitude 6.05e+02 m/s.

10) Relative tangential velocity magnitude is lower at upper surface with magnitude -6.37e+00 and at lower surface it is changing from tip to end from 9.33e to 3.05e m/s.
11) Vorticity is irregularly changing at the upper surface of the airfoil while at tip and ends it is of magnitude 2.305e+02 1/s.
12) Molecular viscosity is changing irregularly different at different locations about 1.79e+05 kg-m/s.
13) Wall shear stress is maximum at few locations of the most thicken areas of the airfoil with magnitude 1.7e-01 Pascal.

RESULTS OF THE 2D ANALYSIS DATA

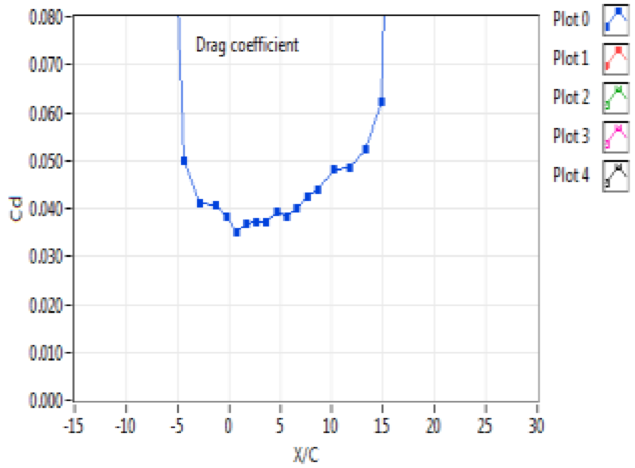
- Static pressure is constant at the thick surfaces of the airfoil.
- Dynamic pressure is constant at the lower ends of the airfoil.
- Density is seems to be constant with magnitude 1.23 kg-m/s.
- Velocity magnitude is also constant whether it is in x, y, or z direction

WIND TUNNEL DATA

1. Coefficient Lift coefficient is maximum at 15 X/C with magnitude 1.65. it is increasing from -15 to 15 X/C then sudden drop in Cl and from 17.5 it is constant up to 30 X/C. (Figure No. 16)

2. Drag coefficient is minimum at 0 with value0.034 and making a irregular parabolic curve. (Figure No. 15)

3. This drag polar is a irregular parabola C_d has its minimum value at 0.034 at 0.75 C_L, and C_L has its maximum value 1.68 at 0.05 to 0.055 of the C_d. (Figure No. 17)



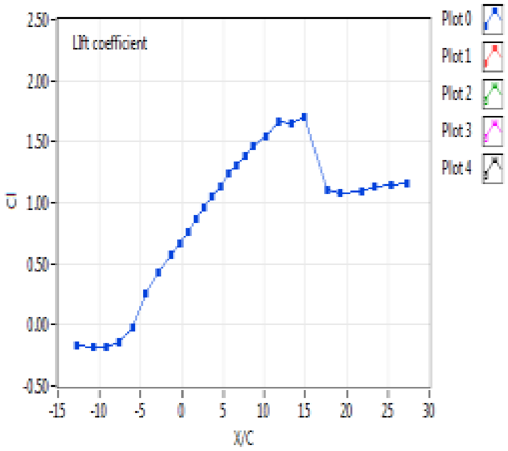


Figure No. 15/ C_d vs X/C **Figure No. 16/ C_L vs X/C**

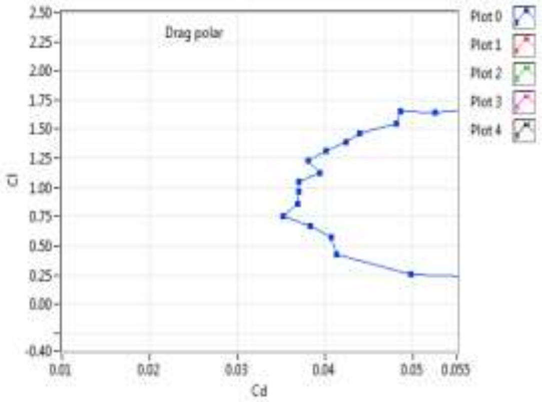


Figure No. 17/ C_L Vs C_D

REFERENCES:

[1] *"Fundamentals of Aerodynamics"* J D Anderson published by Mc Graw Hill publication.
[2] "*Aircraft Design-A Conceptual Approach"* by Daniel P. Raymer published by AIAA Education Series.
[3] www.wikipedia.com/airfoil
[4] www.wikipedia.com/windtunnel
[5] www.airfoildata.com
[6] *"Aerodynamics for engineering students"* E.L. Houghton by Butterworth Heinemann Publication.
[7] *"Introduction to Aerodynamics of Flight"* Theodore A.Talay NASA History Division.
[8] "*Model Aircraft*" by Martin Simons by Argus books Publications.
[9] "*Theoretical Aerodynamics*" by L.M. Milne Thomson published by Dover Publication.
[10] "Design of subsonic airfoil" springer
[11] Use of Javafoil Software
[12] *www.ae.illinois.edu/m-selig/ads/coord_**database**.html*
[13] ***www.airfoil****tools.com/search/index*
[14] www.aerodesign.de
[15] www.designfoil.com
[16] www.wind.nrel.gov