International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 10 | Oct 2018 www.irjet.net p-ISSN: 2395-0072

# STRUCTURAL AND MODAL ANALYSIS OF SUBSONIC AIRCRAFT WING USING ANSYS WORKBENCH

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**Abstract:-** *Structural analysis is an important part of the design and development of the aircraft structure. Design of airplanes depends on their wings for flight. The wing of an airplane is one of the most important and complicated element. The wings are the most important lift-producing part of the aircraft. Wings vary in design depending upon the aircraft type and its purpose. A wing is a type of fin with a surface that produces aerodynamic force for flight through the atmosphere. The lift force is directed upwards and is acting perpendicular to the displacement of the wing and the drag force is exerted in the direction opposed to the displacement of the plane. Hence, this presentation includes the detailed analysis of the structural analysis of wing. 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. In this the NACA-4 digit series is used for making wing skeleton structure and later we made modelling and structural analysis on wing Skelton structure by using ANSYS WORKBENCH. Structural analysis of the wing is carried out to compute the stresses due to pressure and various loads. The modelling, analysis and stresses are estimated using the Ansys software.*

**Keywords**: Aircraft wing, Aluminium alloy, Titanium alloy, ANSYS workbench.

## 1. INTRODUCTION

The design of an aircraft or an aircraft part (in this case, we will be referring to the wing) is a prolonged process that has mainly three phases;

The first is the conceptual design phase, and it is the phase that we have employed here, this phase deals with the layout of the aircraft/aircraft part and what major characteristics it must have in order to achieve its design goals, if the conceptual design is to be a success no major changes should be implemented on it in future phases. Hence, the conceptual design engulfs the major characteristic of the aircraft while delivering a layout of its major components.

The second and third phases of the design process are the preliminary and detail design phases; these phases deal with the analysis of the aircraft components in all major aspects of aerospace such as structures, dynamics, control and others. An aircraft wing is a type of fin that produce lift, while moving through air or. As such, wings have efficient cross-sections that are subject to aerodynamic forces and act as an airfoils. Wing play a key role in aircraft design. Wings generate the lift required to keep airplanes in the air. Lift occurs as the plane is pushed through the air. The top part of the wing is curved while the bottom is straight. Which cause the air on top to move faster, the faster moving air on top of the wing creates a low pressure that lifts while the higher pressure on the bottom of the wing. Aircraft wings are the lifting surfaces with the chosen aerofoil sections. The efficiency as well as the performance of an aircraft mostly depends on the aerodynamic characteristics e.g. lift, drag, lift to drag ratio, etc. of wings. Besides many factors, the effects of wing shape are also crucial to aircraft performance.

## 2. AIRFOIL TERMINOLOGY AND DEFINITIONS

### 2.1AIRFOIL

An airfoil shape is defined by several parameters, which are shown in the figure below.

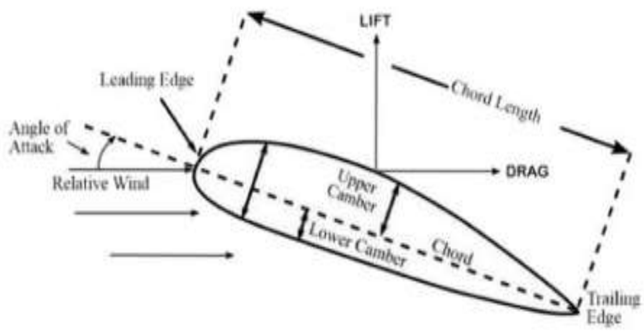


Figure1: Airfoil Geometry

- Chord Line: Straight line drawn from the leading edge to the trailing edge
- Chord Length (c): Length of the chord line
- Mean Camber Line: Curved line from the leading edge to the trailing edge, which is equidistant between the upper and lower surfaces of the airfoil
- Maximum (or just) Camber: Maximum distance between the chord line and the mean camber line.

### 2.2 NACA 4-DIGIT SERIES

Consider the airfoil NACA 4412. The first digit gives maximum camber in percentage of chord, the second digit gives in tenth of a chord where the maximum camber occurs,

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and the last two digits give the maximum thickness in percentage chord.

## 3. MATERIAL SELECTION

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 fibres 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 manoeuvrability and supersonic cruise speed.

### 3.3 MATERIAL PROPERTIES

The material properties used throughout this study are shown below Table 1

Table 1: Material Properties

| Material | Aluminium alloy | Titanium Alloy |
|---|---|---|
| Young's Modulus (Gpa) | 73 | 120 |
| Poisson's Ratio | 0.3 | 0.342 |

## 4. PROBLEM SPECIFICATION

In this project we find which material is best suited for the subsonic aircraft wing (Aluminium alloy or Titanium alloy). For wing Skelton structure we use NACA 4412 co-ordinates. We apply the boundary conditions on the wing. We fixed one end of the wing and we will apply the pressure 500 pa on the top of wing and the gravity along Y-Direction. We are interested to find out the structural parameters like total deformation, equivalent stress, max principle stress, Equivalent Strain, and also shear stress. Comparing of the two materials is done and the best material is chosen for the wing design according to the best suited structural parameters.

## 5. FINITE ELEMENT ANALYSIS

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. In practice, a finite element analysis usually consists of three principal steps:

1. Pre-processing

2. Analysis

3. Post processing

## 6. 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 Ansys 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. As said earlier, for wing Skelton structure we use NACA 4412 co-ordinates.

### 6.1 PHYSICAL MODEL OF WING

The physical structure modelled in this work is an aircraft wing of airfoil cross section NACA 4412 series. Its dimensions are that of a research subsonic aircraft wing. The chord length at the free end is 0.4m and at the fixed end is 1m while the length of the wing is 5m. The dimension of this model is a tapered aircraft wing. It is made of an aluminium alloy (1st case) and titanium alloy (2nd case) structure.

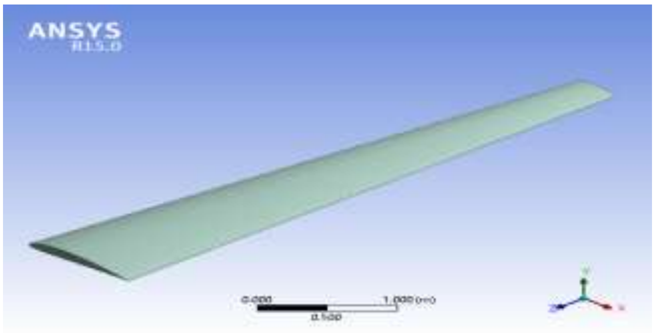


Figure 2: Physical model of aircraft wing

### 6.2 MESHING

The figure shows an example of a possible mesh of the wing.

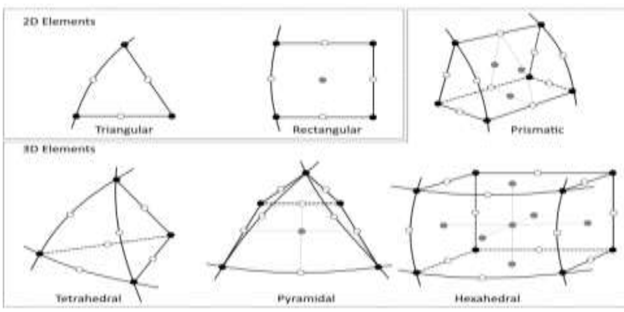


Figure 3: 2D and 3D Mesh Elements

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.

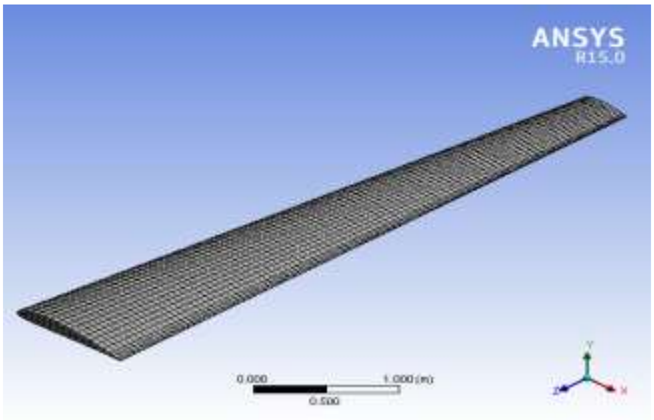


Figure 4: Meshed wing structure

### 6.3 BOUNDARY CONDITIONS

We fixed one end of the wing and we have applied the pressure 500 Pa on top of the wing along with the gravitational force as shown in the figure below.

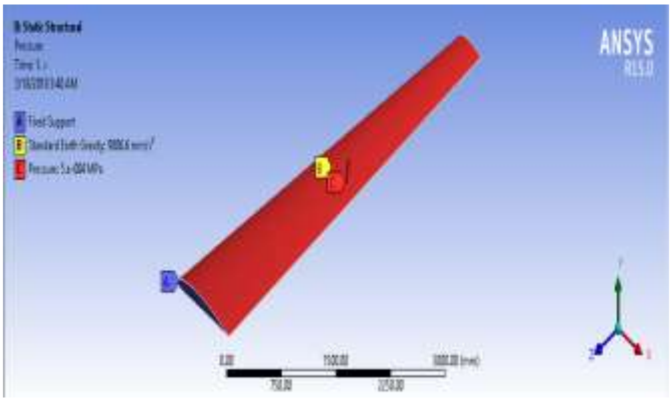


**Figure 5: Wing with Boundary Conditions**

## 7. SOLUTIONS AND DISCUSSIONS

In static structural analysis we are interested to find the total deformation, Von Mises stress which is also known as equivalent stress, shear stress and Von Mises Strain induced in the Skelton structure of the wing. For the 1st case we will be doing the structural analysis of aluminium alloy and the 2$^{nd}$ case we will consider for the titanium alloy.

### 7.1 STRUCTURAL ANALYSIS WITH AL ALLOY

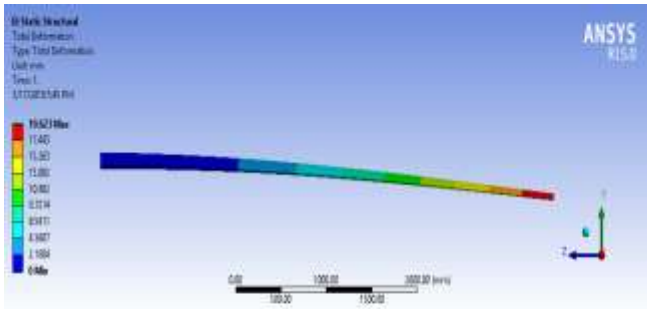


Figure 6: Total deformation value of aluminium alloy at pressure load 500Pa, it shows the max value of Total Deformation is 19.623mm.

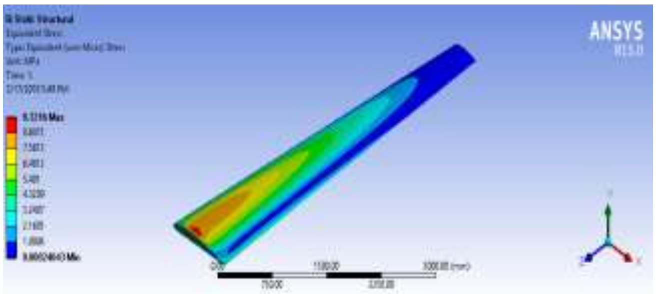


Figure 7: Equivalent stress value of aluminium alloy at pressure load 500Pa, it shows the max value of Equivalent stress is 9.7126 MPa.

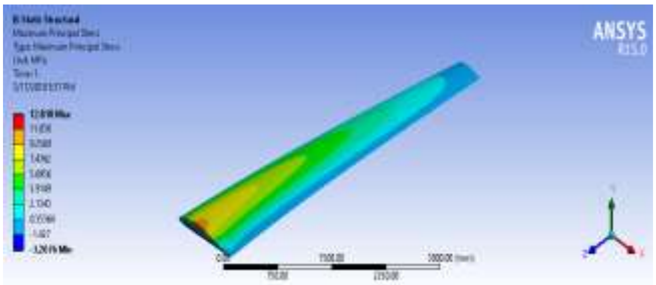


Figure 8: Maximum principle stress value of aluminium alloy at pressure load 500Pa, it shows the max value of maximum principle stress is 12.818 MPa.

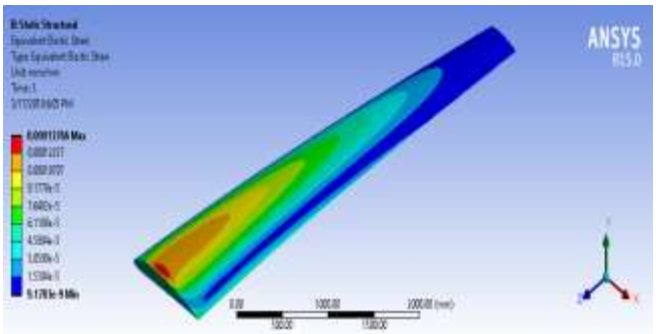


Figure 9: Equivalent Strain value of aluminium alloy at pressure load 500Pa, it shows the maximum value of Equivalent Strain is 0.00013766.

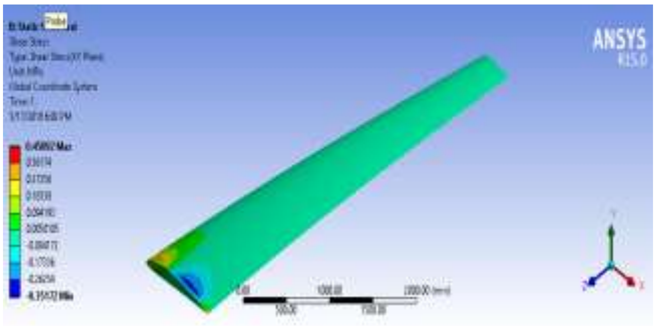


Figure 10: Shear Stress of aluminium alloy at pressure load 500Pa, it shows the maximum value of Shear Stress is 0.45092 Mpa.

### 7.2 STRUCTURAL ANALYSIS WITH Ti ALLOY

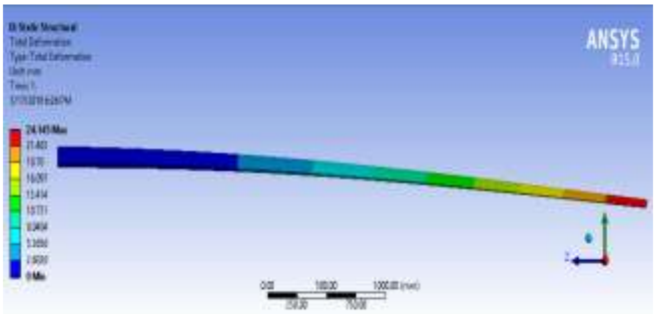


Figure 11: Total deformation value of titanium alloy at pressure load 500Pa, it shows the max value of Total Deformation is 24.145mm.

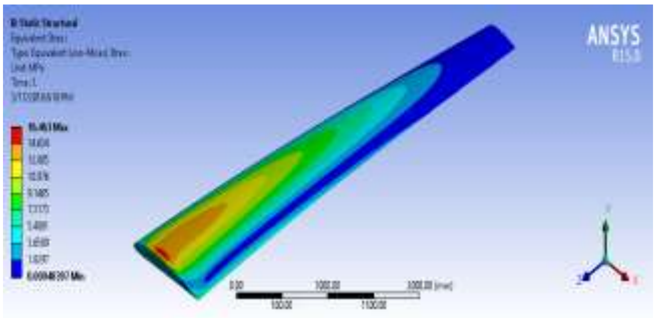


Figure 12: Equivalent stress value of Titanium alloy at pressure load 500Pa, it shows the max value of Equivalent stress is 16.463 MPa.

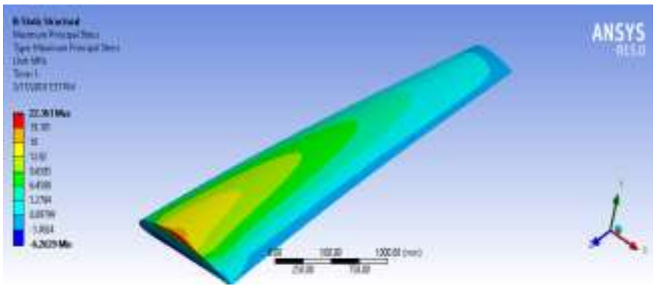


Figure 13: Maximum principle stress value of Titanium alloy at pressure load 500Pa, it shows the max value of maximum principle stress is 2290.9 MPa.

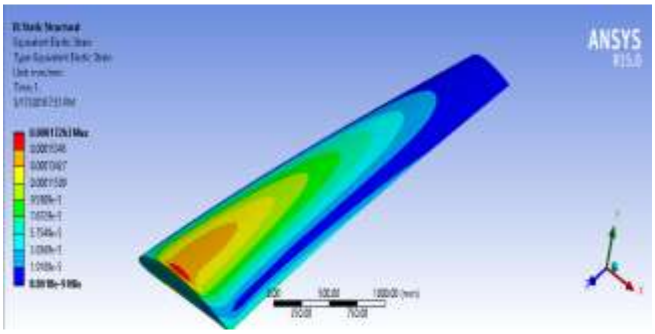


Figure 14: Equivalent Strain value of Titanium alloy at pressure load 500Pa, it shows the maximum value of Equivalent Strain is 0.00017263.

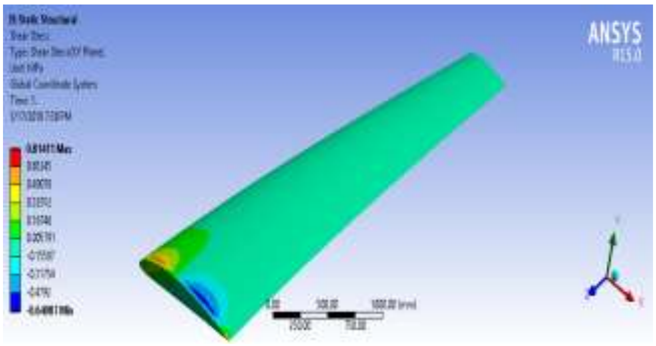


Figure 15: Shear Stress of aluminium alloy at pressure load 500Pa, it shows the maximum value of Shear Stress is 0.81411 Mpa.

### 7.3 RESULTS OF STRUCTURAL ANALYSIS

The Table 2 shows the values of deformation, equivalent stress, Maximum principle stress, Equivalent Strain, shear stress with aluminium alloy and titanium alloy.

Table 2: Structural Analysis Results comparison

| MATERIAL | ALUMINIUM ALLOY | TITANIUM ALLOY |
|---|---|---|
| Deformation (m) | 19.623 | 24.145 |
| Equivalent Stress (MPa) | 9.7216 | 16.463 |
| Maximum Principal Stress (MPa) | 12.818 | 22.361 |
| Shear stress (MPa) | 0.45092 | 0.81411 |
| Equivalent Strain | 0.00013766 | 0.00017263 |

### 7.4 MODAL ANALYSIS

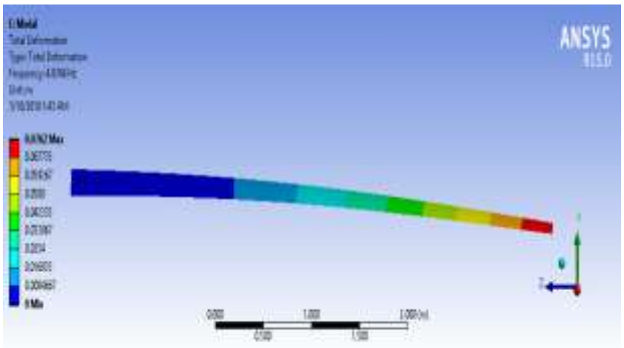


Figure 16: Mode shapes

## 8. CONCLUSIONS

From the above results we can conclude that the values of equivalent stress, maximum principle stress, shear stress, Total deformation and Equivalent strain of Al alloy is minimal.

❖As Ti alloy is much harder to bend, drill and cut than Al alloy so building a wing out of cheap Ti alloy would significantly increase its manufacturing costs over Al alloy.

❖ Ti retains its strength at high temperatures far better than Al alloy but in subsonic aircraft like passenger planes, airframe heating is not a design limiter that would drive a choice between selecting Ti alloy or Al alloy.

❖ 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.

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