

## Dynamic and Static Analysis of NACA 2412 Series

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### ABSTRACT

An aerofoil is the cross sectional shape of a wing, blade or sail. It gives the most favourable ratio of lift to drag. The current design project is focussed on static and dynamic analysis of an aerofoil used in swept back wing. Performance of an aircraft highly depends on shape of an aerofoil, material and angle of attack. Of all the aerofoil shapes available NACA 2412 series has been selected. The current project analyses the effect of drag and lift forces acting on aerofoil .at different angles of attack and various materials. Different parameters like stress, strain and deformation were calculated for different materials by software analysis. The results were compared and best optimum material was selected. The current project design is done in solid works 2016 version by taking coordinates from Aerofoil Database. The stress, strain and deformations are found using ANSYS16.0 for 15 and 25 degree angle of attack. Then dynamic analysis is done for a frequency range of 0 to 1000 Hz. Thus the results obtained are checked for accuracy and the comparisons are made to determine the best suitable material for aerofoil design of an aircraft wing.

### INTRODUCTION

Aircraft wing is the main component of an aircraft. A wing is an appendage with a surface that produces lift for flight or propulsion through the atmosphere, or through another gaseous or liquid. A wing is an aerofoil, which has a streamlined cross-sectional shape producing a useful lift to drag ratio. The wings are aerofoils attached to each side of the fuselage and are the main lifting surfaces that support the airplane in flight. Wings vary in design depending upon the aircraft type and its purpose. Most airplanes are designed so that the outer tips of the wings are higher than where the wings are attached to the fuselage.

This upward angle is called the dihedral and helps keep the airplane from rolling unexpectedly during flight. Wings also carry the fuel for the aeroplane. The wing is a framework made up of spars, ribs, skin and (possibly) stringers. Aircrafts can have one wing, two wings or three wings. And modern aircrafts generally employ mono wing. And the wing design in this project is used in mono wing aircrafts. A single wing usually has a longer wing span compared with two wings (with the same total area). Old manufacturing technology was not able to structurally support a long wing to stay level and rigid. With the advance in the manufacturing technology and also new aerospace strong materials; such as advanced light aluminium, and composite materials; this reason is not valid anymore. Another reason was the limitations on the aircraft wing span. Hence a way to reduce the wing span is to increase the number of wings. Thus, a single wing (that includes both left and right sections) is almost the only practical option in conventional modern aircraft.

However, a few other design considerations may still force the modern wing designer to lean toward more than one wing. The most significant one is the aircraft controllability requirements. An aircraft with a shorter wing span delivers higher roll control, since it has a smaller mass moment of inertia about x axis. Therefore if you are looking to roll faster; one option is to have more than one wing that leads to a shorter wing span. Several maneuverable aircraft in 1940s and 1950s had biplane and even three wings. On the other hand, the disadvantages of an option other than monoplane

**Cite this article as:** Allu Jagadeesh & Kosuru Kumar, "Dynamic and Static Analysis of NACA 2412 Series", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 6, Issue 5, 2019, Page 65-80.

include higher weight, lower lift, and pilot visibility limits. The recommendation is to begin with a monoplane, and if the design requirements were not satisfied, resort to higher number of wings.

## 1.2 TYPES OF WINGS:

One of the wing parameters that could be determined at the early stages of wing design process is the wing vertical location relative to the fuselage centre line. This wing parameter will directly influence the design of other aircraft components including aircraft tail design, landing gear design, and centre of gravity. In principle, there are four options for the vertical location of the wing. They are:

1. High wing
2. Mid wing
3. Low wing

### 1.2.1. HIGH WING:

A high wing is a configuration with the wings set on the top of the airplane's body, called the fuselage. The high wing aircrafts are generally used in cargo planes.

#### ADVANTAGES:

- Eases and facilitates the loading and unloading of loads and cargo into and out of cargo aircraft. For instance, truck and other load lifter vehicles can easily move around aircraft and under the wing without anxiety of the hitting and breaking the wing.
- Facilitates the installation of engine on the wing, since the engine (and propeller) clearance is higher (and safer), compared with low wing configuration.
- Saves the wing from high temperature exit gasses in a VTOL2 aircraft. The reason is that the hot gasses are bouncing back when they hit the ground, so they wash the wing afterward. Even with a high wing, this will severely reduce the lift of the wing structure. Thus, the higher the wing is the farther the wing from hot gasses.
- In a high wing, struts have to withstand tensile stress, while struts in a low wing must bear the

compression stress High wing will increase the dihedral effect. It makes the aircraft laterally more stable

- The wing will produce more lift compared with mid and low wing.



**Figure 1.2.1. High wing**

#### DISADVANTAGES:

- The aircraft frontal area is more (compared with mid wing). This will increase aircraft drag.
- A high wing is structurally about 20% heavier than low wing

### 1.2.2. LOW WING:

The low wing aircrafts are aircrafts whose wings are attached at the bottom of the aircraft fuselage. Now a days almost all passengers aircraft have a low wing configuration.

#### ADVANTAGES:

- The aircraft take off performance is better; compared with a high wing configuration; due to the ground effect.
- Aircraft frontal area is less.
- The aircraft drag is low.
- The aircraft has higher lateral control compared with a high wing configuration, since the aircraft has less lateral dynamic stability, due to the fuselage contribution to the wing dihedral effect.
- The tail is lighter; compared with a high wing configuration.



**Figure 1.2.2 Low wing**

#### DISADVANTAGES:

- The wing generates less lift; compared with a high wing configuration; since the wing has two separate sections.
- The aircraft has a lower landing performance, since it needs more landing run.
- The aircraft is laterally dynamically less stable.

#### 1.2.3. MID WING:

Aircrafts with wings attached at the mid portion (height wise) of the fuselage are known as Mid Wing aircrafts. Generally almost all the combat aircrafts are mid wing aircrafts. The advantages and disadvantages of this wing lie between that of high and low wing. Some new features of a mid-wing configuration are as follows:

- The aircraft structure is heavier, due to the necessity of reinforcing wing root at the intersection with the fuselage.
- The mid wing is more expensive compared with high and low wing configurations.
- The mid wing is more attractive compared with two other configurations.
- The mid wing is aerodynamically streamliner compared with two other configurations.
- The strut is usually not used to reinforce the wing structure.



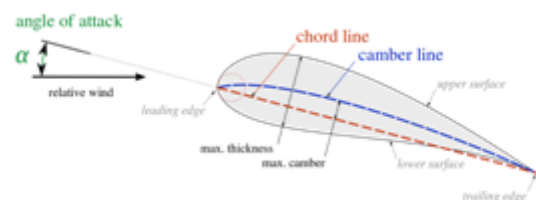
**Figure 1.2.3. Mid wing**

Of the three types of wings mentioned above our current design i.e. NACA 2412 series swept back wing is a high wing and is generally used in cargo planes. By using a modified model of NACA 2412 series wing THE CESSNA 172 SKYHAWK was made.

#### 1.3 AIRFOIL:

AEROFOIL is the cross-sectional shape of a wing, blade (of a propeller, rotor, or turbine), or sail. The aerofoil section is responsible for the generation of the optimum pressure distribution on the top and bottom surfaces of the wing such that the required lift is created with the lowest aerodynamic cost (i.e. drag and pitching moment). Because of the aerofoil section, two other outputs of the aerofoil, and consequently the wing, are drag and pitching moment. The wing may have a constant or a non-constant cross-section across the wing.

##### 1.3.1AEROFOIL GEOMETRY:



**Figure 2.2.1 .1 Geometry of airfoil**

#### Leading edge:

The leading edge is a part of aerofoil that first contacts the air, alternatively it is the foremost edge of an aerofoil section. It is also known as starting node. It separates the air flow to upper and lower surfaces.

### Trailing edge:

It is the rear end of the aerofoil, where the airflow separated by the leading edge is rejoined by this edge only. Essential flight control surfaces are attached here to control the direction of departing air flow, and exert a controlling force on the aircraft.

### Upper surface:

This upper surface is more convex (more positive) because the air has to flow faster on it and the pressure should be low, so it is designed in such a way that the lift will be more.

### Lower surface:

It is also in the shape of upper surface, but this is shorter than the upper surface so as to increase the pressure and slow moving of air on it.

### Chord line:

The straight line drawn from the leading edge to trailing edge of the airfoil is called as the chord line. the chord line cuts the airfoil into upper and lower surfaces.

### Camber line:

If we plot the points that lie halfway between the upper and lower surfaces, we obtain a curve called the mean camber line.

### Pressure surface:

It is the lower surface with comparative higher pressure that is static than the suction one.

### Suction surface:

It is the portion where we get higher velocity and low pressure.

### Mean camber line (MCL):

The line which is exactly in the middle of upper and lower surfaces is mean camber line. The MCL for a cambered aerofoil generally is above the chord line whereas it is coincident with the chord line in case of symmetric aerofoils.

### Maximum Thickness:

It is the maximum separation from the bottom edge to the top edge. It is generally  $0.12c$  or 12% of the chord.

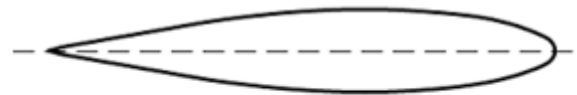
### Maximum camber:

The maximal distance of the MCL from the chord line. Maximum Camber is generally expressed as a % or fraction of the chord.

## 1.3.2 TYPES OF AEROFOIL:

### 1. Symmetrical Aerofoil:

The symmetrical airfoil is distinguished by having identical upper and lower surfaces. The figure below shows the mean camber line and chord line are the same on a symmetrical airfoil, and it produces no lift at zero AOA. Most light helicopters incorporate symmetrical airfoils in the main rotor blades.



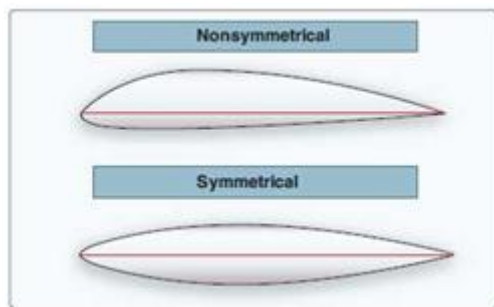
**symmetrical airfoil**

**Figure 1.3.2. Systematic shape of symmetrical airfoil**

### 2. Non-symmetrical Airfoil:

The non-symmetrical airfoil has different upper and lower surfaces, with a greater curvature of the airfoil above the chord line than below. The figure shows the mean camber line and chord line are different. The non-symmetrical airfoil design can produce useful lift at zero AOA. A non-symmetrical design has advantages and disadvantages. The advantages are more lift production at a given AOA. Than a symmetrical design, an improved lift-to-drag ratio, and better stall characteristics. The disadvantages are centre of pressure travel of up to 20 percent of the chord line (creating undesirable torque on the airfoil structure) and greater production costs.

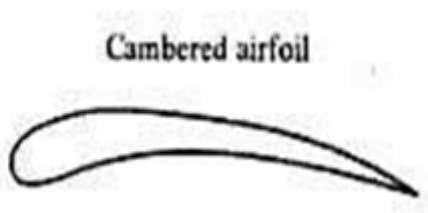




**Figure 1.3.3. Difference between non-symmetrical and symmetrical**

### 3. Cambered Airfoil:

Because of lift differential due to differing rotational relative wind values along the blade, the blade should be designed with a twist to alleviate internal blade stress and distribute the lifting force more evenly along the blade, blade twist provides higher pitch angles nearer the tip where velocity is higher. This increases the induced air velocity and blade loading near the inboard section of the blade. The angular position of the main rotor blades is measured from the helicopter's longitudinal axis, which is usually the nose position and the blade. The radial position of a segment of the blade is the distance from the hub as a fraction of the total distance.



**Figure1.3.4. Cambered Airfoil**

### 1.3.3 NACA SERIES:

The **NACA aerofoils** are aerofoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA aerofoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the aerofoil and calculate its properties.

### 1.4 FORCES ACTING ON AN AIRCRAFT:

There are four types of forces acting on an aircraft. They are as follows:

- **LIFT:** It is produced by a lower pressure created on the upper surface of an aeroplane's wing compared to the pressure on the wings lower surface, causing the wing to be lifted upward. The special shape of the airplane wing is designed so that air flowing over it will have to travel a greater distance and faster resulting in a lower pressure area thus lifting the wing upwards. Lift is that force that opposes the force of gravity.
- **WEIGHT:** The weight acts vertically downward from the centre of gravity of airplane.
- **THRUST:** It is designed as the forward direction pushing or pulling force developed by aircraft engine. This includes reciprocating engines, turbojet engines, turbocrop engines.
- **Drag:** It is the force which opposes the forward motion of airplane. Drag is retarding force acting upon a body in motion through a fluid, parallel to the direction of motion of a body. It is the friction of the air as it meets and passes over an aeroplane and its components. Drag is created by air impact force, skin friction, and displacement of the air

#### 1.4.1 WORKING PRINCIPLE

The basic principle behind an aerofoil is described by Bernoulli's theorem. Basically this states that total pressure is equal to static pressure (due to the weight of air above) plus Dynamic pressure (due to the motion of air). Air that travels over the top surface of the aerofoil has to travel faster and thus gains dynamic pressure. The subsequent loss of static pressure creates a pressure difference between the upper and lower surfaces that is called lift and opposes the weight of an aircraft (or thrust that opposes drag). As the angle of attack (the angle between the chord line and relative air flow) is increased, more lift is created. Once the critical angle of attack is reached (generally around 14 degrees) the aerofoil will stall.

## 1.5 OBJECTIVE AND SCOPE

The objective of this project is to understand the phenomena of the uniqueness of aerofoil shape. Aerofoil shapes are employed in aircraft sectors as well as in automobile and production sectors, e.g. wind turbines, wing of an automobile etc. It can generate lift as well as downforce when used in a specific manner. So it is quite important to decode the phenomena behind its shape and the process by which it produces necessary lift and downforce. The main objective is to study the design process of various aerofoils and their flow simulation to understand how they work. But, the following are the essential objectives of the work:

- Obtain the pressure distribution, lift and drag coefficients on the given aerofoil profile using Ansys at various ANGLE OF ATTACK in viscous domain.
- Experimental investigation on the airfoil at various angle of attacks and materials.
- AOA varies from 0 to 20 degree.

## 1.6 RESEARCH METHODOLOGY

Lots of papers and journals had been referred and some of them have been considered in this project. Later on modelling for airfoils is done using **SOLIDWORKS** 2016 (by importing the co-ordinates from airfoil tools and then it is extruded to required extent). Further analysis is then carried out. 3D model of airfoils is transferred to finite analysis software, which is **ANSYS 16.0**. The 3D model is meshed and analysis is performed. The equivalent stress, strain etc for various loads and materials is determined. Static and dynamic analysis is performed and the results are tabulated and compared. Finally better material for airfoil is proposed.

## LITERATURE REVIEW

This section explains some previous literature on aerofoil sections and their analysis procedure.

**Gultop [1]** contemplated the effect of viewpoint degree on Airfoil execution. The explanation behind this

study was to center the swell conditions not to be kept up all through wind passage tests.

**Guilmineau et al. [2]** talked about the processing of the time-mean, turbulent, two-dimensional incompressible thick stream past an airfoil at settled rate. Another physically reliable technique is exhibited for the reproduction of speed fluxes which emerge from discrete mathematical statements for the mass and energy equalization. This conclusion strategy for fluxes makes conceivable the utilization of a cell-focused network in which speed and pressure questions have the same location, while going around the event of spurious pressure modes.

**Havaladar Sanjay N, Shardul Pawar, Apporva Lele, et al [3]** "Experimental Investigation of Lift for NACA 2412 Airfoil without Internal Passage, with NACA 2412 Airfoil with Internal Passage". Journal of Aerospace Engineering and Technology. 2015; 5(2): 27–33pg.

**J. Anderson,[4]** "Fundamentals of Aerodynamics", 5th ed., New York: McGraw-Hill. p. 20, 2010.

**J. W. Jaworski and R. E. Gordnier,[5]** "High-order simulations of low Reynolds number membrane airfoils under prescribed motion," J. Fluids Struct., vol. **31**, pp. 49–66, 2012.

**Katz,J [6]** "Calculation of the Aerodynamic Forces on Automotive Lifting Surfaces," Journal of Fluid Engineering. Vol.107,Dec. pp.438-443.,1985. Used a vortex-lattice method that included a freely deforming wake to investigate the performance of lifting surfaces close to the ground, such as those found on racing cars.

**Kunz and Kroo [7]** advanced aerofoils at ultra-low Reynolds numbers. These examinations are done to comprehend the aerodynamic issues identified with the low speed and miniaturized scale air vehicle outline and execution. The enhancement strategy utilized is in view of concurrent pseudotime venturing in which

stationary states are acquired by fathoming the preconditioned pseudostationary arrangement of comparisons.

**Newman, J.N [8]** "Analysis of Small-Aspect-Ratio Lifting Surfaces in Ground Effect," *Journal of Fluid Mechanics*, Vol.117, 1982, pp.305-314. The gap flow beneath the lifting surfaces is represented by a simple nonlinear solution in the cross-flow plane, and appropriate conditions are imposed at leading and trailing edges. For steady-state motion of a delta wing with sufficiently large angle of attack, the transition point is upstream of the tail. For oscillatory heaving motion of a delta wing the transition point is cyclic if velocity is sufficiently large.

**P. Watts and F. E. Fish,[9]** "The influence of passive, leading edge tubercles on wing performance," in *Proc. Twelfth Intl. Symp. Unmanned Untethered Submers. Technol*, 2001.

**Rana et al. [10]** studied the flutter characteristics of an airfoil in a 2-D subsonic flow by using CFD solver with a structural code in time domain.

S. Liu and N. Qin, "Modelling Roughness Effects for Transitional Low Reynolds Number Aerofoil Flows," *Aerospace Engineering*, vol. 229, no. 2, pp. 280-289, 2014.

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S. Liu and N. Qin, "Modelling Roughness Effects for Transitional Low Reynolds Number Aerofoil Flows," *Aerospace Engineering*, vol. 229, no. 2, pp. 280-289, 2014.

**S. Liu and N. Qin,[11]** "Modelling Roughness Effects for Transitional Low Reynolds Number Aerofoil

Flows," *Aerospace Engineering*, vol. 229, no. 2, pp. 280-289, 2014.

## NACA SERIES

### 3.1 NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NACA was established by the federal government through enabling legislation as an emergency measure during **World War I** to promote industry, academic, and government coordination on war-related projects.

### 3.2 NACA AEROFOIL SERIES

The early NACA aerofoil series 4-digits, 5-digits, modified 4/5 digits were generated using analytical equations that describes the camber (curvature) of the mean line (geometric centre line) of aerofoil section as well as the sections thickness distribution along the length of the aerofoil. Later the 6- series were also included which deals with the complicated shapes derived using theoretical rather than geometrical.

#### 3.2.1 NACA FOUR- DIGIT SERIES:

The first family of airfoils designed using this approach became known as the NACA Four-Digit Series.

- The first digit specifies the maximum camber (m) in percentage of the chord (airfoil length).
- The second indicates the position of the maximum camber (p) in tenths of chord, and the last two numbers provide the maximum thickness (t) of the airfoil in percentage of chord.

**Eg: NACA2412** determines that the airfoil has a maximum camber of 2% located at 40% from the leading edge, with a maximum thickness of 12%.

#### 3.2.2 NACA Five-Digit Series:

The NACA Five-Digit Series uses the same thickness forms as the Four-Digit Series but the mean camber line is defined differently and the naming convention is a bit more complex.

- The first digit, when multiplied by 3/2, yields the design lift coefficient ( $c_l$ ) in tenths.

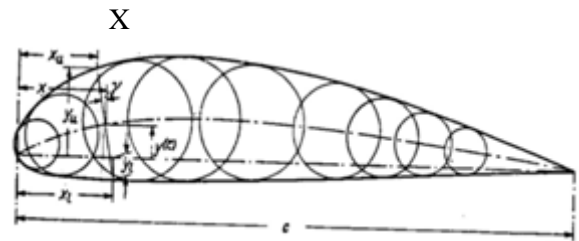
- The next two digits, when divided by 2, give the position of the maximum camber (p) in tenths of chord.
- The final two digits again indicate the maximum thickness (t) in percentage of chord.
- Eg: the NACA 23012 has a maximum thickness of 12%, a design lift coefficient of 0.3, and a maximum camber located 15% back from the leading edge.

### 3.2.3 Modified NACA Four- and Five-Digit Series:

Let us consider the root section, the NACA 0003.46-64.069, as an example. The basic shape is the 0003, a 3% thick airfoil with 0% camber. This shape is a symmetrical airfoil that is identical above and below the mean camber line.

- The first modification we will consider is the 0003-64. The first digit following the dash refers to the roundedness of the nose. A value of 6 indicates that the nose radius is the same as the original airfoil while a value of 0 indicates a sharp leading edge. Increasing this value specifies an increasingly more rounded nose.
- The second digit determines the location of maximum thickness in tenths of chord. The default location for all four- and five-digit airfoils is 30% back from the leading edge.
- In this example, the location of maximum thickness has been moved back to 40% chord. Finally, notice that the 0003.46-64.069 features two sets of digits preceded by decimals.
- These merely indicate slight adjustments to the maximum thickness and location thereof. Instead of being 3% thick, this airfoil is 3.46% thick. Instead of the maximum thickness being located at 40% chord, the position on this airfoil is at 40.69% chord.

### 3.3 EQUATIONS TO CALCULATE THE COORDINATES OF NACA 2412 SERIES



**Figure 3.3.1 Thickness distribution**

$$\begin{aligned}
 X_u &= X - Y_t(X) \sin \gamma & : \\
 Y_u &= Y_c(X) + Y_t(X) \cos \gamma & : \\
 X_l &= X + Y_t(X) \sin \gamma & : \\
 Y_l &= Y_c(X) - Y_t(X) \cos \gamma & : \\
 \text{Where, } \gamma &= \arctan\left(\frac{dy}{dx}\right) \\
 Y_t(X) &= 5t [0.2969 \sqrt{x} - 0.1260x - 0.356 x^2 + 0.2843x^3 - 0.1015x^4] \\
 Y_c(X) &= \frac{m}{p^2} \left( 2p \left(\frac{x}{c}\right) - \left(\frac{x^2}{c}\right) \right) & 0 < x < pc \\
 Y_c(X) &= \frac{m}{(1-p)^2} \left( ((1-2p)+2p \left(\frac{x}{c}\right) - \left(\frac{x^2}{c}\right)) \right) & pc < x < c
 \end{aligned}$$

### MATERIAL

An aircraft must be constructed of materials that are both light and strong. Early aircraft were made of wood. Lightweight metal alloys with a strength greater than wood were developed and used on later aircraft. Materials currently used in aircraft construction are classified as either metallic materials or non-metallic materials. The most common metals used in aircraft construction are aluminium, magnesium, titanium, steel, and their alloys.

### 4.1 WOOD:

The first aircraft was made of wood. There are four different types of wood generally used in the aircraft construction. They are Sitka spruce, birch, ash and Douglas fir. In addition mahogany, balsa, pine, basswood and Gabon fulfil certain duties.



## 4.2 ALLUMINIUM:

Aluminium alloys are widely used in modern aircraft construction. Aluminium alloys are valuable because they have a high strength-to-weight ratio. Aluminium alloys are corrosion resistant and comparatively easy to fabricate. The outstanding characteristic of aluminium is its lightweight.

## 4.3 MAGNESIUM:

Magnesium is the world's lightest structural metal. It is a silvery-white material that weighs two-thirds as much as aluminium. Magnesium is used to make helicopters. Magnesium's low resistance to corrosion has limited its use in conventional aircraft.

## 4.4 TITANIUM:

Titanium is a lightweight, strong, corrosion resistant metal. Recent developments make titanium ideal for applications where aluminium alloys are too weak and stainless steel is too heavy. Additionally, titanium is unaffected by long exposure to sea water and marine atmosphere.

The major advantages of titanium over other metals are:

1. It has good corrosive resistance (that is due to the result of a naturally occurring oxide film that forms on it when it contacts air).
2. It has excellent strength to weight ratio (It is as strong as steel but only has half of its mass).

It can withstand high temperatures (This property is required because the speed and the stresses generated in the flight can cause high temperatures).

## 4.5 STEEL ALLOYS:

Alloy steels used in aircraft construction have great strength, more so than other fields of engineering would require. These materials must withstand the forces that occur on today's modern aircraft. These steels contain small percentages of carbon, nickel, chromium, vanadium, and molybdenum. High-tensile steels will stand stress of 50 to 150 tons per square inch without failing. Such steels are made into tubes, rods, and wires.

## 4.6 COMPOSITE MATERIALS:

Composite materials are also used within the aircraft industry due to their high strength, relatively low weight and corrosive resistance. Composite materials are mainly used in the manufacture of modern aircrafts and their use has been gradually increasing over the last few years leading to the decline in the use of metallic materials.

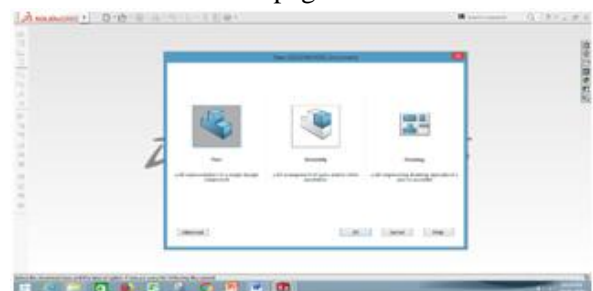
## INTRODUCTION TO SOLIDWORKS

### 5.1 INTRODUCTION

SolidWorks is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program published by Dassault Systems. Drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC). Solidworks main idea is user to create drawing directly in 3D or solid form. From this solid user can assemble it directly on their workstation. Three solidworks component is Part, Assembly and Drawing. Part define by it sketch and selected feature. Assembly is how all parts assemble in one unit, parts assemble by user adding mate between parts. Drawing is for detailing and adding dimensions to part. Here, the geometry of the airfoil is created using SOLIDWORKS 2016 Version.

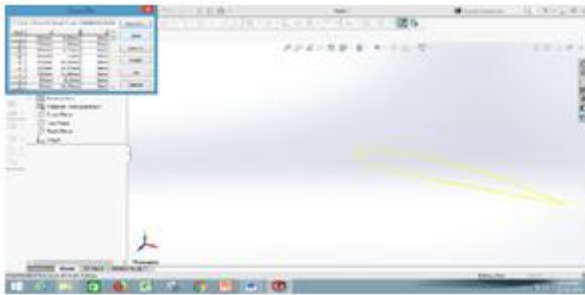
### 5.2 DESIGN AND PROCEDURE:

**Step 1:** The first step is to select the component **part** in solid works new work page.



**Figure 5.1 Mode Selection**

**Step 2:** Then import the co-ordinates from MS Excel(which is saved earlier), for this, go to the option **curves** then to **curve through xyz points**, browse and then **insert** the co-ordinates



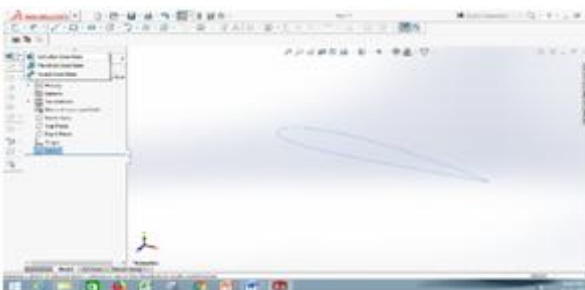
**Figure 5.2 Selection of Co-ordinates**

**Step 3:** The shape of the airfoil thus obtained is in 2D, which should be converted into **3D** for further process.



**Figure 5.3 Basic 2D Model**

**Step 4:** To convert the design into 3D, go to the option **features** then go to **Extruded Boss/Base**.



**Figure 5.4 Extruding 2D model**

**Step 5:** Enter the required length that is to be extruded and select **ok**. Also the direction to be extruded can also be selected.

**Step 6:** Therefore, the required airfoil 3D design with given geometry is obtained which is saved with **.stp** extension for further process to carry out, that is analysis.



**Figure 5.5 Final 3D model**

## INTRODUCTION TO ANSYS

### 6.1 INTRODUCTION

ANSYS is an engineering simulation software (computer aided Engineering). Its tools cover Thermal, static, dynamic, and fatigue Finite Element Analysis along with other tools all designed to help with the development of the product. The company was founded in 1970 by Dr. John A. Swanson as Swanson Analysis System, Inc. SASI. With a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEA). Its primary purpose was to develop and market Finite Element Analysis software for structural physics that can stimulate static(stationary), dynamic(moving), heat transfer(thermal) problems. SASI developed his business in parallel with the growth in computer technology and engineering needs. The company grew by 10% to 20% each year, and in 1994 it was sold. The new owners took SASI's leading software, called ANSYS, as their flagship product and designated ANSYS, Inc. continues its role as a technical innovator. It also supports a process – centric approach to design a manufacturing, allowing the users to avoid expansive and time consuming “built and break” cycles. ANSYS analysis and simulation tools give customers ease-of-use, data compatibility, multi platform support and coupled field multi-physics capabilities.

### 6.1.1 ANSYS workbench 16.0:

To carry out the analysis on swept back wing, ANSYS WORKBENCH mode is used which is one of the auxiliary modes provided along with ANSYS 16.0 version. The key features which make ANSYS WORKBENCH, dominated over conventional classical mode of ANSYS are:

- No need to define element type-like in conventional classic mode, there is no need of remembering bulk data regarding the element type to be defined for an analysis of a model.
- Less mesh time-it is one of the most important key features of utility. ANSYS workbench provides ease of use by taking very less time for meshing even for a large mesh density.
- Importing complete details of modeling-conventional classic mode of ANSYS has a drawback of missing some of the modeling identities while exporting modeling files. This can be overcome in this mode and exports a complete geometry and modeling features.
- Less analysis time-problems having very high mesh density can be solved in ANSYS WORKBENCH within very less time compared to conventional classic mode. This feature plays a major role in problems involving large structures and/or high mesh density which consumes a lot of time when solving in conventional classic mode.
- Ease of use – it is the most effective feature of workbench mode. The tree mode displays of analysis procedure makes the self justification over the current problem and displays tips and guides the analysis procedure to lead to better solution. This features makes the workbench mode very simplified in use compared in use compared to the conventional classic mode.

### CALCULATIONS

Chord length of the aerofoil (c)  
= 0.2 m

Length of the wing model (l)  
= 1 m

Density of air ( $\rho$ )  
= 1.23 kg/m<sup>3</sup>

Relative velocity between aircraft and air (v)  
= 120.37m/sec

For angle of attack of 10° :

Coefficient of lift ( $C_l$ ) = 1.309

Coefficient of drag ( $C_d$ ) = 0.0135

For angle of attack of 15° :

Coefficient of lift ( $C_l$ ) = 1.493

Coefficient of drag ( $C_d$ ) = 0.0228

For angle of attack of 20° :

Coefficient of lift ( $C_l$ ) = 1.409

Coefficient of drag ( $C_d$ ) = 0.0368

### Lift force ( $F_l$ ) acting on the wing at different angles of attack:

$$F_l = \frac{1}{2} \rho A V^2 C_l$$

$$\begin{aligned} F_l (\text{for } 5^\circ) &= \frac{1}{2} \rho A V^2 C_l \\ &= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 0.857 \\ &= 1527 \text{ N} \end{aligned}$$

$$\begin{aligned} F_l (\text{for } 10^\circ) &= \frac{1}{2} \rho A V^2 C_l \\ &= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 1.309 \\ &= 2333 \text{ N} \end{aligned}$$

$$\begin{aligned} F_l (\text{for } 15^\circ) &= \frac{1}{2} \rho A V^2 C_l \\ &= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 1.495 \\ &= 2665 \text{ N} \end{aligned}$$

$$\begin{aligned} F_l (\text{for } 20^\circ) &= \frac{1}{2} \rho A V^2 C_l \\ &= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 1.409 \\ &= 2511 \text{ N} \end{aligned}$$

### Drag force ( $F_d$ ) acting on the wing at different angles of attack:

$$F_d = \frac{1}{2} \rho A V^2 C_d$$

$$\begin{aligned} F_d (\text{for } 5^\circ) &= \frac{1}{2} \rho A V^2 C_d \\ &= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 0.0089 \end{aligned}$$

$$= 15.8 \text{ N}$$

$$F_d (\text{for } 10^\circ) = \frac{1}{2} \rho * A * V^2 * C_d$$

$$= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 0.0135$$

$$= 24 \text{ N}$$

$$F_d (\text{for } 15^\circ) = \frac{1}{2} \rho * A * V^2 * C_d$$

$$= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 0.0228$$

$$= 40 \text{ N}$$

$$F_d (\text{for } 20^\circ) = \frac{1}{2} \rho * A * V^2 * C_d$$

$$= \frac{1}{2} * 1.23 * 0.2 * 1 * 120.37^2 * 0.0368$$

$$= 65 \text{ N}$$

**Lift to drag ratio on an aircraft wing at different angles of attack:**

$$F_l/F_d \text{ for } 5^\circ \text{ angle of attack} = \frac{1527}{15.8}$$

$$= 96.6$$

$$F_l/F_d \text{ for } 10^\circ \text{ angle of attack} = \frac{2333}{24}$$

$$= 97.2$$

$$F_l/F_d \text{ for } 15^\circ \text{ angle of attack} = \frac{2665}{40}$$

$$= 66.625$$

$$F_l/F_d \text{ for } 20^\circ \text{ angle of attack} = \frac{2511}{65}$$

$$= 38.63$$

## DESIGN AND ANALYSIS RESULTS

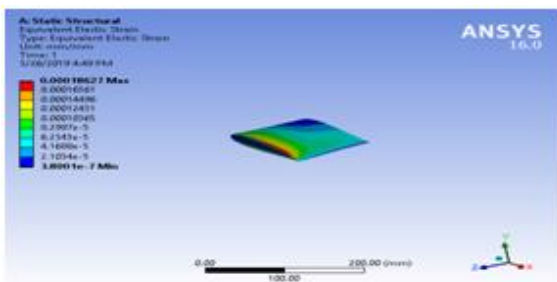


Figure 8.1. Static analysis for Equivalent strain(Al)

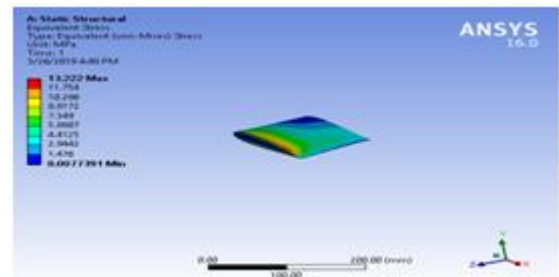


Figure 8.2. Static analysis for Equivalent stress(Al)

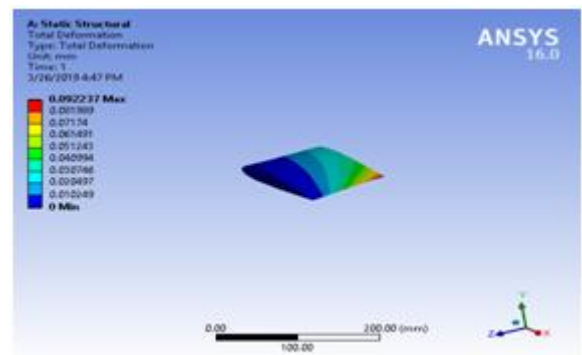


Figure 8.3. Static analysis for Total deformation(Al)

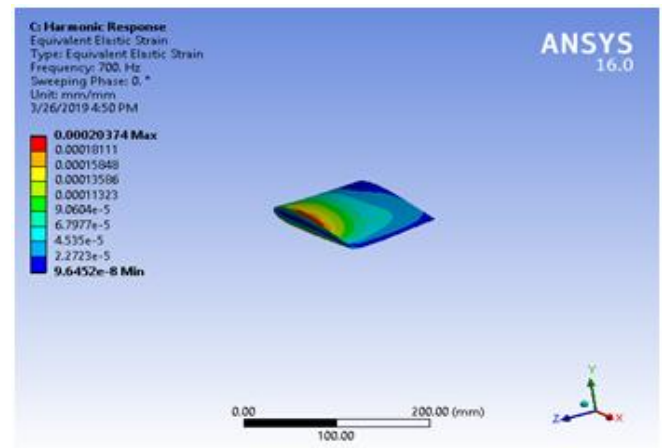


Figure 8.4. Harmonic response for Equivalent strain(Al)



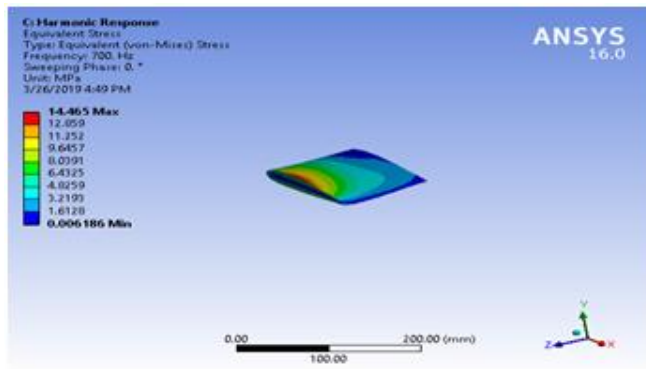


Figure 8.5. Harmonic response for Equivalent stress(Al)

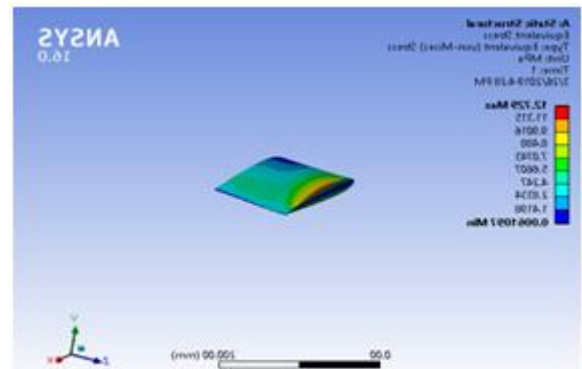


Figure 8.8. Static analysis for Equivalent stress(epoxy glass)

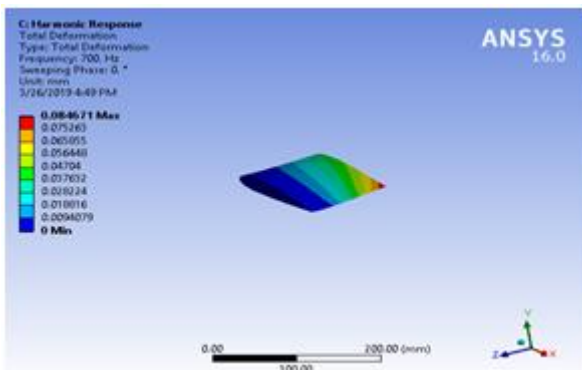


Figure 8.6. Harmonic response for Total deformation (Al)

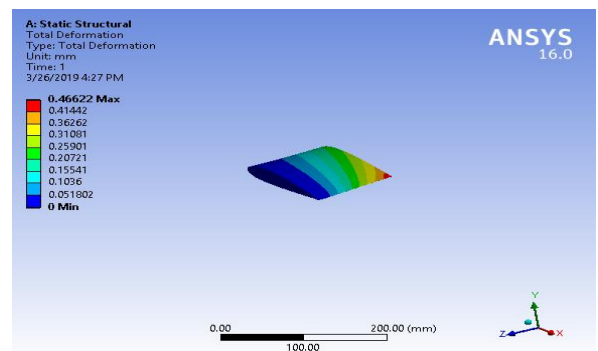


Figure 8.9. Static analysis for Total deformation (epoxy glass)

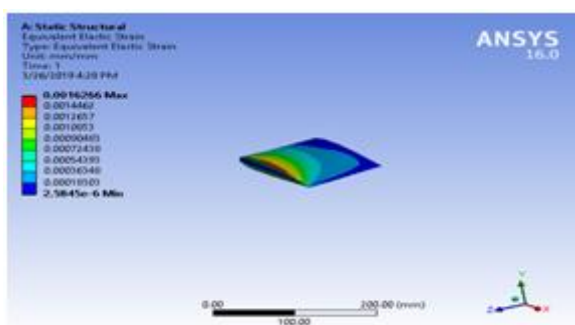
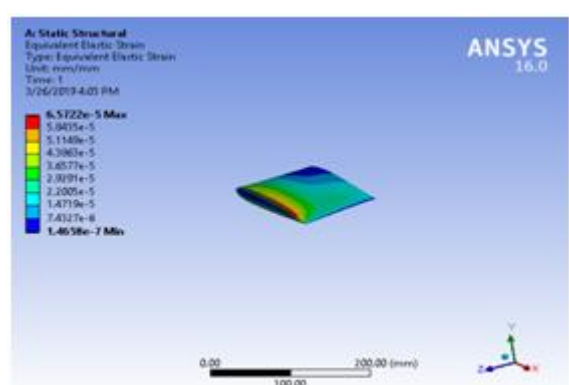


Figure 8.7. Static analysis for Equivalent strain (epoxy glass)



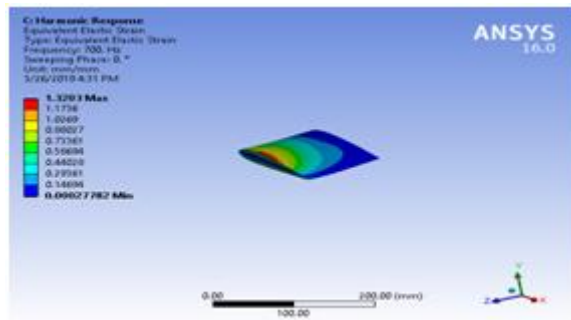


Figure 8.10. Harmonic response for Equivalent strain(epoxy glass)

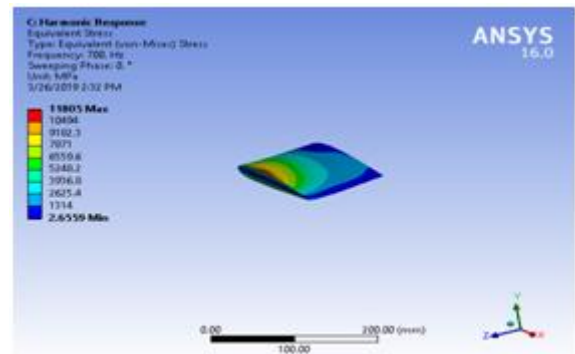


Figure 8.43. Static analysis for equivalent strain(Titanium)

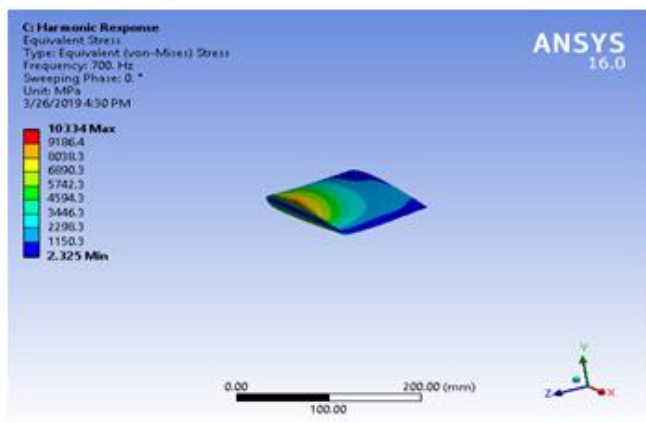


Figure8.11. Harmonic response for Equivalent stress (epoxy glass)

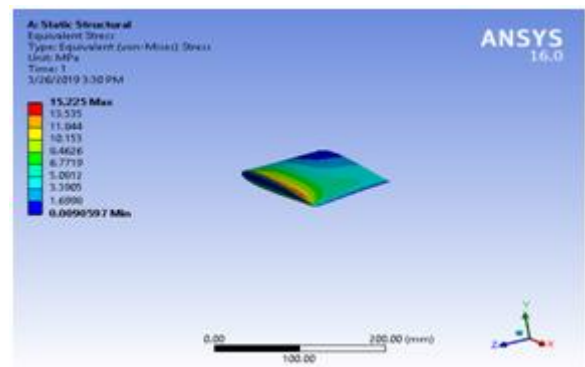


Figure 8.44. Static analysis for Equivalent stress(Titanium)

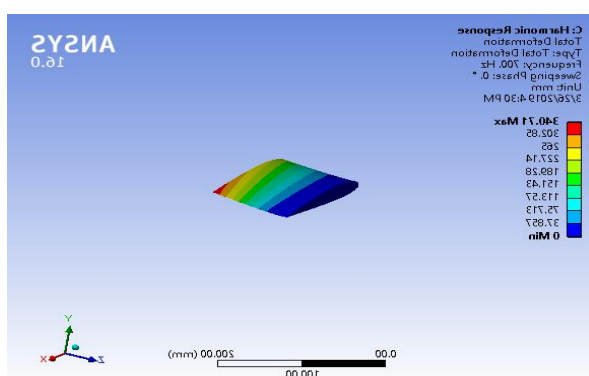


Figure 8.13. Harmonic response for total deformation (epoxy glass) Figure 8.13.Static analysis for equivalent strain(structural steel)

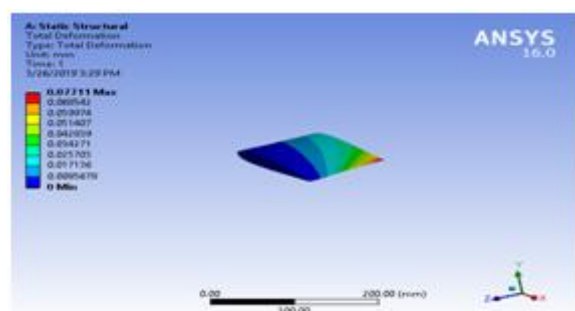


Figure 8.45. Static analysis for total deformation(Titanium)

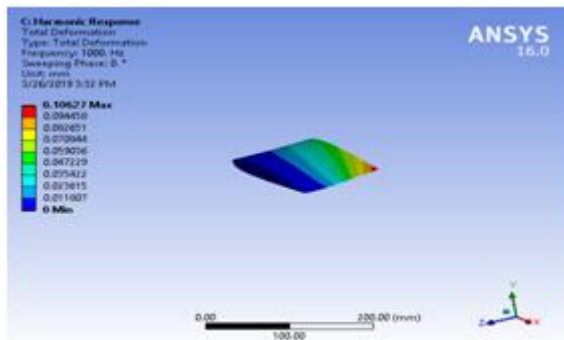


Figure 8.48. Harmonic response for total deformation(Titanium)

## RESULTS

### AT 10° ANGLE OF ATTACK: STATIC ANALYSIS:

MATERIALS	ALUMINIUM	TITANIUM	STRUCTURAL STEEL	EPOXY GLASS
EQUIVALENT STRESS (MPa)	13.22	13.33	13.14	12.73
EQUIVALENT ELASTIC STRAIN	$0.18 \times 10^{-3}$	$0.14 \times 10^{-3}$	$6.5 \times 10^{-5}$	$1.6 \times 10^{-3}$
TOTAL DEFORMATION (mm)	0.092	0.067	0.030	0.466

Table 9.1 Static analysis with different materials comparison

### DYNAMIC ANALYSIS:

MATERIALS	ALUMINIUM	TITANIUM	STRUCTURAL STEEL	EPOXY GLASS
EQUIVALENT STRESS (MPa)	14.46	21.78	19.63	10334
EQUIVALENT ELASTIC STRAIN	$0.2 \times 10^{-3}$	$0.22 \times 10^{-3}$	$9.5 \times 10^{-5}$	1.3
TOTAL DEFORMATION (mm)	0.084	0.093	0.04	340

Table 9.2 Dynamic analysis with different materials comparison

### AT 15° ANGLE OF ATTACK: STATIC ANALYSIS:

MATERIALS	ALUMINIUM	TITANIUM	STRUCTURAL STEEL	EPOXY GLASS
EQUIVALENT STRESS (MPa)	15.09	15.22	15.0	14.54
EQUIVALENT ELASTIC STRAIN	$0.2 \times 10^{-3}$	$0.15 \times 10^{-3}$	$7.5 \times 10^{-5}$	$1.85 \times 10^{-3}$

Table 9.3 Static analysis with different materials comparison

### DYNMAIC ANALYSIS:

MATERIALS	ALUMINIUM	TITANIUM	STRUCTURAL STEEL	EPOXY GLASS
EQUIVALENT STRESS (MPa)	21.6	24.89	21.85	11805
EQUIVALENT ELASTIC STRAIN	$0.3 \times 10^{-3}$	$0.25 \times 10^{-3}$	$0.11 \times 10^{-3}$	1.50
TOTAL DEFORMATION (mm)	0.12	0.106	0.0458	398.2

Table 9.4 Dynamic analysis with different materials comparison

## CONLUISON AND FUTURESCOPE

This project can further be extended by performing Computational Fluid Dynamic Analysis (CFD analysis) to predict the pressure distribution. The numerical studies can also be made to evaluate the effects of adding the sensor module to the wing and the effect of sensor distribution on measured force coefficients. Several other materials can be selected and analysis can be done to decrease the stress and deformation in already existing materials.

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