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VIBRATION ANALYSIS OF AN AIRCRAFT WING

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CERTIFICATE OF RESEARCH

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DECLARATION

THIS IS TO CERTIFY THAT THE WORK PRESENTED IN THIS THESIS IS AN OUTCOME OF THE ANALYSIS, SIMULATION & RESEARCH CARRIED OUT BY THE AUTHOR THEMSELVES UNDER THE WATCHFUL SUPERVISION OF PROF. DR. MD. ZAHID HOSSAIN.

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Contents

ABSTRACT

The report deals with the structural design and modal analysis of wing in an aircraft. Many studies are being carried out for the design of the wings across the globe by the researches to strengthen the aircraft wings for steady and sturdy structures for dynamic conditions. The wing design involves its initial considerations and selection of air foil, area of the wing, wing loading characteristic and weight of the wing. In this project the aircraft wing structures are designed using 2024-T3 aluminum alloy material. Airfoil profile NACA 63-215 as root of the wing and airfoil profile NACA 64-412 as the tip of the wing are selected (as per the specification of mooney M20n aircraft). The generated wing profile is imported to SOLIDWORKS 2017. Modal analysis is carried out in ANSYS WORKBENCH by inputting the specification of the wing geometry and the material properties. The reason behind using modal analysis is to determine the natural frequencies for vibration characteristics of the wing structure. Modal analysis also shows the correlation of the stress, deformation of the corresponding mode of vibration. The main purpose of this report is to compare natural frequency & deformation, structural properties (maximum principle stress, Von mises Stress, Von mises strain etc) of an aircraft wing with different thicknesses.

INTRODUCTION

An aerofoil is a cross-section of wing of the aeroplane. Its main job is to provide lift to an aeroplane during take-off and while in flight. But, it has also a side effect called Drag which opposes the motion of the aeroplane. The amount of lift needed by a plane depends on the purpose for which it is to be used. Heavier planes require more lift while lighter planes require less lift than the heavier ones. Thus, depending upon the use of aeroplane, air foil section is determined. Lift force also determines the vertical acceleration of the plane, which in turns depends on the horizontal velocity of the plane.

The predominant function of the aircraft wing is to generate sufficient lift (L). Drag (D) and nose-down pitching moment (M) are the two other components of wing. The main primary aim of the wing design is to maximize the lift and minimize the other two components. The wing is considered as a lifting surface and works on lift generation theory, that lift is produced due to the pressure difference between lower and upper surfaces.

The particular wing design depends upon many factors for example, size, weight, use of the aircraft, desired landing speed, and desired rate of climb. In some aircraft, the larger compartments of the wings are used as fuel tanks. The wings are designated as right and left, corresponding to the right- and left-hand sides of a pilot seated in the aircraft.

AERODYNAMICS

An aerofoil is the state of a wing or edge or cruise as seen in cross-area. An aerofoil-formed body travelled through a fluid handles an aerodynamic energy. The segment of this power perpendicular to the course of movement is called lift. The segment parallel to the bearing of movement is called drag. Subsonic flight aerofoils have a trademark shape with an adjusted heading edge, emulated by a sharp trailing edge, regularly with uneven camber.

The lift on an aerofoil is fundamentally the consequence of its approach and shape. At the point when arranged at a suitable edge, the aerofoil diverts the approaching air, bringing about an energy on the aerofoil in the heading inverse to the diversion. This power is known as aerodynamic drive and could be determined into two parts: Lift and drag. Most thwart shapes oblige a positive approach to produce lift, however cambered aerofoils can create lift at zero approach. This "turning" of the air in the region of the aerofoil makes bended streamlines which brings about more level weight on one side and higher weight on the other. This weight contrast is joined by a speed distinction, through Bernoulli's standard, so the ensuing stream field about the aerofoil has a higher normal speed on the upper surface than on the more level surface.

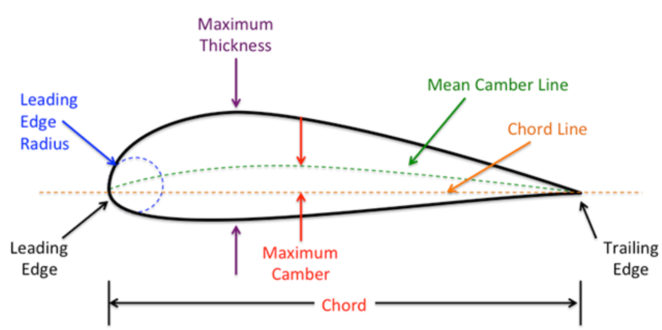


Figure 1 General section of an aerofoil

Some terms related to aerofoil are:

Leading edge: It is the edge of the aerofoil facing the direction of motion of plane. It is generally roundish in shape and deflects the air in such a way that the velocity of air on upper surface of the aerofoil is more than velocity on the lower surface.

Trailing edge: It is the edge of the aerofoil which is pointed in nature. It is located at the back side of the aerofoil.

Chord line: It is a straight line joining the leading edge to the trailing edge. It bisects the aerofoil into two parts for a symmetric aerofoil but may not do so for an asymmetric aerofoil. It defines another important parameter Angle of attack.

Angle of attack: It is the angle which the chord line makes with the direction of motion of plane. It is an important parameter which affects the coefficient of lift and drag.

Chamber line: It is a line joining leading edge and trailing edge and dividing the aerofoil into two symmetrical parts. It may or may not be a straight line.

WING GEOMETRY

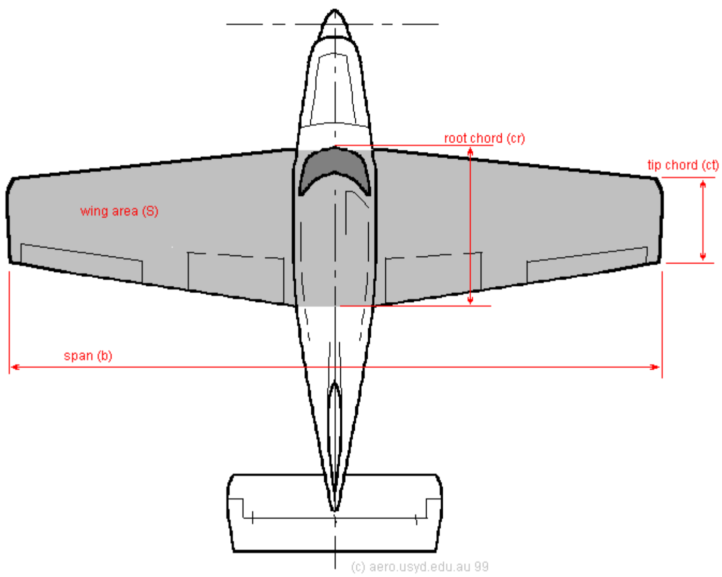


Figure 2 Wing Geometry (Ref:http://www-mdp.eng.cam.ac.uk)

Span: The distance between to tips is known as Span.

Geometric twist: An actual change in the airfoil angle of incidence, usually measured with respect to the root airfoil.

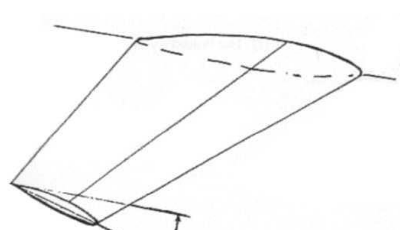


Figure 3 Geometric Twist [1]

Dihedral angle: Dihedral is the upward angle of the wing from the vertical when seen from the front, or nose of the aircraft. If each wing is angled 5° up from the horizontal, then the wing is said to have 5° of dihedral

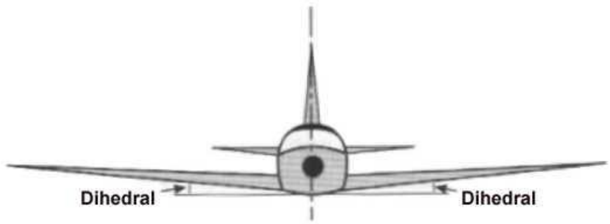


Figure 4 Dihedral angle [1]

Incidence angle: On fixed-wing aircraft, the angle of incidence is the angle between the chord line of the wing where the wing is mounted to the fuselage, and a reference axis along the fuselage.

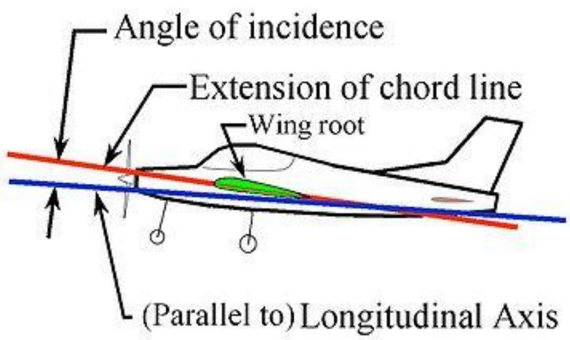


Figure 5 Incidence angle (ref:Wikipedia)

Aspect ratio: Aspect ratio is a measure of how long and slender a wing is from tip to tip. The Aspect Ratio of a wing is defined to be the square of the span divided by the wing area and is given the symbol AR. For a rectangular wing, this reduces to the ratio of the span to the chord length as shown at the upper right of the figure.

$$AR = s^2 / A = s^2 / (s * c) = s / c$$

Taper Ratio: Taper ratio is simply the ratio of the chord length of the tip aerofoi and the root aerofoil chord length.

Taper ratio, λ = Chord length of tip/ Chord length of the root

LITERATURE REVIEW

To claim our objectives and to find out new scopes for any new method of design or to do some modifications a literature survey is done over the researchers concerned with the detailed study of aircraft wing. Fundamental properties like vibration which has an important impact on failure of the structure is desired to explore by this literature survey.

Kakumani Sureka and R Satya Meher in their paper they modelled A300 aircraft wing using standard NACA 64215 airfoil with spars and ribs digitally using different materials. They arrived to the conclusion that Aluminium alloy 7068 is preferred over Aluminium alloy in order to give the more strength to the structure.[2]

K. Sruthi, T. Lakshmana Kishore, M. Komaleswara Rao in their paper conclude that the difference between the values of deformation, equivalent stress, max principle stress, stress intensity and shear stress with Al alloy and Aluminium + Silicon Carbide are minimal. The results obtained are optimum. As the difference between the two result values are minimal. We can use aluminium + Silicon carbide instead of using aluminium alloy in order to give the more strength to the structure. The effect of pressure during take-off condition is more for Aluminium and less for Al + SiC which is strongest and light weight, and also reduces the weight of the wing. Thus we can conclude that at the above assumed loading conditions and constraints flight wing structure will not fail due to material properties. We can conclude that aluminium+ silicon carbide can be replaced with aluminium alloy.[3]

Avnish Kumar in his "Investigation of aerofoil design." Said that Lift coefficient was found to be higher for Asymmetric aerofoil than the Symmetric aerofoil for same chord length and maximum camber of the aerofoil at same angle of attack.[4]

Aswani Kodali and T.N.Charyulu in their paper with the title "modeling and analysis on wing of A380 flight" conducted structural & thermal analysis on AIR BUS A380WING TO Calculate the stress, strain & thermal flux for finding the wing to be safe.For simulation and modeling they used software like CATIA for determining model for analysis FEA package ANSYS. In their simulation the obtained stress and strain values were within the limiting range. The maximum stresses that wing of a flight can with stand are 700pa. But obtained stress wass 400pa.[5]

P.JEEVANANTHAM, L.MANIKUMAR in their paper dealt with the structural design and flow analysis of M wing in an aircraft. The wing design involves its initial considerations and selection of airfoil, area of the wing, wing loading characteristic and weight of the wing. Their design proved to be viable by the results that they obtained from the virtual flow analysis of the wing analyzed by the Design-Foils tool test results.[6]

Dr.R.Rajappan, & V.Pugazhenthi dealt in their papers with bending Finite Element Analysis of monocoque laminated composite aircraft (subsonic and supersonic) wing using commercial software ANSYS.They used NACA 4412 as model.They concluded that wing model was severely affected by the loads on along wing direction, across wing direction, vertical direction. Von misses stress was calculated in order to know the maximum stress levels and minimum stress levels on the wing.[7]

Nikhil A. Khadse & Prof. S. R. Zaweri in their paper presents modal analysis of aircraft wing. Aircraft wing used for investigation is A300 (wing structure consist of NACA64A215). A cad model of a aircraft wing has been developed using modeling software PROE5.0 and modal analysis was carried out by using ANSYS WORKBENCH14.0.modal analysis has been carried out by fixing one end (root chord) of aircraft wing while other end(tip chord) is free. They also used a cantilever beam modal analysis for validation of the simulation of the airfoil. This investigation revealed that natural frequency obtained from numerical and theoretical approach were in close agreement, which validated FE model of the cantilever beam for modal analysis.[8]

T .Gultop, (2005) studied the impact of perspective degree on Airfoil peformance. The reason for this study was to focus the ripple conditions not to be kept up throughout wind tunnel tests. These studies indicate that aeroelastic insecurities for the changing arrangements acknowledged showed up at Mach number 0.55, which was higher than the wind tunnel Mach number point of confinement velocity of 0.3.[9]

Lica Flore and Albert Arnau Cubillo presented the results of the dynamical behaviour on an aircraft wing structure. The study has consisted strain gauges to test aircraft wing dynamically in which the vibration parameters of the structure have been determined.[10]

Dr. M. Neubauer, G. Gunther gave description regarding various loads to be considered in the analysis and design of air frame structures .He also discussed the Conversion of "external loads" into structural airframe loads. He conducted aircraft analysis using static loads and fatigue loads.[11] [12]

METHODOLOGY

The 3D design of the wing was prepared using SOLIDWORKS 2017. Finite element analysis is applied to further our understanding of the mechanics of the wing. Finite element methods have been used by many researchers to aid the process of development of wing structure. For the purpose of simplifying the analysis we have only considered the wing surface as a no joint unit. The design was then imported to ANSYS WORKBENCH. Using modal analysis the natural frequencies and corresponding mode shapes were found.

CAD MODELLING OF WING

The solid model of aircraft wing is made using SOLIDWORKS 2017. We've taken the wing of Mooney M20TN aircraft as our model and followed the dimensions used in this aircraft wing.

Steps to generate the model:

- First by plotting points calculated from the NACA profile standards.[13]
- Creating splines making the shape of the aerofoils at the tip & root of the wing.
- Using Surface Loft feature generating the surface of the aircraft wing.

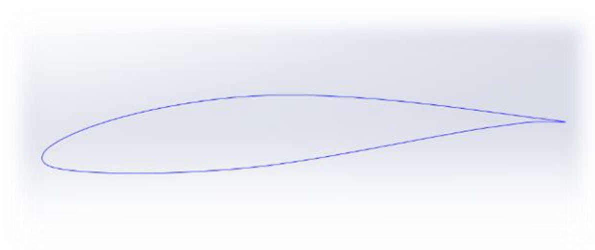


Figure 6 Surface Spline of NACA 63-215 (Root)

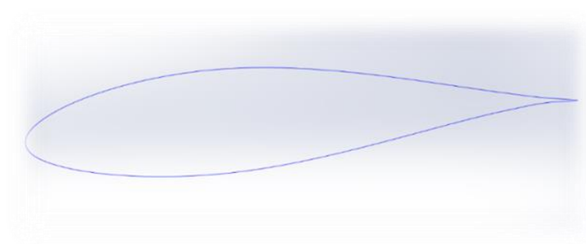


Figure 7Surface Splines of NACA 64-412 (tip)

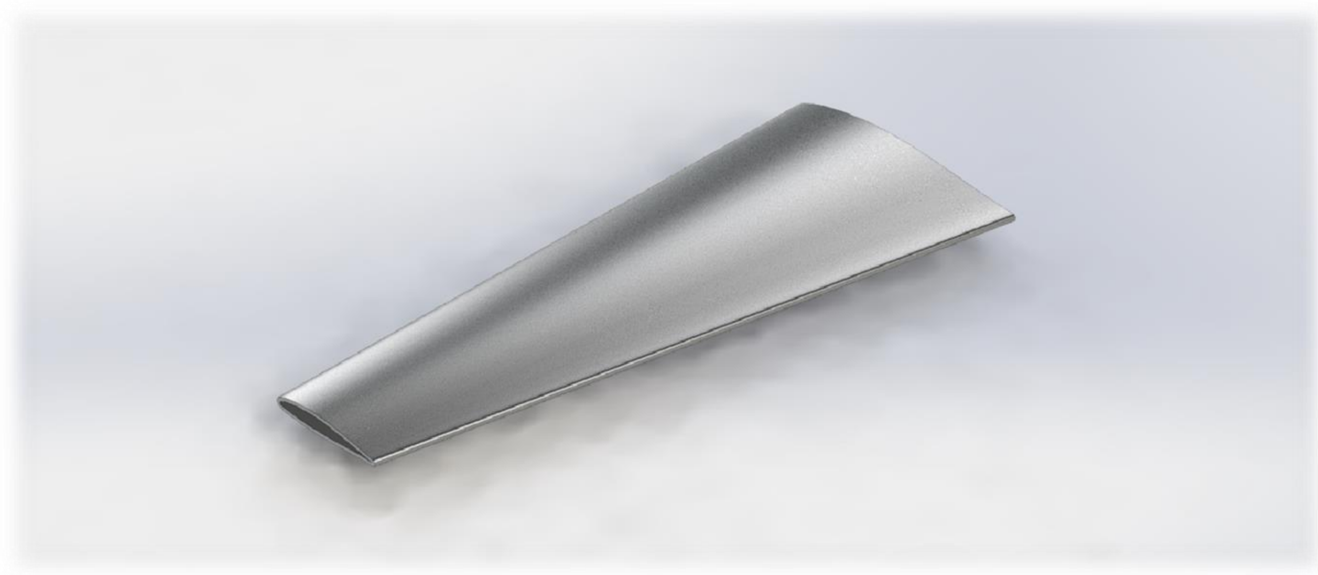


Figure 8 Designed Aircraft Wing

DIMENSIONS [14]

Wing length – 5.01m

Chord length – Root – 1.99m

Tip – 0.88m

Geometric Twist (DEG)	1.5 Degrees
Incidence Angle (DEG)	2.5 Degrees
Dihedral Angle (DEG)	5.5 Degrees
Aspect Ratio	7.448
Taper Ratio	2.271

Table 1 Dimensions of the wing

Thickness of the Surface taken – 30mm & 20mm

MODAL ANALYSIS

Modal analysis is the study if the dynamic properties of structures under vibrational excitation. Modal analysis is the measuring and analyzing the dynamic response of structures or fluid during excitation.

The purpose of modal analysis is to find the shapes & frequencies at which the structure will amplify the effect of load. Modes are inherent properties of the structure and are determined by the material properties and boundary conditions of the structure. Each mode is defined by natural frequencies, modal damping and a mode shape.

MATERIAL PROPERTIES

Advanced aluminium alloys are used for aerospace application. They must possess high fracture toughness, high fatigue performance, high formability, and super plasticity to meet the needs for lower structural weight, higher damage tolerance, and higher durability. In this project **2024-T3 Aluminium alloy** is used because of its attractive features of

- High strength
- Its ductility does not significantly decrease during the strengthening heat treatment.

Element	Wt%
Cu	4.67
Mg	1.50
Mn	0.644
Fe	0.211
Si	0.050
Cr	0.003
Zn	0.073
Ti	0.029
Ni	0.002
Ga	0.0005
V	0.008
Al	Remainder

Table 2 2024-T3 Aluminum alloy composition

MESHING

Unit cell size of a mesh is very important. The accuracy of the result of the experiment depends on the element size of the mesh. Finer element size enhances the precision of the result, but this requires higher computing power and consumes more time. As the total number of nodes increases with the increase of total number of element size, the simulation requires to solve all those points. Keeping the computing power of the computer used, the element size was taken 12.5mm. This provides an acceptable accuracy of result consuming a moderate computation time.

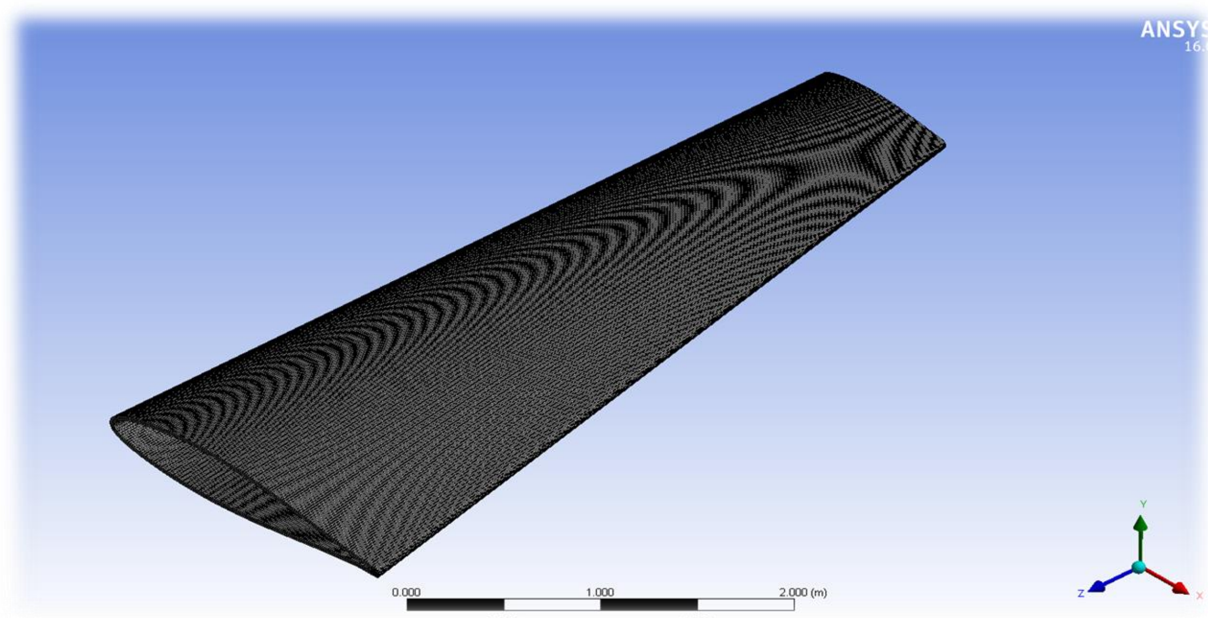


Figure 9 Meshing of wing model surface

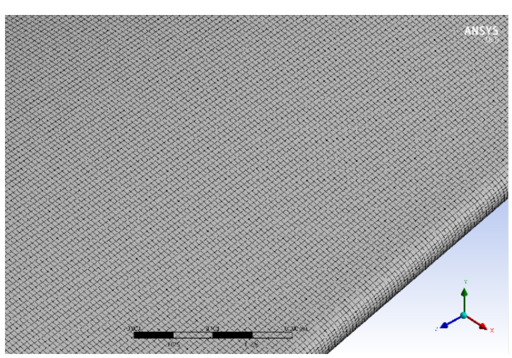


Figure 10 Close view of Mesh elements

BOUNDARY CONDITIONS

At the Root of the wing frictionless fixed support was given. Frictionless support place a normal constraints on an entire surface. Transitional displacement is allowed in all directions.

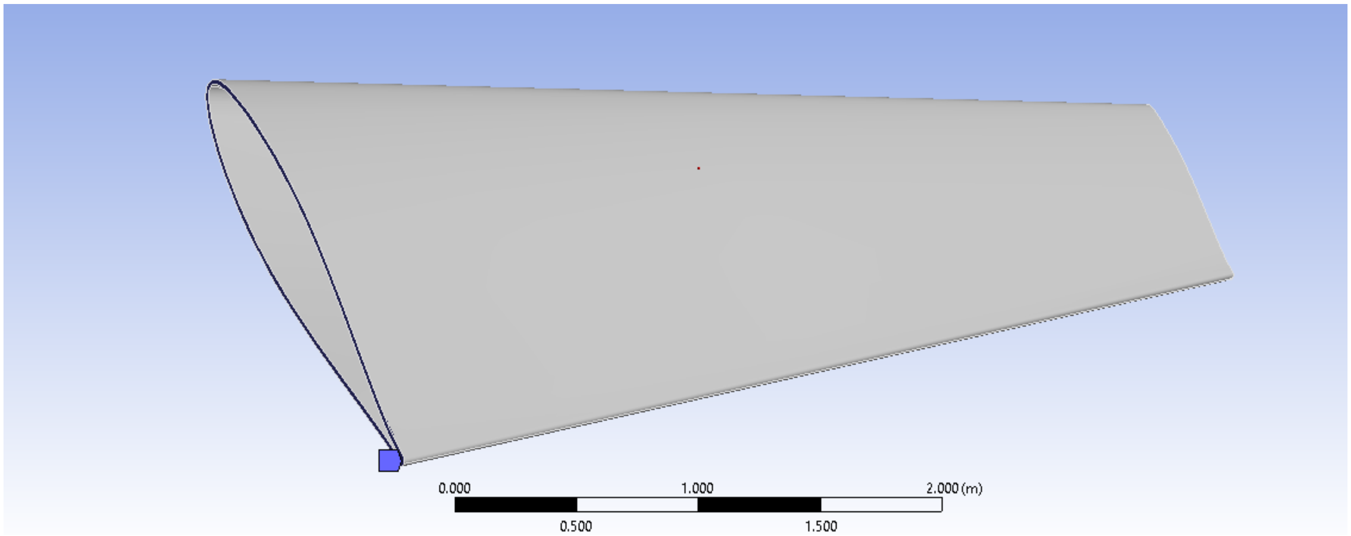


Figure 11 Fixed support on root of the wing

RESULTS

We analysed 5 different wings. All 5 models had the same surface area and other specifications except the surface thicknesses. Those 5 models were analysed in ANSYS WORKBENCH with same boundary conditions. Among these 5 models only two surface thicknesses (30mm, 20mm) are compared with each other because there difference between the properties are closer than other wing surface thicknesses (5mm, 10mm, 15mm).

STRUCTURAL ANALYSIS OF WING

Stress analysis of the wing is carried out to compute the stresses, deformation and strains at aircraft wing structure.

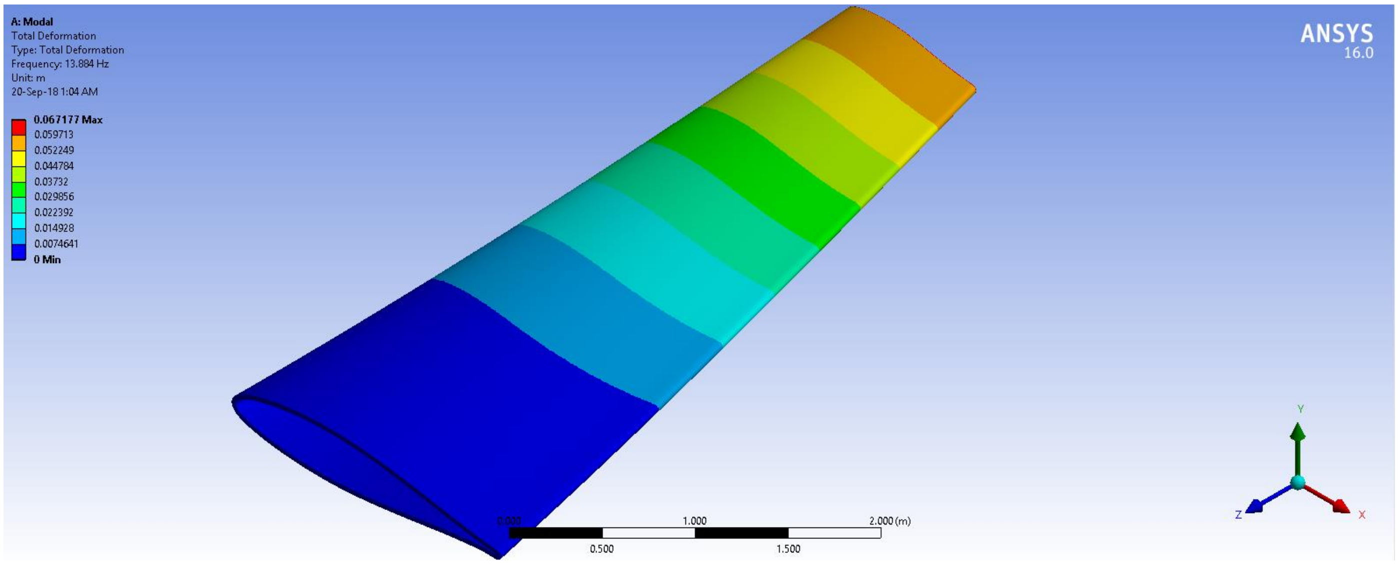


Figure 12 Total Deformation

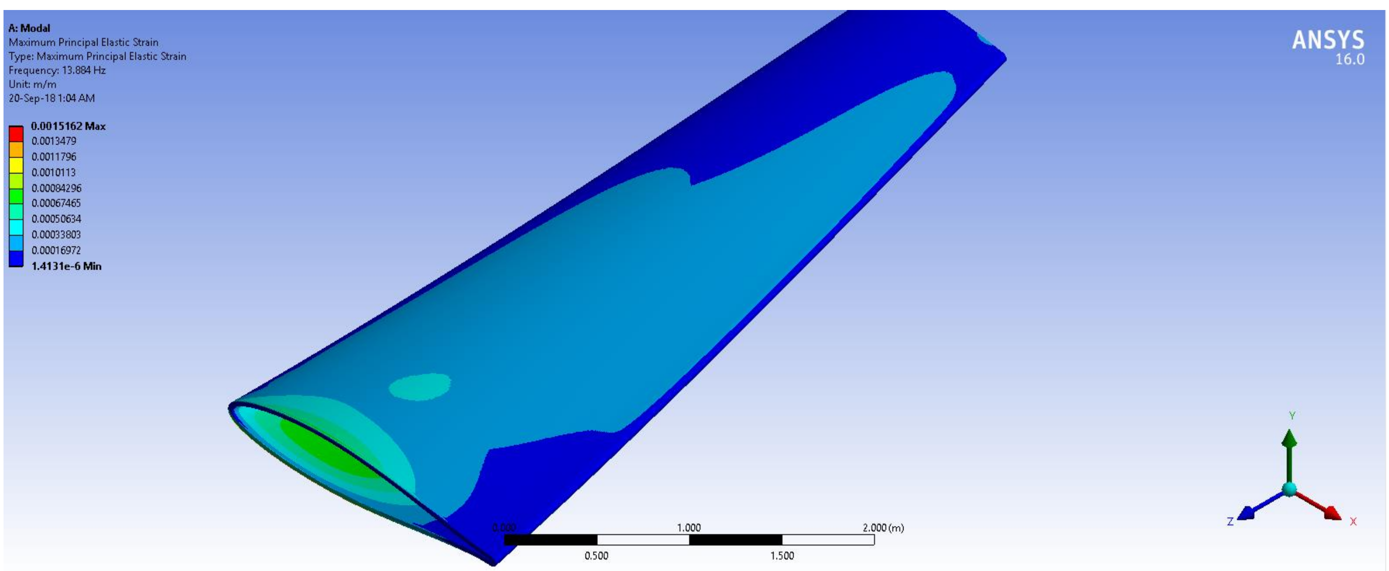


Figure 13 Maximum Principle Elastic Strain

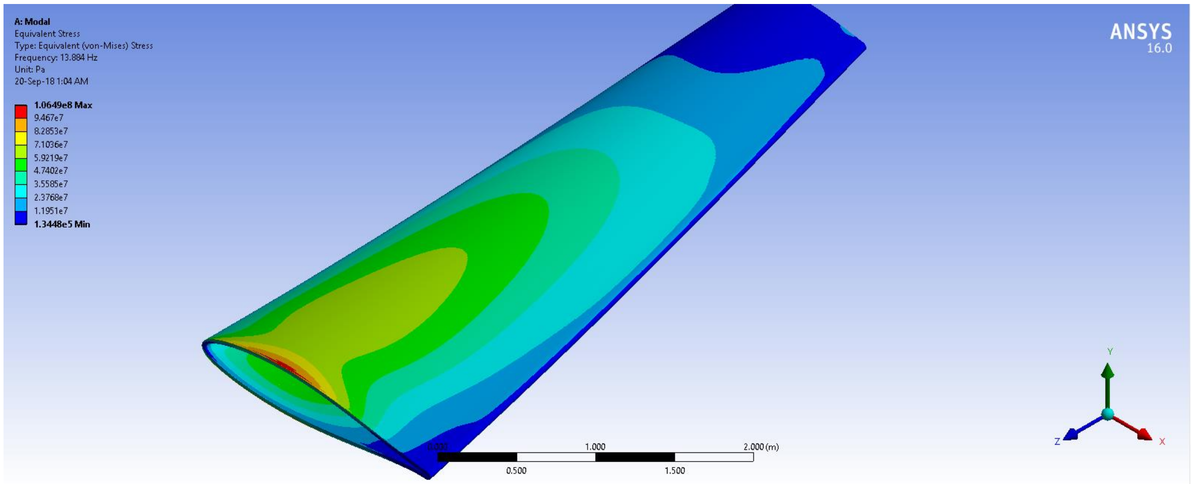


Figure 14 Equivalent Stress

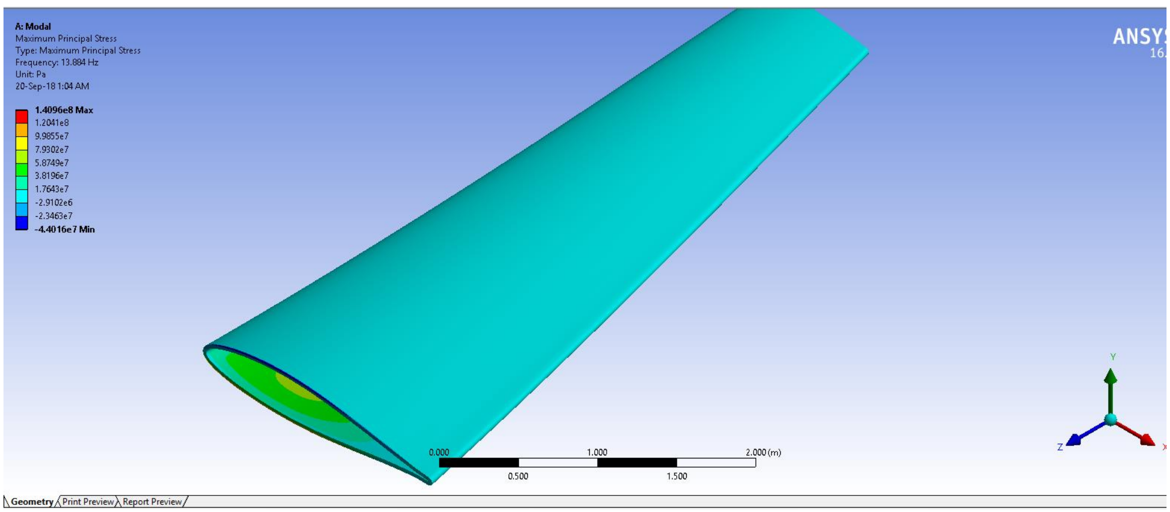


Figure 15 Maximum Principle Stress

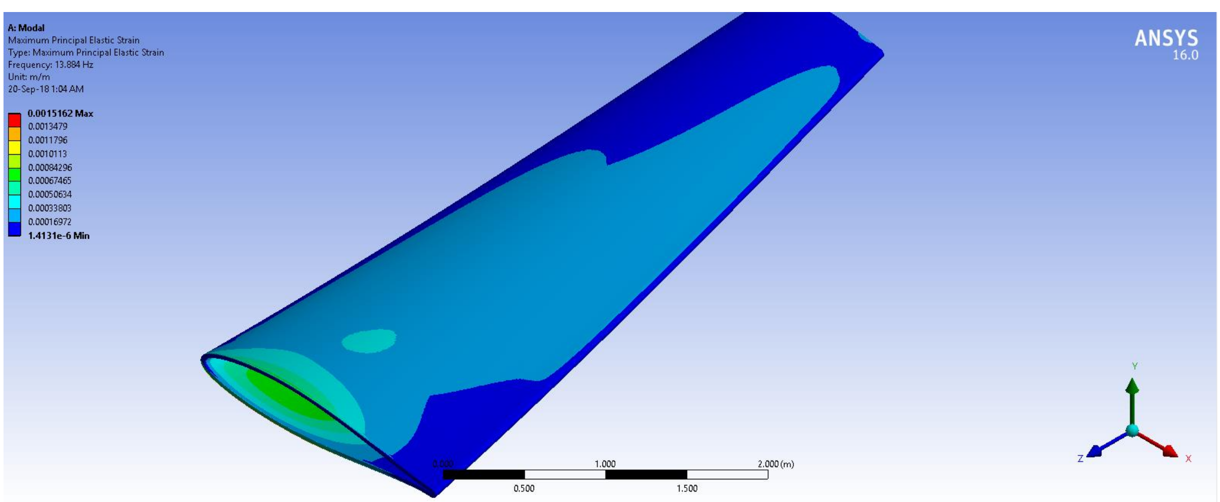


Figure 16 Maximum Principle Strain

Fig.14 shows the Equivalent tensile stress or von-Mises stress. It states that the material starts to yield when the von-Mises stress reaches a critical value, yield strength. Uniform stress distribution is observed all over the wing but maximum stress is developed close to the root section of wing. In this case, the von-Mises stress observed in the wing analysis is 128.83 Mpa which is lower than the yield strength of the 2024-T3 aluminum alloy. Fig. 15 shows maximum principal stress distribution of the wing under pressure load. The maximum principal stress noticed in the structure is 140.96 MPa which is lower than the yield strength of the material. The structure is safe because the stress magnitude which is obtained from the analysis is less than the yield strength of the structural material. Deflection of the wing is shown in Fig.12, the wing bends upwards because of pressure load.

Criteria for the Structural Analysis	**Thickness**	
	30mm	20mm
Total Deformation	67.17mm	83.33mm
Equivalent (von-mises) Stress	106.49 MPa	128.83 MPa
Maximum Principle Stress	140.96 MPa	143.89Mpa
Equivalent (von-mises) Strain	0.001502	0.001667
Maximum Principle Strain	0.0015162	0.00196571

Table 3 Comparision of structural properties

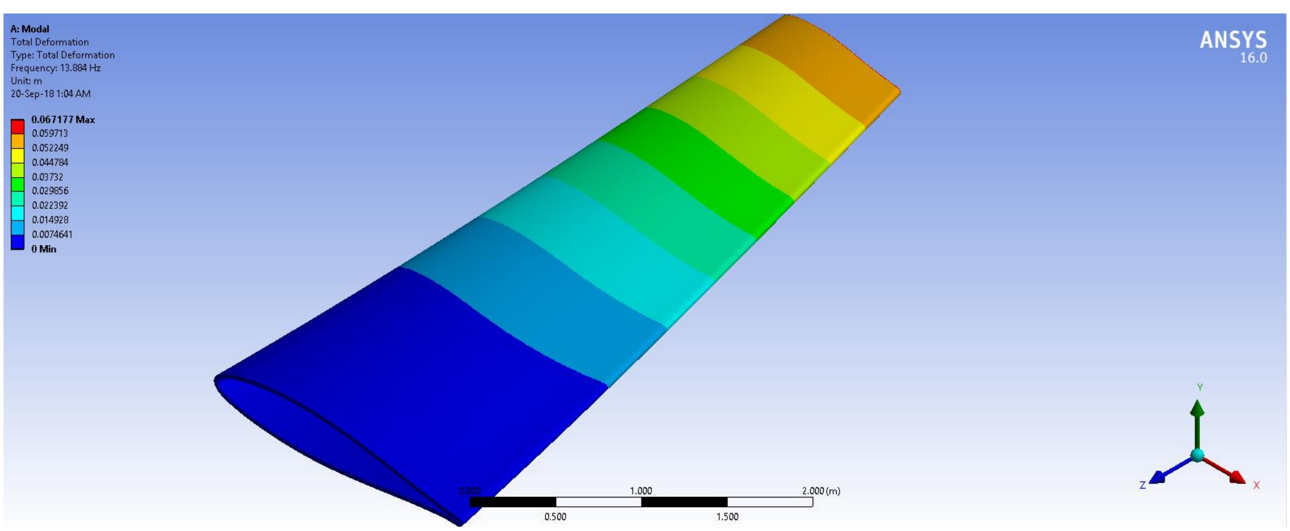
NATURAL FREQUENCY

While running the simulation we set the analysis settings to find the 5 natural frequencies and their corresponding mode shapes. From this 5 node shapes we have only considered only first bending mode of t=30mm and t=20mm

Mode	Frequency (Hz) t= 30mm	Frequency (Hz) t= 20mm
01	13.884	13.274
02	45.885	40.309
03	67.162	55.07
04	72.123	58.367
05	73.348	66.666

Table 4 Comparision of natural frequencies

THE MODE SHAPES OF WING (for 30mm thickness)



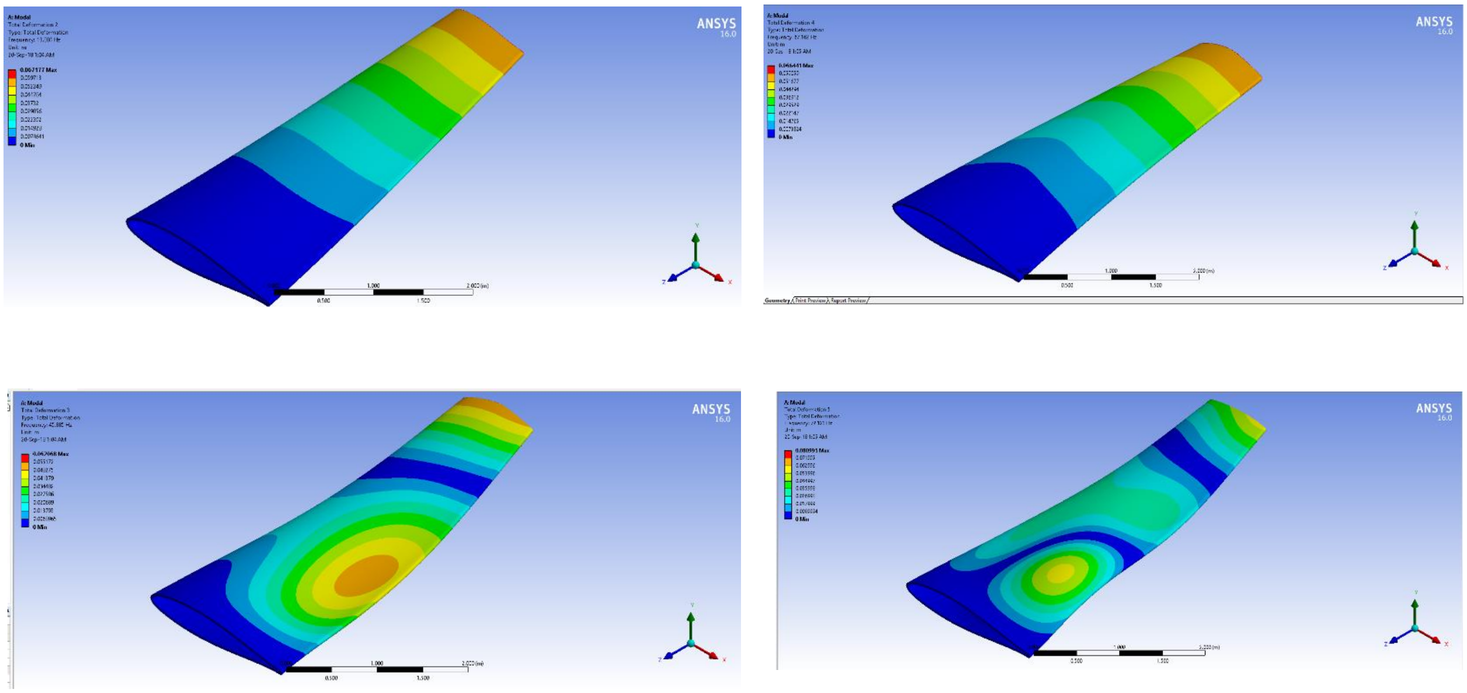
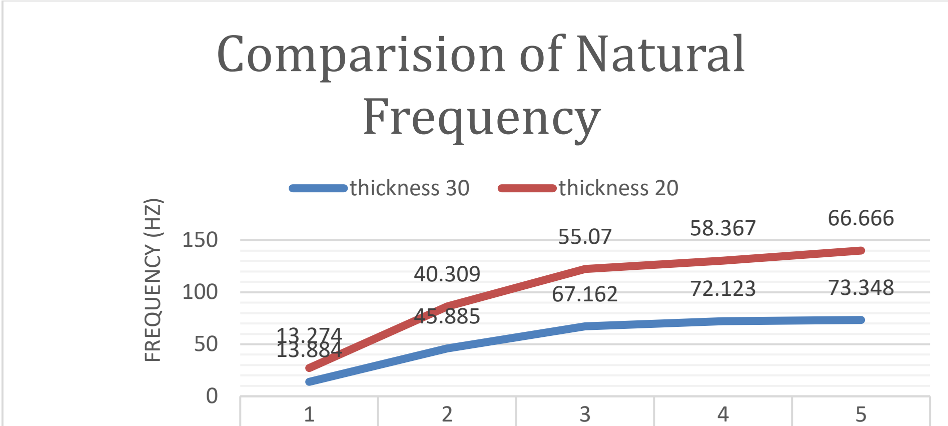


Figure 17 Different mode shapes (30mm thickness)

CONCLUSION & SCOPE FOR FUTURE WORK

The Computer Aided Design Tools and NACA standards have been accomplished to design the wing structure. The vibration characteristics of the wing structures are studied by modal analysis to find the natural frequency of the wing structures. From the above results we can conclude that the difference between the values of natural frequencies, total deformation, equivalent stress, maximum principle stress, stress intensity and shear stress with different surface thicknesses are significant as the increase of surface thickness increases both the natural frequencies and decreases the total deformation of the wing.



	1	2	3	4	5
thickness 20	13.274	40.309	55.07	58.367	66.666
thickness 30	13.884	45.885	67.162	72.123	73.348

As future enhancement, different aerofoils can be tested with different materials & surface thickness conditions to find more suitable aerofoil with good aerodynamic and structural characteristics and analysis can be performed.

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