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INNOVATIVE DESIGN AND ANALYSIS OF A 3D-PRINTABLE QUADCOPTER

Samir Chakravarti*1, Tanay Bhakta*2, Shovan Jana*3, Saptarshi Bandyopadhyay*4

*1Assistant Professor, Department Of Mechanical Engineering, Kalyani Government Engineering College, Nadia, West Bengal, India.

*2,3,4Student, Department Of Mechanical Engineering, Kalyani Government Engineering College, Nadia, West Bengal, India.

ABSTRACT

This paper presents an innovative design of a quadcopter based on a single frame that can be completely 3D printed. The single frame design and 3D printability makes its production easy and can be done automatically. Polymer materials like nylon 6 or carbon fibre reinforced plastic are used for the frame analysis to make it very light weight without compromising its structural strength to carry load or easy maneuverability. Autodesk Fusion 360 software has been used for designing the frame and also to analyse its strength under loaded conditions to identify the critical points of stress concentration and maximum deflection. The stress and deflection analysis is done based on varying thrusts produced due to changing rpm of the rotors. The analysis of this light weight model indicated towards its high reliability and flexibility so that it can be used for various purposes of surveillance, medical delivery, etc.

Keywords: Quadcopter, Frame, Fusion360.

I. INTRODUCTION

Nowadays, drones have become an essential part of thermography, agriculture, disaster management, thermal observation, military surveillance and many more. A quadcopter is a drone with quad or four number of rotors. A pair of diagonal propeller rotates in clockwise direction and another pair in anti-clockwise direction to provide the thrust needed to lift the quadcopter up. The thrust from each motor is proportional to speed of each motor and for a quadcopter the total thrust is four times the thrust from a single motor. The weight of the drone is based on the frame weight, motor, propeller, battery, and other electronic equipments.

Shen et.al [1] presented theory for various weight of drones to take off away from land. The importance of the theory equations lies in its ability to determine which drone will easily take off and fly. Kuantama et. al [2] has shown how rotational velocity in each propellor affected the thrust efficiency and caused flight instability using Finite Element Analysis(FEA) method. Hunsaker et.al [3] presented momentum theory with slipstrim rotation for wind turbines giving a way to evaluate thrust coefficient, power coefficient, axial induction factor and circumferencial induction factorof turbine in terms of tip-speed ratio and torque coefficient through theoretical and experimental analysis. Putra et.al [4] has proposed a way to calculate the maximum take off weight of an aircraft using the motor specifications like angular velocity, current consumption, number of rotors etc.It also estimated the maximum flight time for a specific set of body weight,motor and power system used for a drone design. Yadav et.al [5] investigated efficiency of a propellor to provide more thrust at same power supply. The optimum thrust to weight ratio was also calculated for same configuration of models to increase performance through experimental results obtained using the Ecalc-propCalc calculator on the web. Khan et.al [6] presented a way to adjust thrust of the rotors via voltage supply to perform standard flight operations and to position the quadcopter into certain angular orientation depending on the circumstances of a particular flight routine. Yang et.al [7] developed an origami-inspired foldable quadrotor using cardboard with its arms extended or folded, the foldable quadrotor could change the moment of inertia and ambient air flow velocity. Mahen et.al [9] developed a suitable design configuration for an amphibious quadcopter with the help of CAD and CAE tools and the design was initiated by the approximate payload the quadcopter that should carry the weight of individual components. Virginio et.al [10] achieved a low cost and easy-to-manufacture thrust benchmarking system because of various method implemented during manufacture and assembly.

The objective of this project isto design a single frame based quadcopter body model using Autodesk Fusion 360 software and it can be completely 3d printed. For the stability of the quadcopter the thrust and deflection of the chassis has been analyzed.

II. BODY FRAME MODELLING AND ANALYSIS OF THE QUADCOPTER

In designing the quadcopter's body frame, the total weight which will be carried by quadcopter such as the weight of frame, battery, electronics and motor were taken into consideration. The perforated frame design have the lightest weight possible yet with decent rigidity in order to fly steadily and carry payload. The chasis design in Fusion 360 interface is shown in figure 1.

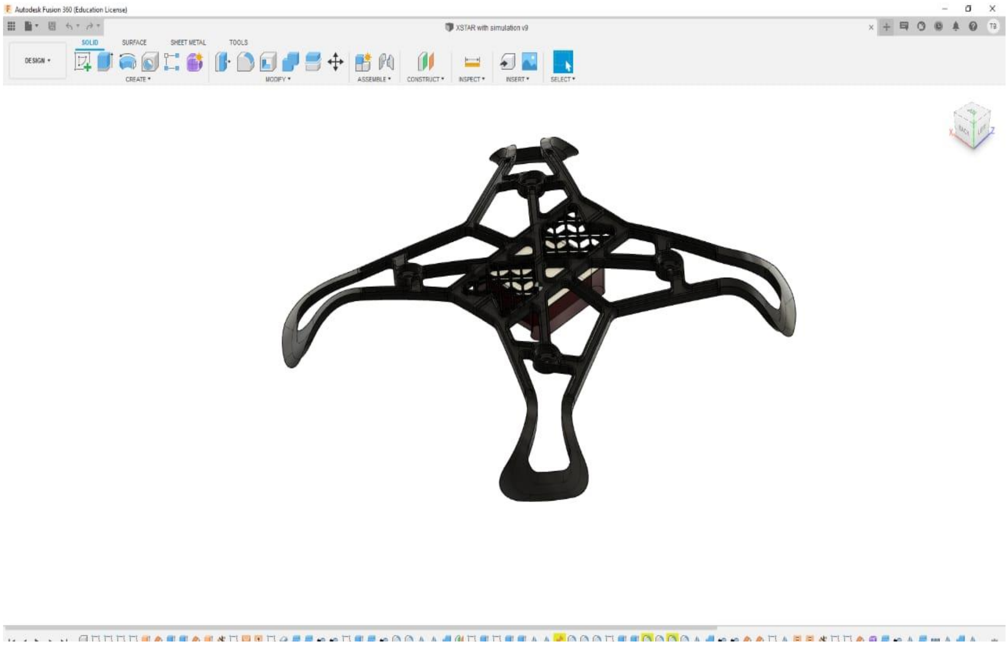

Figure1: Design of the chassis in Fusion 360 interface.

The designed quadcopter has a dimension of 500 mm x 500 mm and volume of 2.008×10^5 mm^3. For this study the quadcopter has been assembled with A2212/13T 1000KV motor with 4S batteries and APC E Series 9*4.5 propellers for the testing purpose. The materials examined for this quadcopter chassis are CFRP(carbon fibre reinforced plastic) and nylon 6 whose yield strengths are 50 MPa and 3.5 GPa respectively. The specificatons of the different components of the quadcopter used for this work are given in the table 1.

The total body weight = weight of frame + 4*weight of motor + weight of battery + 4* weight of electronic speed controller weight = (287.167+ 4*52.7 + 425 + 4*50)*0.0098 N =11.005 N

As more weight may cause failure of the body so in this study this is approximated to 12 N to have greater degree of safety.

Theory analysis of the Propeller thrust:

The thrust force is generated due to the rotation of propellersin each motor. The thrust force is given by [1]

$$T = A \times \rho \times \vartheta \times \nabla\vartheta \qquad (1)$$

Where T is thrust in Newton (N), A is Area in meter square (m^2), ρ is density of air in kilogram per cubic meter (kg/m^3), ϑ is velocity of air at the propeller in meter per second (m/s) and $\nabla\vartheta$ is velocity of air accelerated by propellerin meter per second (m/s).

Table 1: Parameters and Values of the quadcopter components

SN.	Parameters	Values
1	Body Mass	287.167 g
2	Propeller model	9*4.5 STD
3	Propeller radius	0.1143 m
4	Propeller Constant	0.09
5	Power Factor	3.2

6	Air Density	1.225 Kg/m
7	Motor model	A2212/13T 1000KV
8	Motor Weight	52.7 g
9	Battery	Gens Ace 3800mAh 4s
10	Rated Voltage	14.8 Volts
11	Battery Weight	425g
12	Electronic Speed Controller Weight	50 g

In terms of power of the motor and radius of the propeller, the equation of the thrust is given by [1]

$$T = (2 \times \pi \times R^2 \times \rho \times P^2)^{1/3} \quad (2)$$

Where P represents the power of the motor transmitted topropeller in watt [W] which is calculated taking angular velocity as 75% of no load angular velocity in rpm according to the equation [1]

$$P = \text{Propeller Constant} \times (rpm/1000)^{power\ factor} \quad (3)$$

Where the Propeller constant is calculated by P/D ratios, where D is the diameter of a propeller and P is the pitch of the blade. Power factor is the ratio of operation power in kilowatts (kW) to apparent total power in kilovolt-amperes (kVA).

RPM depends on the supply voltage to the motor as

$$RPM = Kv \times Voltage \quad (4)$$

where Kv is rpm per volt from specification of motor.

The equationof the thrust force is written as

$$T = (2 \times \pi \times R^2 \times \rho \times \left(\text{propeller constant} \times (\text{rpm}/1000)^{\text{power factor}}\right)^2)^{1/3} \quad (5)$$

For this analysis, thrust generated by each motor for different angular velocities of the rotor is calculated using the equation (5) and tabulated in the table 2.

For checking the compatibility of the model, the stress and deflection analysis are done for the maximum developed thrust condition i.e. 12.691 N, which is seen from table 2 such that their corresponding design criteria for the lower values of thrust is also satisfied accordingly.

Stress Analysis :

For maintaining structural rigidity of the body the stress developed in it, is tested using fusion 360 software. For the static stress simulation of chassis a maximum thrust of 12.691 N is developed in each motor, acting along upwards direction and total body weight of 12 N is acting in downward direction.

Table 2: Thrust calculated at different rpm

SN.	RPM	Thrust (N)
1	8000	7.88
2	8500	8.98
3	9000	10.14
4	10000	12.691

The values of maximum and minimum stresses and correspondingly their critical points are observed for the frames made of carbon fibre reinforced plastic and nylon 6 materials are shown in the following figure 2 and figure 3 respectively.

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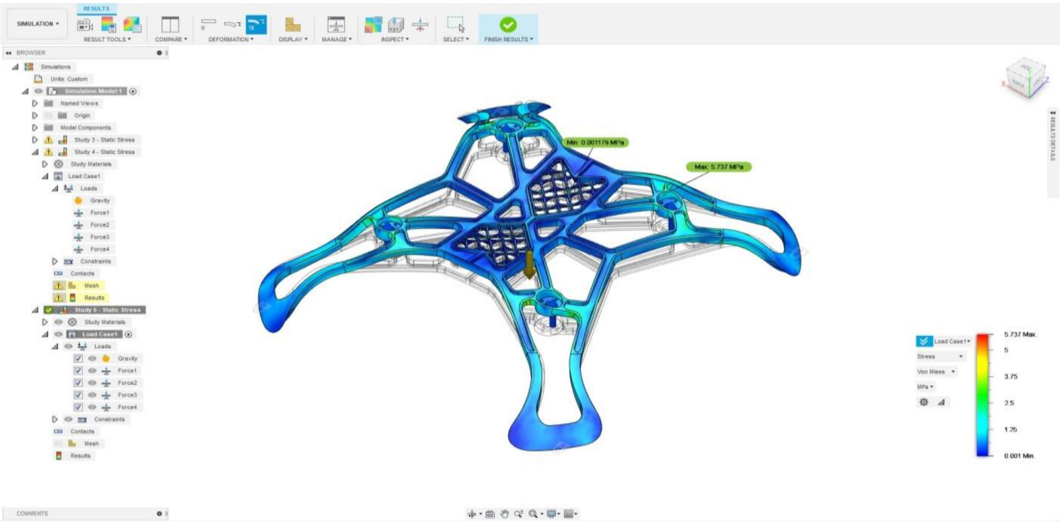

Figure 2: Stress analysis of frame made of carbon fibre reinforced plastic.

Figure 3: Stress Analysis of frame made of nylon 6.

Deflection Analysis:

For the stability and durability of the model, the displacement of the quadcopter chassis under propeller thrust is checked. The total weight of quadcopter chassis and the calculated propeller thrust are taken as input parameters. Figure 4 and figure 5 show the deflection in body frames made of carbon fibre reinforced plastic and nylon 6 materials respectively.

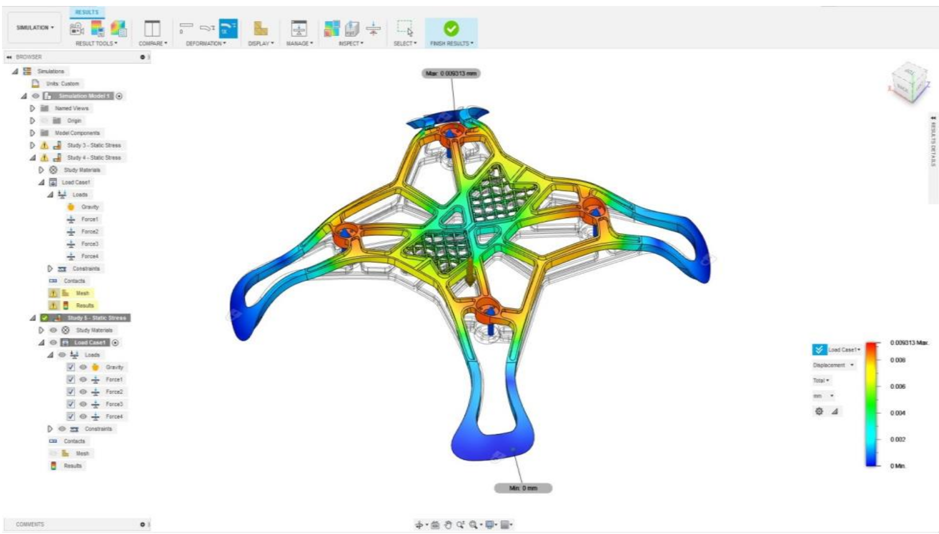

Figure 4: Deflection analysis for carbon fibre reinforced plastic frame

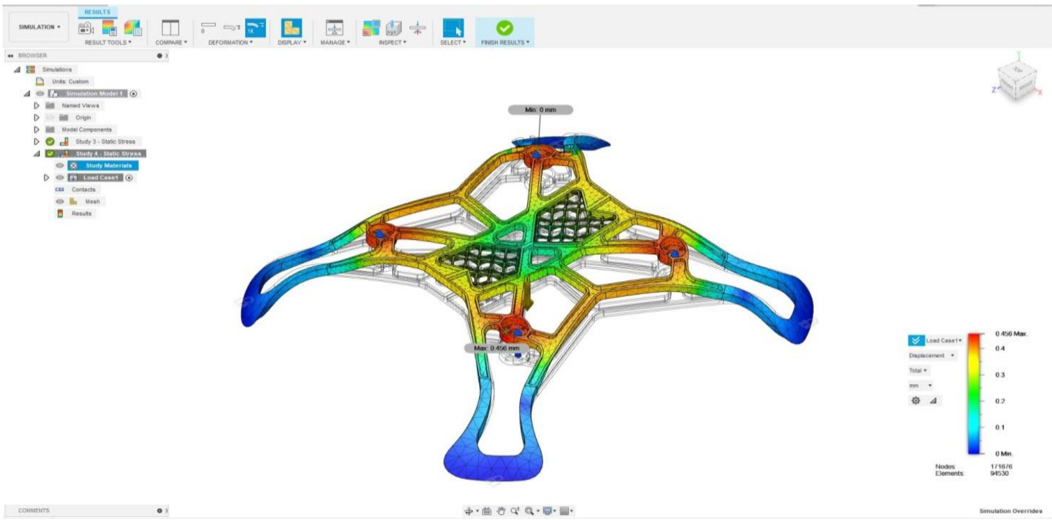

Figure 5: Deflection analysis for nylon 6 frame

III. RESULTS AND DISCUSSION

Total weight of the quadcopter assembly is 12 N and the maximum thrust applied on the chassis is 12.691 x 4 = 50.764 N, which is more than 4 times of the total weight. This implies that the generated thrust by the rotors is 38.764 N more than the combined weight of the quadcopter and its components so extra 38.764 N i.e. 3.95 kg payload can be added to the quadcopter during its operation. It will be helpful for easy lift off and better maneuverability of the quadcopter.

It is observed that for nylon 6 body frame the maximum stress developed is 5.725 Mpa, which is developed around the motor mount region. As it is below the maximum yield stress for nylon 6 material i.e. 50 MPa so this is permissible. Also the minimum stress is 0.001121 MPa which is developed at the weakest section i.e. the perforated region of the body. For carbon fibre reinforced plastic body frame the maximum stress of 5.737 MPa is developed around the motor and the minimum stress of 0.001179 MPa is developed at the perforated region. Since the yield stress of carbon fibre reinforced plastic material is 3.5 GPa so there is no concern for failure.

From the deflection analysis it is seen that for nylon 6 body frame the maximum deflection is 0.456 mm and for carbon fibre reinforced plastic body frame it is 0.0093 mm. For both the cases maximum deflection is seen around the rotor and minimum deflection of 0 mm at the limbs. The maximum deflections are very small which is desirable because if they are large then the attachments at the bottom of the quadcopter may impact the ground clearance. Moreover, if the deflection is high, there will be more vibrations which may lead to dynamic failures.

IV. CONCLUSION

From the above results it is seen that the quadcopter design for both the materials nylon 6 and carbon fibre reinforced plastic respectively have the region of maximum stress concentration around the motor mount and minimum stress concentration is generated at the perforated region of the quadcopter chassis. Simulation results are demonstrated to represent the changes in stress concentration and deflection in body-frame of the quadcopter on varying the power supply and rpm of the rotors. The deflection is minimum in the region of minimum stress concentration. Thus the considered quadcopter design of dimension 500mm x 500mm is compatible with the taken power supply and thrust generated. The chosen materials are also compatible for 3D printing. It can be used for surveillance, agricultural and other light duty applications.

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