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Design and Finite Element Analysis of Aircraft Wing

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ABSTRACT

An aircraft is a machine that is able to fly by gaining support from the air, or, in general, the atmosphere of a planet. A wing is a type of fin that produces lift while moving through air or some other fluid. Aircraft may be classified by different criteria, such as lift type, propulsion, usage, and others. A computer-aided design model of the wing is created by using ANSYS APDL software and analysis is done by utilizing ANSYS workbench 2022 R1. The analysis is done on the wing by considering one end (root chord) of the wing as fixed while the other end (tip chord) as free. Static structural analysis of the wing is done to find deformation, stress, and strain induced in the wing structure. Modal analysis is done to find the natural frequency of the wing to reduce the noise and avoid vibration. The main purpose of this project is to find out which material (Al alloy and Ti alloy) is best suited for making of wing for subsonic flight. The results obtained in structural analysis and modal analysis for aluminium and titanium alloy are compared and conclusions has been drawn on the material to be used for the aircraft wing. Graphs have been drawn for the results obtained to estimate the deformation, stress and strain for aluminium and titanium alloy.

Keywords: Static structural analysis, ansys, modal analysis, materials.

Introduction

The wing is a primary structural component of aircrafts (air breathing engines) which is used to produce lift force during flight. When the engine is started air is sucked into the compressor through the inlet increasing pressure ratio at the exit of the compressor. Then air and fuel is mixed inside combustion chamber and burnt. When high pressure, high temperature gases is accelerated through the nozzle, thrust force is produced which propels the aircraft in forward motion. Due to this forward motion, air flows over the wing whichis aerodynamic in shape. Due to the aerodynamic shape of the wing along with Bernoulli's principle the velocity of flow is less at bottom of the wing and high at top of wing. Due to this pressure difference is created between top and bottom surface of wing and thus lift is generated. Wing must have high strength to weight ratio, high fatigue life since it is subjected to alternate repeated loadings during flight.

A fixed-wing aircraft is an aircraft, such as an aero plane, which is capable of flight using wings that generate lift caused by the vehicle's forward airspeed and the shape of the wings. Fixed-wing aircraft are distinct from rotary-wing aircraft [1], in which the wings form a rotor mounted on a spinning shaft, in which the wings flap in similar manner to a bird. Glider fixed-wing aircraft, including free-flying gliders of various kinds and tethered kites, can use moving air to gain height. Powered fixed-wing aircraft that gain forward thrust from an engine (aero planes) include powered par gliders, powered hang gliders and some ground effect vehicles.

The wings of a fixed-wing aircraft are not necessarily rigid; kites, hang-gliders, variable- sweep wing aircraft and aero planes using wing-warping are all fixed-wing aircraft. Most fixed-wing aircraft are flown by a pilot on board the aircraft, but some are designed to be remotely or computer controlled. Wings The wings of a fixed-wing aircraft are staticplanes extending either side of the aircraft. When the aircraft travels forwards [5], air flowsover the wings which are shaped to create lift.

Fig 1.1 Wing Rib

Scope of the work and its importance:

An attempt is made to design wing using different configuration to determine maximum stress and deformation it can withstand. The design of a replacement wing requires stress analysis. In engineering, stress analysis is a tool rather than a goal; the aim is to determine the stress and to predict the failure in materials subjected to forces or to increase the strength of the wing without increasing the weight. Stress analysis can be performed using conventional and analytical mathematical techniques, an experimental testing or computational simulation. Aluminium alloy Titanium alloy are considered as materials to do static structural analysis.

Aircraft are built to meet certain specified requirements. These requirements must be selected so they can be built into one aircraft. It is not possible for one aircraft to possess all characteristics; just as it isn't possible for an aircraft to have the comfort of a passenger transport and the manoeuvrability of a fighter. The type and class of the aircraft determine how strong it must be built. A Navy fighter must be fast, manoeuvrable, and equipped for attack and defense. To meet these requirements, the aircraft is highly powered and has a very strong structure.

The Airframe Of A Fixed-Wing Aircraft Consists Of The Following Five MajorUnits:

1. Fuselage
2. Wings
3. Stabilizers
4. Flight controls surfaces
5. Landing gear

A rotary-wing aircraft consists of the following four major units:

1. Fuselage
2. Landing gear
3. Main rotor assembly
4. Tail rotor assembly

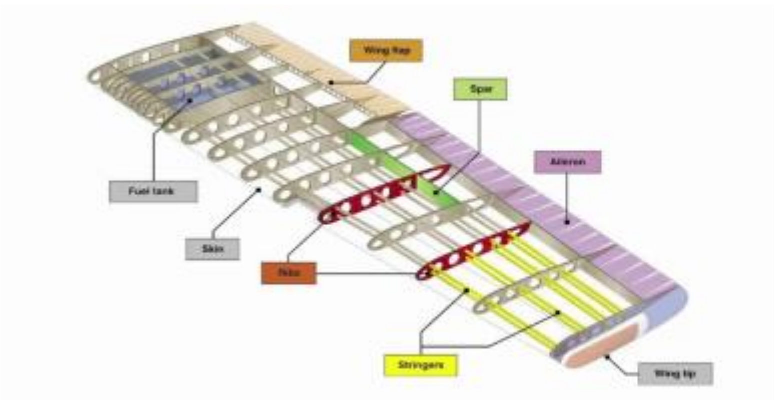


Fig 1.2 Parts Of Wing

Fuselage: The plane's body, or fuselage, holds the aircraft together, with pilots sitting at the front of the fuselage, passengers and cargo in the back.

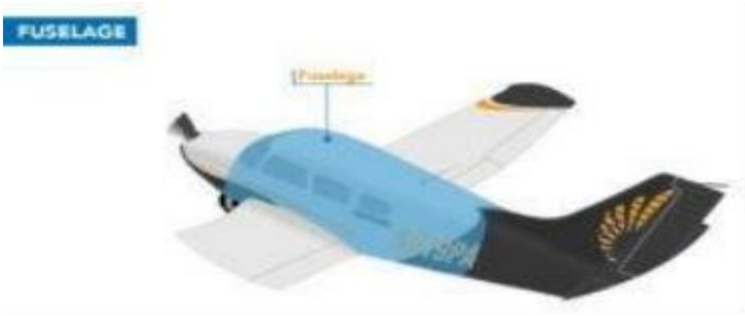


Fig 1.3 Fuselage

Wings: An aircraft's wings are critical to flight through the production of lift, but theyhave many parts of the wing to control this lift amount and direction.

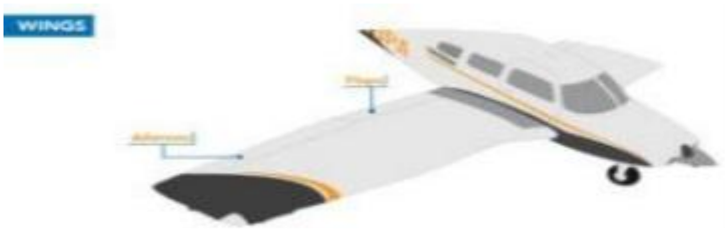


Fig 1.4 Wings

Tail: An aircraft's tail is mainly used for stability, as well as creating lift in combinationwith the wings. It's comprised of several parts.

LITERATURE REVIEW

Rahul Sharma and Garima Garg,[1] [2019]have investigated stress and displacement of wing rib with and without cutouts of 1mm thickness within the application of 0.01Mpa air pressure. CATIA V5 and MSC NASTRAN-PATRAN are the tools utilized in this design and analysis.

Mohamed Amine Bennaceur, Yuan-ming Xu and Hemza Layachi,[2][2019] in their paper they have used the constrained natural element method to optimize the cutout in the wing ribs of a light aircraft by adopting three different configurations.

Bindu H C, Muhammad Muhsin Ali H, [3] in their paper **[2018]** they have demonstrated to increase the critical buckling strength and reduced the weight of rib. Buckling analysis and linear static are performed on the idealized configuration using FEM packages.

S Bairavi, Mr. Suresh Balaji[4], in their paper **[2017]** they have come to the conclusion that when cut outs are present in aircraft wing ribs it creates stress concentration which eventually reduces the mechanical strength of the structure and in extreme cases may cause failure. In this paper the induced stress for ribs with circular, elliptical and rectangular cut outs have been found with the help of finite element software package ANSYS 14.

J.A. Newlin and Geo.W.Trayer[5][2016], they have conducted tests for many designs of wing ribs and these are compared with different types of sizes. They observed that reduction in weight of aircraft wing ribs is even more in efficient designs by greater proportional reduction in strength.

Kakumani Sureka and R Satya Meher[6][2016] in their paper they modelled A300 aircraft wing using standard NACA 64215 airfoil with spars and ribs digitally usingdifferent 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.

K. Sruthi, T. Lakshmana Kishore, M. Komaleswara Rao[7][2015] 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 usingaluminium 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 withaluminium alloy.

Avnish Kumar[8][2015] in his "Investigation of aerofoil design." Said that Lift coefficient was found to be higher for Asymmetric aerofoil than the Symmetric aerofoil for samechord length and maximum camber of the aerofoil at same angle of attack.

Aswani Kodali and T.N.Charyulu[9][2014] 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 8 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.

P.Jeevanantham, L.Mankumar[10][2012] 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.

Dr.R.Rajappan, & V.Pugazhenthi[11][2010] 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.

Nikhil A. Khadse & Prof. S. R. Zaweri[12][2010] 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.

T .Gultop,[13] (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.

Lica Flore and Albert Arnau Cubillo[14][2003] 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.

R. Das, R. Jones[15] "Damage tolerance based design optimization of a fuel flow vent hole in an aircraft structure", Journal of Structural Multidisciplinary Optimization, Volume: 38; Pg: 245–265 **(2002)** demonstrated the application of damage tolerance based optimization to investigate the shape optimization of a Fuel Flow Vent Hole (FFVH) located in the Wing Pivot Fitting of an F-111 aircraft. It is noteworthy that the presence of such 'cutouts' is common in engineering structures used in many industries such as rail, aerospace, naval, and mining. These 'cutouts' are typically used for lightening the structure or for providing passage for equipments and cooling. Hence, the methodologies outlined in this paper to optimize the cutout shape can be easily extended to durability based shape design in similar structures. The shape optimization of the vent hole was performed using the three basic design criteria relevant to damage tolerance design, viz, stress, residual strength, and fatigue life.

K. Kalita, S. Halder[16], "static analysis of transversely loaded Isotropic and Orthotropic plates with central cutout", Journal of Institution of Engineers, India series, C Vol: 95; Issue 4; Pg: 347-358 **(1998)** observed that maximum shear stress in all boundary conditions occurs at the cutout periphery. As expected in all cases, maximum deflection is seen near the cutout and decreases towards the constraints. The variation of SCF for all the plates, in general, is more in orthotropic plate as compared to isotropicplate. It is observed that SCF depends on elastic constants and hence differ from material to material. The induced stresses in all cases have been intentionally limited within the elastic range by selecting a suitable applied load.

Physical Decomposition of the Internal Structuref Aircraft Wings

The load bearing component of an aircraft wing is the wingbox. Fig. 2.1 shows a typical wingbox. It consists of skin, spars and ribs each playing a role in the overall capacity to resist loads. The construction is usually semi-monocoque, where the skin resists tension and shear while the stiffeners resist compression. The skin is stiffened by stringers that run along the span of the wing. The primary function of the spar webs is to resist the shear and torsional loads. If we isolate the rib itself (Fig. 2.2), we see that it is a complex structure. The rib has four primary functions:

1. Maintain the airfoil shape of the wing
2. Transfer air pressure loads from the skins to the spars
3. Resist fuel pressure loading
4. Diffuse local concentrated loads such as engine pylon mounts and movable surface attachment.

In the rib's design, it is idealized as a chord-wise beam that transfers the loads from the skin to the spars. The rib feet transfer the load from the skin to the rib body. The horizontal stiffeners resist the shear loads, while the vertical stiffeners resist the compressive loads due to air pressure. The rib has cut-outs within it, either to reduce weight or to allow for servicing or system holes. The system holes are necessary to enable hydraulic lines to pass through the rib. These geometric intricacies make the design of an aircraft wing complex. Gharbi et al, Mills and Burley, and Gunther et al. Give descriptions of the complexity involved in the design of aircraft wings and ribs.

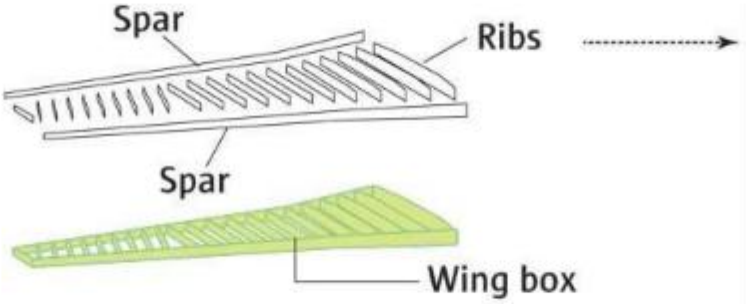


Figure 3.1**:** Breakdown Of Main Components Of An Aircraft Wingbox

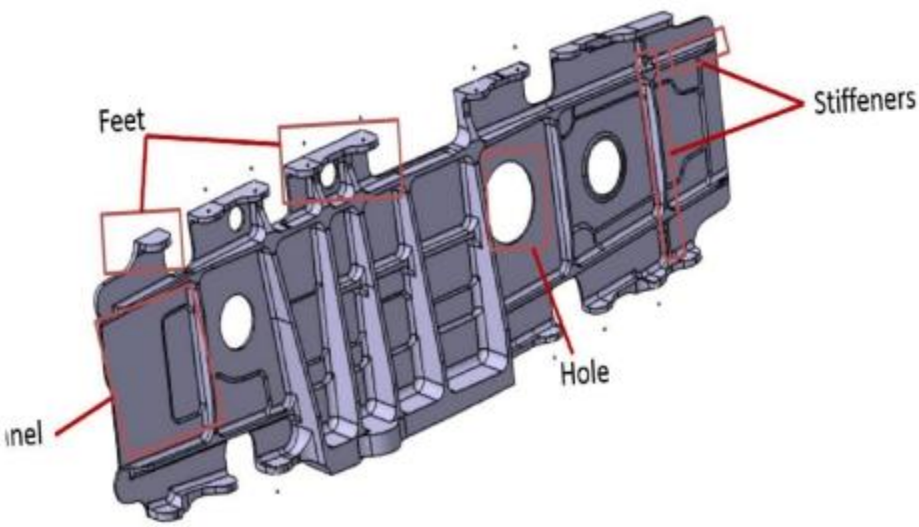


Figure 3.2**:** Aircraft Wing Rib

The complexity of the structural design of aircraft components arises from many features that each component is comprised of. Each of these features has a particular role
and undergoes a unique design process. Consider the rib discretized into n rows and m columns. Each cell is called a panel. Hence there are m _ n panels. Several configurationdecisions are made in each design operation, such as what type of holes to include in a
panel or what shape of castellation is used. Further, each configuration chosen needs to be sized hence having its own design variables.

double lattice method was used for the aerodynamic analysis. Separation control using a small number of fluidic oscillators located near the natural flow separation line is highly effective on a swept-back wing. A higher sweep angle increases the critical Mach number which increases the cruising speed. An increase in wing taper decreases the area of the wingtip of the wing which leads to the increase in wing divergence and flutter speeds. Interaction between the steady aerodynamic forces and static structural elastic forces is known as static aeroelasticity and another one is the interaction between the unsteady.

Design and Construction

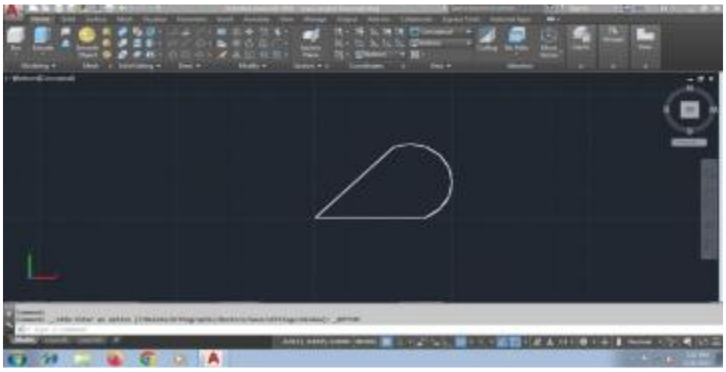
Aircraft is designed according to many factors such as, customer and manufacturer demand, safety protocols and physical and economic constraints. For many types of aircraft the design process is regulated by national airworthiness authorities.

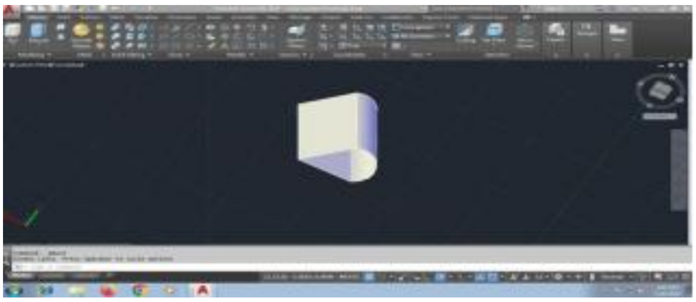
The key parts of an aircraft are generally divided into three categories:

- The structure comprises of the main load bearing element and associatedequipment.
- The propulsion system (If it is powered)comprises of power source andassociated equipment as described above.
- The avionics comprise the control, navitagition and communicationsystems,usually electrically in nature.

Wing Specifications:

- Young's modules=38*10^3 MPa
- Poisson's ratio=0.3
- Density=8.3E-5 g/mm^3
- Slope=0.25





Design of Aircraft Wing in Ansys

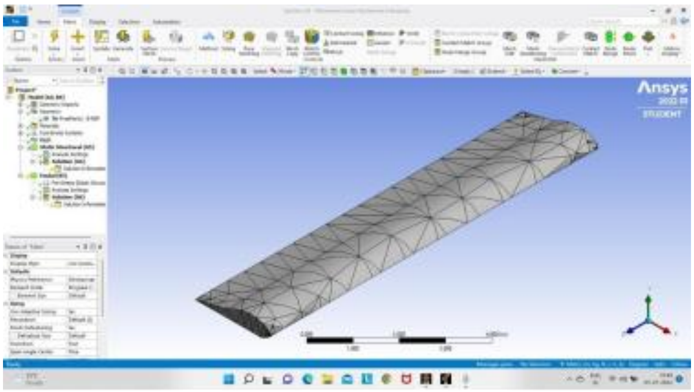


Figure7.10 Meshed Body

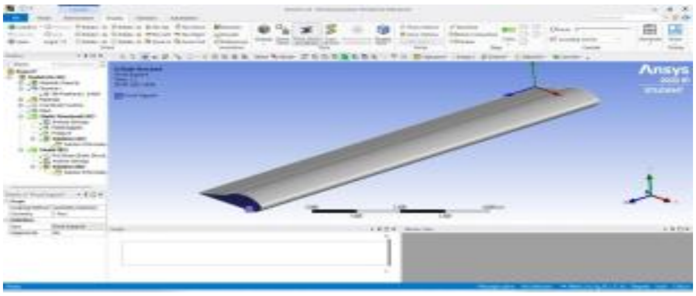


Figure 7.12 Fixed Support

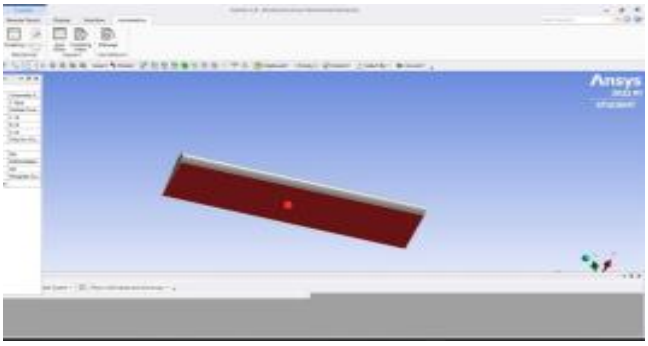


Figure 7.13 Pressure (500 N)

Structural Analysis With Al Alloy

Deformation:

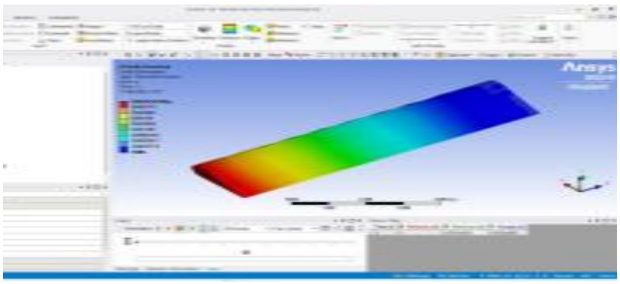


Fig 7.1.1 Total deformation value of aluminium alloy at pressure load 500Pa, it shows themax value of Total Deformation is 2.6745mm.

1. Equivalent stress:

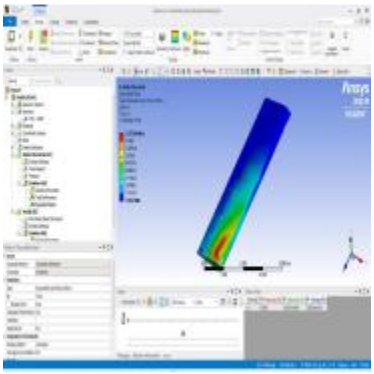


Fig 7.1.2 Equivalent stress value of aluminium alloy at pressure load 500Pa, it shows themax value of Equivalent stress is 1.5525 MPa.

2. Equivalent strain:

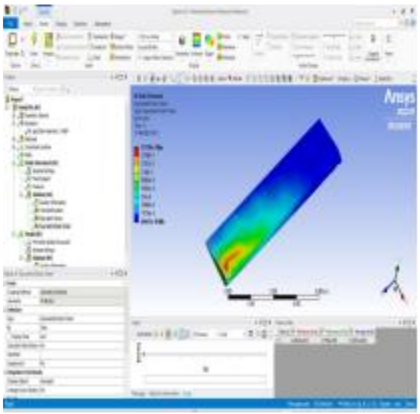


Fig 7.1.3 Equivalent Strain value of aluminium alloy at pressure load 500Pa, it shows themaximum value of Equivalent Strain is 0.00017759.

MODAL ANALYSIS

Modal Analysis With Ai Alloy:

Mode shape deformation 1

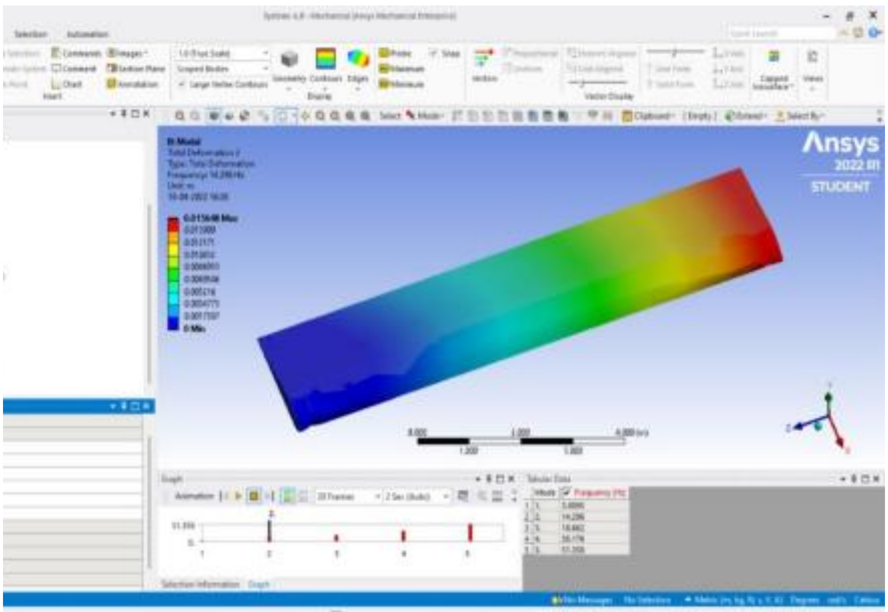


Fig 8.1.1 mode shape deformation

Mode shape deformation 2

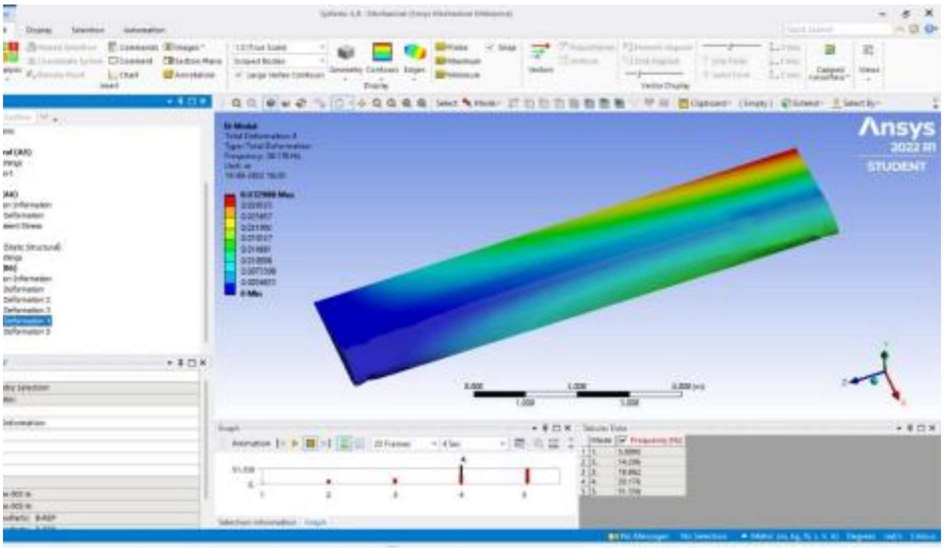
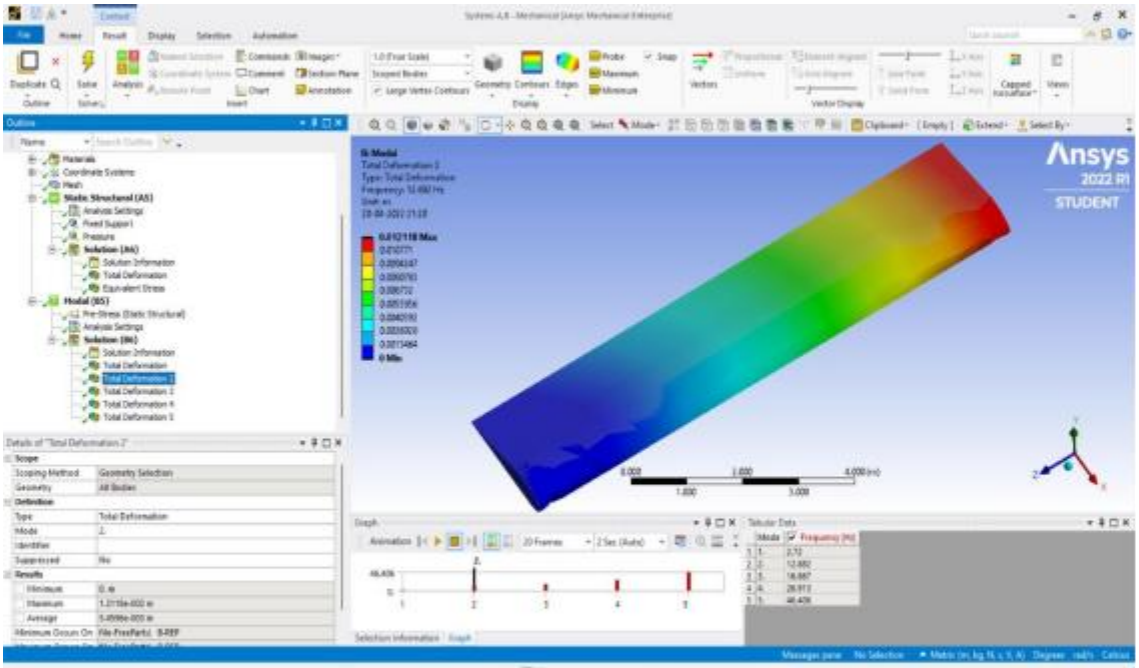


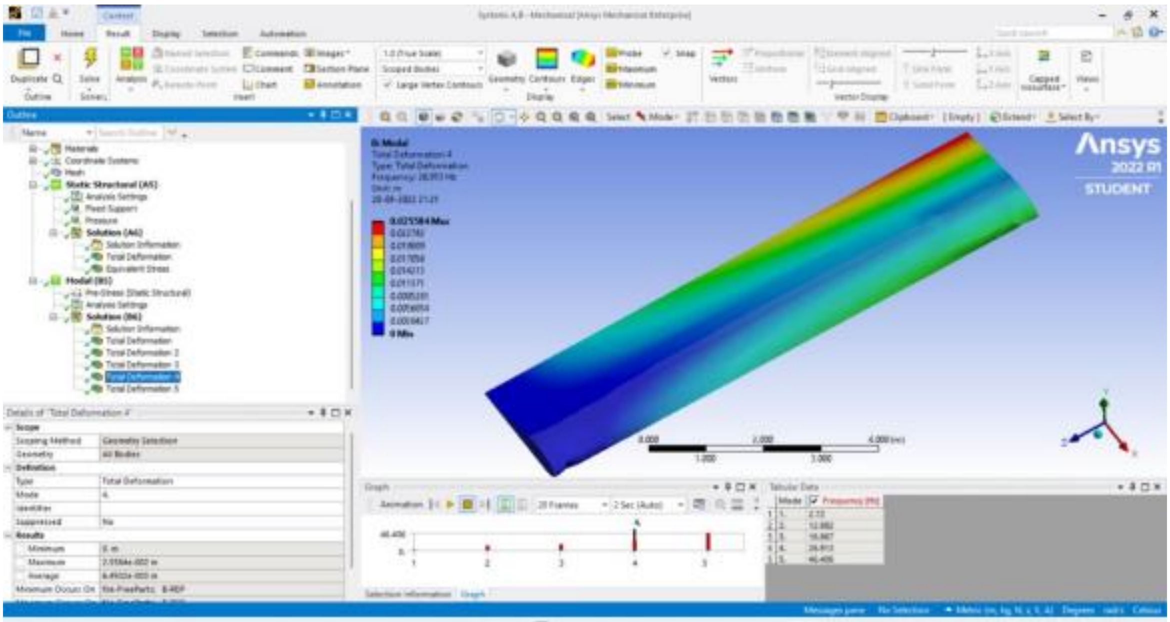
Fig 8.1.2 mode shape deformation

8.1 Modal Analysis With Ti Alloy:



Mode shape deformation 1

Fig 8.2.1 mode shape deformation



Mode shape deformation 2

Fig 8.2.2 mode shape deformation

Results and Graph

Results of Structural Analysis:

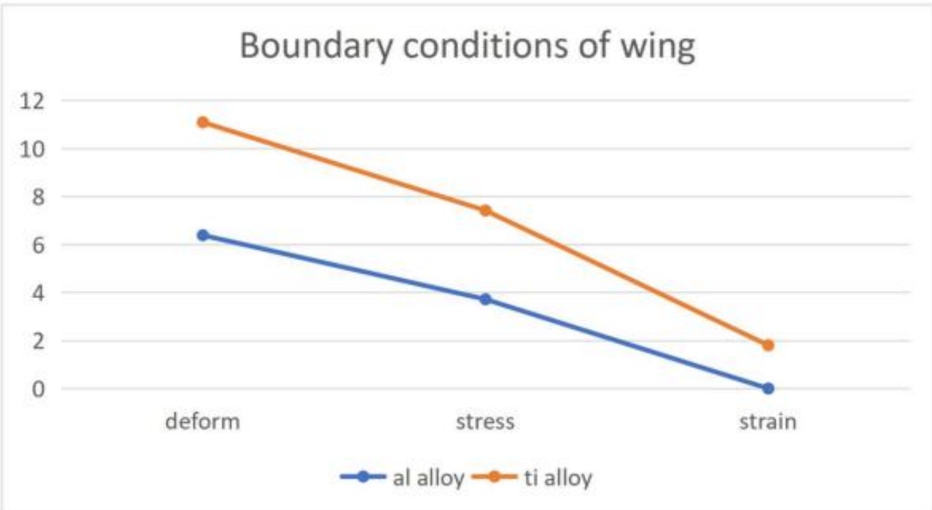
MATERIAL	ALUMINIUMALLOY	TITANIUM ALLLOY
Deformation(mm)	2.6745	1.9663
Equivalentstress(MPa)	1.5525	1.6984
Equivalent strain	0.00017759	0.00021996

Graph For Structural Analysis Of Aircraft Wing:

9.1 Results For Boundary Conditions Of Wing:

MATERIAL	ALUMINIUMALLOY	TITANIUM ALLLOY
Deformation(mm)	6.3819	4.7014
Equivalent stress(MPa)	3.7143	3.6968
Equivalent strain	0.0005254	0.0003869

9.1.1 Graph For Boundary Conditons Of Aircraft Wing:



Results of Modal Analysis:

ALUMINIUM		TITANIUM	
DEFORMATION (mm)	**FREQUENCY(Hz)**	**DEFORMATION (mm)**	**FREQUENCY(Hz)**
15.68	14.296	12.188	12.882
32.988	30.176	25.584	26.913

Future Scope

- In this project, the wing geometry is selected from NACA4412. The work can be extended by selecting other kind of geometry from different sources.
- The work can be extended by selecting different materials other than AL-Zn-Mg alloy 7178, ALUMINIUM LITHIUM A8090 and ALPHA- BETA TITANIUM ALLOY, those mainly provides weight reduction.
- the project can be extended to thermal analysis and vibration analysis with different load conditions.

Conclusions

- From the above results we can conclude that the values of equivalent stress,Total deformation and Equivalent strain of Al alloy is minimal.
- We can use Titanium alloy instead of using Aluminium alloy in order to give the more strength to the structure. The effect of stress during take-off condition is more for Titanium alloy and less for Aluminium alloy which is strongest and light weight, and also reduces the weight of the wing.
- Therefore we can conclude that titanium is best suited material for making of wing.

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