

Design and Analysis of Multirotor Unmanned Aerial Vehicle

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Abstract

This study primarily focuses on the design and structural analysis of the drone body using modern engineering softwares. A structural analysis of the arms of a multicopter with a motor mounted is considered necessary for design optimization and high endurance. The drone body is comprised of multiple components, so it cannot be considered a single body. It is assembled by connecting different components, such as arms, base plate, and top plate. As a result, rather than a linear analysis, a non-linear analysis is carried out for the frame structure. The deformation of the drone body is caused by the maximum payload attached to it. Static structural analysis was carried out in order to create a rigid body that is as light as it can be, while still being able to endure loads applied by thrust, drone weight, and payload. SOLIDWORKS was used to create the CAD model, which was then analyzed using the ANSYS simulation tool. Static structural analysis and impact analysis were performed in order to achieve good strength and optimum weight of the drone body. Because of this, it was opted to build drone body frame design using a material that has adequate strength and is cost effective.

Index Terms— Structural analysis, Light-weight, Heavy Payload, Design, Analysis.

I. INTRODUCTION

Unmanned Aerial Vehicles operate without the presence of a human pilot. This capability of the drone aids in the protection of the pilot's life. Drones are now widely used in a variety of situations, including hazardous and emergency situations, military-prone locations, parcel delivery services, and industrial uses. They have a lot of potential for research in the areas of reducing drone body weight and increasing

flying time, range, and payload carrying capacity. The goal of this study is to analyze the hex copter drone body design in order to obtain good strength and a light weight drone body. The drone body is not treated as a single unit; instead, it is treated as an assembly, with all physical interactions taken into consideration while analyzing the drone body.

II. LITERATURE REVIEW

TABLE I SUMMARY TABLE OF LITERATURE REVIEW

Platform	Specifications	Remarks
A heavy payload hex copter[1]	235 g mass 15 min flight time	A brushless direct current (BLDC) electric motor is used to build the driver in an integrated control system for quad-rotor helicopters
Attitude Control of a Quad-rotor using Speed Sensing[2]	- Robbe RoxyBL-Outrunner 282434motor - PD Controller - Aluminum Frame	the dimensions have been reduced in order to increase mobility. control hardware is limited to an 8-bit CPU like an AVR to keep prices low.
- Design and Control of a Quad-Rotor Flying Robot[3] - Aerial Surveillance - CCTV Camera	- PID Controller - RC Dragan flyer - Carbon Fiber Frame	The playroom and CUC's square are too tiny for the global positioning, there is still some bias in the building of the three-dimensional model.
Real-time Attitude Stabilization of a Quad-rotor[4]	- Back-stepping Technique 3 DOF - PD controller	STARMAC has a lot more to offer researchers, with the possibility to become a one-of-a-kind testbed for trimming multi-agent control systems.
Quad-rotor Dynamics and Spatial Navigation[5]	3D Movement 6 DOF - BLDC Motor	The mechanical design was fine-tuned based on the study of flyer attitude dynamics in order to provide the highest control sensitivity.
Aerodynamics and Control of Autonomous Quadrotor[6]	- Complex Maneuvering - X-4 Flyer 1.5 Kg mass 1 Kg payload 1.5 m diameter	The MAV's target tracking improved from 0.5 m/s to 1 m/s using the Fernet formulae in the guiding module.

• Quadrotor Control Using Dual Camera Visual Feedback[7]	• HMX-4 type • 2 camera System • 6 DOF • 0.7 Kg mass	The rotating controller's primary goal is to keep the roll, pitch, and yaw angles all at equal degrees of rotation.
• Nested Saturations, Backstepping and Sliding modes[8]	• 3 DOF • Euler-Langrange Equations • PD • 800 g motors	The thrust efficiency and dynamic performance of the experimental rotor-motor plant were both good.
• Speed Variator IMCS 25, Nominal Voltage of battery is 12 V, Accelerometer (MEMSIC 2125)[9]	• 6 DOF • 2500 RPM motor speed • 0.4 Kg weight	These findings might be used to six-rotor crop security UAVs that are used for pesticide sprinkling and spray width detection.
• Robot frame and a coincident instantaneous frame[10]	• 6 DOF • Carbon Fiber Frame • 2500 RPM • LQG Controller	The team is also working on designing an automated flight control system that makes use of recently found advanced control methods.
• Attitude and Trajectory Tracking[11]	• 4 DOF • 4.34 Kg • 0.315 m diameter • 3D positional	Four input variables are used to examine a multi orientation and a one-dimensional orientation.
• Collision Avoidance[12]	• 230 g battery • BLDC Motor • 520 g Total mass • PID and LQR controller	The vision sensor must be upgraded to produce a somewhat more stable yaw measurement
• Robust Landing & Perching[13] • Control Of Complex Maneuvers[14]	• 1200-7800 RPM • 8 cm height • 500 g Payload • 20 mins battery • 4 DOF • 360 Deg Rotation • VTOL	The quadrotor was taught to sit on something like a vertical surface for ten tries. In all 10 trials, the robot was able to maintain a stable hover. When the initial slope error is less than 90 degrees, and once the initial slope error would be less than 180 degrees, the quadrotor demonstrates exponential stability
• Backstepping and sliding Technique[15]	• Gyroplane N0. 1 • Simulink • 200g mass • Small DC motor • 26 Deg roll angle	A back-stepping controller can regulate orientation angles even in the face of large disturbances.
• Simple Controller of a Quadrotor[16]	• 3 Axis Gyro • 500 Hz Control Frequency • Mega 644p Flight Control • 4 BLDC motors	A quadrotor of this type can retain its steadiness and elevation in the presence of an external disturbance after 100 hours in the air testing (force 4 wind).
• Designing Real Time Control System[17]	• BLDC Motor • C++ and ANSI C • 85% Efficiency • 11.1 V/4800 mAh Li-Po Battery	In order to build and develop a quad-rotor, brushless DC motors, may be used. Using them in potentially explosive areas is a lot safer since they don't produce any sparks.
• Design of a Four Rotor Aerial Robot[18]	• X-4 Flyer • High Density Polyethylene	The tilt roll camera is used by the controller to improve quad-rotor positioning capabilities, according to the simulation system.
• Velocity Control for a Quad-Rotor[19]	• 2.7 Kg Mass • 6 DOF • 2.034 Nm Max Yaw Torque	Made by mixing loop shaping is used in the design to suit a wide range of performance requirements.



Fig. 1 Research methodology

III. RESEARCH METHODOLOGY

A CAD model of a multirotor is designed to meet the payload criterion. Since, hex copter is not a single body therefore, all its parts will be modelled and assembled using SOLIDWORKS. After the designing process, analysis will be performed on the drone body to justify whether it will sustain our desired payload capacity.

A) Hex copter Design

The drone body is modeled using SOLIDWORKS. The next task is to assemble these parts (body, landing gears, and arms). The final design for the hex copter is shown in the figure below.

B) Material Selection

Due to its many benefits, such as its high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance, and low thermal expansion, carbon fiber was chosen as the material for the multirotor design.

High mechanical qualities of carbon-carbon composites include: Enhanced strength and lightweight materials that are 5 times lightweight and 3 times lighter than aluminum. Stiffness is crucial in automotive and aeronautical applications. Strength to weight ratios.

TABLE II MECHANICAL PROPERTIES OF CARBON FIBER

Mechanical Properties	Value
Young's Modulus (GPa)	27.6
Poisson's Ratio	0.23
Density (Kg/m ³)	2.49
Elastic Limit (MPa)	76
Modulus of Rupture (MPa)	110



Fig. 2 CAD model of drone

C) Weight Estimation for Analysis:

Weight of the hex copter is given in the table below:

TABLE III WEIGHT ESTIMATION OF THE DRONE BODY

Serial No.	Components	Weight (g)	No. of Components	Total Weight (g)
1	Frame	6500	1	6500
2	Motors - propellers combo	720	6	4320
3	Battery	5500	2	11000

The weight with batteries and payload weight are nearly 22 kg and 28 kg, respectively. Thus, the overall payload weight of hex copter is about 50 kg.

IV. MATHEMATICAL MODELING

Moment of inertia:

$$I = \frac{\pi}{64} (d_o^4 - d_i^4) \quad (1)$$

$$I = \frac{\pi}{64} (0.030^4 - 0.028^4)$$

$$I = (9.588 \times 10^{-9} m^4)$$

Here,

I = Moment of inertia

d_o = Outer diameter of the arm of hex copter

d_i = Inner diameter of the arm of hex copter

Bending Stress:

$$\sigma = \frac{My}{I} \quad (2)$$

M = Moment

y = distance from neutral axis

For 50 Kg:

$$\sigma = \frac{(81.75 \times 0.610)(0.015)}{(9.588 \times 10^{-9})}$$

$$\sigma = 117 \text{ Mpa}$$

Maximum Deflection:

$$\delta = \frac{PL^3}{3EI} \quad (3)$$

δ = Deflection

P = Load on each arm

L = Length of arm of hex copter

E = Modulus of elasticity

For 50 Kg

$$\delta = \frac{(81.75 \times 0.610)^3}{3(240 \times 10^9)(9.588 \times 10^{-9})}$$

$$\delta = 2.68 \text{ mm}$$

For 75 Kg:

$$\delta = \frac{Pl^3}{3EI} \quad (4)$$

$$\delta = \frac{(122.625)(0.610)^3}{3(240 \times 10^9)(9.588 \times 10^{-9})}$$

$$\delta = 4.03 \text{ mm}$$

V. MODELING AND SIMULATION

We have performed the static structural analysis to check the strength of the Hex copter frame selected. The material of the chosen frame is carbon fibre-reinforced composite (Carbon fibre + Nylon). Using reverse engineering, we have designed the CAD model of the frame using SolidWorks 2018, which meets the overall dimensions provided by the manufacturer. The CAD model is an estimation because the exact dimensions and drawings of the frame were not available.

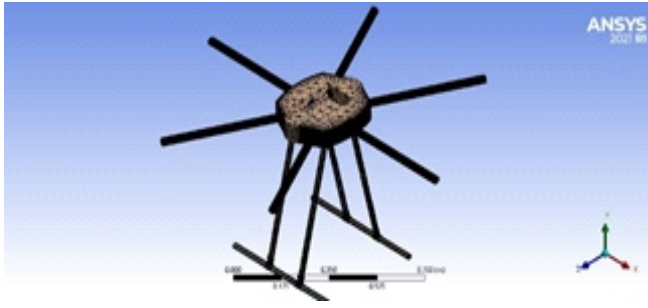


Fig. 3 Meshing on whole drone body

For the static structural analysis, ANSYS 18.1 software was used. The material used for manufacturing were not available. Hence, the literature on the mechanical properties of the CFRP was consulted to get the strength range of the carbon fiber laminates which varies from 50-240 GPa. The modulus of elasticity of laminate was considered homogeneous. In the model section, the motors, propellers and a few other components were suppressed, and the material CFRP was assigned to the remaining parts. The mesh size on the arms and the area where the arms are connected to the hub of the frame is kept at about 2mm. On the landing gears and battery stand, the mesh size was set to 5mm, and the mesh size was kept coarse on the remaining areas. The main reason for applying sizing on the frame was limited computational power.

The number of nodes and elements generated from mesh sizing are attached

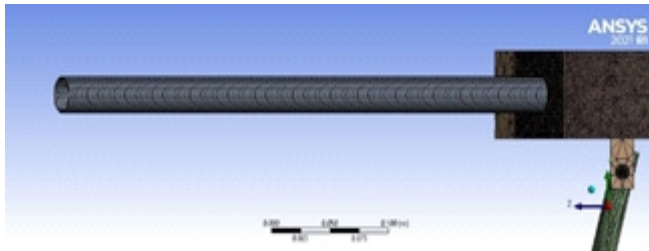


Fig. 4 Meshing on the hex copter arm

TABLE IV NODES AND ELEMENTS OF MESH

Nodes	693958
Elements	187221

In the setup section, the boundary conditions were applied. The frame is tested under two loading conditions. Firstly, the load of 50kg was used in such a way that the total load was divided into six arms equally.

In this way, each arm was subject to a load of 8.33 kg (81.63N), and the frame's hub was subjected to fixed support.

VI. RESULTS AND DISCUSSION

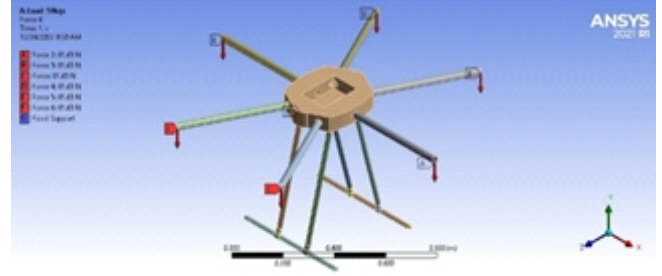


Fig. 5 Boundary conditions of CAD model

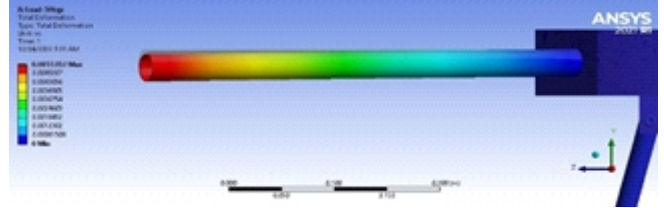


Fig. 6 Total deformation at 50 kg

The results of total deformation and equivalent stress were extracted. Similarly, the second iteration of the analysis was performed with load of 75 kg equally divided among the six arms. In this way, each arm was subject to a load of 12.5 kg (122.625N), and the frame's hub was set as a fixed support. The results of total deformation and the equivalent stress were generated.

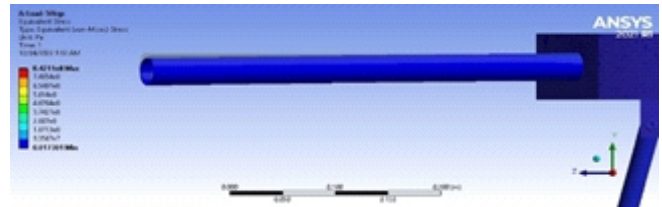


Fig. 7 Equivalent Stress at 50kg

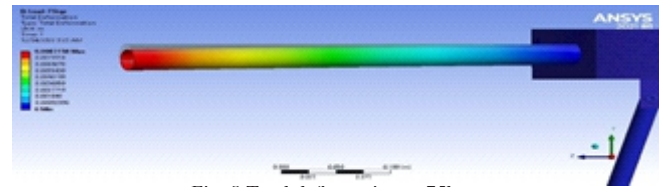


Fig. 8 Total deformation at 75kg

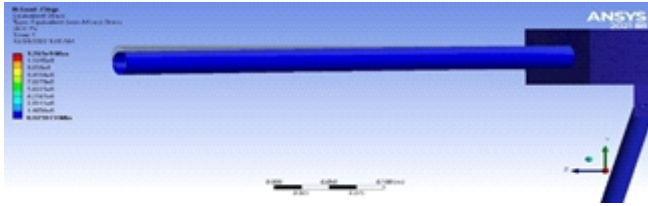


Fig. 9 Equivalent stress at 75kg

The total deformation at the arms for 50 kg load was 5.53mm and at 75 kg load was 8.31mm. Similarly, the equivalent stress was 842 MPa and 1265 MPa for 50kg and 75kg load respectively. The factor of safety at 50 kg was 1.78 and at 75kg it was reduced to 1.19 which is less than the standard factor of safety for the aerodynamic structures that is 1.5.

VII. DYNAMIC ANALYSIS

A Hex copter frame requires dynamic analysis since it assists in assessing the frame's structural stability and integrity under different operating situations. Hex copter employs six rotors to provide lift and control. Hex copter frames are subjected to a variety of dynamic stresses during flight, including vibrations, accelerations, and decelerations, which may compromise the structural integrity of the frame. We have performed a dynamic analysis to check the stability and endurance of the Hex copter frame. For this purpose, we have used the ANSYS 18.1 Modal module to check the modes and frequencies at which resonance may occur. The frame's material specification and CAD model were the same as those used in the static analysis.

In this analysis, the arms of the frame are kept as fixed support and the rest of the frame is set free. There is no external load is applied to the frame because the purpose of modal analysis is to determine the structure's natural frequencies and mode shapes, which are the frequencies at which the structure will vibrate if it is excited by an external force. As mentioned above the material specification is used Carbon fiber as used in the static analysis. In the meshing section, the mesh size of 5mm is applied on the arms of the Hex copter especially. In the solution section, the subspace solver technique has been used to solve the model.

With respect to these six degrees of freedom, the six modes are produced by modal analysis. They are also known as the translational and rotational modes of rigid bodies. Translational motion is represented by the first three modes, whereas rotating motion is represented by the final three modes. Overall, the six modes generated in the modal analysis of a Hex copter correspond to the six degrees of freedom of the system and provide valuable insights into its dynamic behavior. Following are the six modes generated in the results of the analysis.

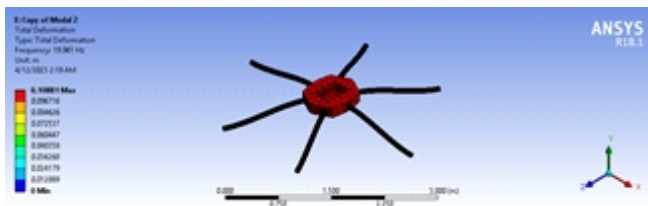


Fig. 10 Representation of Mode 1

In the first mode, the deformation came out is 10.8 cm at the frequency of 19.961 Hz.

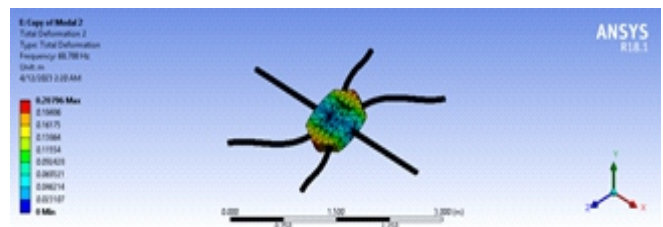


Fig. 11 Representation of Mode 2

In the second mode, the deformation came out is 20.79 cm at the frequency of 68.788 Hz.

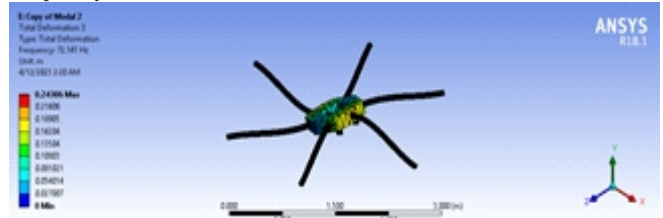


Fig. 12 Representation of Mode 3

In the third mode, the deformation came out is 24.30 cm at the frequency of 72.141 Hz.

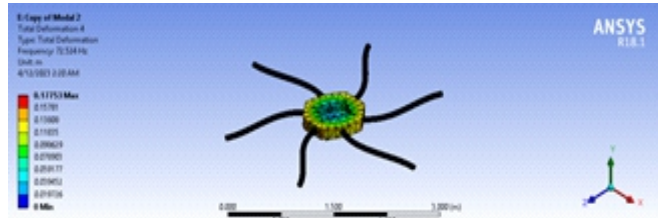


Fig. 13 Representation of Mode 4

In the fourth mode, the deformation came out is 17.75 cm at the frequency of 72.524 Hz.

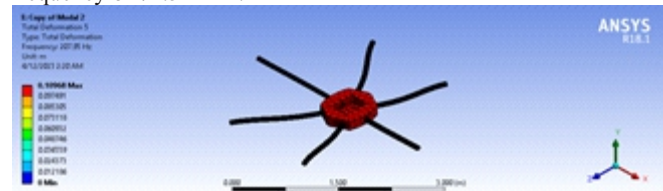


Fig. 14 Representation of Mode 5

In the fifth mode, the deformation came out is 10.97 cm at the frequency of 207.95 Hz.

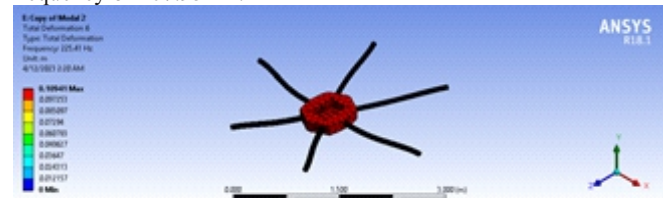


Fig. 15 Representation of Mode 6

In the sixth mode, the deformation came out is 10.94 cm at the frequency of 225.41 Hz.

In all of the six modes, the peak frequency is 225.41 Hz which can affect the frame in the presence of the external load and may cause the resonance.

VIII. CONCLUSION

This study involved an analysis of a hex copter frame under both static and dynamic conditions. In the static analysis, we tested the safety and endurance of the frame by applying a total load to the arms. The results showed a deflection of approximately 5.53mm under a 50kg load and approximately 8.31mm under a 75kg load. Based on these results, we determined that the structure is safe under the applied loading conditions.

Similarly, we performed modal analysis to evaluate the endurance of the hex copter under dynamic conditions. The analysis generated six modes at different frequencies, and we used the participation factor to identify that mode 1, mode 5, and mode 6 would significantly affect the frame in the event of a failure due to excessive vibration. This information can be used to optimize the design of the structure or system, improving its performance and reducing the risk of failure.

IX. RECOMMENDATIONS

The results from SolidWorks show satisfactory results but if the hex copter fails to carry the payload of 50 kg, then we can go for the different changes including changing the size of drone, changing the blade angles or using a more powerful battery. Furthermore, we can go for optimizing the flight time and the range of the drone. Changing one parameter will affect all the other perimeters and hence the capabilities of the drone.

Present study will be used for the fabrication of the first prototype of the hex copter which we will test for different payloads and flight time. If it does not work for our proposed payload of 50 kg the design will be optimized

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