ISSN No:-2456-2165

Developing a Quadcopter Frame and its Structural Analysis

Malothu Kirankumar, Rayudu Santhoshchandra
Students,
Department of Mechanical (Mechatronics) Engineering,
Mahatma Gandhi Institute of Technology, Affiliated to JNTUH, Ranga Reddy District, Hyderabad, Telangana

R. Uday Kumar
Associate Professor,
Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Affiliated to JNTUH, Ranga Reddy District, Hyderabad, Telangana

Abstract:- A quadcopter is one of the most versatile unmanned aerial vehicles (UAV) used for a variety of tasks. Quadcopters are symmetrical and use the simplest principle of operation for controlling roll, pitch, yaw, and motion. A DJI F450 quadcopter frame design with optimized geometry is used in this project.All the frame's components were designed using Fusion 360.Based on the results of stress analysis with Fusion 360, the proposed design is validated for its feasibility, and a suitable material for fabrication is selected through comparison with five other materials.In this paper, we investigate the static stress in the quadcopter frame and the modal frequencies in the quadcopter arm.

Keyword:- *Quadcopter, Static Structural, Constraints, Structural Geometry, Design, Analysis, Modal Frequencies, Unmanned Aerial Vehicles.*

I. INTRODUCTION

The structural design of UAVs has changed over their developmental history to serve a variety of purposes. UAV design and advancement is a global activity. As technology and needs change, UAVs can be improved to serve these needs. There are several design considerations that are constant. The first of these design criteria is the degree of autonomy. Early UAV designs were mostly set to fly a specified path until they ran out of fuel. They carried a camera onboard, which would be recovered after the UAV landed. Later, the advent of radio control systems allowed UAVs to be piloted from the ground. Modern UAVs often combine these two basic functionalities. These two modes of operation do not strictly signify autonomy. True autonomy suggests the ability of the aircraft to operate without human interaction.

Drones are now being implemented in various fields such as agriculture, delivery, mining, surveillance, mapping, etc. The versatility of drones has been expanding due to the highly advanced electronics available today. Imaging sensors, thermal sensors, passive infrared sensors, obstacle detection are some of the most used ones today. Infrastructure surveillance and maintenance is done with less use of manpower using drones. Critical structures that require a lot of energy and time for inspection such as cable towers, windmills, solar farms, industrial buildings walls and dams, can be easily inspected with the help of drones. This paper uses a new DJI F450 streamlined geometry which has been designed to be fully sealed to carry the components and all the circuits. This is done to fully protect the circuits. The model will be designed based on a basic quadcopter. The frame size, position and angle of arms are same as DJI F450 frame. The entire frame will be modeled using Fusion 360 using the chosen material's properties the weight of the structure will be estimated. The structural stability of the drone plays an important role as its application involves exposure to different pressure environments. The stability of the frame will thus be validated using analysis through software. The entire frame of the drone is subjected to static structural analysis using Fusion360.

Fig. 1: Quadcopter frame

II. PROBLEM DEFINITION

The main requirements for a drone to be able to travel in air is to have the ability to withstand the pressures which will be experienced in air and the electronic components should also not be exposed to the atmosphere as it may damage it. So, the design should be made in such a way that the electronic components like ESC, FC, battery, etc., are not exposed to atmosphere and the frame should be able to withstand air pressure till certain height. Testing quadcopter every time is costly affair hence numerical simulation provides the better and cheap way to design.

III. METHODOLOGY

The method is adopted from previous literature[1),3)]. The model is selected, modelled, and analysed as represented in Fig. 2.

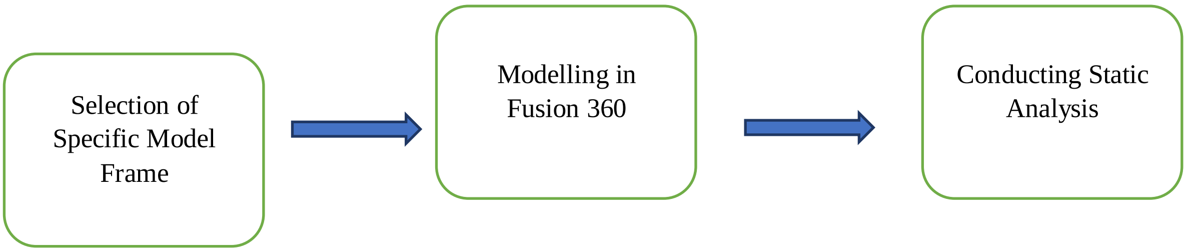

Fig. 2: Methodology block diagram

DJI F450 quadcopter frame structure is used for this analysis[2)]. The model is created in Fusion 360 with dimensions obtained from product user manual and other literature[5)]. The total loads the quadcopter will carry was determined likewise and represented in Table1.

Sl. No	Components	Quantity	Mass (gram)
1.	Quadcopter Frame	1	282
2.	Propellers	4	60
3.	Electric Speed Control	4	24
4.	BLDC Motor	4	280
5.	Lipo Battery	1	278
6.	Flight Control Unit	1	21
7.	Raspberry Pi 3	1	42
8.	Power Distribution Board	1	8
9.	Camera	1	40
10.	Payload	1	1000
	Total		2035

Table 1: Weight estimation

A. *DESIGN CALCULATIONS*

The frame mass is obtained using Fusion 360 mass property function. The total weight $W_t$is obtained using Eq. 1[4)]

$$W_t = W_E + W_P \quad (1)$$

Where, W_E are the empty weight in Newton (N) and W_P is the payload weight in N. The empty load includes the frame, battery, electronic speed controllers (ESCs) and motor weights while the payload are additional weights on the frame. Weight acting directly on the upper plate is determined as 8.47 N, this is the weight that directly acts on the plate. It includes the weight of the components listed in Table1.Except for the frame, propellers, motors, and the electronic speed controllers (ESC). The mass is determined as 1.271 kg and is converted to weight by multiplying with acceleration due to gravity.

$$1.271 \times 9.81 = 12.46 \text{ N}$$

The required thrust T in N is the minimum thrust that will be able to lift the total Drone weight. It was determined using Eq. 2 as stated by Saheb and Babu[3), 6)].

$$T = (W_t \times 2)/4 \quad (2)$$

A 10.46 N thrust was obtained as the required thrust to hover the quadcopter in the air. To calculate the produced thrust for the system three (3) components are selected.

- Propeller 1045
- Battery with capacity 4000 mAh 12V
- 1400 Kv motor

Eq. 3 is used to determine the thrust produced by the motor, T_m in N[7)]

$$T_m = \sqrt[3]{2 * \pi * r_p{}^2 * \rho_{air} * (p * \eta_h)^2} \quad (3)$$

Where r_p is the radius of the propeller in m, ρair is the air density 1.225 kg/m3, P is the power in W and η_h is the hovering efficiency. P is obtained from Eq. 4[5)]

$$P = k \times N^{pf} \quad (4)$$

Where k is the propeller constant, N is the speed in revolutions per minute ((rpm) in thousands) and pf is the power factor. N is determined using Eq. 5, as stated by Huang et al. [8)]

$$N = Kv \times V \quad (5)$$

Where Kv represents the rpm per volt from the specification of the motor and V is the voltage supplied in V, from the battery to the motor. k and pf for 1045 propeller values are 0.144 and 3.2 respectively[8)].The produced thrust is 22.94 N.

B. STATIC STRUCTURAL ANALYSIS

In the Fusion 360, the materials were selected and applied from the material library from Fusion 360 material database. The material used are Nylon 6 for the arms and ABS Plastic for the frames. The properties are given in Table2.From the Fusion 360 database are used for the analysis.

Material	Property	Value	Mass (gram)
Nylon 6,6			514.252
	Density	**1120 Kg/m^3**	
	Young's Modulus	**2758 MPa**	
	Poisson's Ratio	**0.35**	
	Yield Strength	**70.4 MPa**	
	Ultimate Tensile Strength	**75.7 MPa**	
	Thermal Conductivity	**0.281 W/m°C**	
	Thermal Expansion Coefficient	**9.53E-05 / C**	
	Specific Heat	**1670 J / (kg C)**	
ABS Plastic			161.172
	Density	**1060 Kg/m^3**	
	Young's Modulus	**2240 MPa**	
	Poisson's Ratio	**0.38**	
	Yield Strength	**20 MPa**	
	Ultimate Tensile Strength	**29.6 MPa**	
	Thermal Conductivity	**0.16 W/m°C**	
	Thermal Expansion Coefficient	**8.57E-05 / C**	
	Specific Heat	**1500 J / (kg C)**	

Table 2: Material Properties

The analysis was conducted in two phases: (i) Analysis of the complete frame and (ii) Analysis of single arm. Mesh was applied to both geometries separately. The mesh from frame structure is given in Fig.3.

After setting the fixtures the loads were applied as depicted in Fig.4. and analysis conducted.

The same procedure is used for the single arm investigation as seen in Fig.5.

Fig. 3: Mesh results for frame structure

Fig. 4: Meshed frame with load

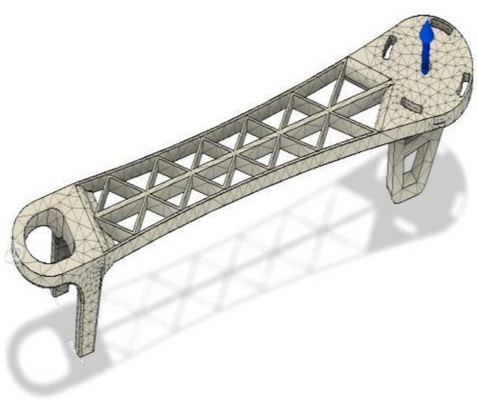

Fig. 5: Meshed Arm with load

IV. RESULT AND DISCUSSION

The total deformation, reaction forces, contact pressures, principal stresses, for the above-mentioned loading conditions and materials were obtained using structural analysis tool in Fusion 360. The deformation results are shown in the figures below. The deformation values are shown in Table 3.

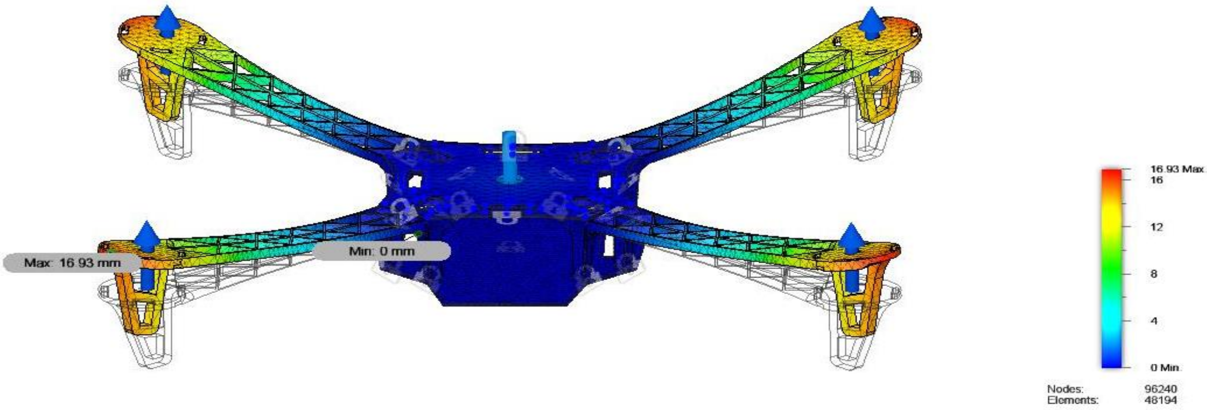

Fig. 6: Nylon 6,6 – Total Deformation

Fig. 7: ABS Plastic – Total Deformation

Sl. No	Material	Total Deformation (mm)	Von mises stress (Mpa)	Reaction force (N)	Contact pressure (Mpa)
1.	Nylon 6,6	66.77	30.07	17.83	2.359
2.	ABS Plastic	16.93	7.581	291.1	2.505

Table 3: Deformation Values

A. MODAL FREQUENCIES

The total deformation results are shown in the figures below. The deformation values are shown in Table 4.

Frequency	Participation X	Participation Y	Participation Z
Mode 1: 0 Hz	100	0	0
Mode 2: 0 Hz	0	100	0
Mode 3: 0 Hz	0	0	100
Mode 4: 0 Hz	0	0	0
Mode 5: 0 Hz	0	0	0
Mode 6: 0 Hz	0	0	0
Mode 7: 53.09 Hz	0	0	0
Mode 8: 81.99 Hz	0	0	0

Table 4: Modal frequencies deformation values

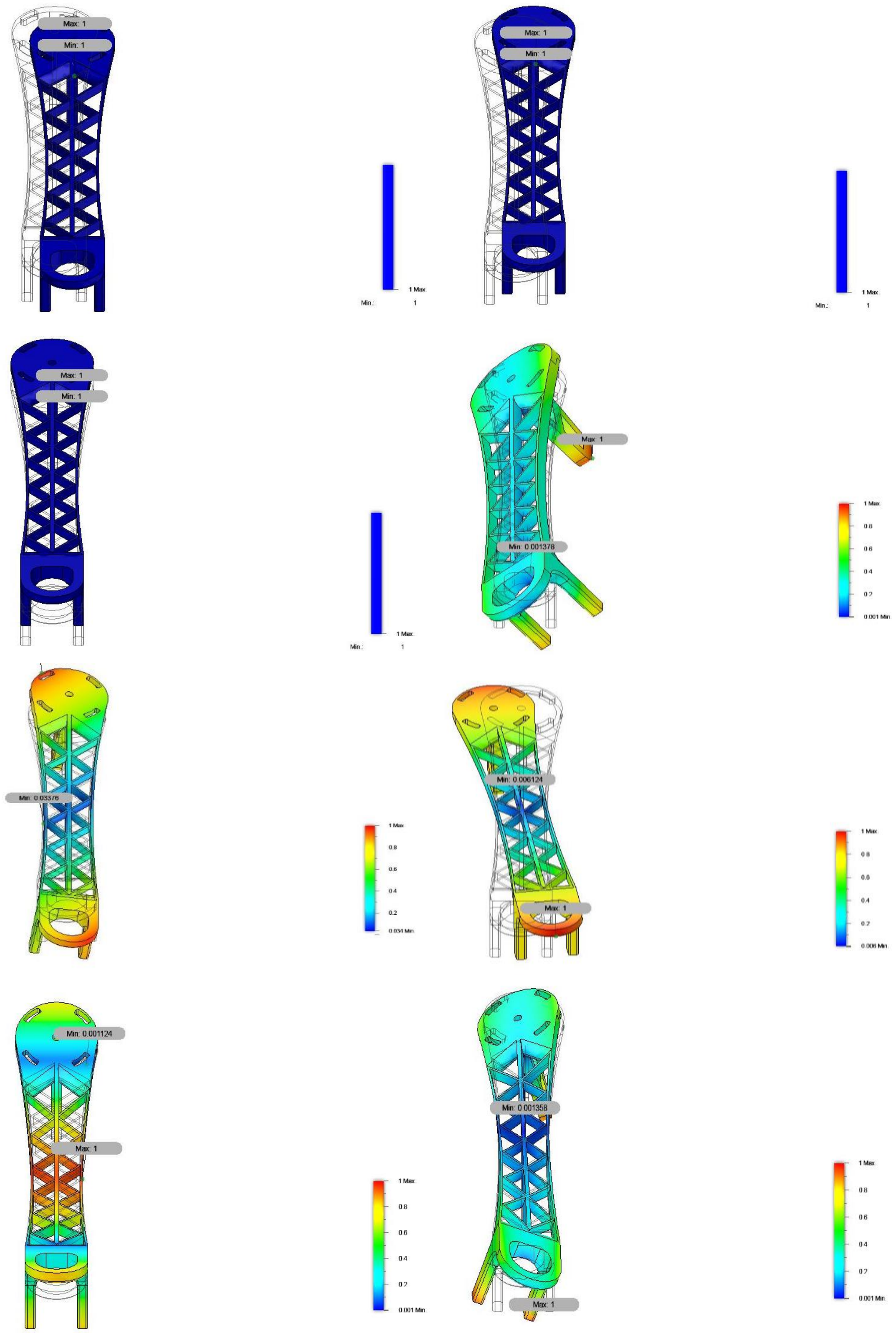

Fig. 8: Total deformation of modal frequencies

V. CONCLUSION

The center of gravity was calculated, and it was found to satisfy the balancing condition for this case. From the total deformation results obtained in Fusion 360 we inferred that the deformation for all the chosen materials was within negligible limits. Therefore, the most suitable material was chosen based on the weight of the frame.The structure was modelled in Fusion 360 and analysed using Fusion 360. Maximum stresses obtained are 7.581 and 30.07 MPa for the frame and arm structures respectively. The stress is well within safe working limits for the material, therefore safe for use.

REFERENCES

[1.] Sulaiman, A. Babawuya, O. Adedipe, B.A. Salihu, A.A. Aliyu, and A.G. Ibrahim, "A Review of Bird Pest Repellent Systems in Farms," 2020 1st International Business Management Conference Wukari, 1-13 (2020).

[2.] R. Singh, R. Kumar, A. Mishra, and A. Agarwal, "Structural analysis of quadcopter frame," Materials Today Proceedings, 22 3320-3329 (2019).

[3.] S.H. Saheb, and G.H. Babu, "Design and Analysis of Light Weight Agriculture Robot," Global Journal of Researches in Engineering," 17 (6) 1-19 (2017).

[4.] A.M.M. Ismaiel, S.M. Metwalli, B.M.N. Elhadidi, and S. Yoshida, "Fatigue analysis of an optimised HAWT composite blade," EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 4 (3) 1-6 (2017).

[5.] E. Kuantama, D. Craciun, and R. Tarca, "Quadcopter body frame model and analysis" Annals of the University of Oradea, 1, 71-74 (2016)

[6.] P.V. Sawalakhe, and J.A. Shaaikh, "Simulation and analysis of a quadcopter UAV while landing," International Journal of Recent Technology and Engineering, 8 (6), 672-680 (2020).

[7.] Yousefian, N. Yamamoto, "3D finite difference time domain simulation of microwave propagation in a coaxial cable" EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 5 (3) 1-11 (2018).

[8.] C.S. Huang, F.Y.C. Albert, C.K. Ang, J.T. Dwee, and C.K. Chan, "Theoretical development and study of takeoff constraint thrust equation for a drone," Institute of Electrical and Electronics Engineers (IEEE), 1-5 (2017).

[9.] Sulaiman Ibrahim, Babawuya Alkali, AdedipeOyewole, SalihuBala Alhaji, Ibrahim Aku G. EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 08, Issue 03, pp667-672, September 2021

[10.] Chokkarapu Sai Kalyan, MudumbaiSrujana, A Nikhil Reddy, P Pavan Kalyan, M Abhilash, Volume 3, Issue 7 July 2021, pp: 3565-3568