MODELING AND STRUCTURAL ANALYSIS OF AIRCRAFT WING USING ALUMINIUM ALLOY AND TITANIUM ALLOY

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Abstract - *A wing is a structural component of aircraft which is used to produce lift during the flight. Wing is initially inclined at certain angle of attack. When the flow passes over it, due to the pressure difference at top and bottom surface of the wing lift force is generated. The main purpose of this project is to find out which material (Aluminium alloy or Titanium alloy) is best suited for making of wing for subsonic flight. The wing is designed in solid modeling software CATIA V5 R21 and analysis is done using finite element method by using ANSYS. Static structural analysis of the wing is done to find deformation, stress, and strain induced in the wing structure. In this study, the aircraft wing structure with skin, 2 spars and 10 ribs are considered for the analysis. The ribs are running from leading edge to trailing edge and 2 spars running longitudinally along the length of wing. In conclusion, the recreation consequences indicate that the arrangement is possible and by comparing the results it is found that the Titanium alloy offers more flexural strength and mechanical properties.*

Key Words: Structural Behaviour, Deformation, Stress, Strain, Aircraft Wing, ANSYS.

1. INTRODUCTION

The composition and manufacture of aircraft wings demand attention to several unique structural requirements. High strength and lightweight are the two primary functional needs to be considered in selecting materials for the construction of an aircraft wing. Different material used to manufacture wing will experience a different type of structural behaviors. As the chief assembly to generate lift, the lifting surface is the total critical share of an airplane. The wing not lone assures flying steadiness but also provides a facility to support the strategic operation unit. There are many types of wing aircraft, such as the conventional wing, delta wing, wings having sweep, dihedral wing, tapered wing, and flexible geometry wing, and each wing will produce different aerodynamic characteristics, stability, and maneuverability.

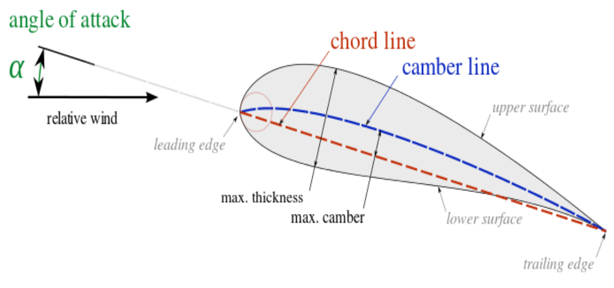
We know two basic methods of the modal analysis, namely the numerical modal analysis and the experimental modal analysis. The experimental modal analysis deals with measurements input data from which a mathematical model is derived. This paper is mainly concerned about numerical modal analysis. Wing construction is similar in most modern aircraft. In its simplest form, the wing is a framework made up of spars and ribs and covered with metal. Spars are attached to fuselage and the tip chord is free, hence aircraft wing is considered as a simple cantilever beam.

There will be several limitations and assumptions made throughout the analysis. Finally, the structural analysis of stress, strain, and deformation data of the wing is acquired from end to end transient structural analysis, which is smeared for optimization and improvement to the design of the aircraft for the future.

2. AIRFOIL TERMINOLOGY AND DEFINITIONS

2.1 AIRFOIL

In the airfoil profile, the forward point is called the leading edge and the rearward point is called the trailing edge. The straight line connecting the leading and trailing edges is called the chord line of the airfoil. The distance from the leading edge to the trailing edge measured along the chord line is designated as a chord (c). The mean camber line is the locus of points midway between the lower surface and upper surface when measured normal to the mean camber line itself. The camber is the maximum distance between the mean camber line and the chord line, measured normal to the chord line. The thickness is the distance between the upper and lower surfaces also measured normal to the chord line. The shape of the airfoil at the leading edge is usually circular, with a leading-edge radius of 0.02c, where c is the chord length. The upper and lower surfaces are also known as suction and pressure surface respectively.



2.2 AIRFOIL CLASSIFICATION

The Network of Aquaculture Centers in Asia-Pacific, airfoil series, the 4-digit, 5-digit, and the updated 4-/5- digit, were generated using analytical equations and analogies that described the curvature of the airfoil's mean-line (geometric centerline) as well as the section's thickness distribution along the length. Also, the families, which included the 6-Series, were more complex shapes which were derived using theoretical methods.

(I) NACA Four-Digit Series:

The family of airfoils which was curated by utilizing this approach was called the NACA Four-Digit Series. Here in, the maximum camber in the percentage of the chord (airfoil length) is given by the first digit, the second indicates the position of the maximum camber and lastly, the maximum thickness of the airfoil in the percentage of the chord is provided by the last two numbers. For example, the NACA 2415 airfoil has a maximum thickness of 15% with a camber of 2% located at 40% chord from the airfoil leading edge (or 0.4c). Using these values, one can compute the coordinates of the entire airfoil using specific equations.

(II)NACA Five-Digit Series:

The NACA Five-Digit Series and the Four-Digit Series are quite similar as they use the same thickness forms, but the mean camber line is defined differently and the naming convention is a bit more complex. The design lift coefficient (cL) is given by the first digit, when multiplied by 3/2, yields it in tenths. The next two digits, when divided by 2, give the position of the maximum camber in tenths of the chord. The final two digits again indicate the maximum thickness in a percentage of chord. Taking an example, the NACA 24013 has a peak thickness of 13%, a design lift coefficient of 0.3, and the maximum camber located 20% behind the leading edge.

At present, the resources available for computation allow the designers to design and optimize the airfoils specifically tailored to a particular application.

3. MATERIAL SELECTION

The metals used in the aircraft manufacturing industry include steel, aluminium, titanium and their alloys. In this project two materials are used, they are Aluminium alloy and titanium alloy, both materials have some characteristics which are best suited for wing design.

3.1 ALUMINIUM ALLOY

It is easily machined in certain tempers, and it has good strength as well as having high hardness. Mainly this material used in aerospace industry. Each material has some chemical composition.

3.2 TITANIUM ALLOY

Titanium alloys are more compatible with carbon fibers and are used to avoid galvanic corrosion problems. The greater use is driven by design in response to mechanical and thermal loads associated with high maneuverability and supersonic cruise speed.

3.3 MATERIAL PROPERTIES

The physical structure modelled in this work is an aircraft wing of airfoil cross section BOEING BACXXX. Its dimensions are that of a research subsonic aircraft wing. It is made of an aluminium alloy (1st case) and titanium alloy (2nd case) structure. The material properties used throughout this study are shown below:

Material	Young's Modulus (GPa)	Poisson's Ratio
Aluminium alloy	73	0.3
Titanium alloy	120	0.342

Table 1: Properties of materials.

4. WING DESIGN PROCEDURE

The amount of lift produced by an airfoil depends upon many factors. They are angle of attack, the lift devices used (like flaps), the density of air, the area of wing, the shape of wing, the speed at which the wing is travelling. Some Factors affecting wing size they are cruise drag, stall speed, take-off and landing distance. The first step is to get the airfoil shape in the CATIA workbench. As we are considering that wing is designed with only one airfoil throughout, it has to be scaled down accordingly to get the required shape of a wing profile.

4.1 SELECTION OF AIRFOIL

Beforehand the scheme plans underway, values for several constraints must be selected. These comprise the airfoil as, in numerous venerations, it is the core of the aircraft. Correspondingly, the airfoil upsets the voyage quickness, take-off, and landing stage spaces, cubicle speed, management abilities, and total aerodynamic efficacy through all stages of voyage. BOEING BACXXX airfoil is being used in Boeing 747-400 and the design has a high lift characteristic in subsonic speed, and thus it is very suitable for the transport aircraft of Boeing 747-400. Therefore, for wing Skelton structure we use BOEING BACXXX airfoil co-ordinates.

4.2 WING COMPONENT DESIGN

The physical structure modelled in this work is an aircraft wing of airfoil cross section BOEING BACXXX. Its dimensions are that of a research subsonic aircraft wing. It is made of an aluminium alloy (1st case) and titanium alloy (2nd case) structure.

Since there are several limitations and due to the wing structure complexity and tremendously laborious if not challenging to convey out, the geometry of the exemplary is streamlined by declining the scale of the wing and omitting numbers of struts as they do not underwrite in contradiction of bending. This can be finished since collapsing on the membrane was not shaped. Moreover, this wing component design is made up of a 1:4 ratio since there are limitations that the software cannot solve the design problem. Thus, the wing structure design specifications are made purposely for this research paper is as follows

Wing Span		4500mm
Chord Length		1000mm
Airfoil		BOEING BACXXX
Taper Ratio		1
Sweep Angle		0°
Ribs Design	Root and Tip Thickness	40mm
	Other Ribs	20mm
Spars	Length	4500mm
	Thickness	60mm

Table 2: Wing component design specification.

4. FINITE ELEMENT GEOMETRY AND MODELLING

Firstly, to have a very smooth curved line of BOEING BACXXX airfoil, the point co-ordinates were exported from the airfoil tools and UIUC airfoil Coordinates Database. It is much accurate compared to sketching the curved line of BOEING BACXXX airfoil.

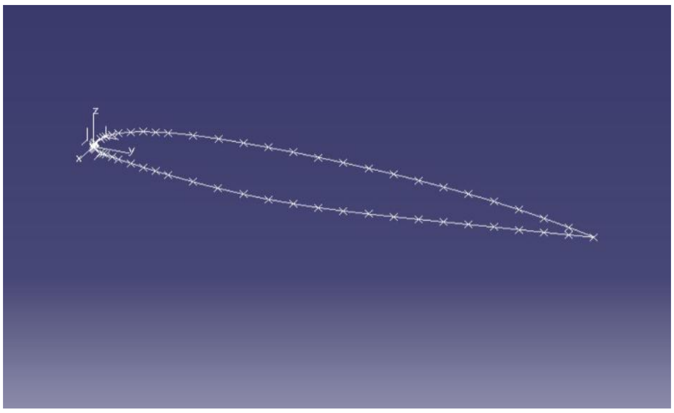


Figure 1: Airfoil Co-ordinates.

Secondly, spars and holes are sketched at the front plane. The dimensions of main spars, secondary spars, and holes are shown in figure below.

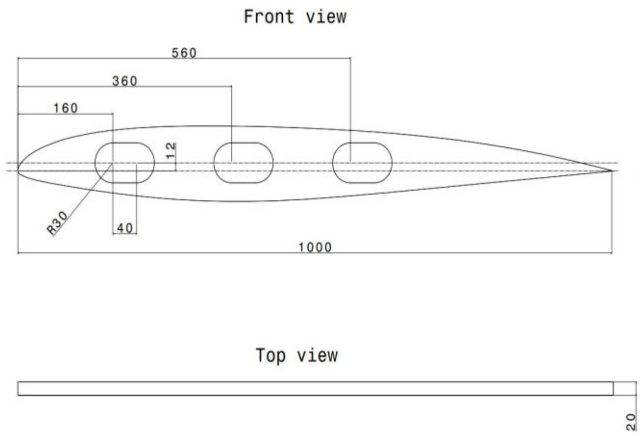


Figure 2: Dimension of the rib.

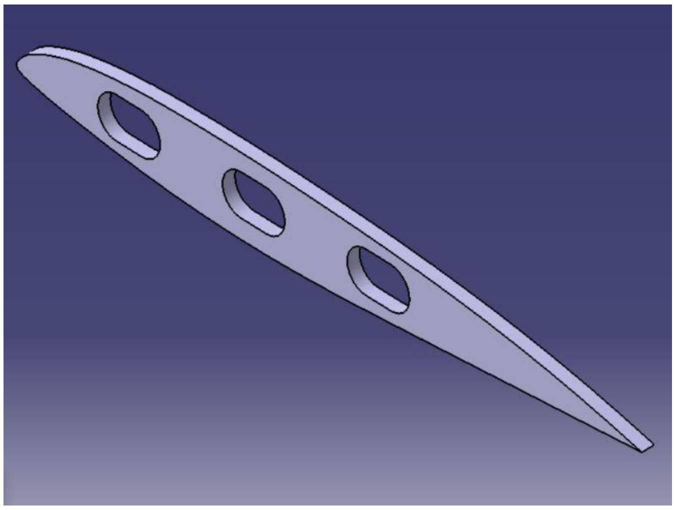


Figure 3: Isometric view of the rib in XYZ-plane.

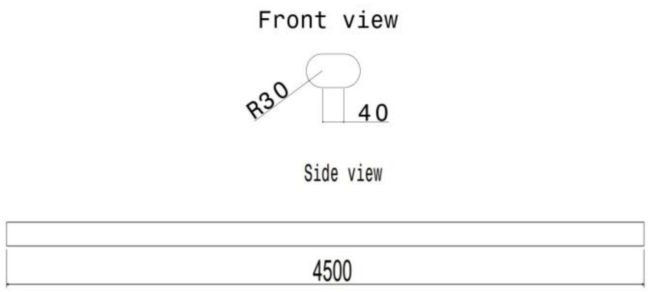


Figure 4: Dimension of both primary and secondary spars.

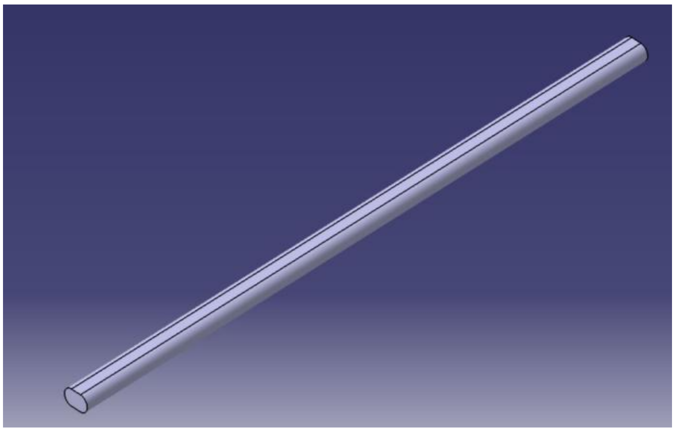


Figure 5: Isometric view of the spar in XYZ-plane.

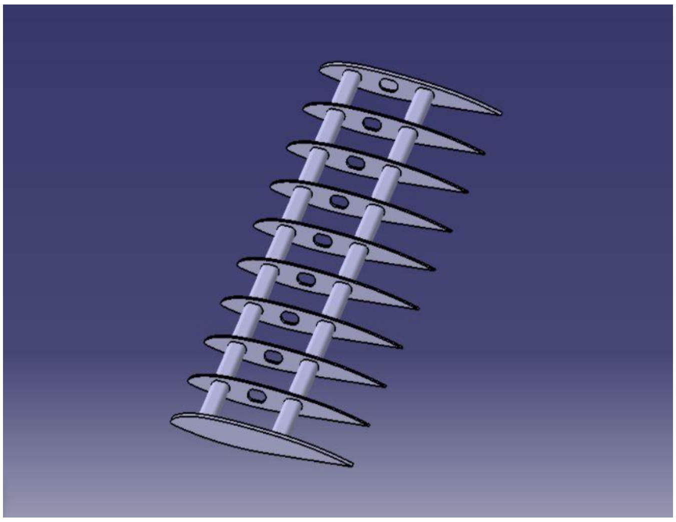


Figure 6: Internal structure of the wing model.

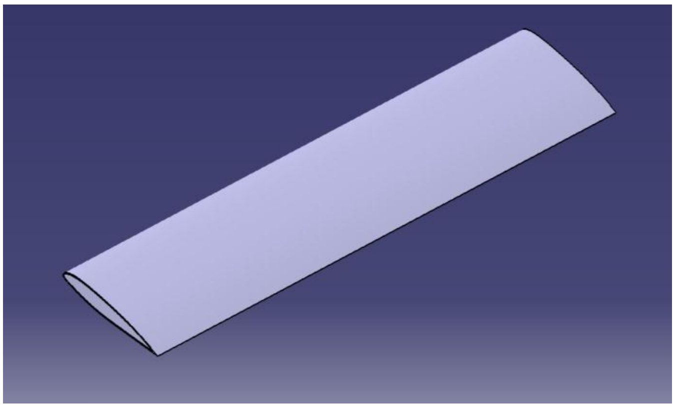


Figure 7: Wing skin of the wing.

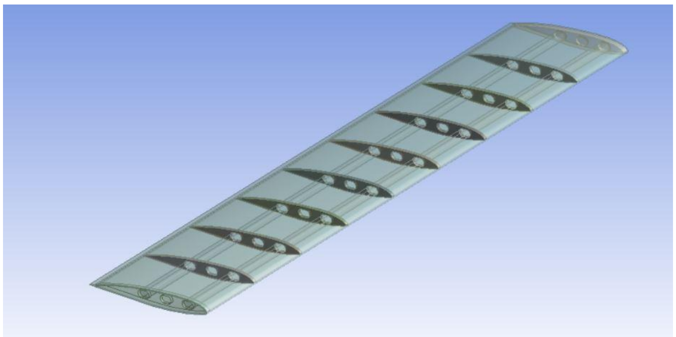


Figure 8: Assembly of the wing.

5. FINITE ELEMENT MESHING AND BOUNDARY CONDITIONS

Generating a mesh is one of the most critical steps in FEM for obtaining reasonable results. Many types of, 2D and 3D, elements can be used. Figure illustrates some mesh elements. The type of elements chosen depends on the type of geometry and the nature of the analysis. Each element has an ideal shape and due to complex geometries, the element has to be deformed so that it fits. This is referred to as mesh skewness and the bigger it is the less accurate approximations are. Increasing the number of elements solve the issue of overly skewed elements.

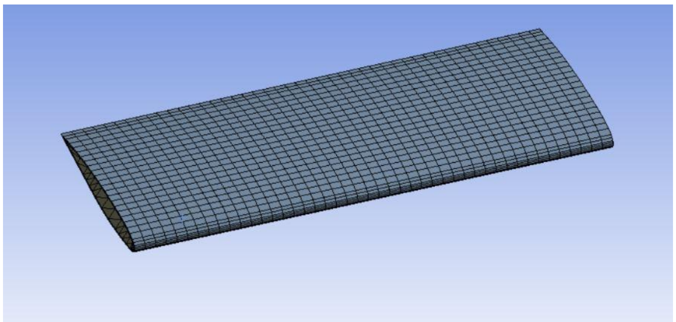


Figure 9: Meshed wing structure.

In boundary condition one end of the wing is fixed because it is embedded inside the fuselage and other end is left free with 6 degree of freedom. Pressure force of 500Pa is applied at the bottom surface of the wing at center of pressure. Center of pressure is a point at which total pressure is assumed to be acted.

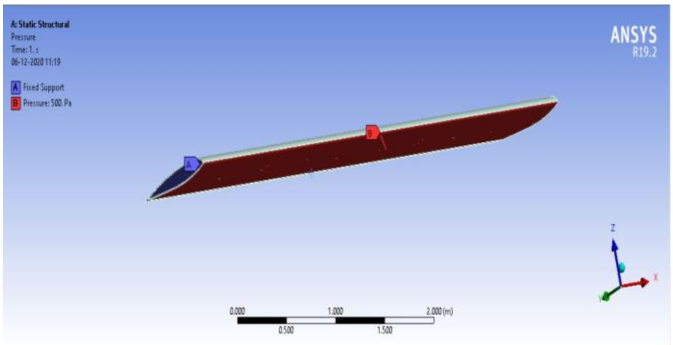


Figure 10: Boundary conditions.

6. STATIC STRUCTURAL ANALYSIS

Static structural scrutiny is functional to analyze the wing as it does not depend on the time motion. The aim of this study is to do the analysis and the structural trend of a three-dimensional wing with no motion of time. Thus, to observe the structural behavior of the wing, static structural analysis is the best pick.

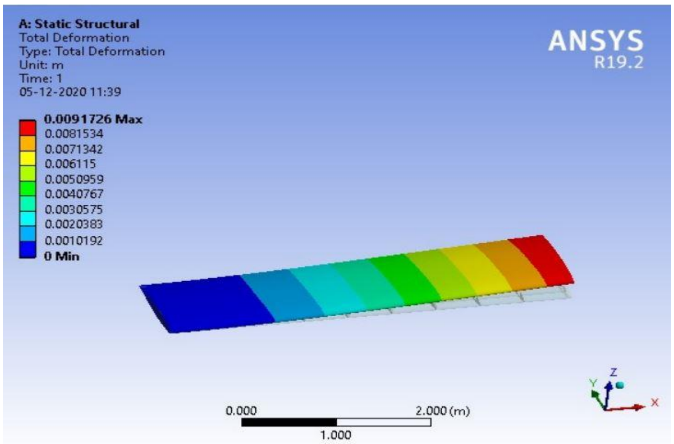


Figure 11: Total Deformation for aluminium alloy.

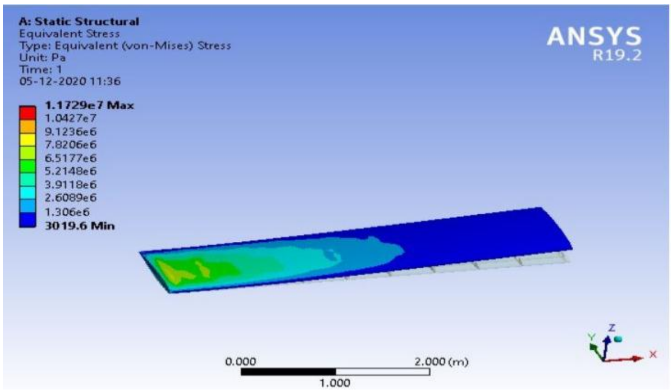


Figure 12: Equivalent (Von-Mises) Stress of aluminium alloy.

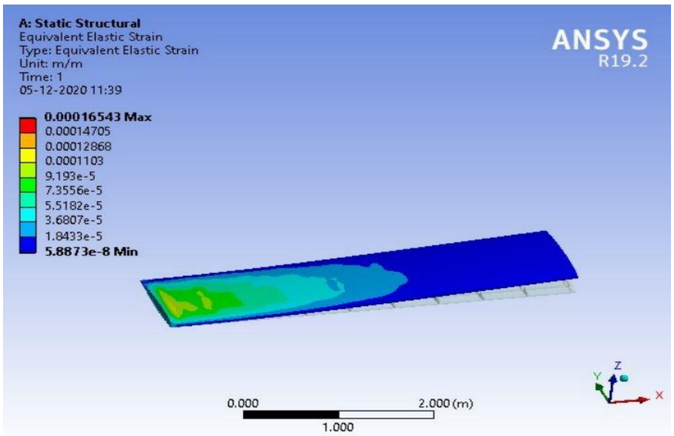


Figure 13: Equivalent Elastic Strain of aluminium alloy.

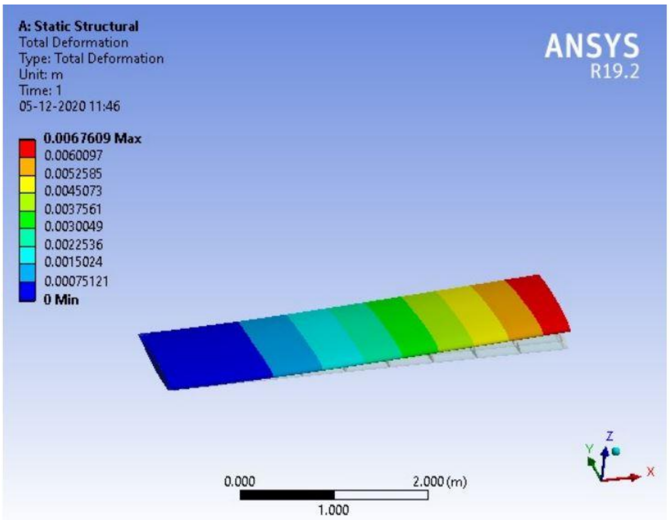


Figure 14: Total Deformation of titanium alloy.

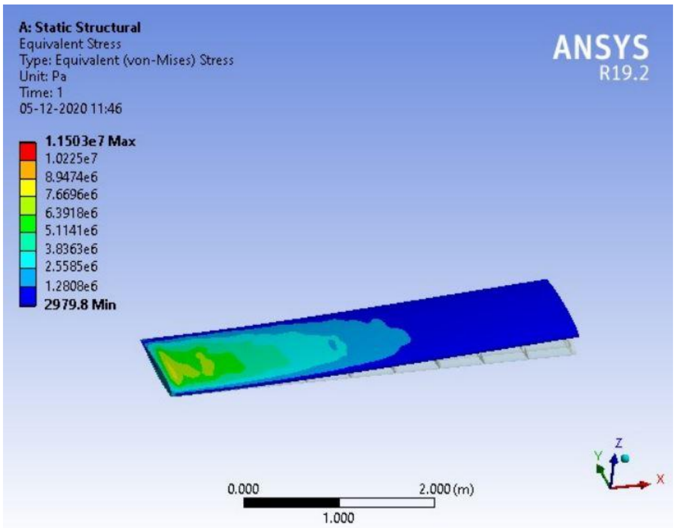


Figure 15: Equivalent (Von-Mises) Stress of titanium alloy.

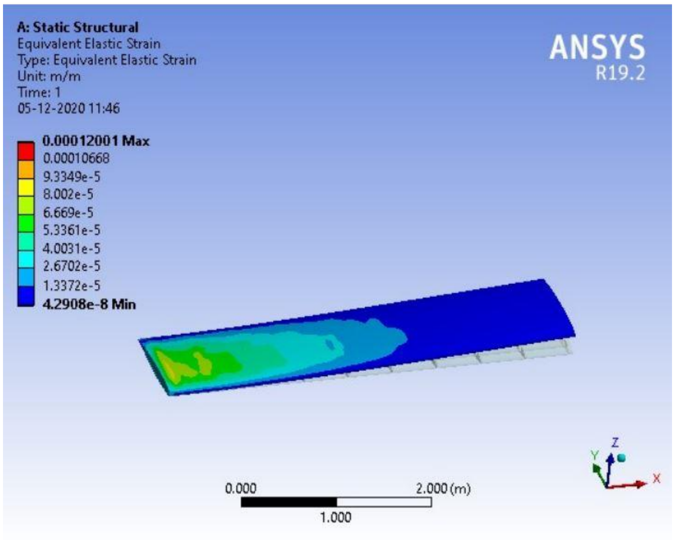


Figure 16: Equivalent Elastic Strain of titanium alloy.

Material	Range	Total Deformation (m)	Equivalent (Von-Mises) Stress (pa)	Equivalent Elastic Strain (m/min)
Aluminium alloy	Min	0.00000	3019.6	5.8873×10^{-8}
	Max	0.00917	1.1729×10^{7}	0.00016
Titanium alloy	Min	0.00000	2979.8	4.2908×10^{-8}
	Max	0.00676	1.1503×10^{7}	0.00012

Table 3: Result of static structural analysis

7. CONCLUSION

In conclusion, the structural behavior of a BOEING BACXXX airfoil three-dimensional wing has been simulated through two different cases of wing structure, which contain aluminium alloy in first case and titanium alloy in second case. The second case of the wing shows lower deformation compared to the first case in both fixed structural investigation and modal investigation. Besides, the validation of results from the past studies using ANSYS is considered as a success and dependable as the percentage error is allowable. Finally, through the static structural investigation, the deformation of the lifting surface structure has also been observed and is figured out. As future enhancement, different materials can be tested with different boundary conditions to find more suitable materials with good aerodynamic and structural characteristics.

8. REFERENCES

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