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OPTIMIZATION OF TUBERCLE WING

Submitted **by**
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INTRODUCTION

Biomimetics:

- The term 'biomimicry' or 'biomimetics' refers to drawing inspiration from the natural world design innovative engineering solutions.
- In Aviation industry the first flying machine heavier than the air from the Wright brothers, in 1903, was inspired by flying pigeons.
- Recently the bio mimics applications widely used in aviation. The new flow control method was discovered from Humpback whale.

Fig 1. Humpback Whale

- Humpback whale performs better maneuverability in both air and water. The special biological modifications in their flippers used to perform better maneuverability.
- The large rounded protuberances present in the leading edge of the flippers that are unique in nature. The combined protuberances are known as 'tubercles'.

ABSTRACT

'Biomimicry' or 'Biomimetics are currently being used in many aviation applications. Under the category of ‘biomimicry’, the tubercles used in aircraft wings for passive flow control devices. The tubercles used in ocean engineering for better hydrodynamic performance. In aviation also tubercles used to reduce wing tip vortex strength, induced drag, boundary layer separation and better aerodynamic performances. But some amount of skin friction drags increased. For the above reasons new type of tubercle leading edge wing model is designed and analyzed. The results are checked and compared to the smooth leading- edge wing. Finally, the wing which have lower drag co-efficient CAD model is developed.

INTRODUCTION

Tubercle wing:

A wing which has sinusoidal leading edge is called tubercle wing.

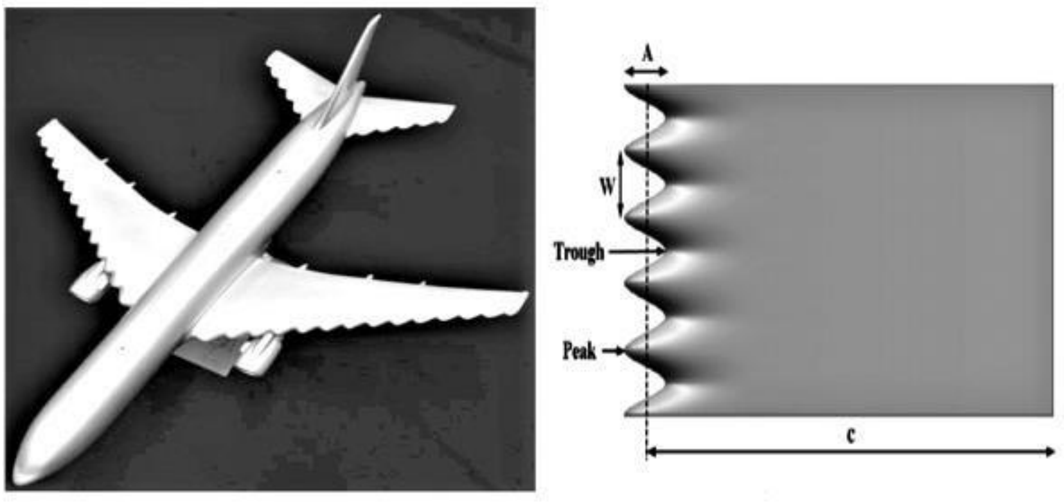


Fig 2. Basic Tubercle wing aircraft

Tubercle Mechanisms:

It is known that tubercles produce pairs of streamwise counterrotating vortices, but the way in which these vortices interact with the flow over a foil or wing is unknown. There have been many attempts to explain how tubercles affect the flow over a foil or wing; however, none has been conclusive. It should be pointed out that by applying the method of images to these vortices, it can be seen that vortices with a common downwash will move down and away from each other. The opposite will occur for vortices with a common upwash. Therefore, the net effect of vortices in the regions of downwash will be greater than the net effect of vortices up washing. This is important, as many theories explaining how tubercles work suggest that the vortices have one effect in the common downwash regions, while having the opposite effect in the common upwash regions.

LITERATURE SURVEY

1. Aerodynamic characteristics and surface flow structures of moderate aspect ratio leading edge tubercle wings

Zhaoyu Wei, J.W.A Toh, I.H Ibrahim, Yanni Zhang.

Aerodynamic characteristics for a series of NACA634-021 wings with leading- edge tubercles were experimentally studied in two low speed close-loop wind tunnels at a Reynolds number of Re = 1.8 × 105, under both finite- and infinite- wing configurations. Fluorescent oil visualization technique was also used to reveal the surface flow patterns for the finite-wings. The results show that the wings under both flow conditions attain quite similar aerodynamic characteristics. Finite-wings attain comparatively lower lift and higher drag at small pitch angles, but lower drag in the post-stall regime. In general, larger tubercle amplitude (A) could lead to more gently stall, while smaller A can enhance the maximum lift and the lift in the post-stall regime. The wing with the smallest Amplitude and wavelength shows the best lift performance, with its maximum lift enhanced and the lift is also improved significantly in the post-stall regime under both infinite and finite-wing configurations.

2. Aerodynamic performance and wake development of airfoils with wavy leading edges

Weijie Chen, Weiyang Qiao, Zuojun Wei c.

The objective of the present study is to investigate the effect of the WLEs on the airfoil aerodynamic performance and wake development. Numerical simulations are carried out to study the flow patterns around the airfoils with various angles of attack at a Reynolds number of 400 000. Five wavy airfoils with different amplitudes and wavelengths and one baseline airfoil with a straight leading edge are simulated.

The aerodynamic performance of the wavy airfoil is sensitive to both the amplitude and wavelength. The WLE with the largest amplitude and smallest wavelength generally result in the worst aerodynamic performance in terms of the above parameters. The maximum lift coefficient is reduced from 1.29 to 0.79 and the maximum lift-to-drag ratio is reduced from 37.4 to 24.4 by the wavy A10W10 airfoil with the largest amplitude and smallest wavelength.

3. Characterization of Tubercle Effects on Finite Span Wings Stewart J Ried, Ruban E Perez, Asad Asghar.

Experimental wind tunnel testing was used to compare the performance differences between straight leading-edge (SLE) rectangular wings and tubercle rectangular wings. In total, nine tubercle rectangular wing designs were tested, each compared against an equal span SLE wing baseline.

In this study rectangular finite wings with a A3λ11 tubercle shape were tested at 8.0×104,1.20 × 105 and 2.00 × 105 Reynolds numbers to quantify both tubercle wing end shape effect as well as aspect ratio effects. The apparatus, acquisition system and wing performance was validated against published straight leading- edge finite wing results. Tubercle wing tests showed that although CL,max is approximately 2% lower for tubercle wings, stall angle is delayed by 3−5° (an improvement of 3%) and lift drop off is smoothened without sharp decrease in lift up to the maximum tested angle of 25 degrees.

4. Effect of surface blowing on aerodynamic characteristics of tubercled straight wing

N. Ganesh, S. Arunvinthan, S. Nataraja Pillai.

In this study, the effect of blowing velocity ratio (R) and blowing location (L) has been studied on a baseline tubercle wing and a modified tubercle wing with blowing. Blowing velocity ratio has been varied with R = 0.5, 1 and 2 for various locations 0.3c–0.8c at various angles of attack ranging from 0° to 45° in increments of 5°.

The optimized blowing location is found as 30% of the chord on the wing. Beyond 0.3c, the influence of blowing is less significant irrespective of various blowing velocity ratios.

5. Formation of Vortices on A Tubercled Wing, And Their Effects on Drag

Michael D. Bolzon, Richard M Kelso, Maziar Arjomand.

Wake surveys of 2 swept NACA 0021 wings were conducted at angles of attack of 0°, 3°, 6°, 9°, and 12°. One wing had a smooth leading edge and the other had a tubercle leading edge. The smooth wing produced relatively uniform profile and induced drag coefficient distributions along its entire span with peaks at the wingtip. Conversely, tubercles modulated the profile and induced drag coefficients along the entire span, with local maxima and minima in the profile drag coefficients forming in the troughs and over the peaks, respectively.

Typically, tubercles produced local maxima and minima in the induced drag coefficients over the peaks and in the troughs, respectively. The majority of change in either the profile or induced drag coefficients occurred over the wingspan, but small changes were also observed in the wingtip region. tubercles did not significantly affect the induced drag coefficient.

6. Influence of Leading-Edge Tubercles on Aerodynamic Characteristics of a High Aspect Ratio UAV

S. Sudhakar, N. Karthikeyan, L. Venkatakrishnan.

An experimental investigation was carried out to study the aerodynamic performance of a typical UAV whose wings were modified to incorporate tubercles on the leading edge. The aerodynamic characteristics of three configurations: a baseline (without leading edge tubercles), one with tubercles of constant wavelength and amplitude along the span (Case I) and the third with tubercles of varying amplitude and wavelength along the span (Case II).

The surface flow topology from the oil flow visualizations shows attached flow on the modified wings even beyond the stall angle of the baseline, which correlates well with the improved aerodynamics characteristics seen from force measurement. Among the two modified wing configurations.

The wing having tubercles with varying amplitude and wavelength along the span excelled over the constant amplitude and wavelength wing in terms of better aerodynamic characteristics with lesser drag.

MODELLING

CATIA

Computer Aided Design (CAD) is the use of computer software to design a product or an object. Computer Aided Manufacturing (CAM) is the use of computer software and hardware to plan, manage and control the operations of a manufacturing plant.

Computer Aided Engineering is the use of computer software to solve engineering problems and analyze products created using CAD. CATIA is an acronym for Computer Aided Three-Dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products.

CATIA is a multi-platform 3D software suite developed by Dassault Systems, encompassing CAD, CAM as well as CAE. Dassault is a French engineering giant active in the field of aviation, 3D design, 3D digital mock-ups, and product lifecycle management software. CATIA is a solid modelling tool that unites the 3D parametric features with 2D tools and also addresses every design-to-manufacturing process. In addition to creating solid models and assemblies, CATIA also provides generating orthographic, section, auxiliary, isometric or detailed 2D drawing views. It is also possible to generate model dimensions and create reference dimensions in the drawing views.

Smooth leading-edge wing

step 1 - point the y & z coordinates for NACA 634221 airfoil

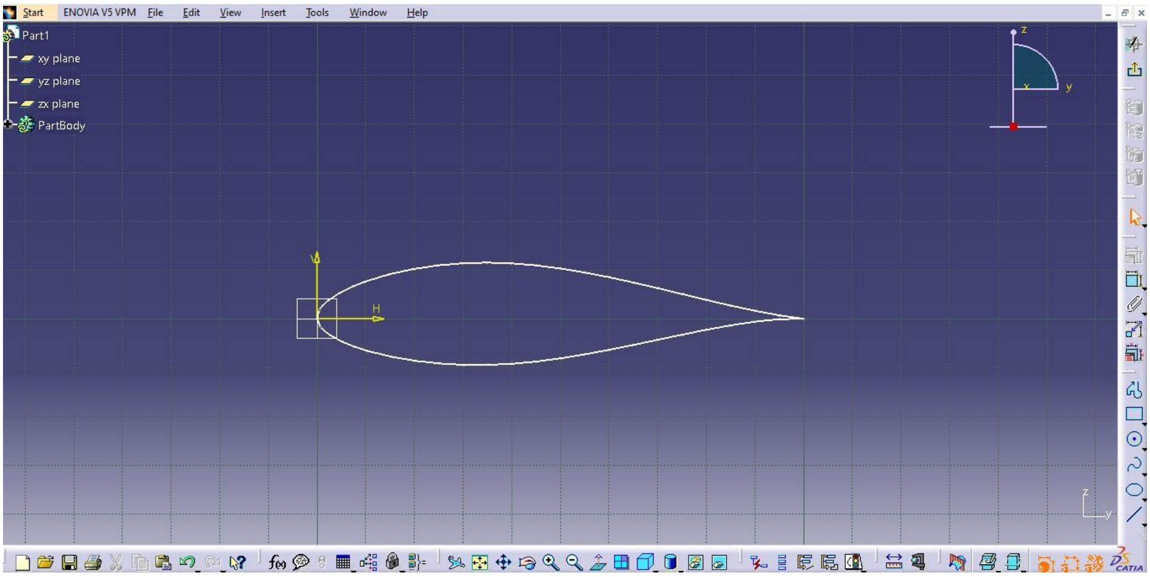
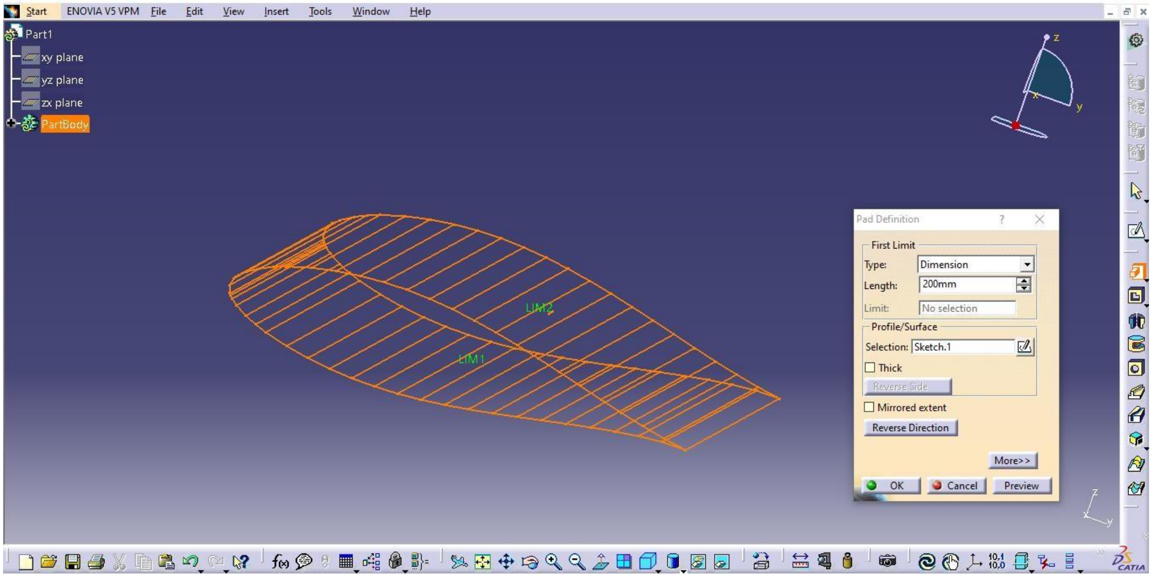


Fig 4

step 2 - Using pad definition with 200mm span length



Pad Definition

First Limit

Type: Dimension

Length: 200mm

Limit: No selection

Profile/Surface

Selection: Sketch.1

☐ Thick

Reverse Side

☐ Mirrored extent

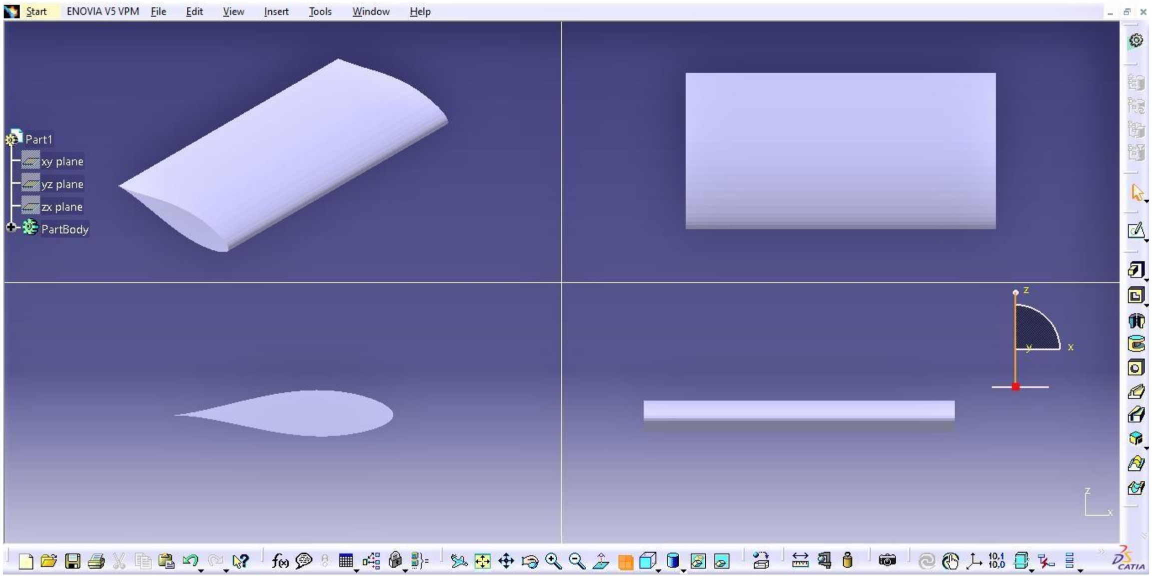
Reverse Direction

More>>

OK Cancel Preview

Fig 5

Three view diagrams of smooth leading-edge wing



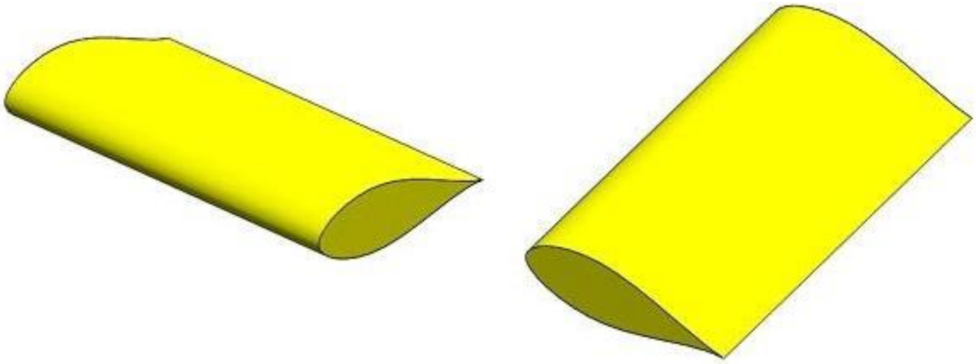


Fig 6. Three view diagrams of smooth leading-edge wing

Tubercle leading edge wing

step 1 - Point the y & z coordinates for NACA 634221 airfoil

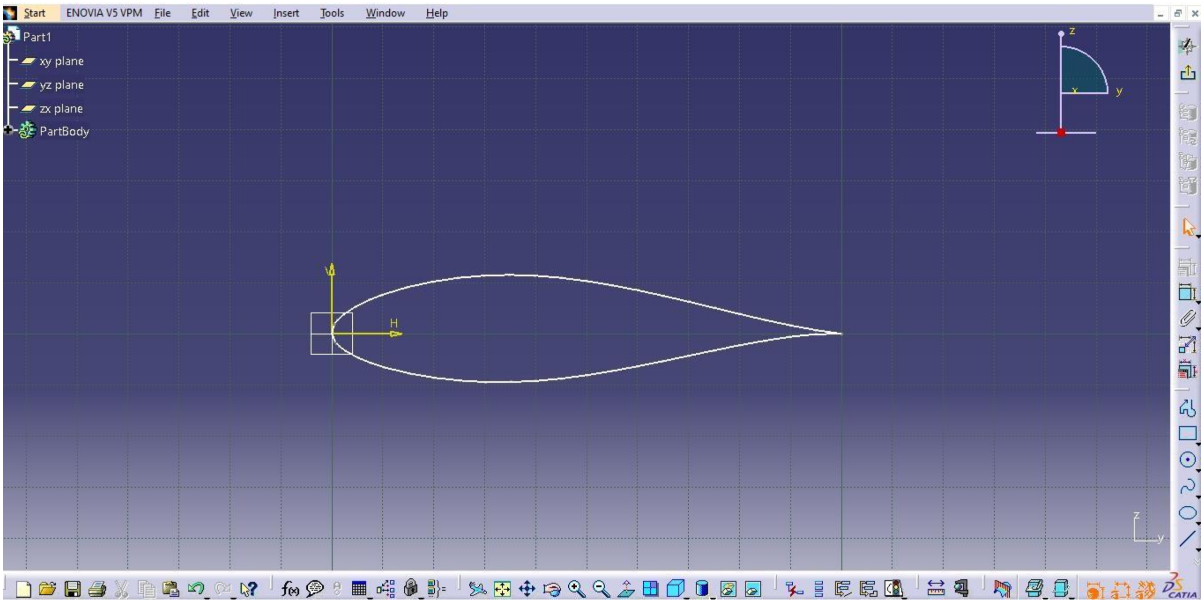


Fig 7

step 2 - Using pad definition with 200mm span length

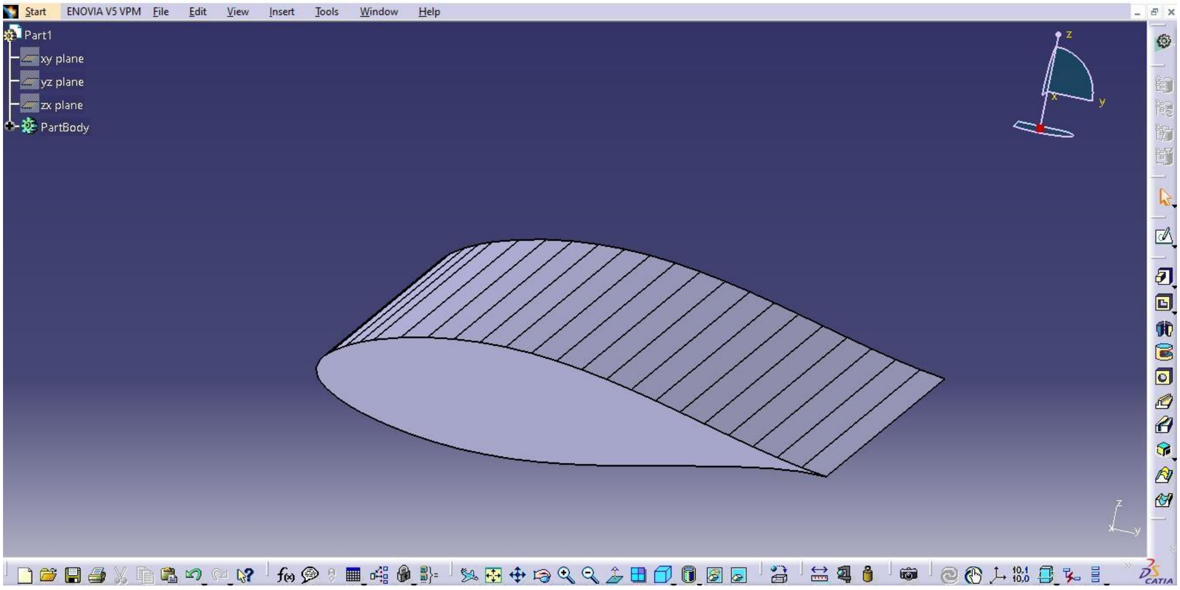
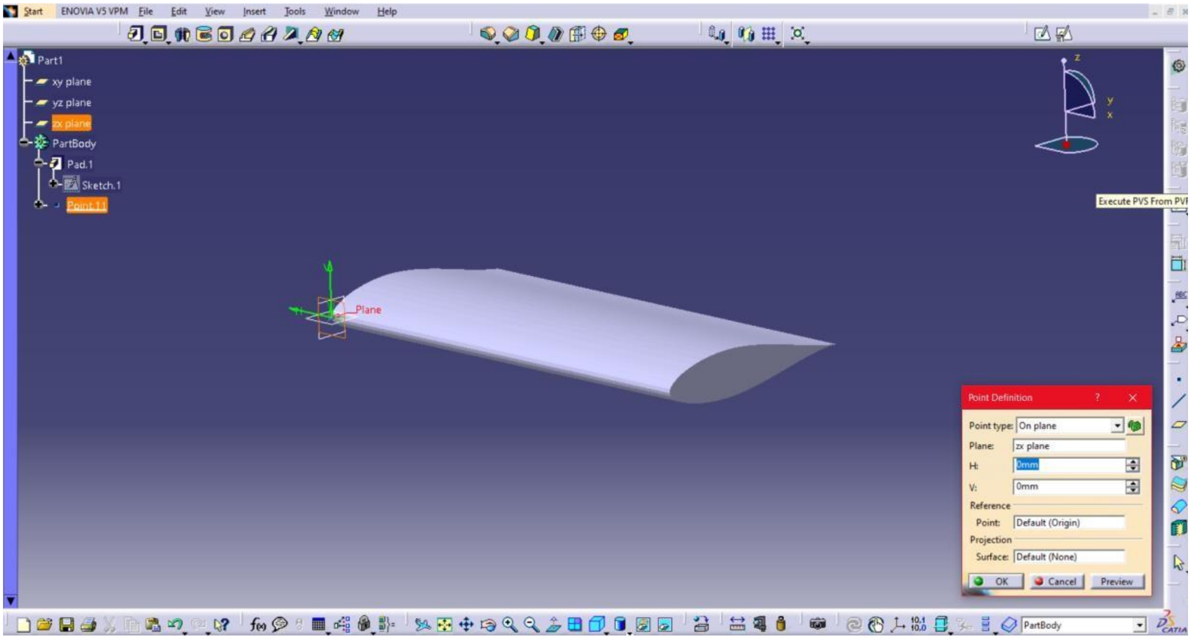


Fig 8

step 3 - Using point definition



Point Definition

Point type: On plane

Plane: zx plane

H: 0mm

V: 0mm

Reference

Point: Default (Origin)

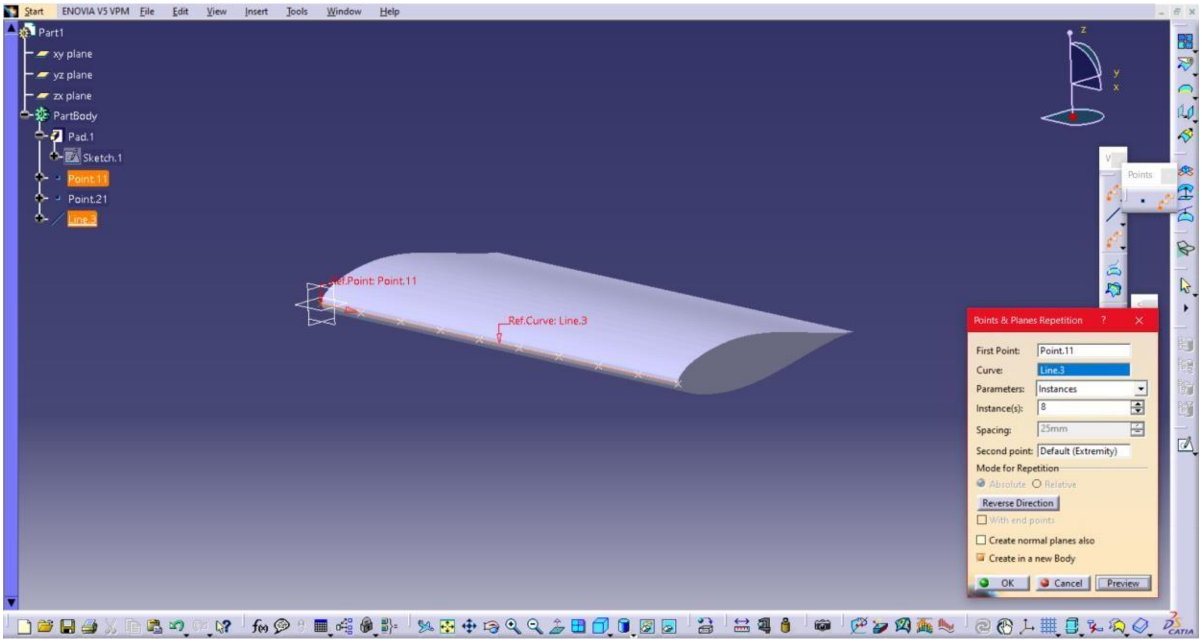
Projection

Surface: Default (None)

OK Cancel Preview

Fig 9

step 4 - Using points and planes repetition with wavelength 25mm



Points & Planes Repetition

First Point: Point.11

Curve: Line.3

Parameters: Instances

Instance(s): 8

Spacing: 25mm

Second point: Default (Extremity)

Mode for Repetition

● Absolute ○ Relative

Reverse Direction

☐ With end points

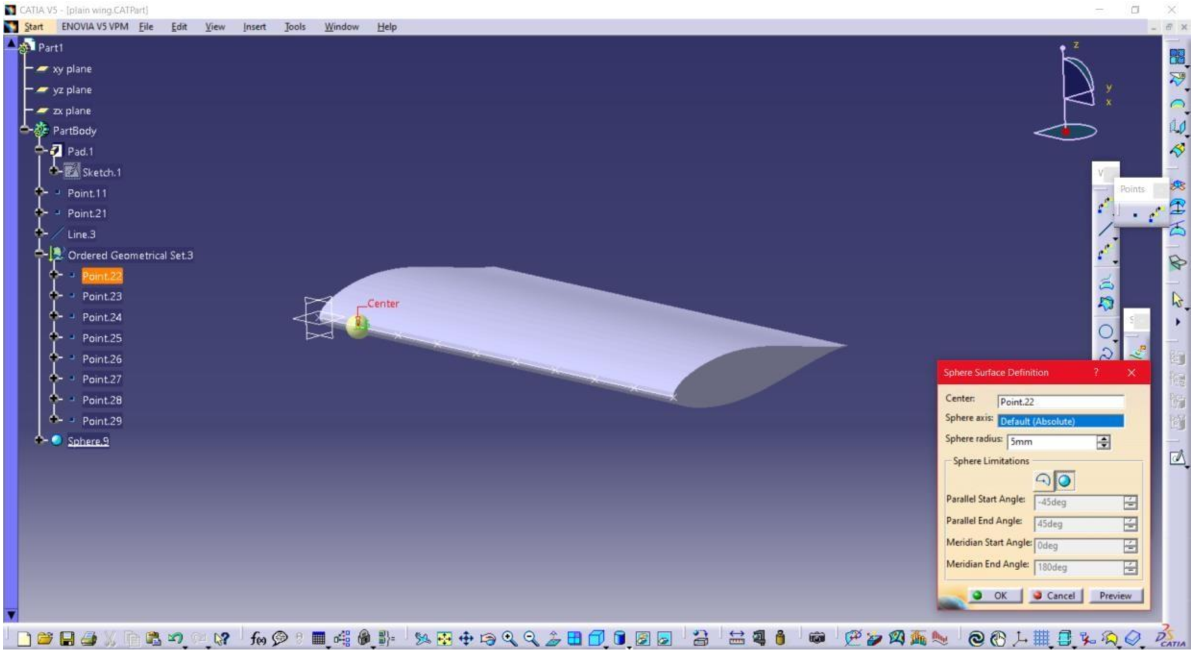
☐ Create normal planes also

☑ Create in a new Body

OK Cancel Preview

Fig 10

step 5 - Using sphere surface definition with amplitude of 5mm



Sphere Surface Definition

Center: Point.22

Sphere axis: Default (Absolute)

Sphere radius: 5mm

Sphere Limitations

Parallel Start Angle: -45deg

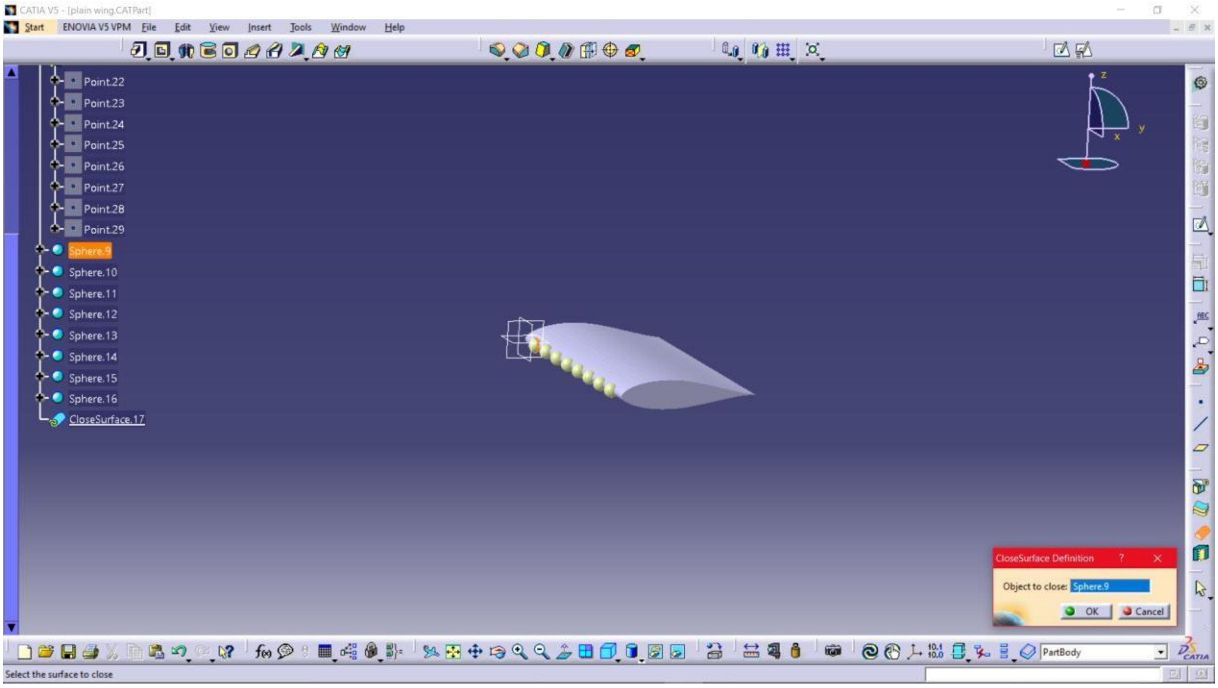
Parallel End Angle: 45deg

Meridian Start Angle: 0deg

Meridian End Angle: 180deg

Fig 11

step 6 - Close surface definition



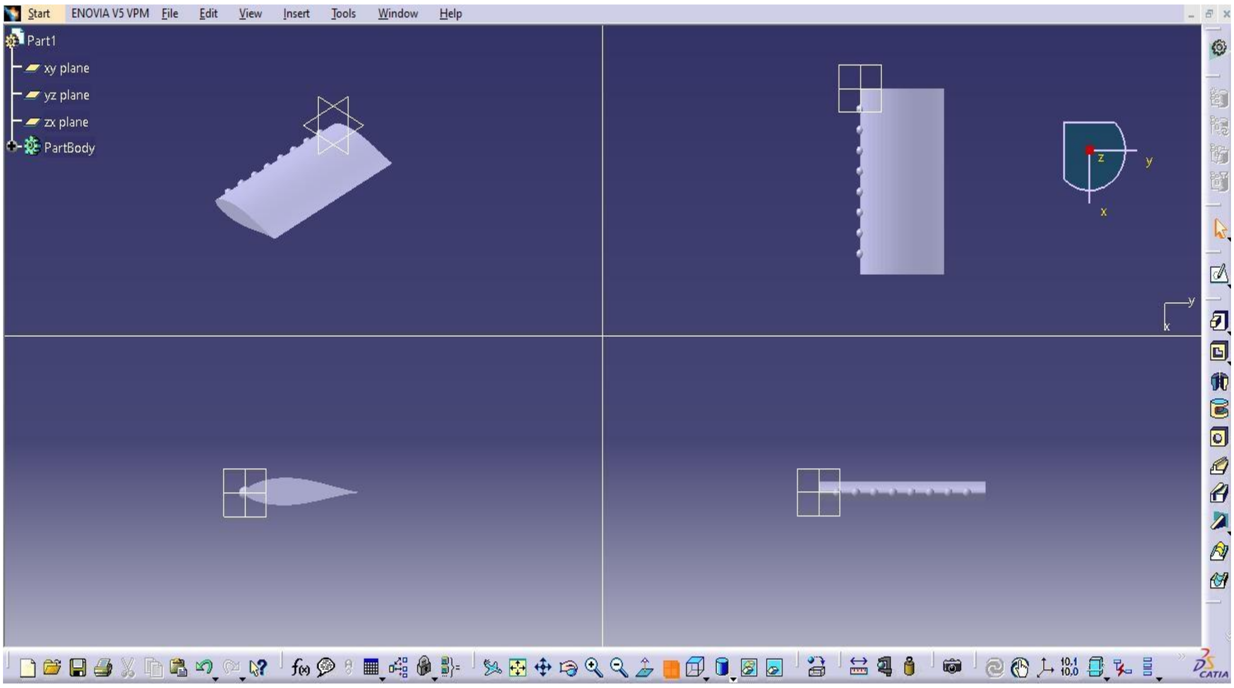
CloseSurface Definition

Object to close: Sphere.9

Select the surface to close

Fig 12

Three view diagram of tubercle leading edge wing



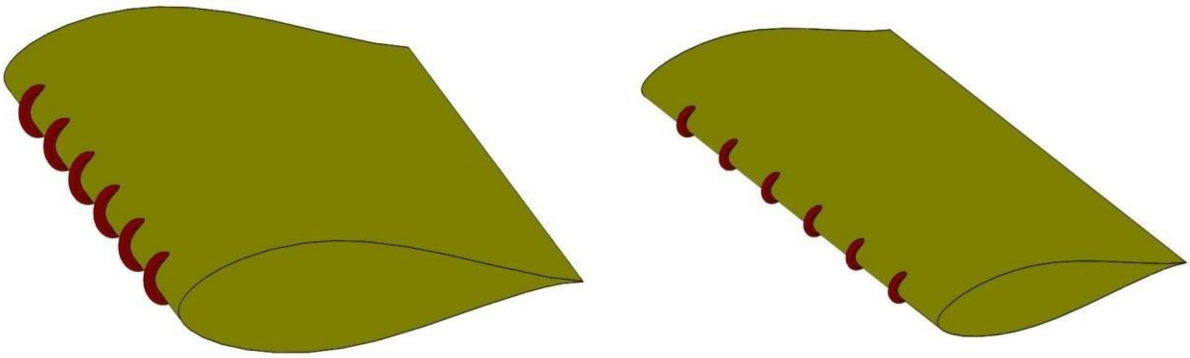


Fig 13. Three view diagram of tubercle leading-edge wing

NUMERICAL SIMULATION

ANSYS

ANSYS is a general-purpose finite element modeling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic structural analysis, heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. In general, a finite element solution may be broken into the following three stages. This is a general guideline that can be used for setting up any finite element analysis.

Preprocessing: Defining the problem

The major steps in preprocessing are given below:

a. Define key points/lines/areas/volumes
b. Define element type and material/geometric properties
c. Mesh lines/areas/volumes as required

The amount of detail required will depend on the dimensionality of the analysis (i.e., 1D, 2D, axi-symmetric, 3D).

Solution: assigning loads, constraints and solving-

here we specify the loads (points or pressure), constraints (translational and rotational) and finally solve the resulting set of equations.

Postprocessing: Further processing and viewing of the results- In this stage one may wish to see:

i) Lists of nodal displacements
ii) Element forces and moments
iii) Deflection plots
iv) contour diagrams.

Boundary conditions

Solver

- Type-Pressure based
- Time-Steady
- Velocity formulation-Absolute

Model

- Viscous model-Realizable k epsilon-standard wall function

Inlet

- Velocity inlet-50m/s
- Turbulent intensity-5%
- Turbulent Viscosity ratio-10

Outlet

- Gauge pressure-0 Pa
- Backflow Turbulent intensity-5%

- Backflow Turbulent Viscosity ratio-10

Wall

- Wall motion-Stationary
- Shear condition-No slip
- Wall roughness-Standard

Solution methods - second order upwind

Solution controls

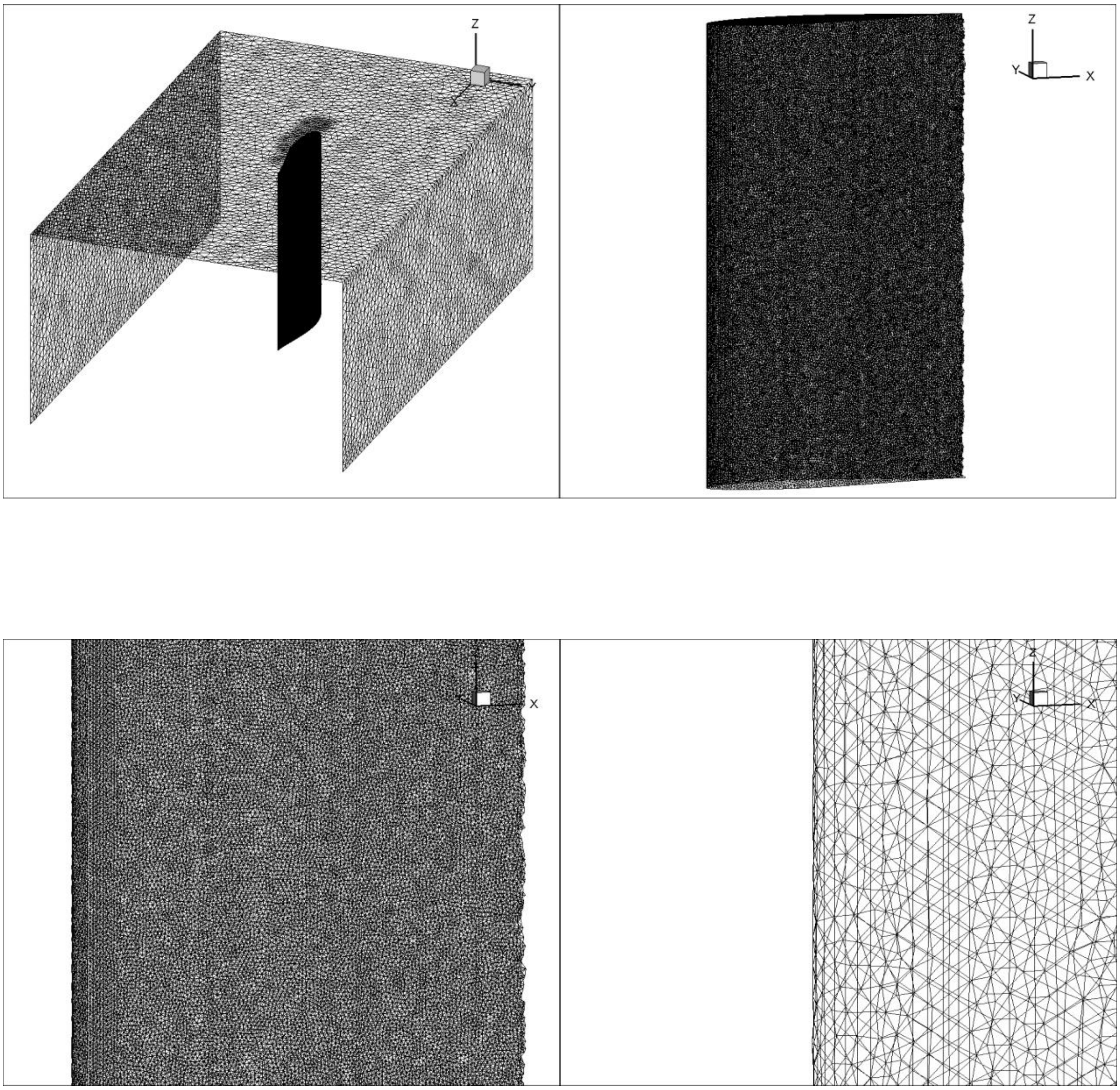
- Flow courant number-200

Residuals

- X velocity-0.001
- Y velocity-0.001
- Z velocity-0.001
- Continuity-0.001
- K-0.001
- epsilon-0.001

Smooth leading-edge wing

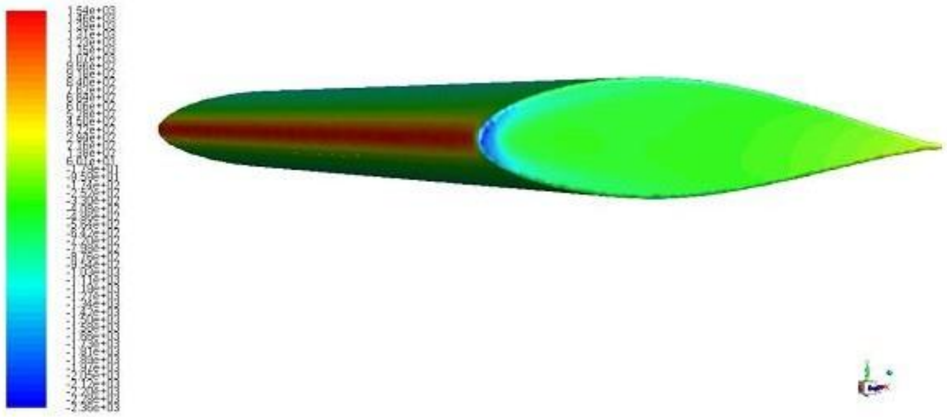
Fig 14. mesh generation



Mesh Information for CFX

Domain	Nodes	Elements
Default Domain	331430	1198914

Fig 15. Static pressure distribution



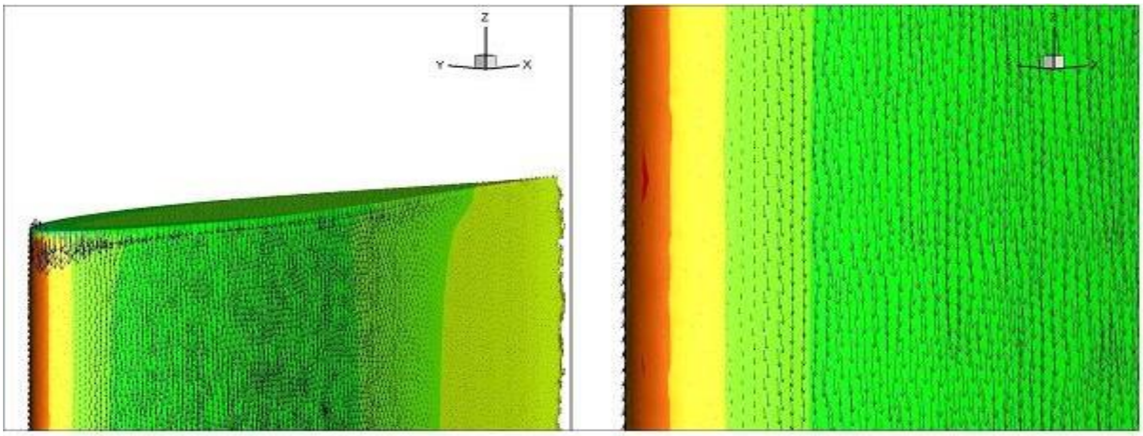


Fig 16. X Velocity at central plane Z=0 location

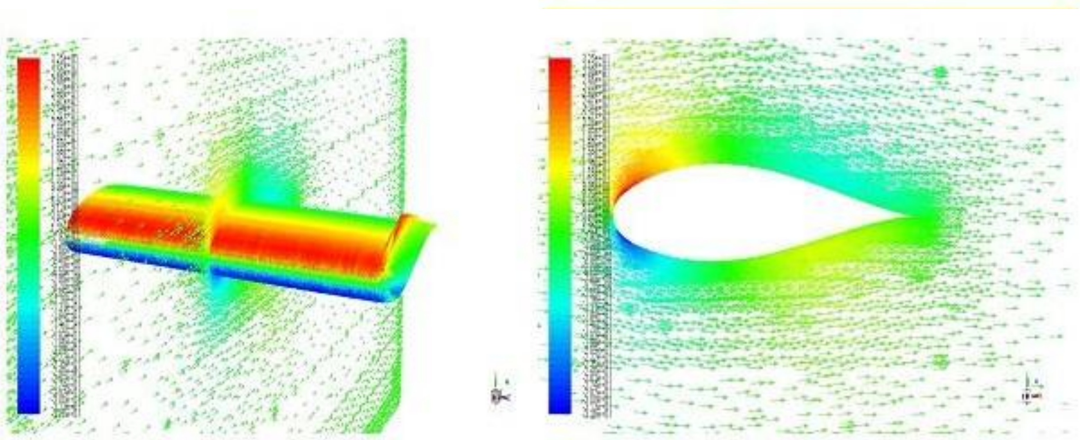
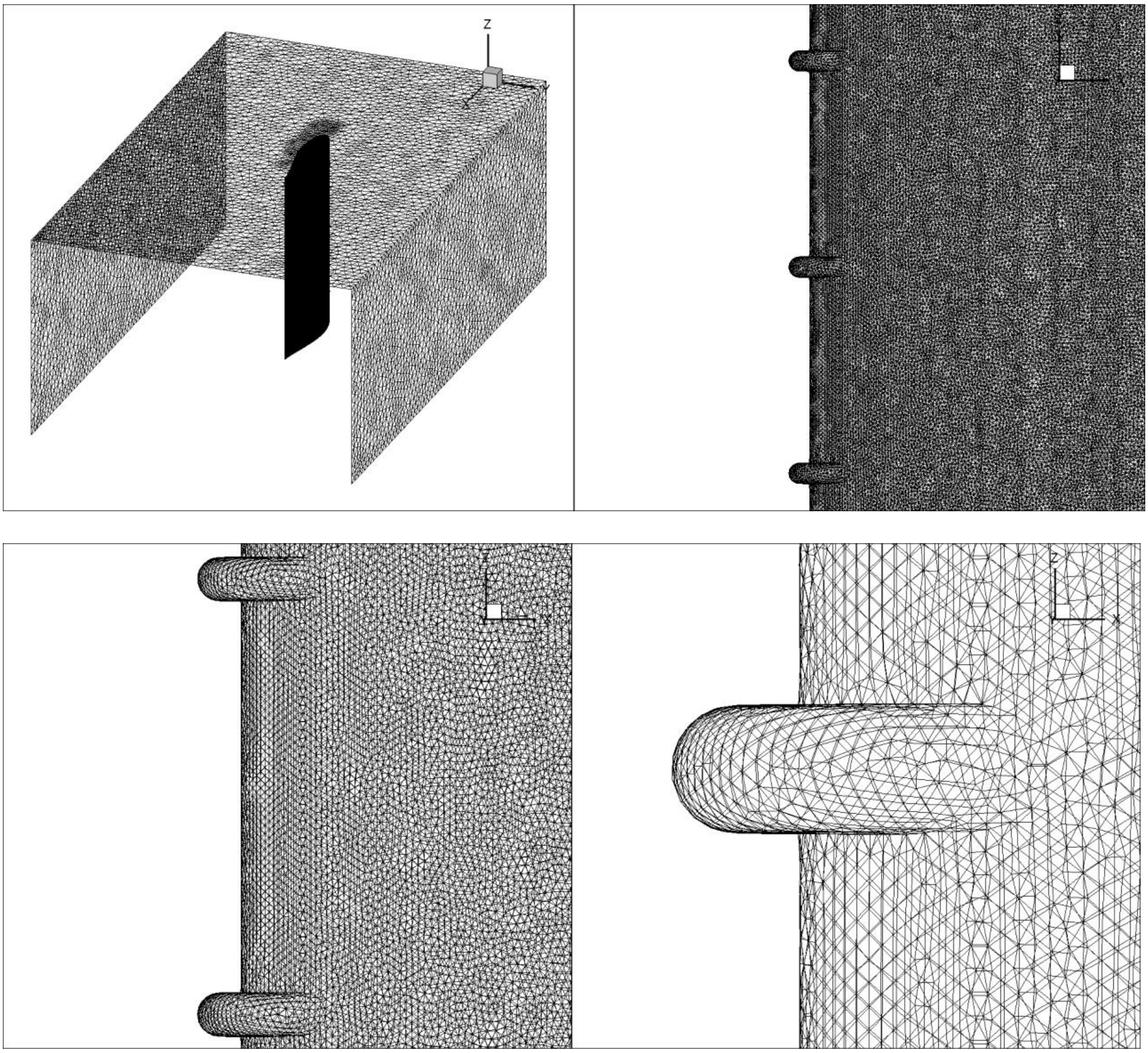


Fig 17. Y Velocity Vectors at central plane Z=0 location

Fig 18. velocity vectors

Tubercle leading-edge wing

Fig 19. mesh generation



Mesh Information for CFX

Domain	Nodes	Elements
Default Domain	869721	4450268

Fig 20. Static pressure distribution

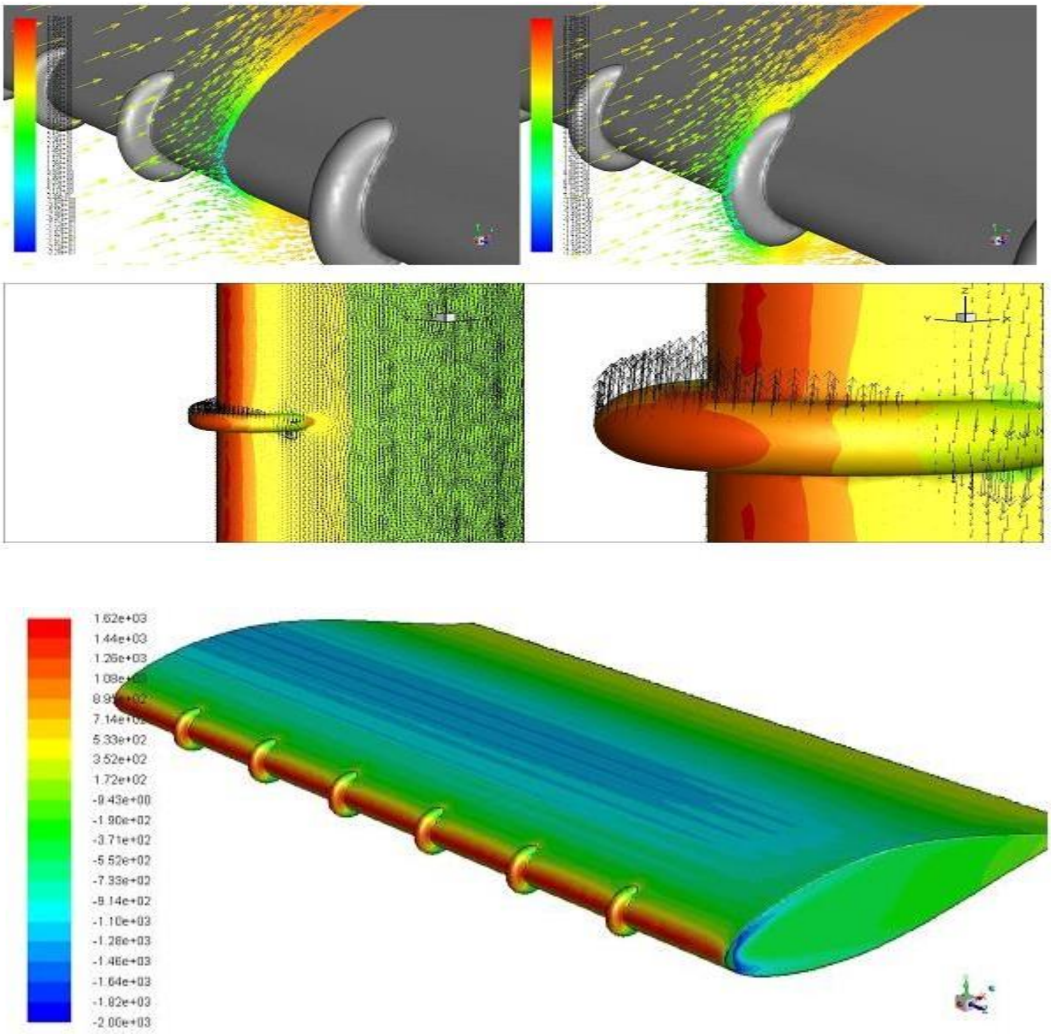


Fig 21. static pressure on flippers and symmetric plane

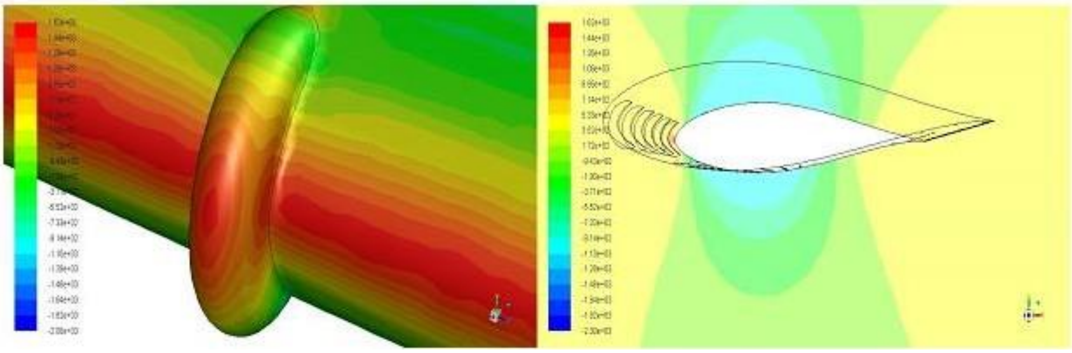
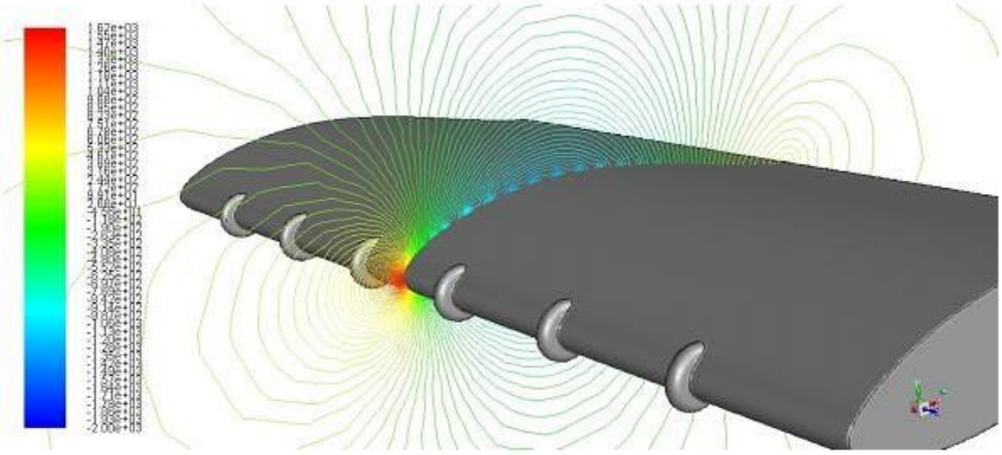


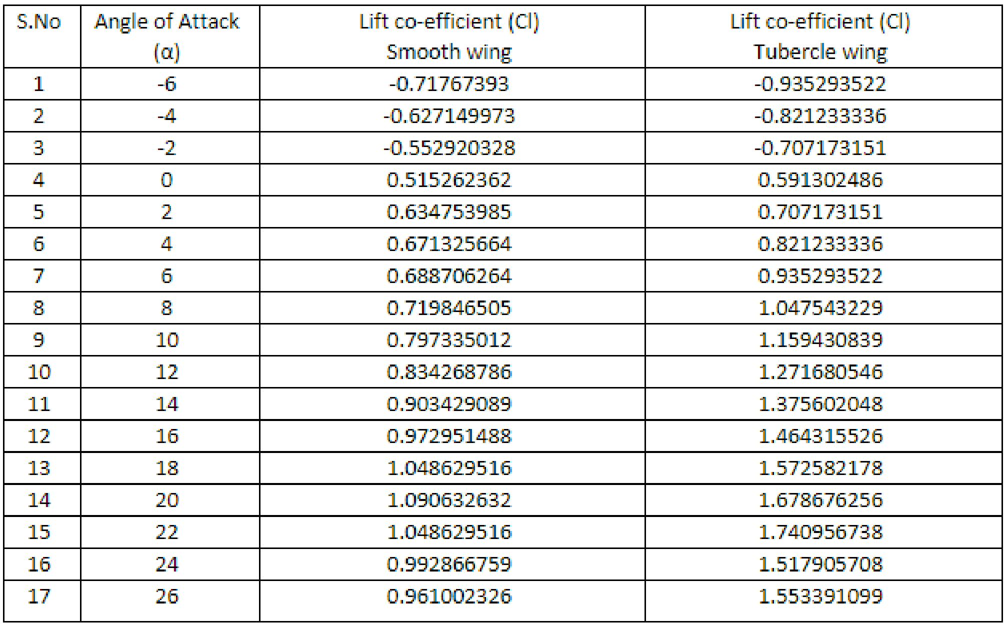
Fig 22. velocity vectors

Fig 23. Static pressure on cross section



Comparison between smooth wing and tubercle wing

Table 1. Co-efficient of Lift



S.No	Angle of Attack (α)	Lift co-efficient (Cl) Smooth wing	Lift co-efficient (Cl) Tubercle wing
1	-6	-0.71767393	-0.935293522
2	-4	-0.627149973	-0.821233336
3	-2	-0.552920328	-0.707173151
4	0	0.515262362	0.591302486
5	2	0.634753985	0.707173151
6	4	0.671325664	0.821233336
7	6	0.688706264	0.935293522
8	8	0.719846505	1.047543229
9	10	0.797335012	1.159430839
10	12	0.834268786	1.271680546
11	14	0.903429089	1.375602048
12	16	0.972951488	1.464315526
13	18	1.048629516	1.572582178
14	20	1.090632632	1.678676256
15	22	1.048629516	1.740956738
16	24	0.992866759	1.517905708
17	26	0.961002326	1.553391099

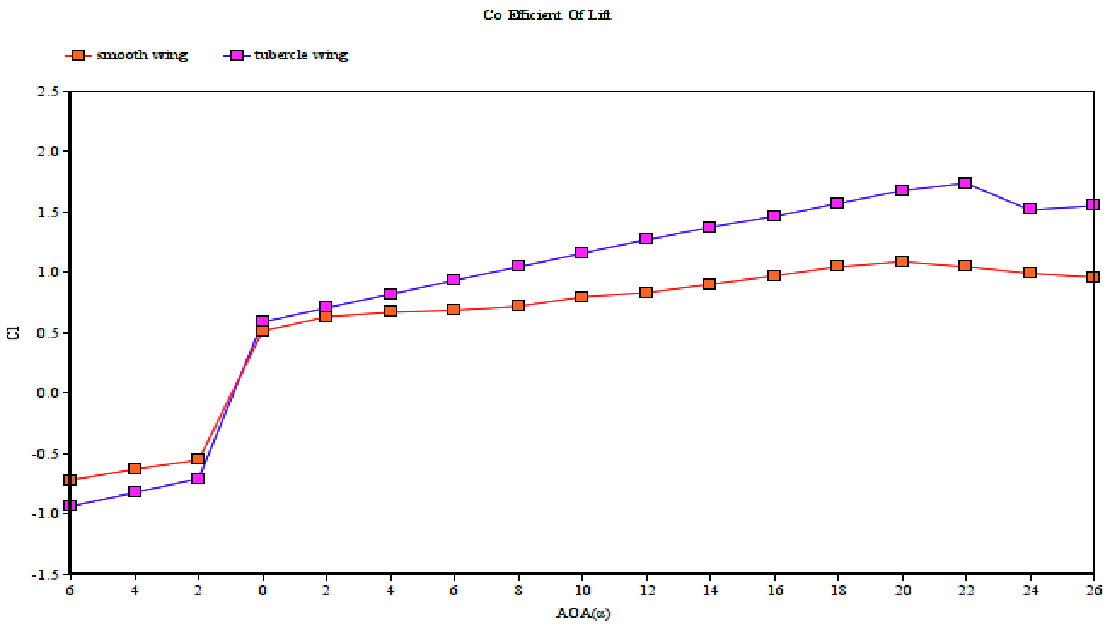


Table 2. Co efficient of Drag

S.No	Angle of Attack (α)	Drag co-efficient (Cd) Smooth wing	Drag co-efficient (Cd) Tubercle wing
1	-6	-0.046710362	-0.044899883
2	-4	-0.060470003	-0.056849045
3	-2	-0.069522399	-0.066625632
4	0	0.077126411	0.073505453
5	2	0.069160303	0.066625632
6	4	0.059383716	0.056849045
7	6	0.045261978	0.044899883
8	8	0.035485391	0.030053954
9	10	0.016294312	0.01303545
10	12	-0.012673354	-0.007241917
11	14	-0.035485391	-0.030416049
12	16	-0.058659524	-0.05467647
13	18	-0.09197234	-0.083644136
14	20	-0.132164977	-0.114422281
15	22	-0.102111023	-0.099576353
16	24	-0.064453057	-0.061556291

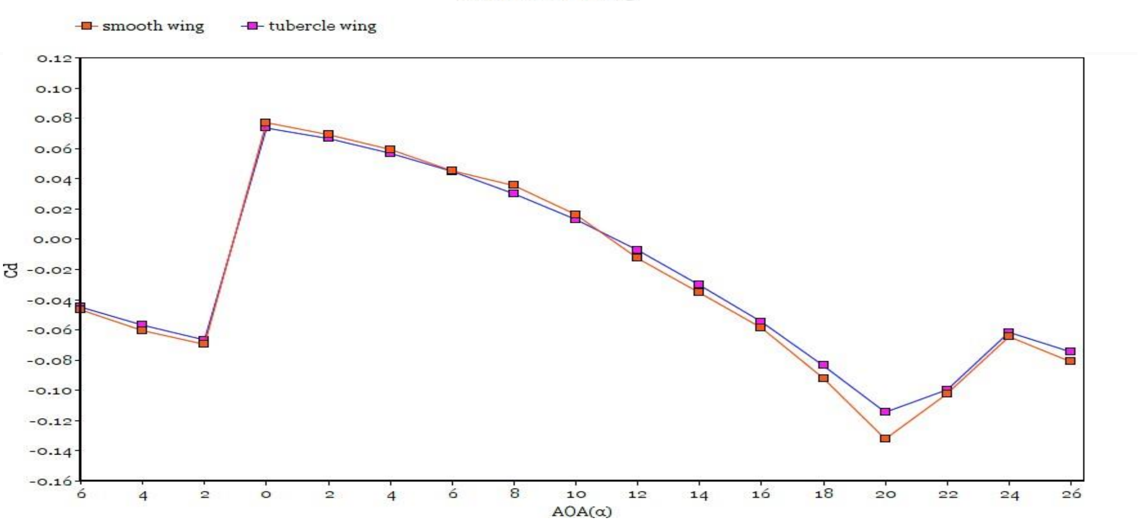
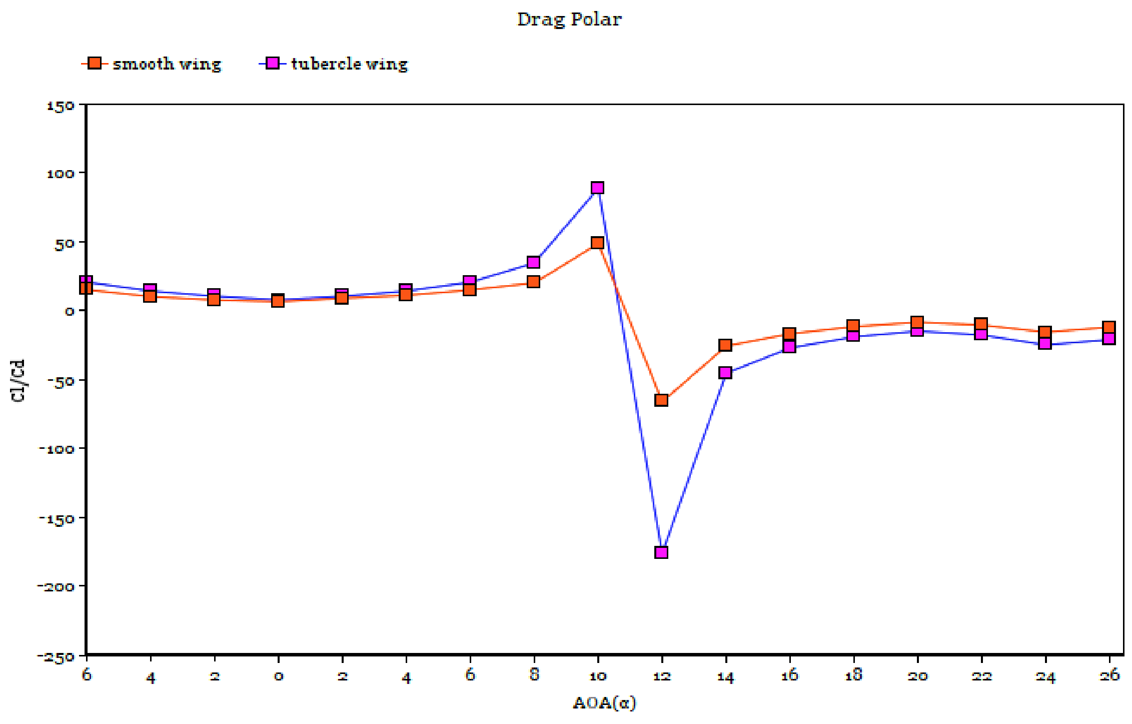


Table 3. Drag Polar

S.No	Angle of Attack (α)	Drag polar (Cl/Cd) Smooth wing	Drag polar (Cl/Cd) Tubercle wing
1	-6	15.36434109	20.83064516
2	-4	10.37125749	14.44585987
3	-2	7.953125	10.61413043
4	0	6.680751174	8.044334975
5	2	9.178010471	10.61413043
6	4	11.30487805	14.44585987
7	6	15.216	20.83064516
8	8	20.28571429	34.85542169
9	10	48.93333333	88.94444444
10	12	-65.82857143	-175.6
11	14	-25.45918367	-45.22619048
12	16	-16.58641975	-26.78145695
13	18	-11.4015748	-18.8008658
14	20	-8.252054795	-14.67088608
15	22	-10.26950355	-24.65882353
16	24	-15.40449438	-24.65882353
17	26	-11.84821429	-20.82524272



RESULT AND DISCUSSION

- ✓ The above contents present the modelling and analyzing of tubercle wing with separated protuberances in NACA 63(4)-221 airfoil with velocity of 50m/s airflow. Tubercles act as a passive flow control device.

- ✓ In this experiment two type of wings aerodynamic characteristics are analyzed and compared.

- ✓ comparing the both wings tubercle leading edge wing having better lift co- efficient then smooth leading-edge wing.
- ✓ Up to 45% lift force is increased when using tubercle wings.
- ✓ drag force also increased but the lift to drag ratio also increased. When using tubercles leading edge wing induced drag will be reduced up to 50%.
- ✓ In low angle of attack tubercle leading edge wings performs better then smooth leading-edge wing.
- ✓ In high angle of attack both wings having identical aerodynamic performance.
- ✓ Basically, we are taking this project because of increase skin friction drag, boundary layer separation and high wing tip vortex strength.
- ✓ The new model of tubercle leading edge wing is designed and analyzed.

CONCLUSION

The present design involves the identification of aerodynamic performance of the NACA 63(4)-221 airfoil with smooth leading edge and tubercle leading edge has been taken, model wing is developed by using Catia software and the numerical simulation done by using the Ansys software. A turbulent flow passing on both wings in 50m/s velocity the aerodynamic characteristics such as co efficient of lift, coefficient of drag, drag polar are analyzed and compared.

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