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Analysis of Delivery Drone for Payload Optimization

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***Abstract:** In the rapidly evolving world of drone technology, payload optimization has emerged as a critical factor for maximizing efficiency, reducing costs, and unlocking new possibilities across industries. Whether you're a professional in logistics, agriculture, or surveillance, understanding how to optimize drone payloads can significantly impact your operations. This comprehensive guide dives deep into the nuances of drone payload optimization, exploring its benefits, challenges, industry applications, and future trends. By the end of this article, you'll have actionable insights to implement proven strategies for success in your field. A drone frame, commonly referred to as a quadrotor, represents an advanced evolution of conventional helicopter systems, offering enhanced dynamic stability and maneuverability. These systems have become essential across a wide range of applications, including surveillance, defense operations, fire detection, and other complex mission environments. The performance and reliability of a drone largely depend on the effectiveness of its frame design. This study concentrates on the aerodynamic characteristics of the drone frame while also considering associated mechanical and electronic components involved in its construction.*

I. INTRODUCTION

A helicopter is an aerial vehicle that achieves lift through rapidly rotating blades that force air downward, generating an upward thrust that sustains flight. Traditional helicopter designs typically employ two rotors. These may be configured as dual coaxial rotors rotating in opposite directions to counterbalance torque, or as a single main rotor combined with a smaller tail rotor positioned laterally to offset the rotational torque produced by the main rotor. While effective, these configurations rely on complex mechanical systems to control motion and stability. A swashplate mechanism is used to vary the blade pitch of the main rotor, enabling directional control by adjusting the angle of attack during different phases of rotation. This intricate mechanical arrangement increases design complexity, manufacturing cost, and maintenance requirements. A quadrotor helicopter, commonly referred to as a drone frame, utilizes four rotors positioned symmetrically, typically at the corners of a square or cross-shaped structure. Each rotor operates independently, eliminating the need for a swashplate assembly. In conventional helicopters, the swashplate is essential for achieving multiple degrees of freedom; however, in a quadrotor system, equivalent control authority is attained through differential speed variation among the four rotors. The additional rotors allow for precise control of motion without relying on mechanically complex components.

II. LITERATURE SURVEY

According to the WHO (World Health Organization), more than 1 million pesticide case sare reported annually. More than one lakh people die every year, mostly in underdeveloped nations, as a result of human handling and pesticide spraying. In addition to cancer, hormone disruption, and issues with reproductive and foetal development, pesticide exposure has been linked to asthma, allergies, and hypersensitivity. The skin and eyes may become inflamed by other insecticides.

Martinetti, A., Margaryan, M., & Dongen, L. van. (2018) [1] In this paper the author gives guidelines and suggestions to maintain quadcopter. On three analysis of structure and flying modes is done. First it studied about the mechanical stress on body frame using Finite Element Methods (FEM). Second analysis shows the weak points in the design to give the possible failure in mechanism of drone. Finally discussed about the performance and mechanical properties of the quadcopter.

Prajwal Kumar M. Patil et al (2019) [2] The paper concentrates on modelling, analysis and fabrication of quadcopter with payload drop mechanism. The payload weight was adjusted around 5 Kg and the static, dynamic and CFD analysis were performed. The author compared three different materials which are Aluminum, carbon fiber and Balsa wood. The author advocates the use of Aluminum for his design being lightweight, cheap and strong.

Swapnil Yelmle [3] The authors focus is reducing the cost of drone frame by replacing the carbon fiber pipe frame with the

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aluminum frame while keeping the weight constraint. The designed frame capacity is 2.5 kg. The drone weighs about 3207 grams. The analysis in Ansys 19.2 yields 0.83 mm deformation at the motor end and 367 MPa of maximum principal stress at the center of the frame. The obtained factor of safety is 3.

P. Jagadeeshwaran et al [4] In this paper author is numerically analyzing the tilt- Hexacopter for finding out its maximum speed. The drag force and coefficient of drag is performed as an evaluation parameter. The maximum forward selected for the configuration selected by the author is 40 m/s with maximum vertical speed of 30 m/s. The variation of drag force is from 1.5 to 2 kg for 40 m/s to 45 m/s for the forward motion. While for the vertical motion is 30 m/s to 35 m/s is from 3.34069 to 4.69479 kg respectively.

III. METHODOLOGY UNDERSTANDING THE BASICS OF DRONE PAYLOAD OPTIMIZATION

Drone payload optimization refers to the process of maximizing the efficiency and effectiveness of a drone's carrying capacity. This involves balancing the weight, size, and type of payload with the drone's capabilities, such as battery life, flight range, and stability. Payload capacity the maximum weight a drone can carry without compromising performance.

1) Step – 1

Drone payload optimization refers to the process of maximizing the efficiency and effectiveness of a drone's carrying capacity. This involves balancing the weight, size, and type of payload with the drone's capabilities, such as battery life, flight range, and stability. Payload capacity the maximum weight a drone can carry without compromising performance. In practice, drone payload optimization involves a series of calculations and adjustments to ensure the drone operates at peak efficiency. Payload weight distribution ensuring the weight is evenly distributed to maintain balance during flight. Battery management calculating the energy consumption based on payload weight and flight distance. Software integration using advanced algorithms to simulate flight paths and optimize payload configurations. Material selection choosing lightweight and durable materials for payloads to reduce strain on the drone. The widespread availability and increasing computational power of modern computer systems have made an indispensable tool in contemporary engineering practice. Due to its substantial economic and industrial significance, it has also been a major driving force behind research advancements in computational geometry, computer graphics (hardware and software), and discrete differential geometry.

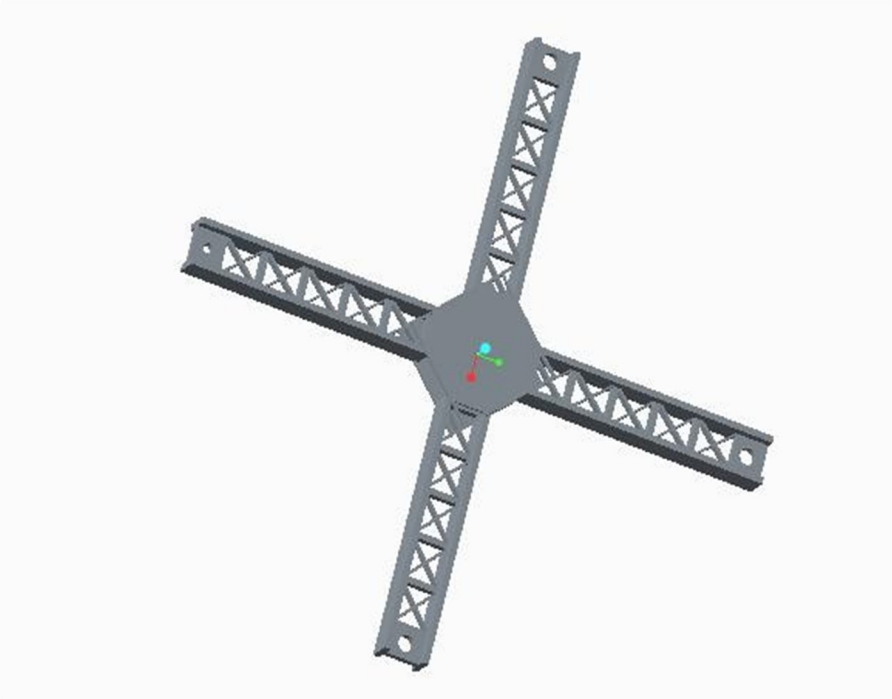


Fig No.1. 3D Drone Frame Chassis Model

2) Step – 2

Once the individual parts are designed in the sketch section, then some required sub- assemblies are made in the Assembly section of the ANSYS,CREO software. These sub- assemblies make the final assembly much easier.

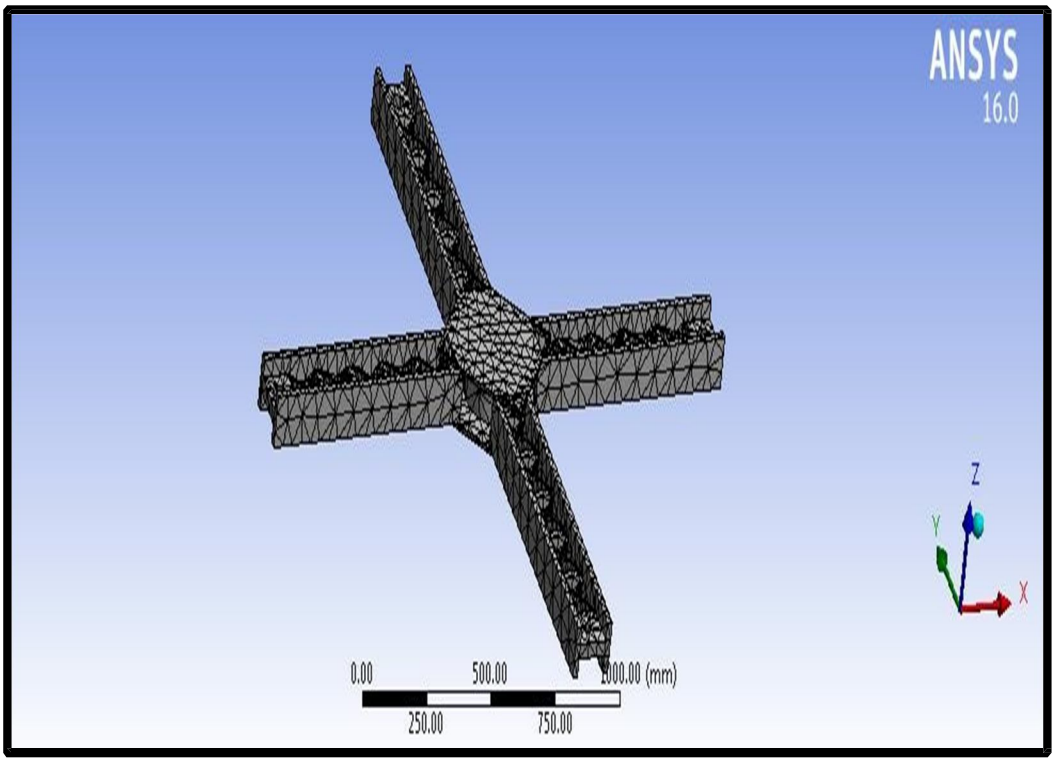


Figure 3.3 Meshing

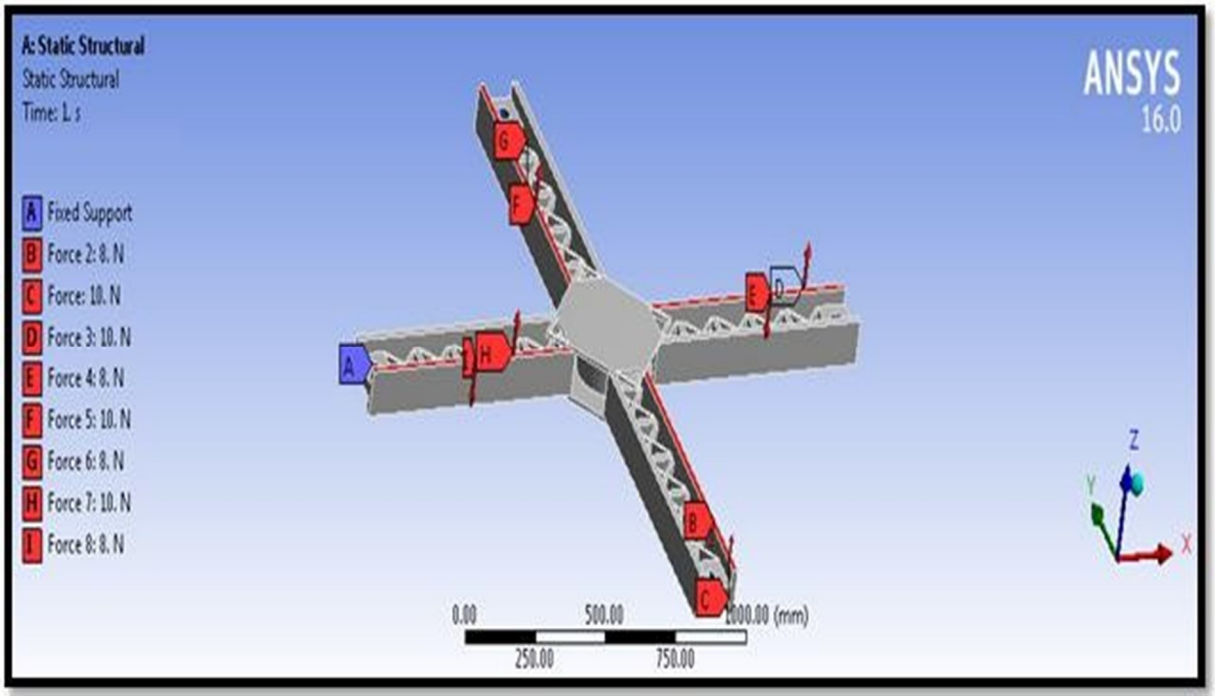


Fig No.7. Boundary Conditions

3) Step – 3

Finally, static analysis of drone frame, model analysis of drone frame.

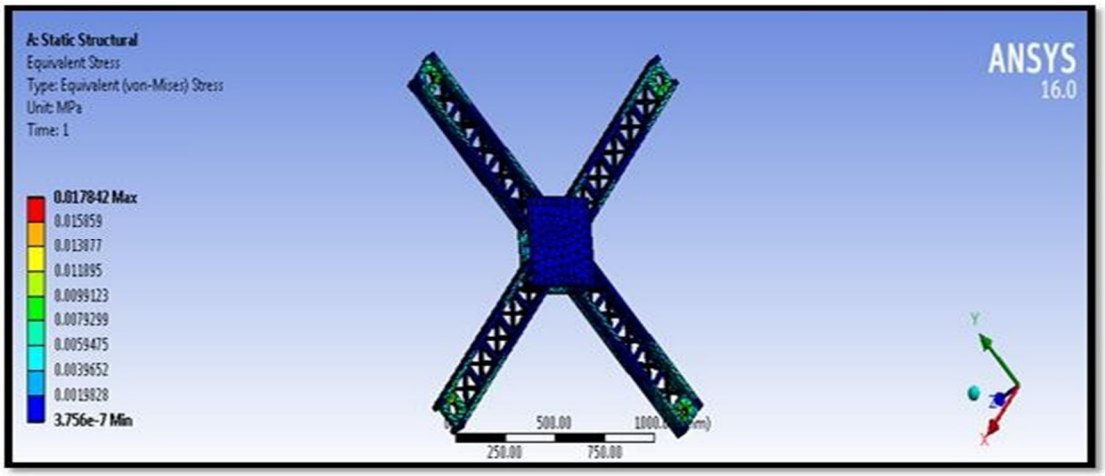


Figure 3.4 Stress

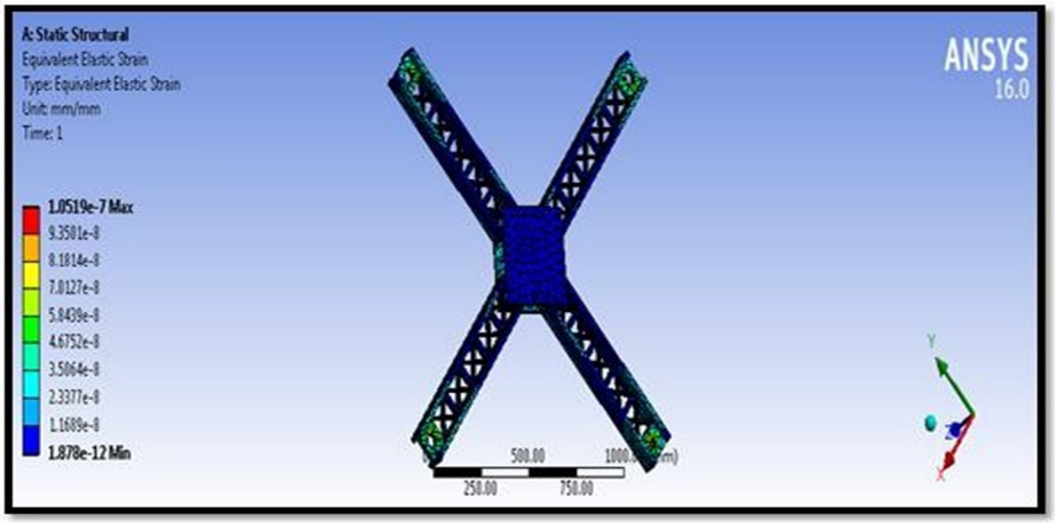


Fig 3.5 Strain

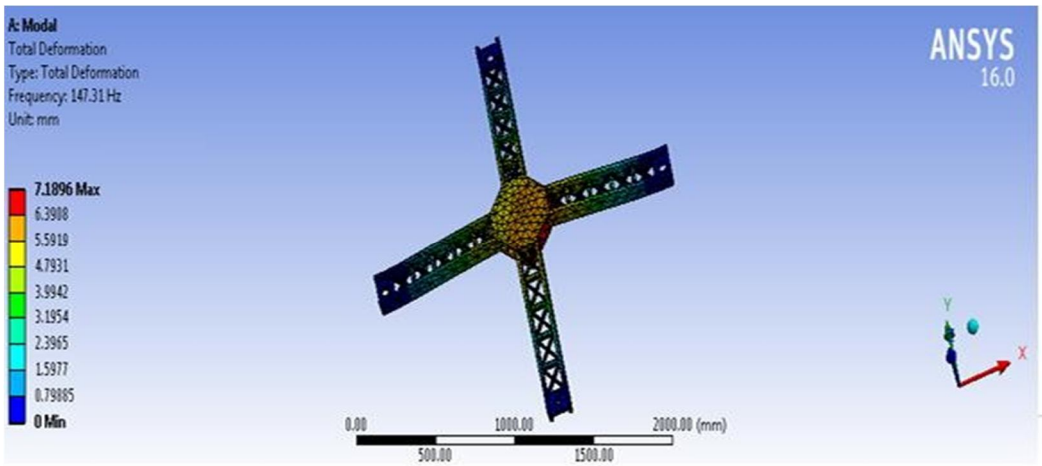


Fig No.20. Mode shape -1

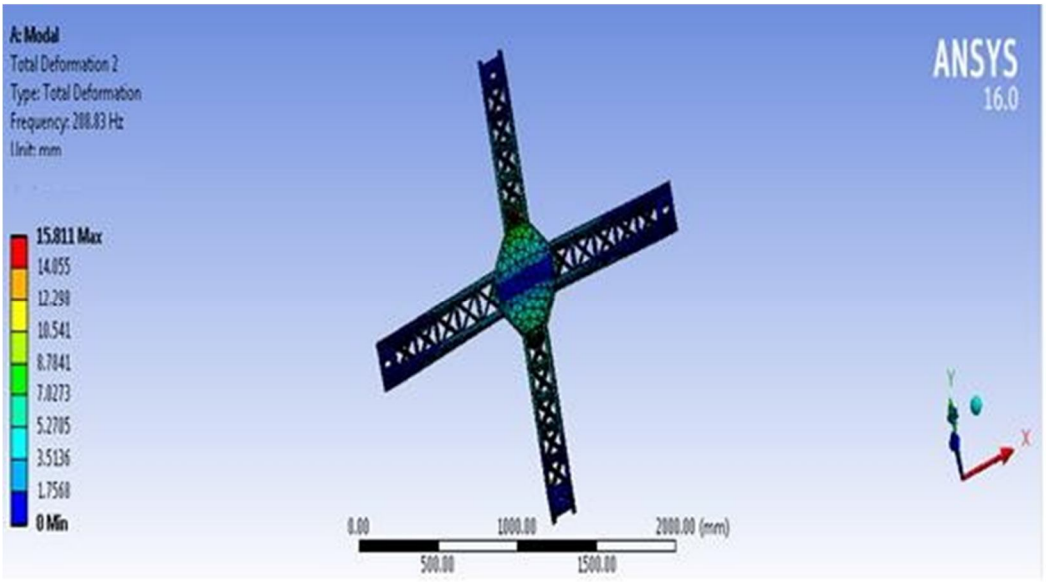


Fig No.21. Mode shape -2

IV. RESULTS AND DISCUSSIONS

A 3D printed frame can provide a number of advantages for an agriculture drone, including improved durability, reduced weight, and potential cost savings.

In addition to extending flight time, a lighter drone can cover more ground more effectively. A seed dispersal system for urea fertiliser that incorporates a storage tank can deliver accurate and controlled fertiliser application, resulting in better crop yields and more effective resource usage. The fertiliser may be applied evenly and strategically using the seed dispersal system, which lowers waste and increases fertilisation efficiency overall.

The weight of drone along with payload (storage tank) consists of ~1.5 kgs. Take-off of drone without payload after many unsuccessful attempts gives flight time of ~10 minutes, which is average outcome of a quadcopter. On other side, Testing is done manually with storage tank placing at certain height Fixed and done some trial-and-error method to find out speed required for serve motor to seed dispersing. Speed of servo motor with 60 value gives optimum outcome with dispersal of seed in close range with length of dispersal 1.27 M. So, drone stops at every ~1.30M range for seed dispersal for around 2 seconds. The attachments of both storage tank with drone eliminated the aurdino board connections as flight controller software operated by giving specific commands. This process resulted in decreasing of flight time as load on battery is more. Drone with payload results in unsuccesful attempt as there is mis- match in thrust of 1St motor, replacing with other motor and proper ESC calibration gives proper take-off drone. Duration of the flight time is ~6 minutes with urea dispersal of 500grams.with at an altitude hold of 2 Meters.

A. Design & Structure

Lightweight frame using carbon fiber or aluminum for durability and reduced energy consumption. Four brushless DC motors with electronic speed controllers (ESCs) for stable flight.

Payload integration: pesticide/fertilizer spraying tanks (typically 1–5 liters capacity) mounted with pumps and nozzles.

- Performance Outcomes
- Flight stability: Achieved through PID controllers and GPS modules for autonomous navigation.
- Coverage efficiency: Spraying drones cover 5–10 acres per hour depending on tank size and battery capacity.
- Precision agriculture: Equipped with cameras and sensors (NDVI, multispectral) for crop health monitoring.
- Cost & Energy

Fabrication cost is significantly lower than commercial agricultural drones when built with locally sourced materials. Battery endurance: 20–30 minutes per charge, requiring multiple batteries for extended field use.

B. Advantages

Reduces farmer exposure to harmful chemicals during pesticide spraying. Saves labor and time compared to manual spraying. Enables precision farming by integrating sensors for crop monitoring. Environmentally friendly when optimized for minimal chemical usage.

C. Challenges

1) Battery limitations: Frequent recharging or swapping needed for large fields.
2) Payload constraints: Limited tank capacity restricts spraying duration.
3) Weather dependency: Wind and rain affect spraying accuracy and drone stability.
4) Maintenance: Requires technical knowledge for calibration and repair.

D. Future Improvements

Hybrid power systems (solar-assisted charging or fuel cells). AI-based autonomous navigation for obstacle avoidance. Larger payload capacity with modular designs.
Integration with IoT for real-time data transmission to farmers

CALCULATIONS

Materials used AS34 carbon fibre and aluminum alloy 7075

Material properties

AS34 CARBON FIBRE

Young's modulus = 7.50g/cc

Poisson's ratio = 213GPa

Density = 0.30

Aluminum alloy

Young's modulus = 2.81g/cc

Poisson's ratio = 71.7 GPa

Density = 0.33

.Motor Selection Calculation

Assume using 100KV–170KV brushless motors (common in agri drones).
Example class: 100KV motor with 30–34 inch propeller.
From typical performance charts:

- At 12S (44.4V)
  - Current ≈ 40A–50A
- Thrust ≈ 10–12 kg per motor

Power per motor: $P = V \times I = 44.4 \times 45 = 1998W \approx 2kW$
Total power: $2kW \times 4 = 8kW$

Battery Capacity Calculation

Assume:

- Total current = 45A × 4 = 180A
- Battery voltage = 44.4V (12S LiPo)

- Desired flight time = 12 minutes (0.2 hr)

Required battery capacity: $Capacity = Current \times Time = 180 \times 0.2 = 36Ah$

So required battery:

12S 35Ah–40Ah LiPo

Energy: $E = V \times Ah = 44.4 \times 36 = 1598Wh \approx 1.6kWh$

ESC Rating Calculation

Each motor current ≈ 45A

Safety margin 30%: $ESC = 45 \times 1.3 = 58.5A$

Select:

60A–80A ESC (HV compatible)

Propeller Calculation

Thrust equation: $T = C_T \rho n^2 D^4$

Where:

- C_T= thrust coefficient
- ρ= air density (1.225 kg/m³)
- n= revolutions/sec
- D= diameter (m) For heavy-lift drones:

Typical choice:

30–34 inch carbon fiber propeller (0.76–0.86 m diameter)

Large diameter → Higher efficiency → Longer flight time

Frame Strength Calculation

Assume carbon fiber arm length = 800 mm

Load per arm: $\frac{20}{4} = 5kg$

Force: $F = mg = 5 \times 9.81 = 49N$

Bending moment: $M = F \times L = 49 \times 0.8 = 39.2Nm$

Spray System Calculation

Pump flow rate:

Assume spraying 1 hectare in 10 minutes.

Typical requirement: 5 L per hectare For 10L tank:

Covers 2 hectares per flight

Flow rate: $= \frac{10L}{10min} = 1L/min$

Cost Estimation (Approx.)

Total ≈ $3,000 – $3,500

Final Specification Summary

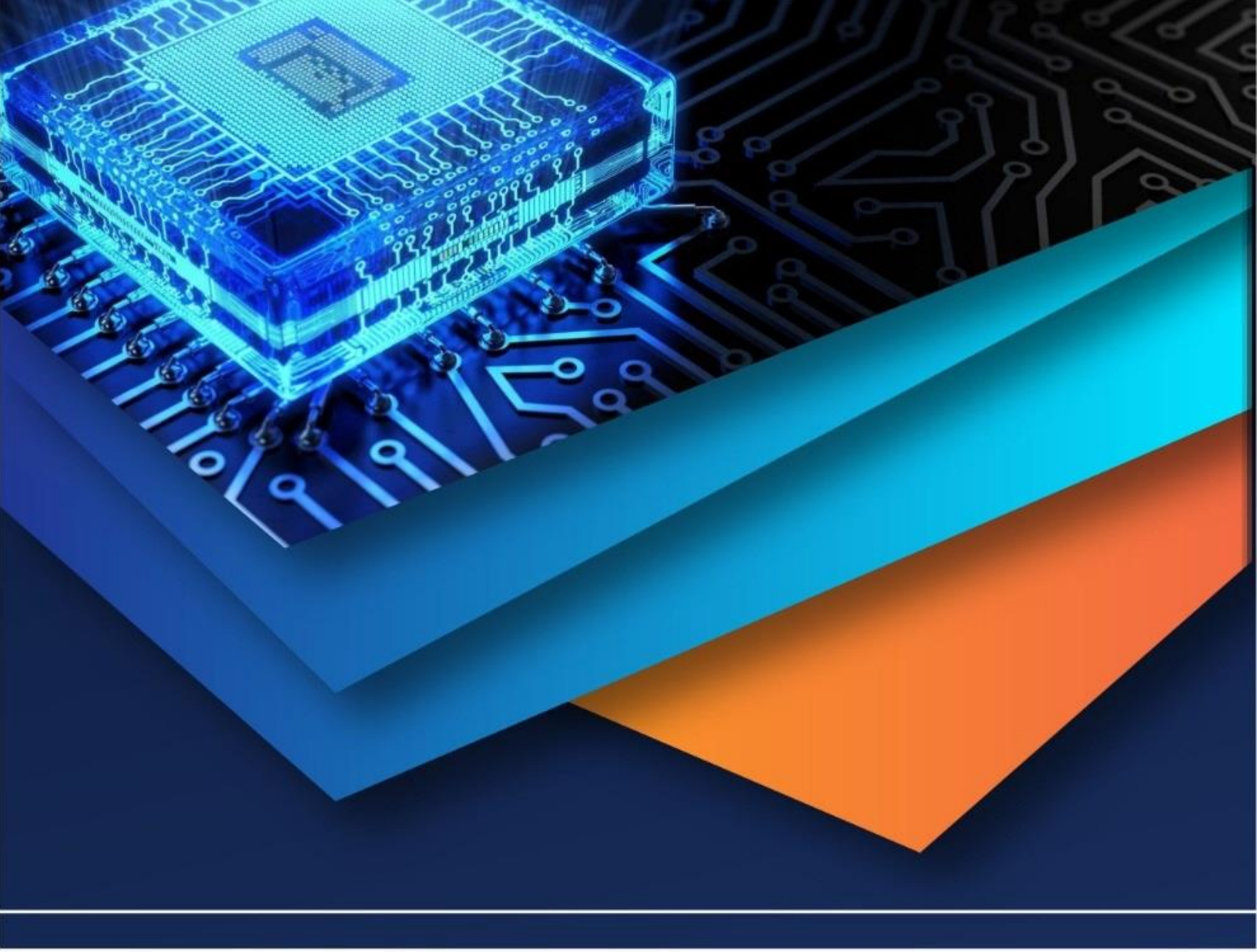
V. CONCLUSION

A drone frame, commonly referred to as a quadrotor, represents an advanced configuration of rotary-wing aircraft that offers greater dynamic stability compared to conventional helicopters. Due to their maneuverability, compact structure, and operational flexibility, quadrotor drones play a significant role in a wide range of applications, including surveillance, military operations, fire detection, and other complex mission-critical tasks. This work primarily focuses on the aerodynamic and structural aspects of the drone frame. It presents a comprehensive study encompassing both mechanical design and electronic subsystem integration. The selection of individual components is justified using established analytical formulations and validated research literature.

In addition, a detailed evaluation of component weights and associated costs is carried out to support optimal design decisions. To ensure structural reliability, finite element analysis (FEA) is performed on the drone frame to assess its ability to withstand operational loads. The study includes static structural analysis to determine deformation, stress, and strain characteristics for different frame materials, namely steel, aluminum alloy 7075, and AS34 carbon fiber. Furthermore, modal analysis is conducted to identify natural frequencies and corresponding mode shapes, which are critical for understanding vibration behavior and ensuring flight stability. The three-dimensional geometric model of the drone frame is developed using CREO Parametric software, while structural and modal analyses are carried out using ANSYS simulation software. Comparative results obtained from the modal analysis indicate that the natural frequencies are higher for aluminum alloy 7075 when compared to steel and carbon fiber materials. Higher natural frequencies reduce the likelihood of resonance during operation, thereby improving structural performance and stability.

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