

PEER-REVIEWED ARTICLE

**FINITE ELEMENT ANALYSIS OF BI COPTER
BODY FRAME MODEL**

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ABSTRACT

Bi copters are one of the rarely seen rotary wing vehicles in real world. Bi copters are difficult to manufacture and stabilise. Selection of proper materials and design for fabrication of a bi copter is crucial. This paper gives structural analysis of different materials using ANSYS as the software tool. Such an analysis can be done to any design model, here bi copter is under consideration. Carbon fibre and aluminium are taken as test materials for the purpose of analysis and structural analysis is done and the results are analysed and compared. It is found that carbon fibre has three times the load bearing capacity when compared to that of aluminium frame of a bi copter.

Keywords: Bi copters, rotary wing vehicles, load bearing capacity, carbon fibre, structural analysis

Introduction

Bi copter is a device in which electrical, electronic and mechanical components are integrated as a single unit to give us our desired aviation and to meet our objectives.

Bi copter is a field in which extensive research is being done, one of the major researches done recently as proposed by Gress, G. R. (2018). It incorporates the advantages of both a helicopter and a quadcopter as detailed by Bhavik Gupta, Ankit Patel, Anurag Kumar, Mohit Ujjwal (2015). Stabilised bi copter has higher payload lifting capabilities consuming lesser power since the number of rotors are less. Consumption of less power leads to higher endurance as discussed by Kanaiya Agrawal, Punit Shrivastav (2013). These features are of utmost importance in rescue operations conducted by the military whenever the need arises as described by Nataraj, Madhukumar, Karthik (2017). Unlike a quadcopter whose frame design can be done on existing literature and that which has almost reached level of saturation, bi copter is still under areas of research. Stability of a bi copter electronically alone is difficult to achieve as discussed by Qimin Zhang, Zihe Liu, Jieru Zhao, Shuguang Zhang (2016).

Bi copter body frame model is done using solidworks and analysis is done using finite element analysis with the help of ANSYS as analysed by Endrowednes Kuantama, Dan Craciun, Radu Tarca, (2016). Body frame model is done keeping in mind various pre-requisites needed such as payload carrying capacity, strength to weight ratio, centre of gravity, positioning of electrical and electronic components etc detailed by Parag Parihar, Priyanshu Bhawsar, Piyush Hargod (2016). Body frame model is designed taking various concepts from vertical take-off and landing (VTOL) and hover bike to achieve maximum structural stability as discussed by Ninad R. Patil, Ashish A. Ramugade (2017).

On completion of analysis of the model, frame can be built or 3Dimensionally (3D) printed. 3D printing is preferred owing to its advantage of having higher strength to weight ratio and its ability to craft intricate designs. The electronic components required are selected beforehand based on ideal required thrust calculations and on the objectives of bi copter to be met as discussed by Prof. Javir, A. V. Ketan Pawar, Santosh Dhudum, Nitin Patale, Sushant Patil (2015).

Objectives

The major objectives of this paper are as follows:

1. Primary objective is to analyse the load deformation (ductility) characteristics of different materials and the sequential process to do the same for a bi-copter.
2. Secondary objective is to go through the sequential steps of designing and building a structural stable bi-copter.

Methodology

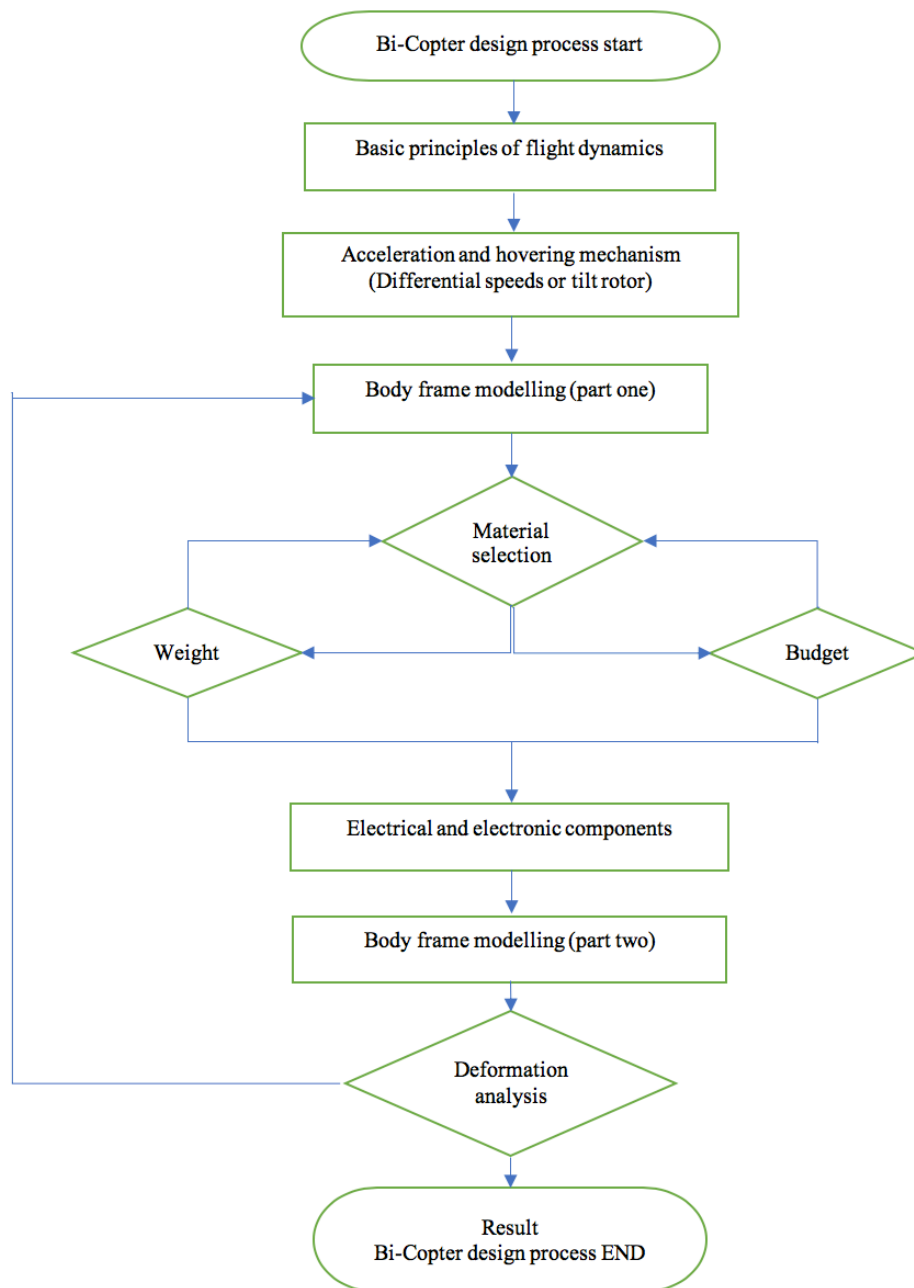


Figure 1. Design process of bi-copter body frame model

Figure 1 shows the flow chart that represents the various stages in carrying out the structural analysis. Bi copter is a device in which electrical, electronic and mechanical components are integrated as a single unit. These components must work hand in hand with each other to become a homogeneous system. Each component must be compatible with all of the other components to enhance the overall performance of the copter, else the copter fails.

Electronic components are the brains behind the flight of the copter. They control the stability and manoeuvring of the copter. All low power components come under electronics. They are also responsible for enhancing the capabilities of the copter by integrating various electronic components performing different functions. Electronic components include electronic flight controller, receiver, global positioning system (GPS), sonar, gimbal, camera, first person view (FPV), power module, etc.

Electrical components are the main power supplying and distributing part of the copter. It gives sufficient power to power the copter for it to hover, accelerate, decelerate, or to perform acrobatics if needed. High power components come under electrical. Electrical components include battery, electronic speed controller (ESC), motors, power distribution board, etc.

Mechanical components are the supporting structure which holds all the other components in its appropriate or designated place. It mainly consists of body frame and landing gear designs. Other components can be added later which enhances the durability, compactness or appearance.

Electronic and electrical components cannot be placed adjacent to each other, since the high-power lines of electrical components has a probability of destroying the electronic components. Also, magnetic fields are induced due the current flowing through the electrical components which in turn induces current in electronic components in addition to the signal currents flowing through it. So, the information signals being sent are disrupted and copter loses its stability. Hence sufficient clearance must be maintained between these two components to minimize the effects as much as possible which is looked after in mechanical design of the copter.

Flight Dynamics

Bi copter is a two-rotor device. Movement in all 3 axis needs to be controlled by the two rotors present. Directional movement of the copter can be controlled in two ways. By differential increase in the speeds of the rotors or by tilting the rotors to a very small degree. Motor with a propeller spinning at its designated speed has certain thrust being produced along with inherent torque due to its rotation. Controlled speed of rotors thus leads to differential speeds and torques relative to the two rotors present which enables the movement of the copter in different directions. Bi copter movement in x and y axis are called roll and pitch respectively. Rotation of copter about its axis in x-y plane is called yaw.

Hovering and Acceleration:

Bi Copter having only two rotors is one of the most difficult ones to hover at a place but also is one of the easier ones to accelerate swiftly and make tight turns. It is ideally suited for acrobatics. But it is also imperative that it stays hovering at a place without drifting. In this regard, the flight control systems must be very well tuned and as far as possible the centre of gravity of the entire copter along with its electronic components must be below the position of motors, so that it eases the level of complications on the rotors. In order to accelerate, the two rotors are tilted in the forward or backward direction by few degrees and the copter accelerates rapidly. Care must be taken that restriction is provided on the maximum tilt of rotors, else there is a chance that copter might topple or flip.

Body frame modelling (Part-1)

In order to design the body frame model of any Copter, first we need to have a clear picture so as to the approximate weight and size of the copter we desire to build. Depending on the total weight of the copter, material needed to build our copter is decided. Sometimes multiple materials can be used in order to build our copter. In such cases, our budget restriction comes into play and we can use the material which is economical to us.

Electrical and Electronic aspects

These form the power supply and brains behind the working of a copter. Depending on the approximate weight of the copter, thrust required is calculated. Minimum of 2:1 thrust to weight ratio is preferred and can go as high as 8:1 or more for acrobatic copters. Based on individual needs, thrust is calculated and appropriate motors are chosen with its prescribed propeller length. Base on maximum current that can be drawn by the motors, electronic speed controllers (ESC's) are determined and the maximum total current drawn by all ESC's combined and the endurance of the copter desired by each individual determines the minimum milliamp hour (MAH) and 'C' rating of the battery needed. This fixes the basic power housing or the electrical components of the copter. Now depending on the level of stability, ease of operation, ease of tuning needed, and most importantly economic restrictions, flight controllers are chosen. various types of flight controllers are available in the market, from simple low cost to complicated, superior heavy budget flight controllers. Ex: KK2.0 Flight Controller, CC3D, Pixhawk, NAZA Flight Controllers etc. Finally, a receiver bound to the transmitter that is used is connected to the flight controller. This forms the basic brains and electronic components behind the operation of a copter.

Body frame modelling (Part-2)

Once the electrical and electronic components are decided, it is easier to get the exact weight of the copter and the strength of the frame required to carry the weight. Propellers are decided which gives the exact size of the copter being designed. Depending on the clearance left between the ends of propeller, size of copter is fixed from one axis of the propeller to its adjacent one. Sufficient clearance must be given between propellers so as to minimize the interference between the two rotors. Ideally, the clearance needed to be given to get the interference as zero is very high and cannot be accomplished practically. Hence some compromise is done, and an appropriate clearance is given. Exact turbulence effect between the two rotors and downwash from the rotors can be seen or calculated using computational fluid dynamics (CFD). Depending on positioning of various electrical and electronic components, the entire frame of the copter is designed. Designing is preferably done using a computer aided design (CAD) modelling software like SolidWorks, Catia Etc.

Deformation analysis of bi copter body frame model

Depending on weight of copter and maximum payload it needs to carry, different materials can be used for copter construction. Relatively few are strong but brittle, or ductile but weak or have high strength to weight ratio but expensive. Hence, while designing, a compromise needs to be done between materials by analysing properties of various materials. ANSYS is one of the software used to analyse various materials.

An analysis is done taking two materials into consideration, Aluminium 6061 alloy as shown in Figure 2 and carbon fibre epoxy composite as shown in Figure 3. A bi copter frame is designed in CAD (SolidWorks) and ANSYS deformation analysis is done on it by applying various loads taking both these materials into consideration.

Both these materials are assigned to the same frame to avoid the ambiguity of change of dimensions while analysing. Weight of frame when the frame is made by each of these materials are calculated. To avoid ambiguity, weight of electronics is considered to be zero just for the sake deformation analysis. Weight imparted by electrical and electronic components relatively vary considerably from one copter to another. This depends on the needs and ability of the individual building the copter. Weight of frame relatively remains the same for a given size and shape for similar copters. Hence, analysis is done considering just the weight of frame and weight of other components are considered as zero. Thrust given by motors are considered to be point loads acting at the centre of each rotor.



Figure 2. aluminium body frame model



Figure 3. carbon fibre body frame model

First analysis is done, taking the total thrust produced by rotors equal the weight of the frame, i.e. an ideal case when the copter just hovers. Weight of aluminium frame is 442.12 grams and weight of carbon fibre frame is 326.5 grams. Aluminium frame in Figure 4 shows maximum deformation of 3.33mm and carbon fibre frame in Figure 5 shows maximum deformation of 0.91mm respectively.

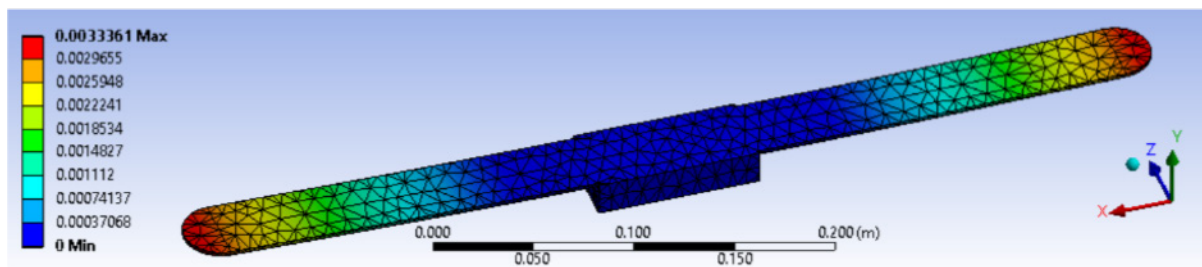


Figure 4. Aluminium Frame, Max Deformation = 3.33mm

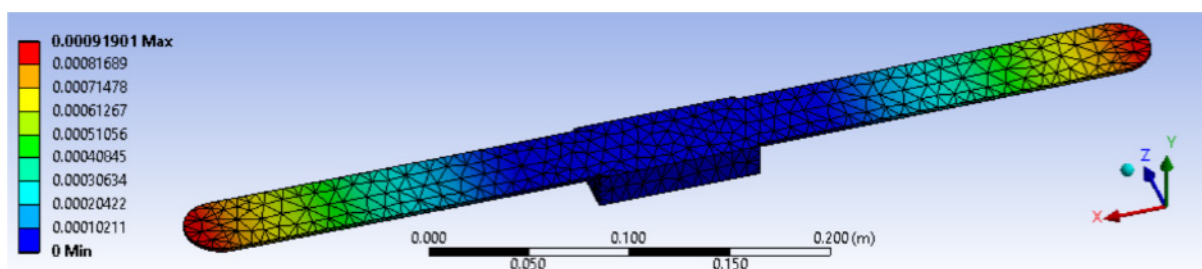


Figure 5. Carbon fibre Frame, Max Deformation = 0.91mm

Second analysis is done, taking the total thrust produced by rotors approximately equal to that which causes one-degree deformation in both the frames independently. Aluminium frame in Figure 6 shows maximum deformation of 3.69mm and Carbon fibre frame in Figure 7 shows maximum deformation of 3.73 mm respectively.

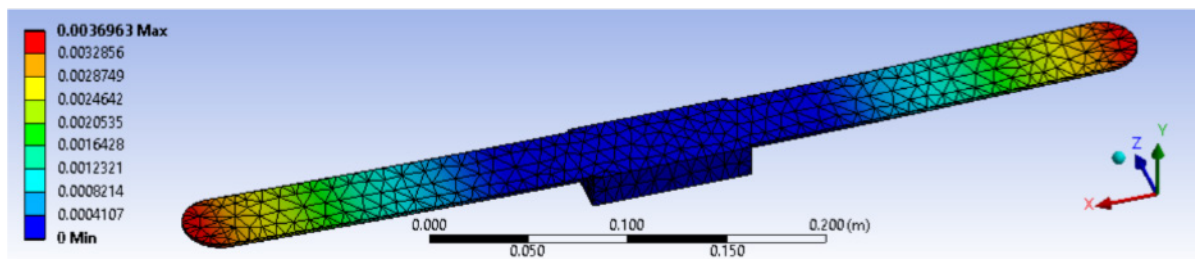


Figure 6. Aluminium Frame, Max Deformation = 3.69mm

Thrust produced by each motor = 2.4 Newtons

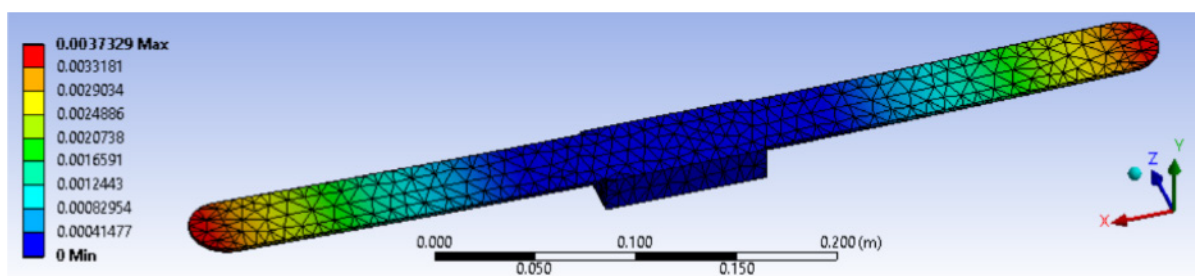


Figure 7. Carbon fibre frame, Max Deformation = 3.73mm

Thrust produced by each motor = 6.5 Newtons

Third analysis is done, taking the total thrust produced by rotors approximately equal to that which causes two-degree deformation in both the frames independently. Aluminium frame in Figure 8 shows maximum deformation of 7.46mm and carbon fibre frame in Figure 9 shows maximum deformation of 7.45 mm respectively.

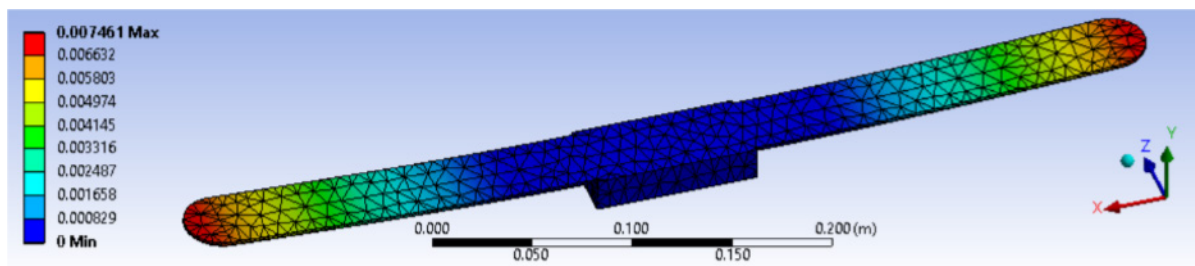


Figure 8. Aluminium Frame, Max Deformation = 7.46mm

Thrust produced by each motor = 4.85 Newtons

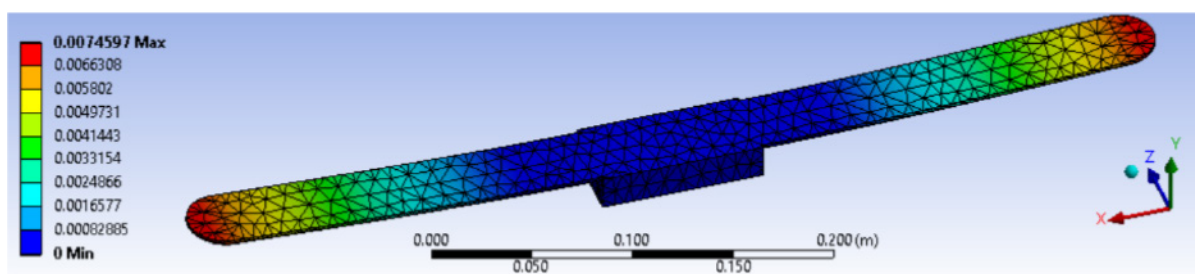


Figure 9. Carbon fibre Frame, Max Deformation = 7.45mm

Thrust produced by each motor = 13 Newtons

Fourth analysis is done, taking the total thrust produced by rotors approximately equal to that which causes three-degree deformation in both the frames independently. Aluminium frame in Figure 10 shows maximum deformation of 11.13mm and carbon fibre frame in Figure 11 shows maximum deformation of 11.17 mm respectively.

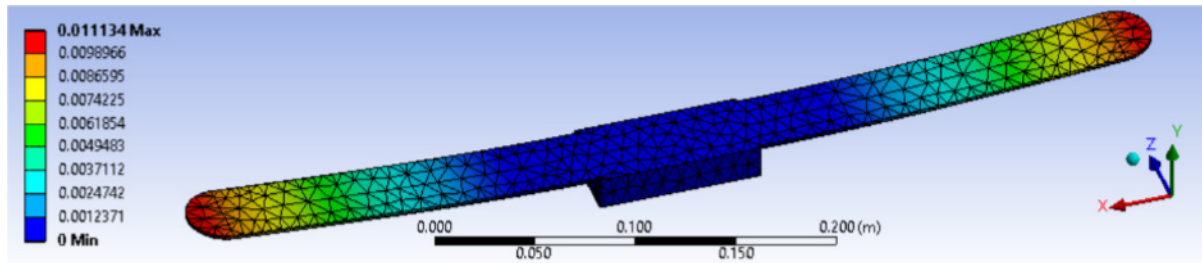


Figure 10. Aluminium Frame, Max Deformation = 11.13mm

Thrust produced by each motor = 7.25 Newtons

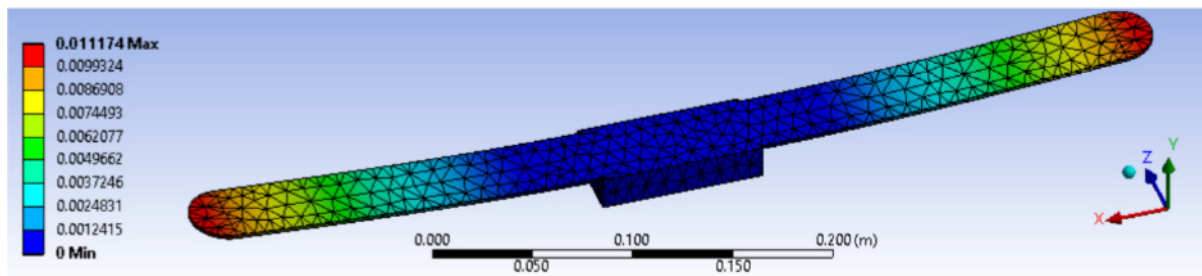


Figure 11. Carbon fibre frame, Max Deformation = 11.17mm

Thrust produced by each motor = 19.5 Newtons

Fifth analysis is done, taking the total thrust produced by rotors approximately equal to that which causes four-degree deformation in both the frames independently. Aluminium frame in Figure 12 shows maximum deformation of 14.86 mm and carbon fibre frame in Figure 13 shows maximum deformation of 14.86 mm respectively.

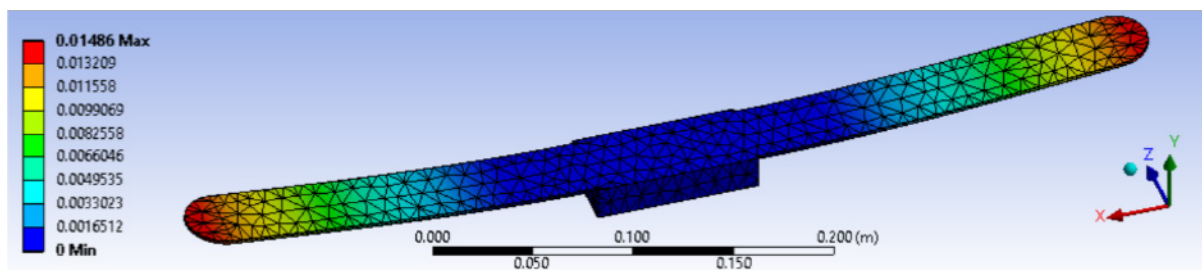


Figure 12. Aluminium frame, Max Deformation = 14.86mm

Thrust produced by each motor = 9.7 Newtons

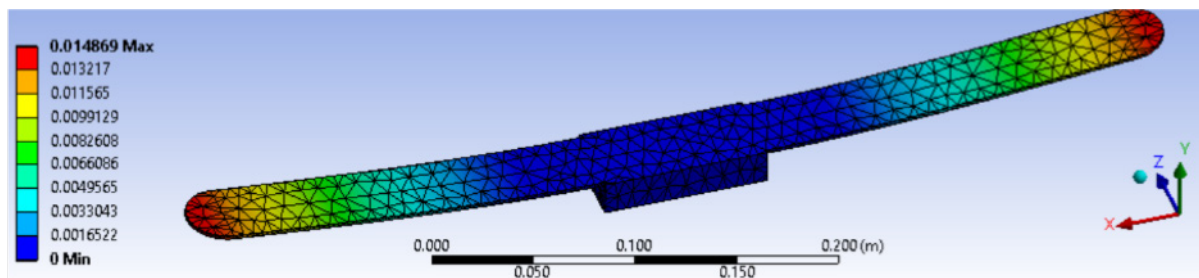


Figure 13. Carbon fibre Frame, Max Deformation = 14.86mm)

Thrust produced by each motor = 26 Newtons

Sixth analysis is done, taking the total thrust produced by rotors approximately equal to that which causes five-degree deformation in both the frames independently. Aluminium frame in Figure 14 shows maximum deformation of 18.63 mm and carbon fibre frame in Figure 15 shows maximum deformation of 18.54 mm respectively.

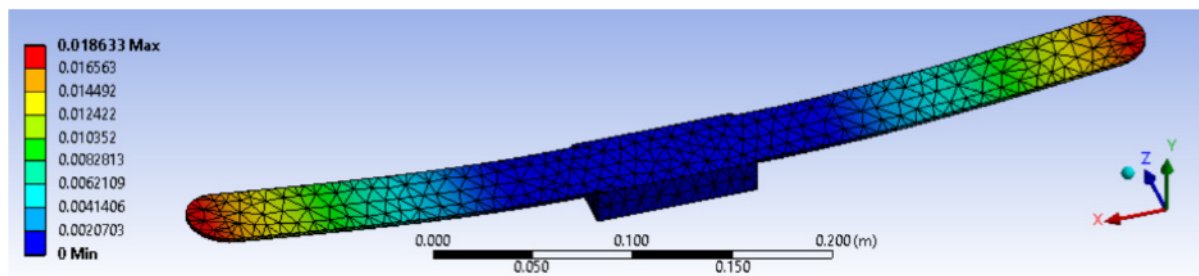


Figure 14. Aluminium frame, Max Deformation = 18.63mm

Thrust produced by each motor = 12.2 Newtons

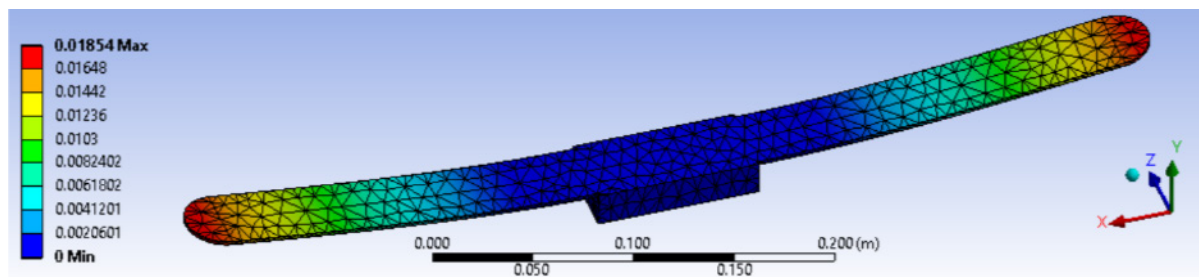


Figure 15. Carbon fibre frame, Max Deformation = 18.54mm

Thrust produced by each motor = 32.5 Newtons

Results

Table 1: Deformation results of carbon fibre and aluminium frame of bi copter

| Material | Weight (gram) | Lift-Off Thrust (newton) | Thrust of single motor at one-degree deformation (newton) | Thrust of single motor at Two-degree deformation (newton) | Thrust of single motor at Three-degree deformation (newton) | Thrust of single motor at Four-degree deformation (newton) | Thrust of single motor at Five-degree deformation (newton) |
|------------------------------|---------------|--------------------------|---|---|---|--|--|
| Aluminium Frame | 442.12 | 4.33 | 2.4 | 4.85 | 7.25 | 9.7 | 12.2 |
| Carbon Fibre Composite Frame | 326.5 | 3.19 | 6.5 | 13 | 19.5 | 26 | 32.5 |

Conclusion

Deformation in aluminium and carbon fibre for various loads were observed. These two materials were compared based on common grounds and on ideal cases. These were Analysed for a maximum deformation of approximately 5 degrees or 2cm. Deformation of lengths greater than these are not advisable in copters as part of thrust is lost or wasted.

Similarly, analysis for different materials can be done and the best one suited for each individual can be chosen. This helps us in quantitative and qualitative view on selection of proper material for copters.

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