DESIGN OF SURVEILLANCE AIRCRAFT

A thesis submitted

in Partial Fulfillment of the Requirements for

the Degree of

Bachelor of Technology

in

Mechanical Engineering

by

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Under the Supervision of

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to the

SCHOOL OF MECHANICAL SCIENCE

INDIAN INSTITUTE OF TECHNOLOGY BHUBANESWAR

April , 2021

CERTIFICATE

It is certified that the work contained in the thesis titled **DESIGN OF SURVEILLANCE AIRCRAFT**, by **D KRISHNA VAMSI**, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Prof *******

School of Mechanical Science

IIT Bhubaneswar

April, 2021

ABSTRACT

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The design analysis of a "Surveillance aircraft's wing" has been presented in this paper. The objective of this paper is to analyze the dynamic structural response of an aircraft wing and to simulate it for various boundary conditions. The dynamic structural response of an aircraft wing is to ensure the behavior of the structure in which the vibration tends to occur. This analysis is considered as the modal analysis, the goal of the modal analysis in the structural mechanics is to determine the natural mode shapes and frequencies of an object or a structure during free vibrations. This report will help to explain some concepts about how structures vibrate and the use of some of the tools to solve structural dynamic problems.

The analysis is done for two different shapes of wings and for two different materials and the comparison between the results is studied. The report briefly explains the aircraft wing vibration and its application using Ansys. The loading conditions are the self-weight of the wing. The output extracted is the mode shapes of the wing at different frequencies. The design of this surveillance aircraft wing is done for better stability and strength of the surveillance aircraft.

Keywords – Aircraft wing, Dynamic Structural response.

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I would like to express my deepest and sincere gratitude to my supervisor Dr. Yogesh G Bhumkar, School of Mechanical Sciences, IIT Bhubaneswar for his endless encouragement and supervision throughout my research.

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I would like to express my heartfelt thanks to everybody who has provide me support, motivation and guidance during my Undergraduate training at the Indian Institute of Technology, Bhubaneswar without which I would never have achieved the desired results of my project today.

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Chapter 1

INTRODUCTION

In Today's world, with the advancement in technology in our day to day life, there's simultaneous increase in this technology being used for wrong deeds. It is necessary to have high tech security and surveillance wherever it is required.

The conventional way of surveillance which refers to the surveillance done by security guards is not that much reliable in current times as there is always a chance of human error and human greed and risks involving losing a life.

This leads to usage of CCTV (closed circuit television) and often referred as video surveillance. But there are downsides to these as it can't provide us surveillance over large area and there are always blind spots in CCTVs field of views. Which makes the usage of CCTVs less effective when the surveillance is to be done continuously over a large area.

The best alternative is the usage of surveillance aircrafts and surveillance drones, which provide the same surveillance capabilities by using cameras installed on these aircrafts and these can provide surveillance over a large area by giving us the aerial view of the required area.

Now the question comes how to design different parts of this aircraft, like the aircraft wings and what should be the appropriate size and what materials are to be used in the construction so that we can have our requirements fulfilled.

My paper consists of two Sections :-

Section 1

In this section I have done static analysis of aircraft wing which is rectangular in shape and I used rectangular wings having NACA4415 Profile (Airfoil shape) with two different materials to perform this analysis. The first wing uses Aluminum alloy and the second wing uses Titanium alloy.

For design purpose I used fusion 360 software and for static analysis purpose I used Ansys workbench.

Firstly, I used the airfoil profile named NACA4415 which is already in existence and the design is available on the fusion 360 store, then I designed a rectangular aircraft wing from the airfoil.
Then I used Ansys workbench to perform the static analysis and thereby determining which material is best suitable and gives better strength and less deflection for my design.

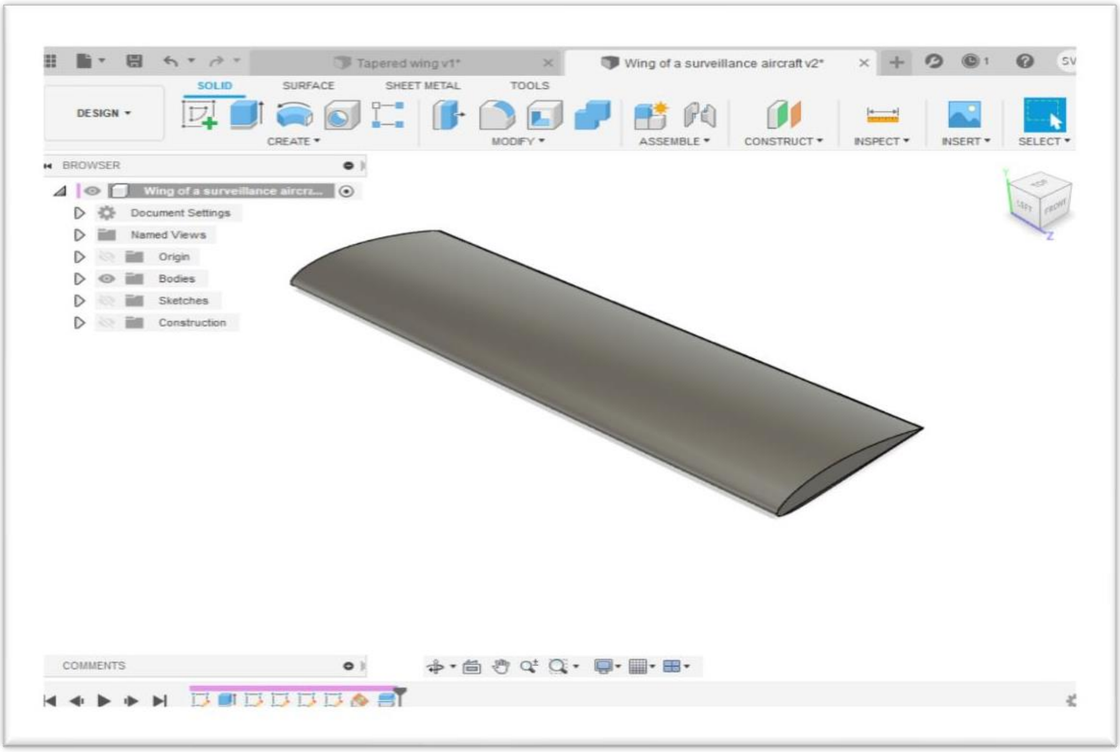

Fig 1.1 – Rectangular wing design in Fusion360

Then I used the same airfoil design (NACA4415) and designed a tapered wing. This tapered wing has the same dimensions as compare to the previous rectangular wing but the only difference will be that this wing will be tapered from both sides at different angles. Then again static analysis will be performed by using two different materials. The first wing uses Aluminum alloy and the second wing uses Titanium alloy.

As mentioned previously I used fusion 360 software to design this wing and then I used Ansys workbench to do the analysis

Firstly, I used fusion 360 and designed the wing shape and gave it the required measurements and then I did static analysis on Ansys workbench by analyzing Which shape of wing provides minimum deflection when same pressure is applied and thereby determining which shape is best for Surveillance aircraft.

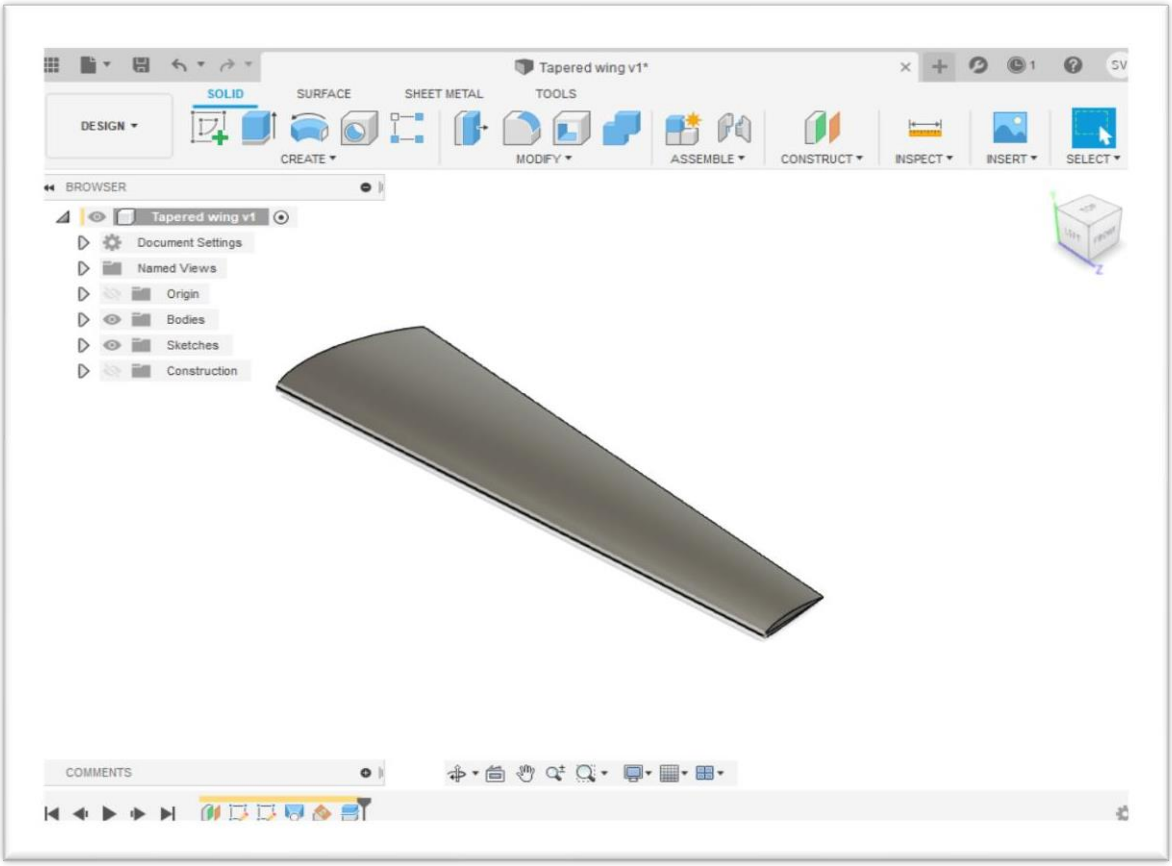

Fig 1.2 – Tapered wing design in Fusion360

Section 2

After deciding the preferrable shape and material to be used for the aircraft wing, I designed the aircraft in fusion 360 using the same wings that I previously worked on in Ansys software.
For designing the aircraft, I used the similar dimensions, as I have taken in my wing analysis and then according to wing size, I considered the wing to body ratios and designed the fuselage of the model aircraft.

Some dimensions of the designed aircraft are :-

- Semi span length of wing – 0.4572 m
- Total length of the aircraft – 1.12m

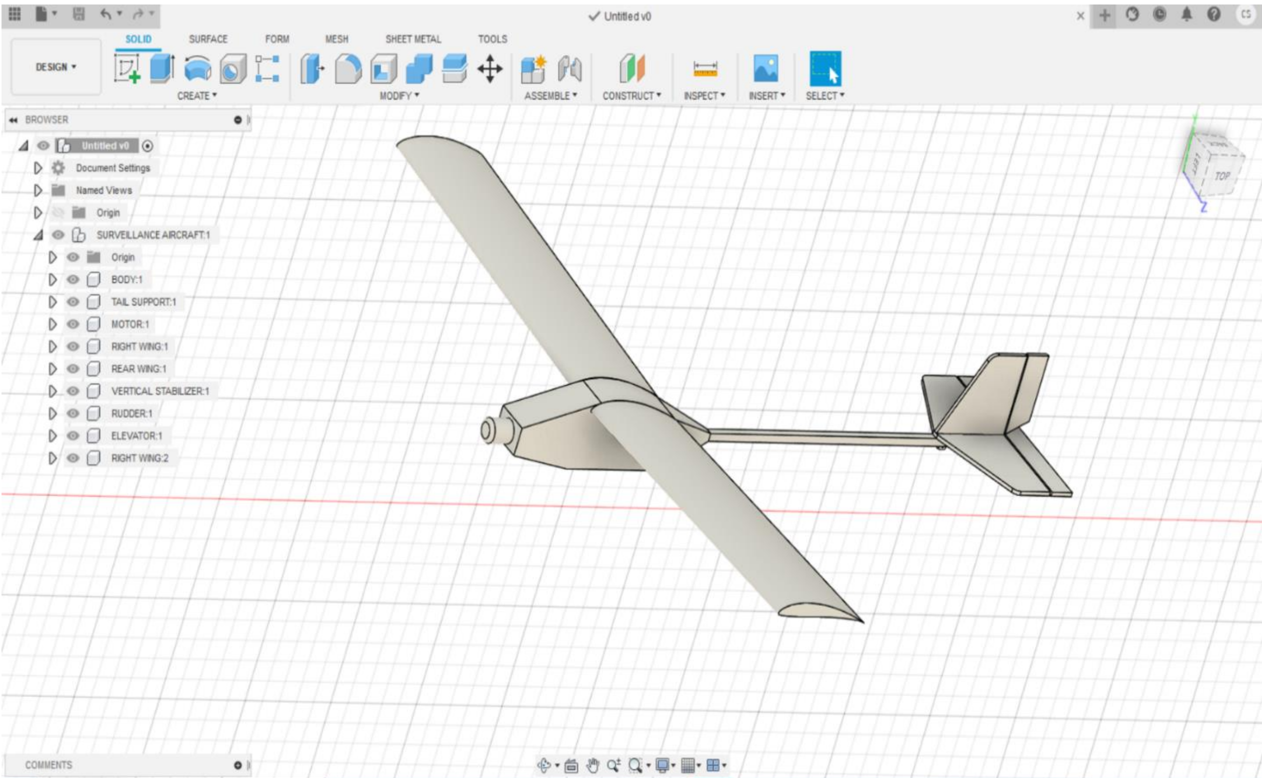

Fig : design of aircraft in fusion 360

Then, I developed the working model of aircraft which closely resembled the design that I made in the Fusion360 software.

For the raw materials and the other electrical devices related to the aircraft, We ordered a kit from Rc.vortex.com.

As for the remote control, we ordered it from the same website which will be further used to remotely control the aircraft during its flight.

Chapter 2

LITERATURE REVIEW

1) Dynamic Structural response of an Aircraft wing using Ansys, S. Senthil kumar, A. Velayudham, P. Maniarasam Department of Aeronautical Engineering, NIET Coimbatore, 2013.

In this research paper they did Dynamic Structural response of an Aircraft wing using Ansys.

They designed an Aircraft wing using the Airfoil design – NACA65210.

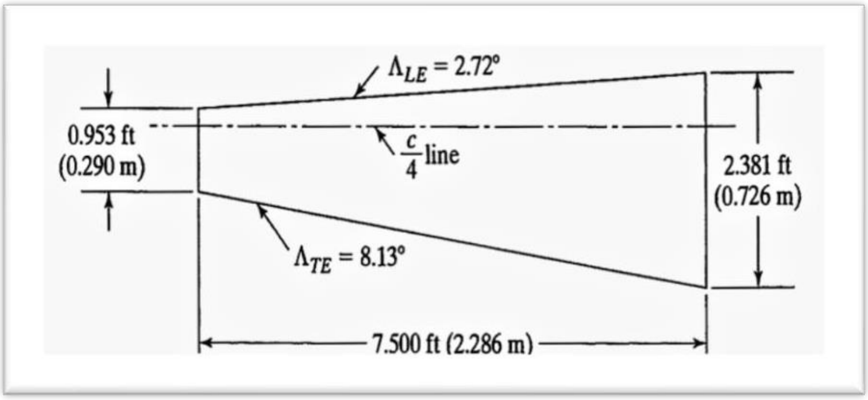

Fig 2.1 – Taper wing dimensions

Wing specifications as mentioned below –

- Semi span length of wing – 2.286 m
- Root chord width – 0.726 m
- Tip chord width – 0.290 m
- Aspect Ratio – 9.0
- Taper Ratio – 0.4

This paper concludes that, from the modal analysis, the results show that the natural frequency calculated for taper wing is higher than the normal rectangular wing and also the displacement for taper wing is less than the rectangular wing.

2) Static and Dynamic Structural Response of Aircraft wing by, Mr.Madhu H Mtech (machine design), Mr.Pavan Kandole Asst Professor, T.John Institute of technology, Bangalore.

In this Research paper, they started with the nomenclature of the wing, like what different parts of wing are called.

Wing Spar – these are the principle structural members of the wing. These run parallel to lateral axis of the aircraft, these can be made up of a variety of materials like metals, wood, composite materials.

Wing Ribs – Ribs are the structures that combines the spars and stringers to complete the framework of the wing. These ribs help in the transmission of the load. These are also made up of wither wood or metal.

Wing Skin – this combined with wing spar and wing ribs, carry part of the flight and the ground loads.

Then they explained about the Symmetrical and Unsymmetrical bending and gave expressions for them respectively.

Then they gave equation for the first bending Frequency.

$$Frequency = \frac{1.875^2}{2 \times \pi \times l^2}\sqrt{\frac{EI}{m}}$$

where, l= span of the wing

E = Young's modulus

I = Moment of Inertia of the wing

m = mass/unit length

Finally, they did static analysis on an Aircraft wing in Ansys and gave the results of Deformation and Stress on wings.

3) Analysis of Natural frequency for an Aircraft wing Structure under Pre-stress condition. By V.Sravan, V.jayakumar, G.Bharathiraja of Department of Mechanical Engineering Saveetha University, Chennai, Tamilnadu.

This paper contains the analysis of Natural frequency for avoiding resonance on the material which may lead to the failure of the wing. The software used to design the wing and identify the vibrations in this were Catia and Ansys.

The natural frequency of the wing is analyzed by the frequency at which it vibrates, when not subjected to continuous external force. Wing acts like a cantilever beam which is fixed from one end and is free at the other end.

By analyzing the frequency of the wing, we can calculate resonance and see that if the Resonance exceeds the natural frequency which is dangerous and will lead to its failure.

Then modal analysis was performed on the wing to calculate the first six frequencies, which occur at different levels of deformations of the wing.

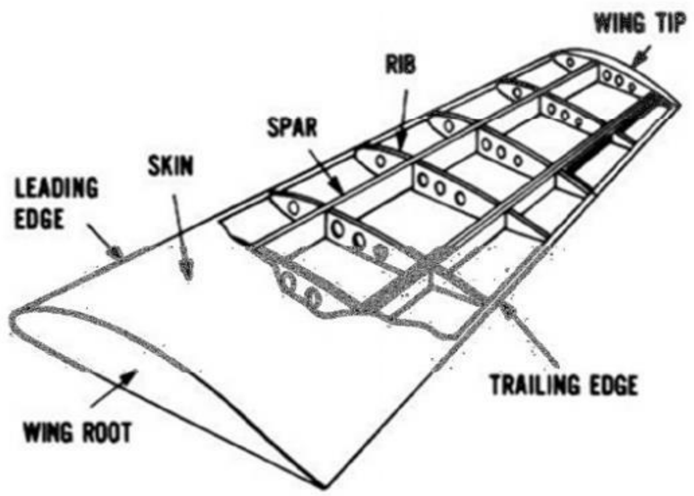

Figure 2 Wing Structure

They finally concluded that their wing model failed as the resonance factor is high, they calculated the overall deformation of the wing structure, under pre-stress while the aircraft is flying using the modal analysis in Ansys.

4) Free Vibration of an Aircraft Wing by Considering as a Cantilever beam. By Ali Demirtas and Meral bayraktar of department of Mechanical engineering, Yildiz Technical university, Istanbul, Turkey.

This Research paper presents the theoretical and numerical calculations of Natural frequency by considering the Aircraft wing as a cantilever beam.

The natural frequencies are calculated and then related to the mode shapes obtained in the simulations done in Ansys.

The modal analysis is done to understand how the aircraft wing behaves when it is subjected to Dynamic excitation.

This helps in finding out the reasons of vibrations that can cause damage to the aircraft wing.

In this paper they firstly derived a generalized equation for the natural frequency that varies with the point taken on the aircraft wing. Then these values are tabularized.

Then modal analysis is done on Ansys and natural frequencies under the same boundary conditions are found out.

Then both these values were compared and then the error ratio was calculated for every mode and its corresponding natural frequency.

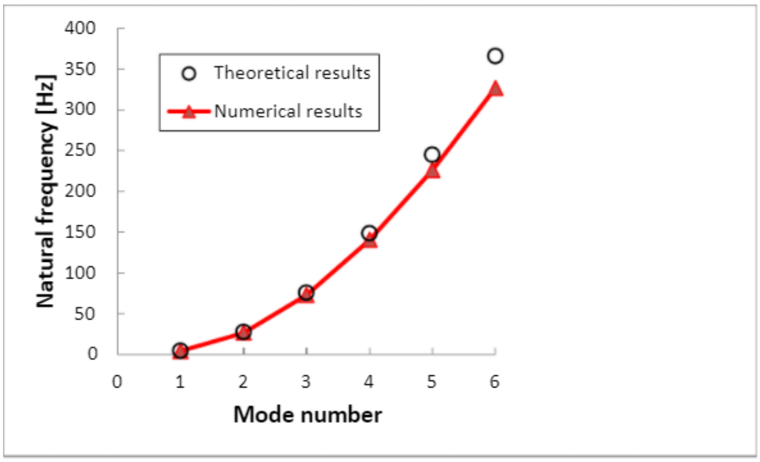

Figure 6. Comparative curves of cantilever beam frequency.

The results were pretty good as the difference between the theoretical and the experimental values were very less.

5)

Chapter 3

OBJECTIVES

1) The first objective of this paper is to analyze the dynamic structural response of an aircraft wing and to simulate it for various boundary conditions and to decide which shape of the airplane wing and which material will give us better strength and provides better stability in flight and more life to the wings.

I used the already existing airfoil design named NACA4415 for the designing purpose of each individual wing and the design is done on Fusion 360 software.

We have 4 different Aircraft Wings -

(i) Rectangular aluminum alloy wing.

(ii) Rectangular titanium alloy wing.

(iii) Tapered aluminum alloy wing.

(iv) Tapered titanium alloy wing.

My first objective was to do the dynamic static analysis on all these wings using Ansys workbench and thereby determining which wing gives us the least deformation while the wing is under pressure from the bottom. The loading conditions are the self-weight of the wing. The output extracted is the mode shapes of the wing at different frequencies. This analysis is considered as modal analysis and the main goal of the modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibrations.

2) My second objective is to design an Aircraft by using Fusion 360 software and while designing, I used the same aircraft on which I did analysis and concluded the most preferable shape of the wing.

   Then I designed the fuselage of the aircraft in the same software and this fuselage will be housing different components required for the flight of the aircraft.

   Then I designed a two-blade propeller which will be rotating with high speed with the help of motor and this will enable the aircraft to fly.

   In this way I got a rough sketch for how my aircraft should be, now I have to make a working model for the same.

3) My third objective is to make a working model of Aircraft and for this we bought a kit from Vortex.com

   I considered the kit which closely resembled the design of the aircraft which I designed in the fusion 360 software.

   From the raw materials which I got in the kit I needed to do machining of the different parts of the aircraft and then I needed to assemble the aircraft along with all its electrical components.

   After the development of the aircraft I have to check weather the weight distribution is correct, the location of the centre of gravity for the aircraft and the total weight of the aircraft.

   After the work with the assembly of the aircraft is over, I have to connect it to the remote controller, and check whether the pitch and yaw functions of the tail and rudder are working in sync with the remote controller, and check if the propeller was properly rotating at high speed which could enable the aircraft's flight.

Chapter 4

SIMULATION DATA

As mentioned earlier for designing of aircraft wings fusion 360 software was used and for performing dynamic structural analysis Ansys workbench was used.

The analysis was done on two different types of wing with same measurements but with different materials, so the analysis was done on four wings in order to reach on a conclusion that which wing will give us better results in real life, by performing simulation in Ansys.

Specification of wings –

~ Airfoil profile chosen for design - NACA4415
~ Semi span length of wing – 0.4572 m
~ Root chord width – 0.1524 m

(Only for tapered wing)
~ Tip chord width – 0.058 m
~ Taper ratio – 0.4

S. No	Material	Young's Modulus N/m^2	Density Kg/m^3	Poisson's Ratio
1	Aluminum	7.20E+10	2810.00	0.33
2	Titanium	1.10E+11	4420.00	0.34

Table 4.1 – Material properties

Case 1

❖ Rectangular Aluminum alloy wing

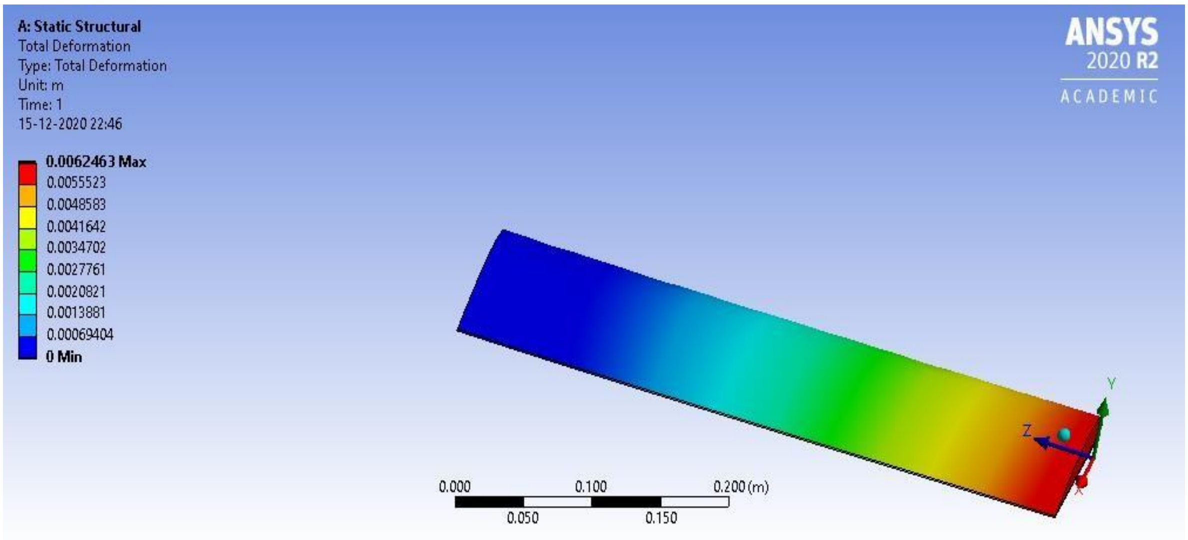

Fig 4.1 - Maximum deformation for aluminium alloy rectangular wing

❖ Rectangular Titanium alloy wing

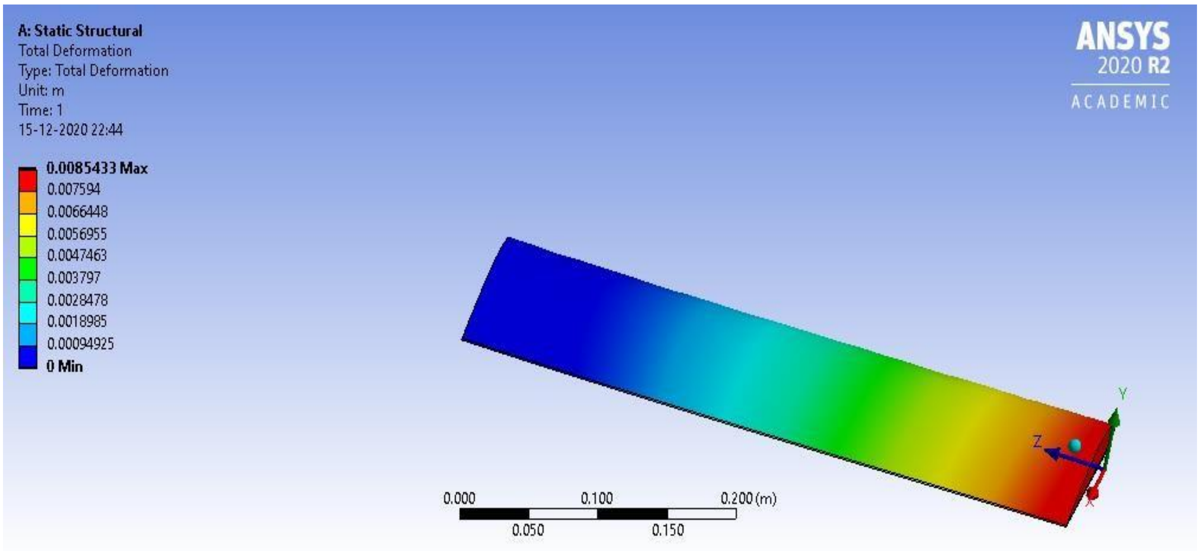

Fig 4.2- Maximum deformation for Titanium alloy rectangular wing

Case 2

❖ Tapered Aluminium alloy wing

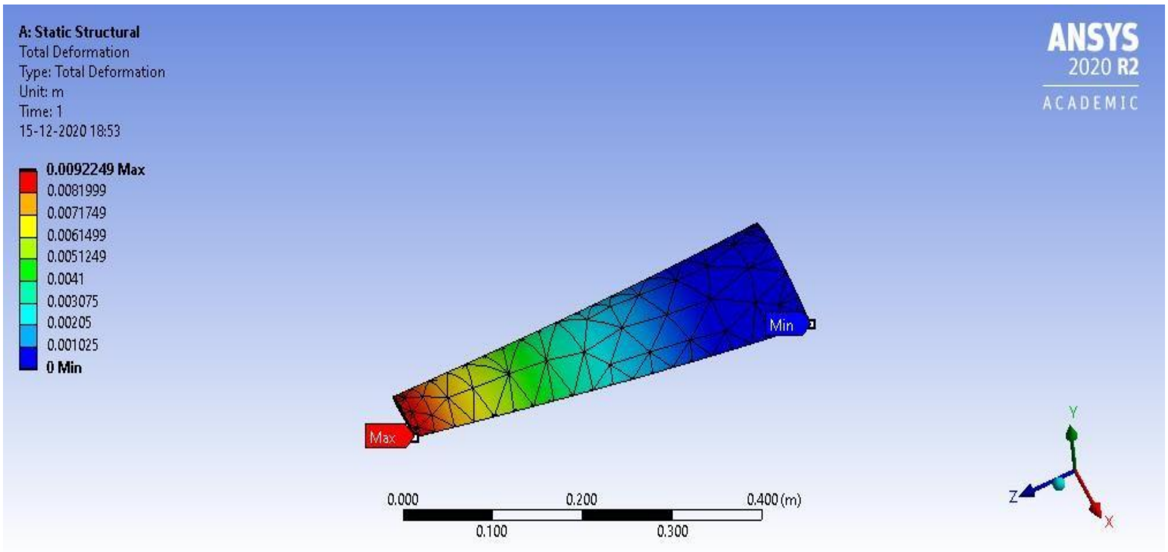

Fig 4.3 - Maximum deformation for tapered Aluminium alloy wing

❖ Tapered Titanium alloy wing

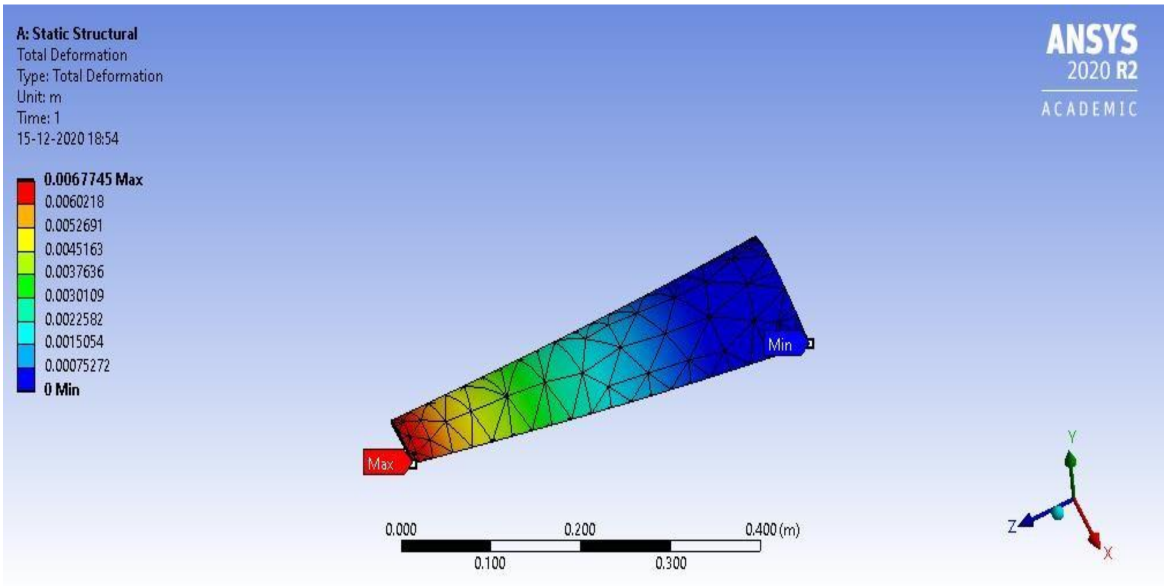

Fig 4.4 - Maximum deformation for Titanium alloy wing

CASE 1

❖ Rectangular Aluminium alloy wing

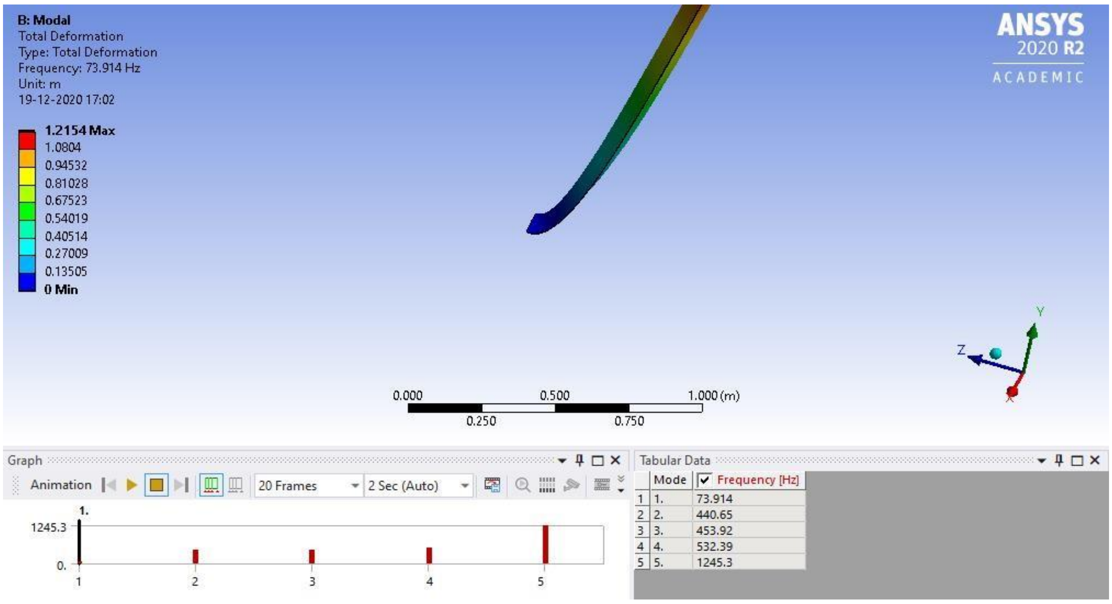

Fig 4.5 – Modal analysis of Rectangular Aluminum alloy wing

❖ Rectangular Titanium alloy wing

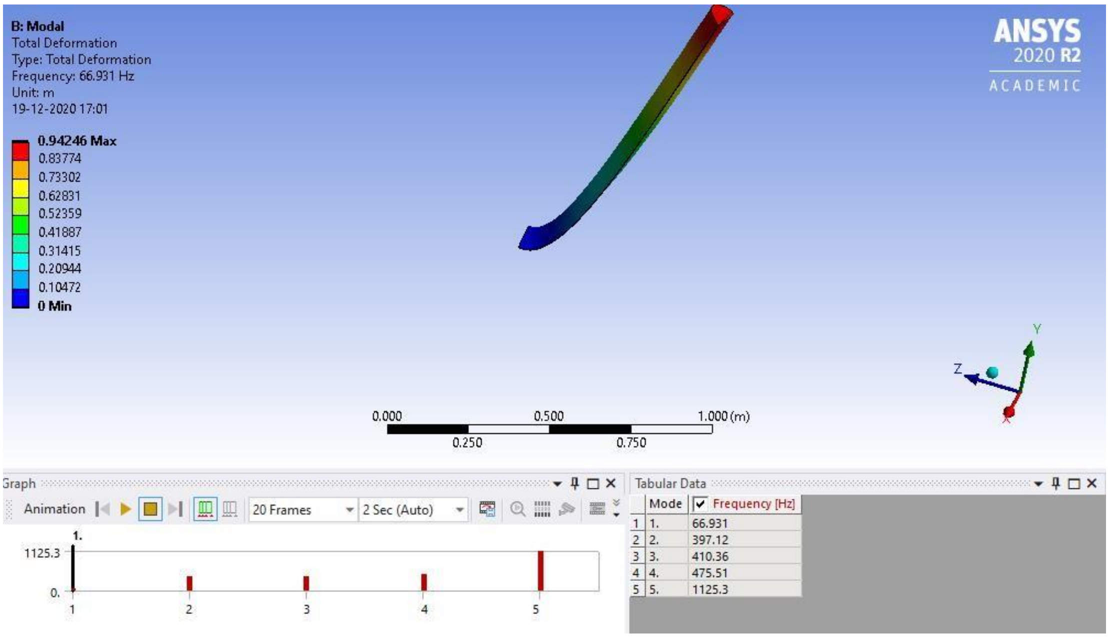

Fig 4.6 – Modal analysis of Rectangular Titanium alloy wing

CASE 2

❖ Tapered Aluminium alloy wing

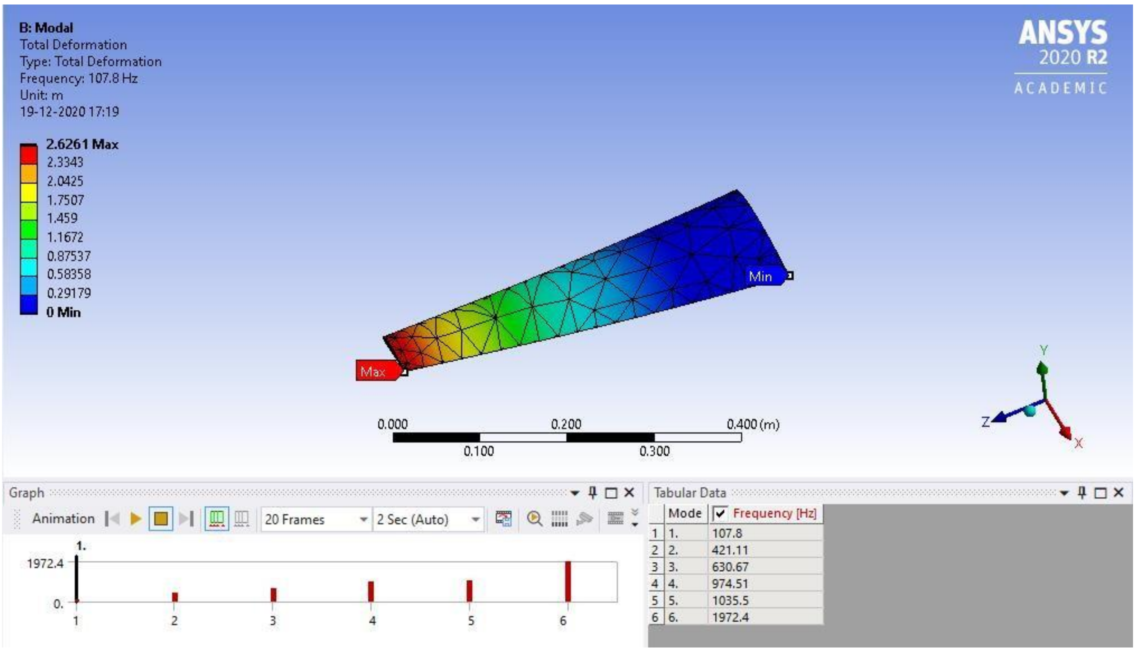

Fig 4.7 – Modal analysis of Tapered Titanium alloy wing

❖ Tapered Titanium alloy wing

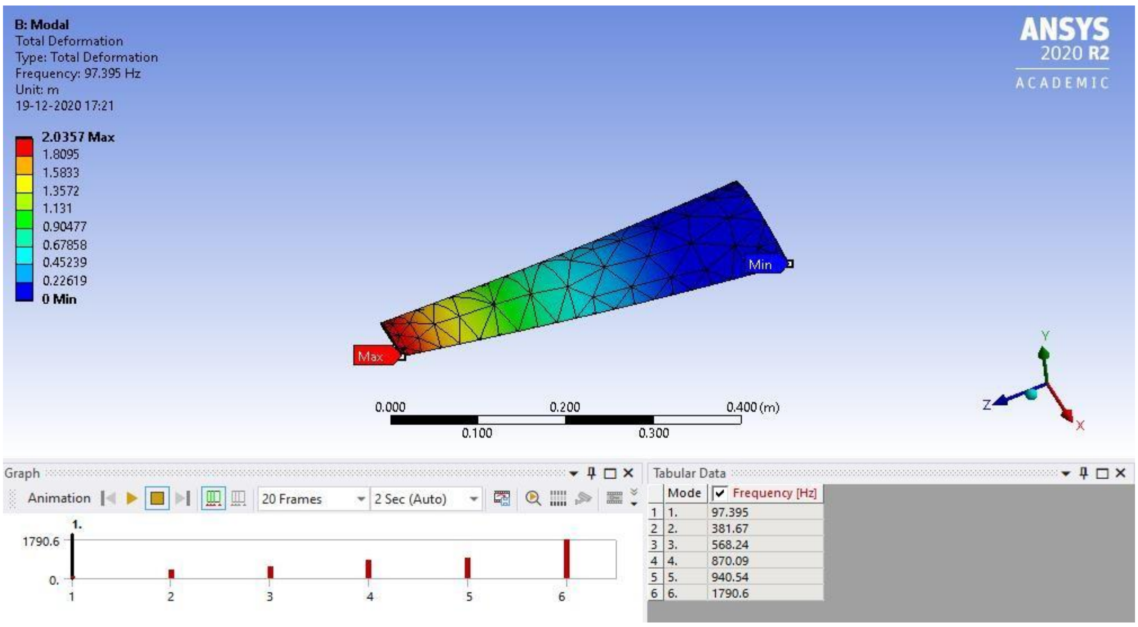

Fig4.8 – Modal analysis of Tapered Titanium alloy wing

Chapter 5

DESIGN AND DEVOPMENT

Design (fusion 360)

For the purpose of designing my model aircraft I used the software Fusion360.

After deciding the preferrable shape and material to be used for the aircraft wing, I designed the aircraft in fusion 360 using the same wings that I previously worked on in Ansys software.

For designing the aircraft, I used the similar dimensions, as I have taken in my wing analysis and then according to wing size, I considered the wing to body ratios and designed the fuselage of the model aircraft.

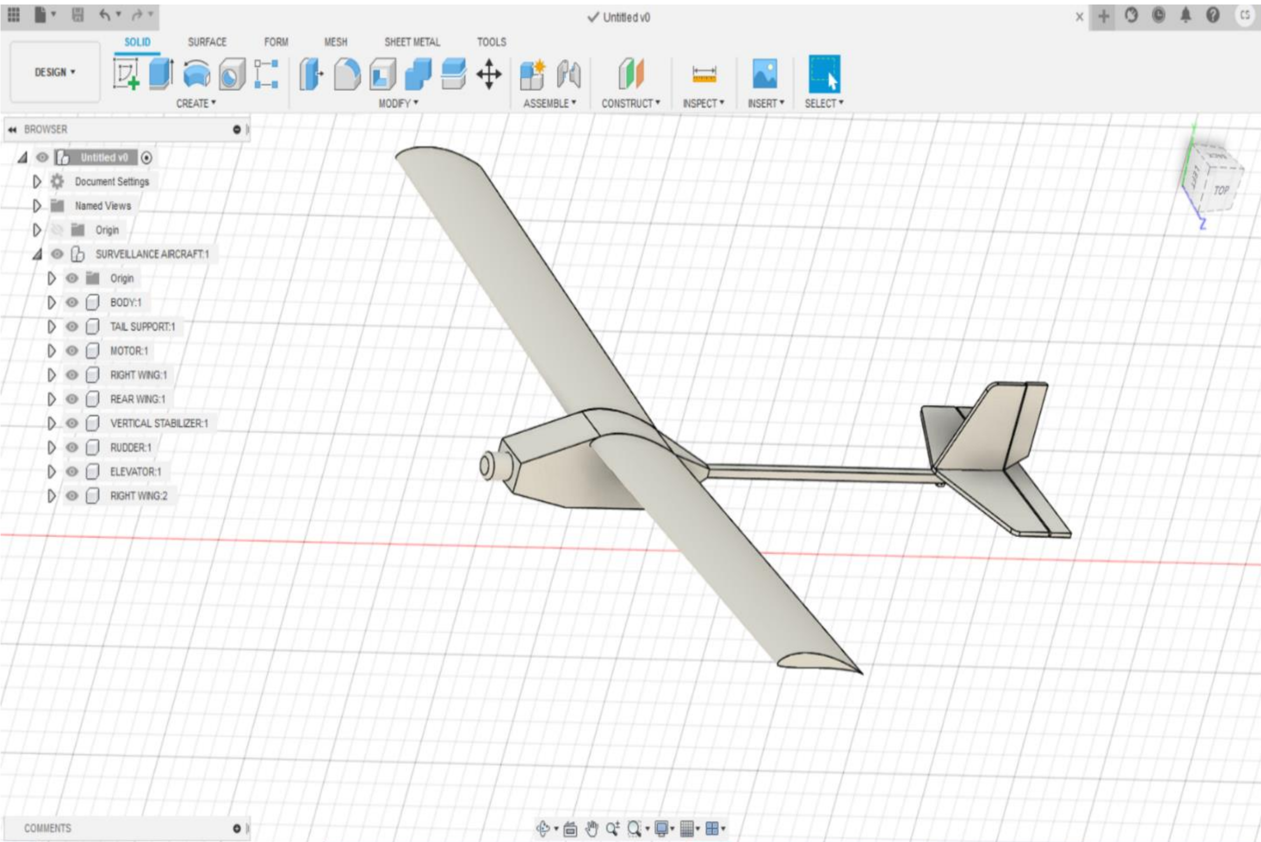

Fig: design of model aircraft in fusion360

The design of my model aircraft in 4 different views namely:

- Top view
- Front view
- Side view
- Bottom view

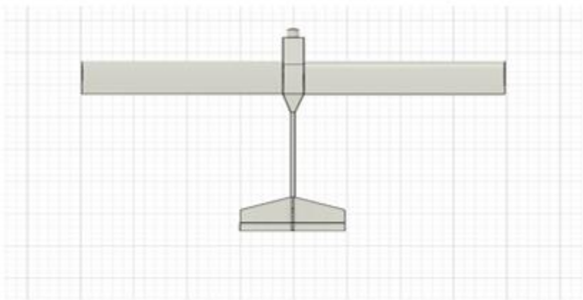

Fig :Top view

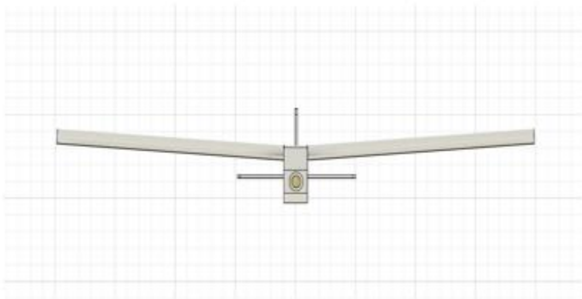

Fig : Front view

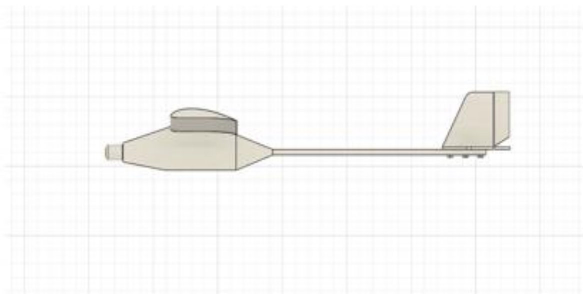

Fig : Side view

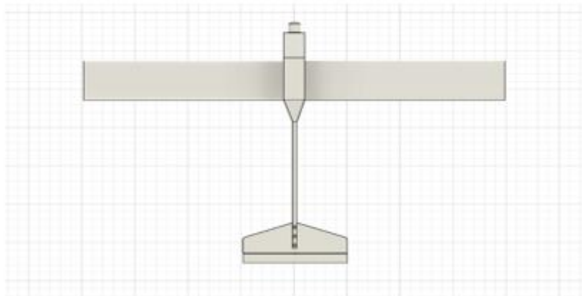

Fig : Bottom view

Some design features of the model aircraft I designed:

1) The model of the aircraft which I designed has rectangular shape wings.
2) It has vertical and horizontal stabilizers which are fixed and can't move.
3) It has a Rudder and elevator which can move to give the required lift to the aircraft and provide the movement in sideward direction respectively.
4) The aircraft has rectangular shaped fuselage which should be enough to store al the electrical components which are required for the flight of the aircraft.
5) The model aircraft has two-blade propeller.

Development:

For developing the Aircraft which closely resembled the model which I designed in the fusion360 software, I ordered a kit online from vortex-rc.com.

❖ The components which I received in this kit are:

❖ Depron sheet pack: this pack had Extruded polystyrene (XPS) closed cell foam in sheet form, it is a fantastic medium for building model aircraft, and also a popular medium for architectural model building, as well as model boats and prototype design, XPS foam is stronger than traditional EPS thermocol and can also be further strengthened by using wood strips.
The main advantages of this material are:
1) Strength to weight ratio and rigidity
2) Easy to cut with precision knife.
3) Sheets are flat and have smooth finish.

❖ Push rods and push rod guides: these push rods are connected to the rudder and elevator and provide the required movement to them when command is given.

❖ Landing gear equipment: which will be necessary for the landing and taking off for the aircraft.

❖ Strong latex rubber bands for the connection of wings and landing gear.

❖ DYS CF2822 1200 KV brushless DC motor which will draw the power from battery and rotate the propeller.

❖ 30A Electronic speed controller (ECS), it an electric circuit which will control and regulate the speed of the electric motor of the aircraft.

❖ Tower pro 9gm Servos they are used to provide rotatory or linear actuators that rotate and push the rudder and elevator with precision when commands are given.

❖ Propeller (9*4.7): it is connected to the motor and provide the necessary speed to the aircraft.

❖ Rechargeable Battery with 1000-1300 Mah capacity.

❖ Male bullet connectors, servo extension cable, heat-shrink tube and other miscellaneous equipment.

❖ <u>The specifications of the aircraft which will be assembled are:</u>

❖ Total weight of the aircraft including the battery is 500 grams and the total weight without the battery will be 350 grams only, which is ideal for the size.

❖ Total wing span of the aircraft is 55 inches (140 cm).

❖ Total length of the aircraft is 31.5 inches (80cm).

❖ Centre of gravity location is 5.8 cm from the nose (this is because most of the heavy equipment like motor and battery are placed towards the front side of the aircraft).

Fig: The components of the kit and Remote control

❖ Steps involved in making the working model:

1) Firstly, the wing part is made according to the dimensions provided in the kit, for the wings part depron sheets which are made up of extruded polystyrene (XPS) closed cell foam in sheet form is used. As mentioned previously, the total wing span of this aircraft is 55 inches (140 cm). The airfoil shape is formed by bending the depron sheets in the correct way. The left and right wings are made separately and then they are attached to each other by using glue gun and then tape is applied to increase the strength. After they are attached to each other, dihedral angle (the angle between wing plane with the horizontal and this provides roll stability to the aircraft) is given to the wings by using a gauge which is provided in the kit.

Fig: Aircraft wing (55 inches long)

2) Next the Fuselage of the aircraft was made by using the same depron sheets and folding them in the required ways in order to get a cuboidal shape which will house all electrical components of the aircraft like battery, transmitter, electronic speed controller along with the servo motors which will be attached to the the push rods using connectors. And these push rods will be linked to the elevator and the rudder in the tail part. So, the control of the aircraft will be completely dependent upon these push rods.

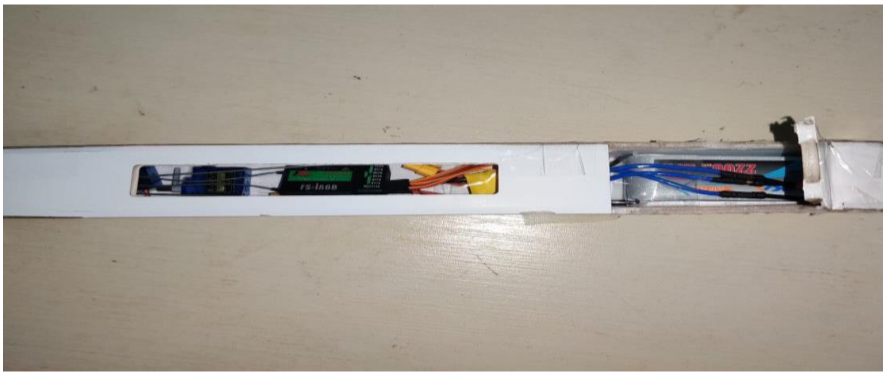

Fig: Fuselage of the aircraft

3) After the fuselage part of the aircraft is made and all the electrical components are placed inside the fuselage, the motor is attached to the front end of the fuselage by using a wooden plate. Then the propeller is attached to the motor, we must also make sure that motor is properly connected to the electronic speed controller, which will decide the rpm of the propeller rotation when the aircraft flies.

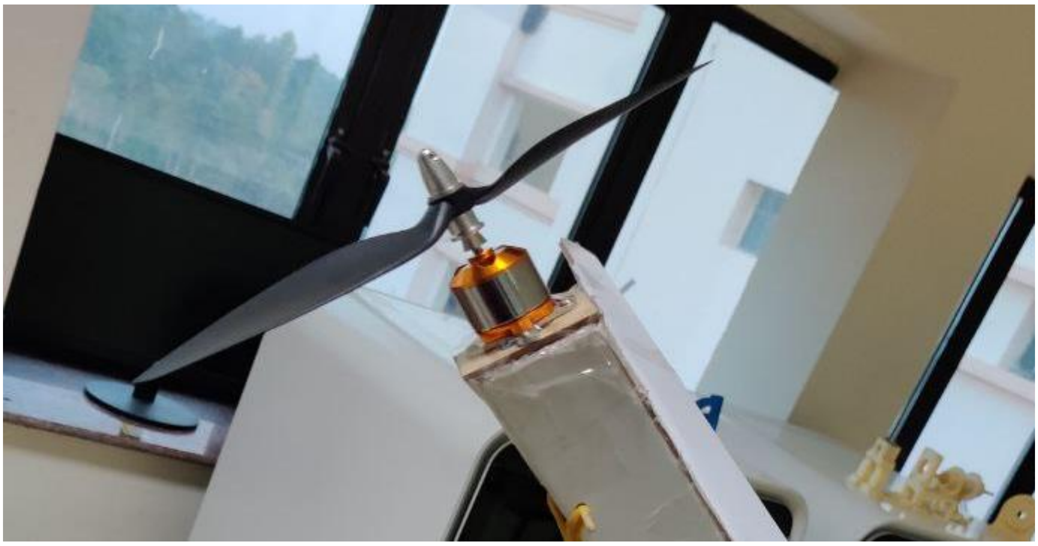

Fig: Motor and propeller

4) After attaching the motor and propeller the front part of the aircraft is completed, but the tail part is also very much important. It consists of two parts namely the vertical stabilizer and the horizontal stabilizer. The vertical stabilizer has rudder and the horizontal stabilizer has elevator, both of these are connected to the other ends of the push rods.

Fig: Horizontal and vertical stabilizers

5) One of the most important part of an aircraft are the wings, they should be properly attached to the fuselage for the aircraft to fly as intended. In this model strong latex rubber bands are used along with long wooden sticks to attach the wings to the fuselage. Wings should be rigidly attached, it shouldn't move.

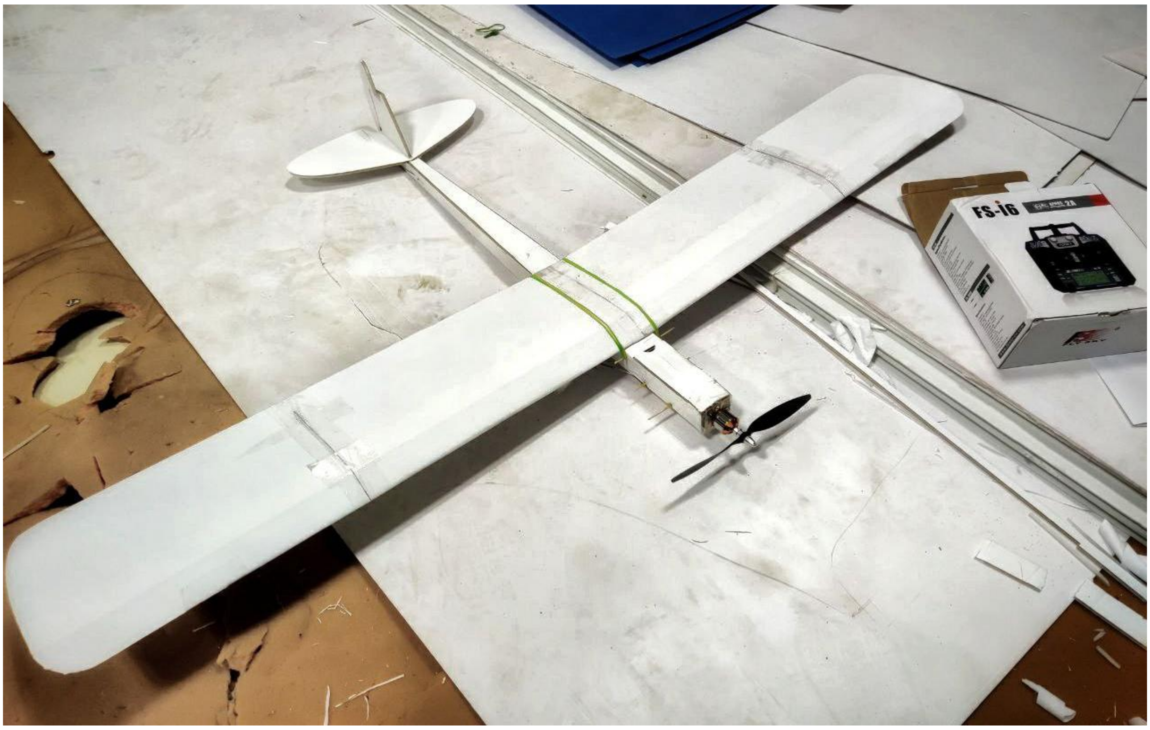

Fig: wings attached to the fuselage

6) Landing gear is also attached to the bottom part of the fuselage using latex rubber bands, wheels are made by cutting out perfect circles from the material provided and using a plastic sheet over it., for its proper movement over any plane.

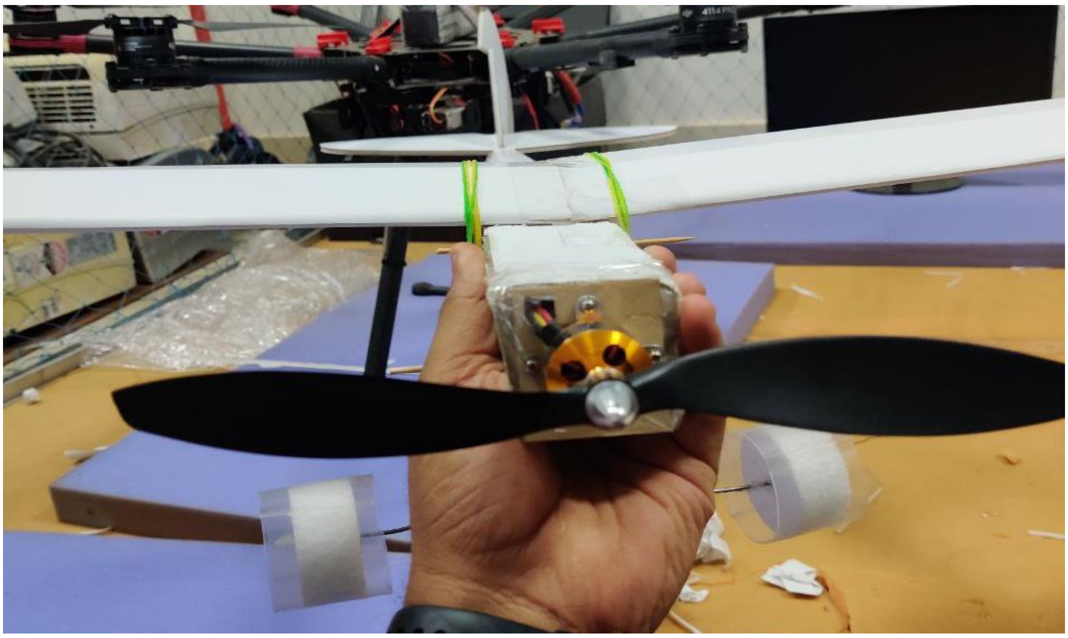

Fig: landing gear

7) The next step is very important, it has to do with the remote control, we purchased a FlySky FS-i6 2.4G 6CH AFHDS Transmitter With FS-iA6B Receiver for RC FPV Drone. The transmitter is fitted inside the fuselage of the aircraft and proper connections are given with the push rods and battery. The transmitter is 6 channeled, and the radio frequency range is 2.40-2.48 Ghz, and weighs around 390 grams.

Fig: Remote controller and transmitter

8) The final step involves testing, whether the aircraft is powered up properly and see whether the aircrafts rudder and elevator are moving with the commands of the remote controller.

Fig: Aircraft full working model

Chapter 5

RESULTS AND DISCUSSION

From the experimental data, the following results have been drawn –

Table 5.1 showing Maximum deformation

S No.	Material	Shape	Maximum Deformation (mm)
1	Aluminium alloy	Rectangular	8.543
2	Titanium alloy	Rectangular	6.243
3	Aluminium alloy	Tapered	9.224
4	Titanium alloy	Tapered	6.774

- Based on the simulations done on each wing the following results are obtained as shown in the above table, for same set of conditions and same measurement of wings. Rectangular titanium wing shows the least deformation and the highest strength whereas the tapered Aluminium alloy wing shows maximum displacement.

Natural Frequencies of first mode for each wing was found out by Modal analysis done in Ansys.

Table 5.2 showing Natural Frequencies

S No.	Material	Shape	Natural Frequency (Hz)
1	Aluminum alloy	Rectangular	73.9
2	Titanium alloy	Rectangular	66.9
3	Aluminum alloy	Tapered	107.8
4	Titanium alloy	Tapered	97.4

- ❖ Based on the simulations done on each wing the following results are obtained as shown in the above table, for same set of conditions and same measurements of wings.

- ❖ Rectangular titanium wing shows the least frequency, which means it will have lesser vibration as compared to other and will ideal for a stable flight whereas again the Tapered Aluminum alloy wing shows the maximum frequency of vibrations which means it will have more vibrations as compared to other model of wing.

Chapter 6

CONCLUSION

- In this thesis, by performing various simulations in Ansoys workbench, we can conclude that the Titanium alloy wings shows better dynamic structural response as compared to wings made up of Aluminum alloys.

- The results of simulations conclude that the Rectangular shaped wings give the least displacement when subjected to pressure.

- By knowing the natural frequency of an aircraft, we can calculate the resonance of the wing structure. This Resonance of the wing structure is determined to prevent the aircraft wing from failing.

- Thereby, finally it can be concluded that the wing which made up of Titanium alloy and Rectangular in shape gives us the best dynamic structural response by displacing the least and having the least frequency of vibrations when subjected to the pressure and conditions.

6.1 Scope for further work

In this thesis, dynamic structural analysis of Aircraft wing is done, however this cannot give us a clear idea on how the wing will perform when it is moving with certain speed and what will be the displacement when the wing is at different angles of attack. So further work can be done on how the wing will behave when it is under motion.

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