

Abstract

This research focuses on the design, optimization, and fabrication of a lightweight drone using Additive Manufacturing (AM) with Topology and Parametric Optimization. Finite Element Analysis (FEA) facilitated a 65% weight reduction while maintaining structural integrity and optimal flight performance. Polylactic Acid (PLA) was chosen for its lightweight properties and 3D printability. Topology optimization minimized material usage in non-load-bearing regions, while parametric optimization refined the geometry for improved aerodynamics. Flight testing validated the feasibility of AM in efficient drone design, demonstrating its potential in sustainable aerospace applications.

Mechanical Design and Fabrication

The drone frame was designed using CAD modeling software to ensure structural integrity and aerodynamic efficiency. The optimized design incorporated lightweight yet durable materials, strategically reinforcing high-stress regions while reducing weight in non-critical areas by integrating topology optimization to remove excess material while maintaining strength. Key structural features included reinforced motor mounts, aerodynamic arms, and strategically placed cutouts to enhance weight reduction and flight performance. The CAD model was essential in validating the design before fabrication, ensuring the final prototype met structural, stability, and performance requirements.

- **Frame Design:** Developed using CAD with integrated topology optimization.
- **Material Selection:** PLA was chosen for its lightweight properties and 3D printability.
- **Manufacturing Process:** The optimized frame was fabricated using Fused Deposition Modeling (FDM) 3D printing.
- **Structural Features:** Reinforced motor mounts, aerodynamic arms, and strategically placed cutouts for weight reduction.

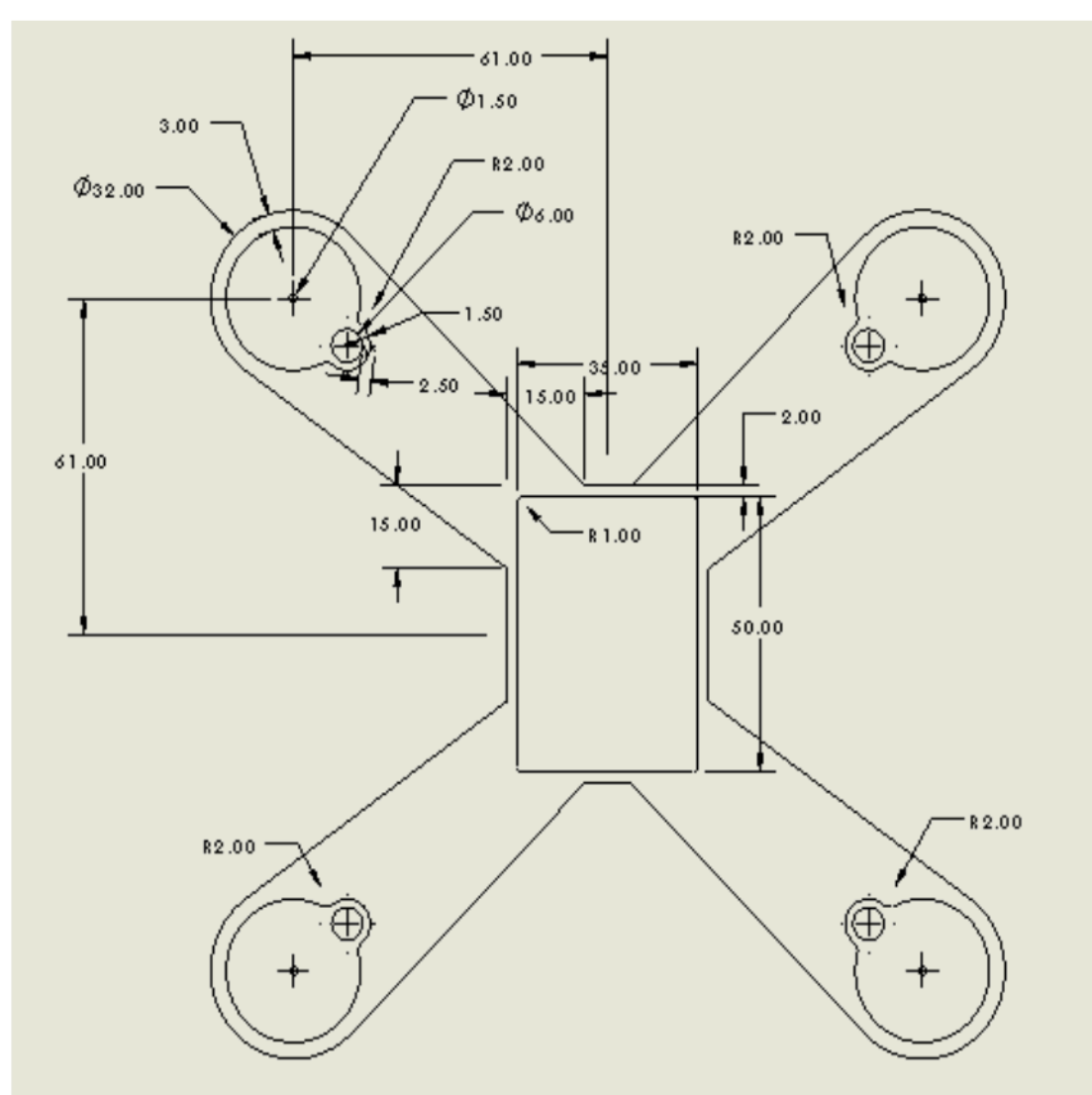


Figure 1: Top View of the Drone Frame Design with Dimensions

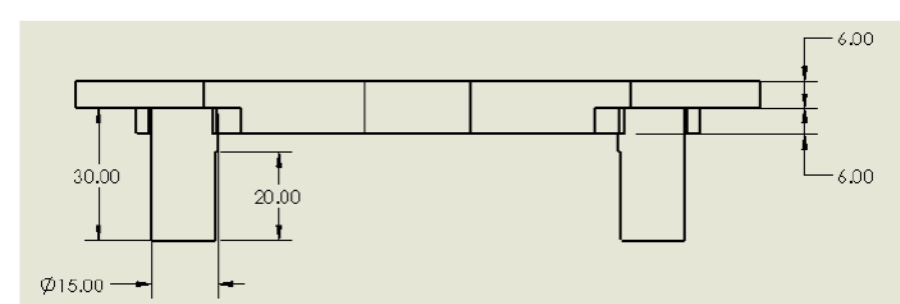


Figure 2: Side View of the Drone Frame Design with Dimensions

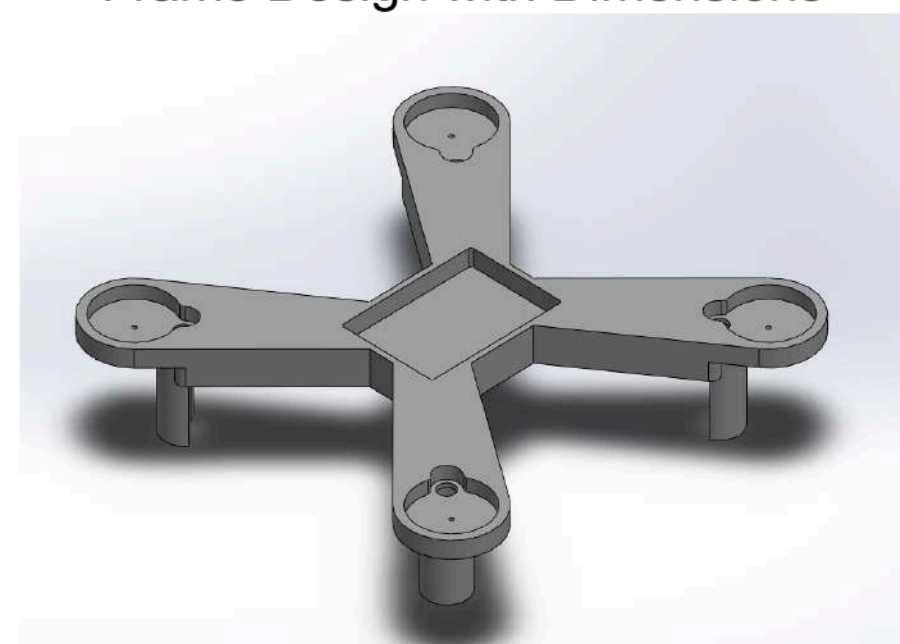


Figure 3: CAD Model of the Drone Frame

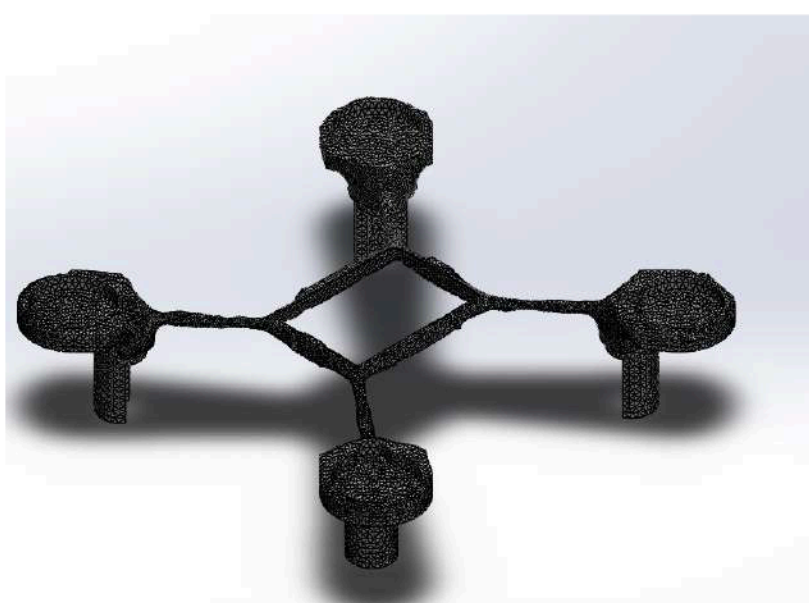


Figure 4: Topology Optimized Mesh

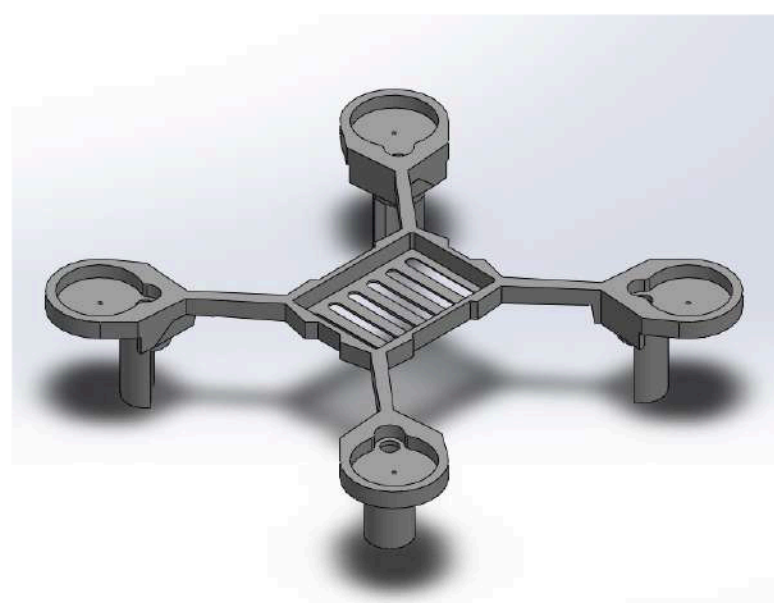


Figure 5: Topology Optimized

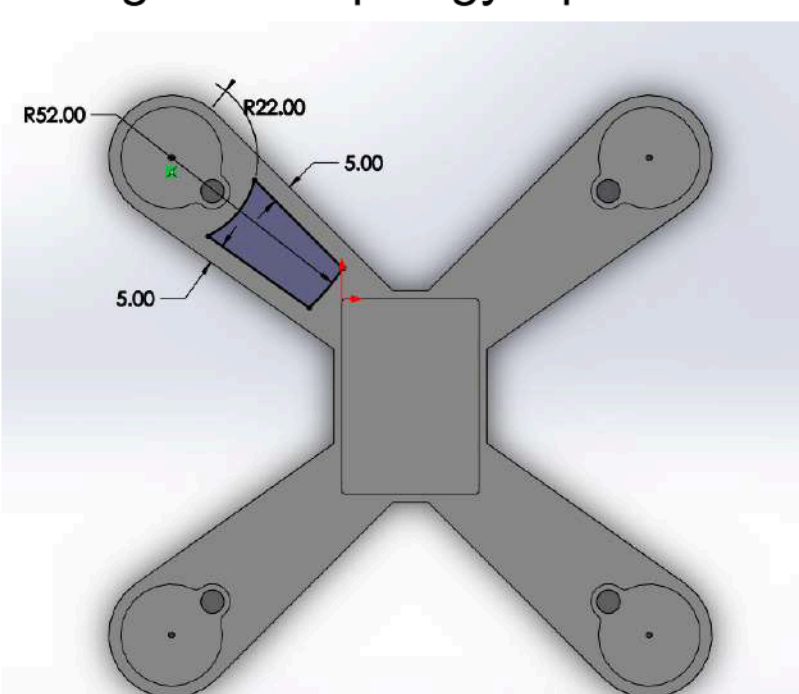


Figure 6: Parametric Optimization Dimensions

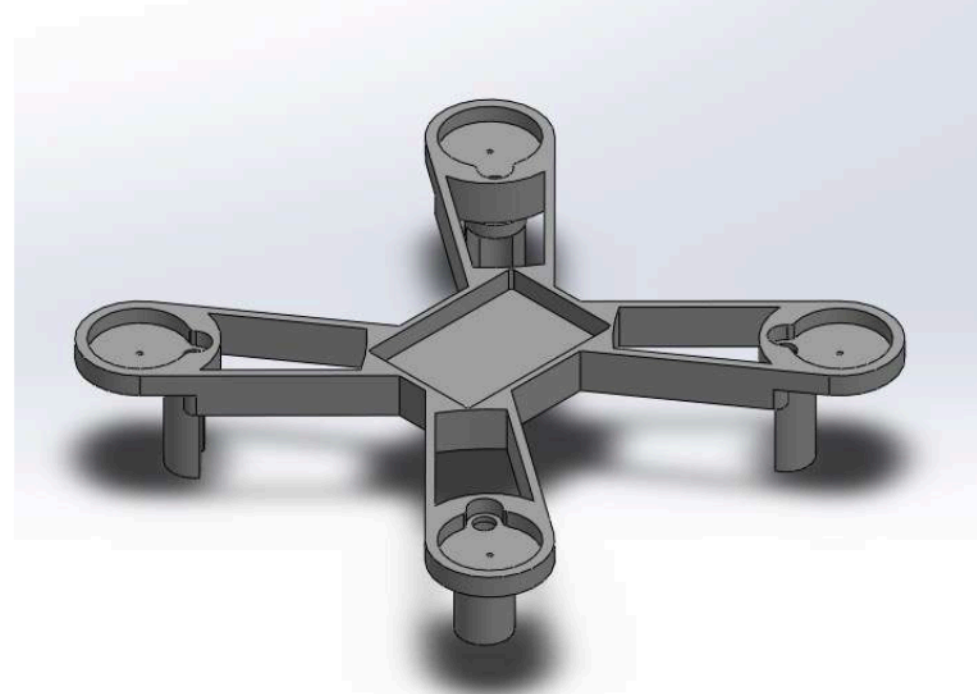


Figure 7: Parametric Optimized

Circuit Design

The drone's electronic system was designed to ensure efficient power management, sensor integration, and motor control. The circuit consists of a flight controller, electronic speed controllers (ESCs), brushless motors, a power distribution board (PDB), and a lithium-polymer (LiPo) battery. The flight controller processes sensor data and stabilizes the drone, while the ESCs regulate power to the motors. The power distribution board ensures stable voltage supply to all components, preventing fluctuations that could impact performance. The integration of sensors, including an inertial measurement unit (IMU), enhances flight stability and maneuverability. The circuit was optimized for lightweight and energy-efficient performance, ensuring reliable operation during flight.

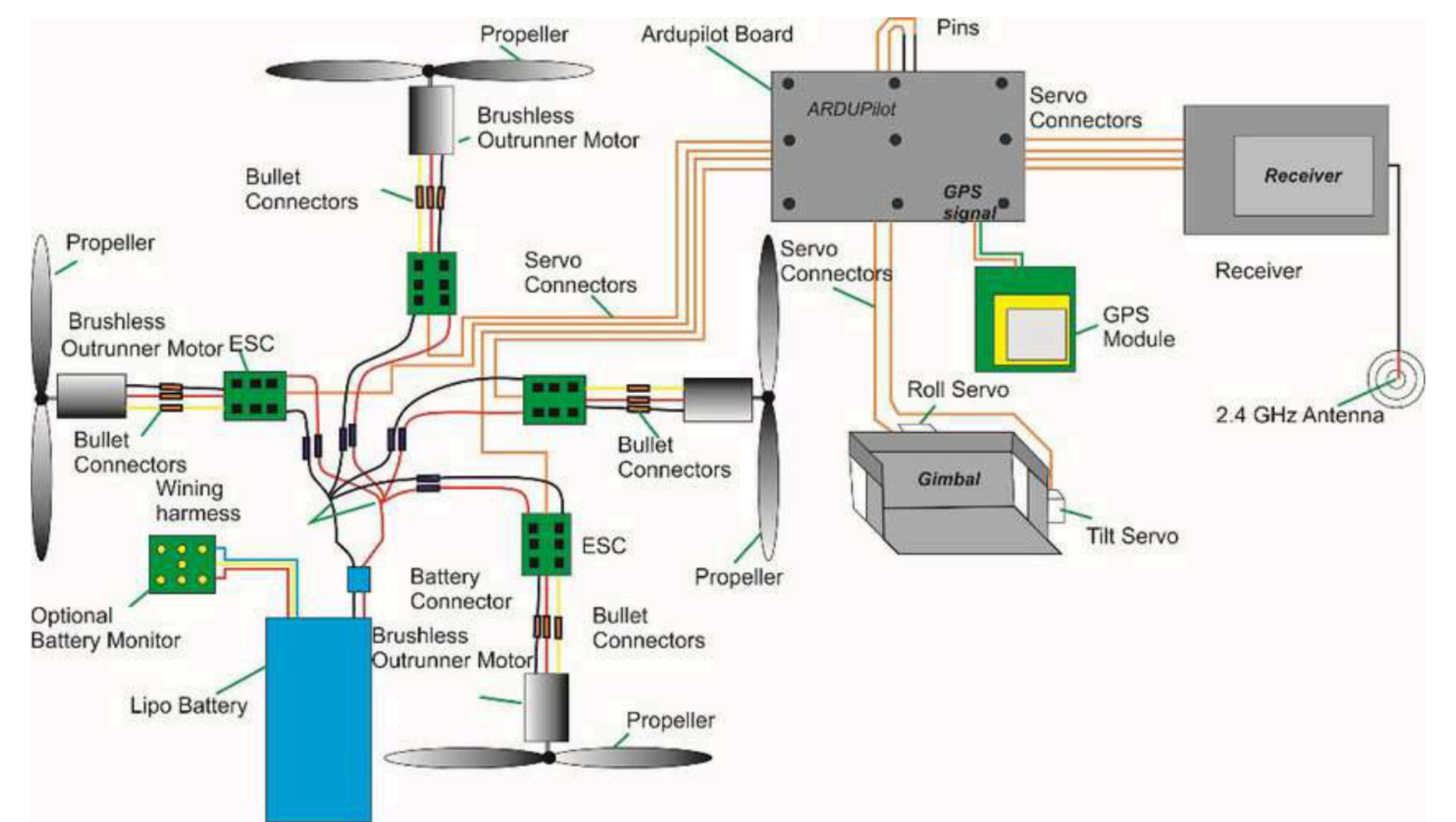


Figure 8: Circuit Diagram for the Drone

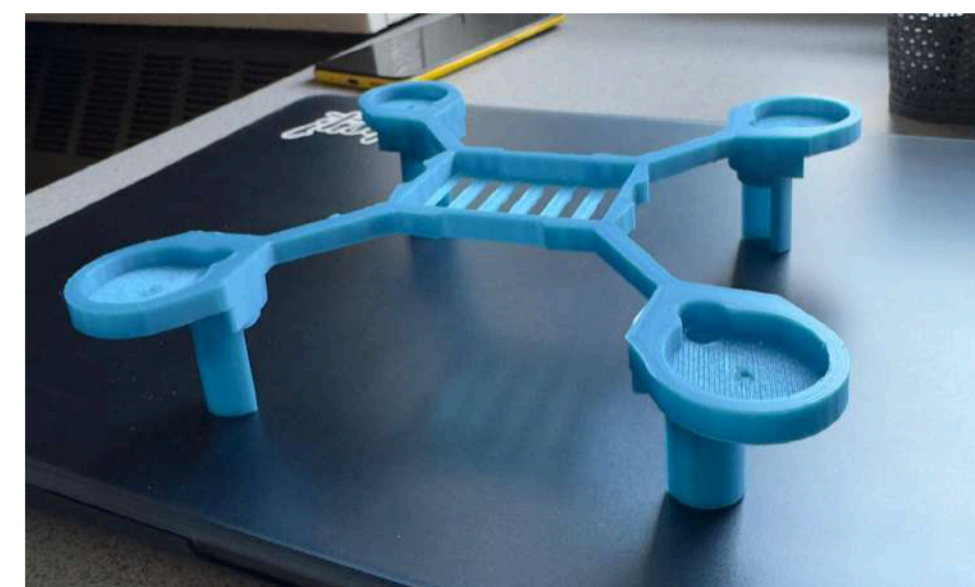


Figure 9: 3D Printed Drone Frame



Figure 10: Drone Prototype

Results and Discussion

The optimized drone frame demonstrated a 65% weight reduction while maintaining structural integrity and flight performance. FEA simulations confirmed that stress and displacement values remained within safe limits, ensuring durability. Topology Optimization effectively reduced material in non-load-bearing regions, while Parametric Optimization refined geometries for better aerodynamics and load distribution. The final design showed improved weight efficiency, making it suitable for aerospace applications. These findings highlight the potential of Additive Manufacturing (AM) with advanced optimization techniques in achieving lightweight, high-performance drone structures.

Table 1: FEA Analysis Results

Analysis Type	Max Stress (MPa)	Max Displacement (mm)	Weight (g)	Weight Reduction (%)
Initial Design	15.0	0.8	110.07	-
Topology Optimized	5.4	0.046	40.62	65%
Parametric Optimized	5.9	0.048	64.34	40%

Conclusion

This study successfully demonstrates that AM combined with topology and parametric optimization can significantly reduce drone weight while maintaining structural integrity. The optimized design achieved 65% weight reduction, proving the feasibility of AM in aerospace applications. Future research will explore alternative materials and real-world flight testing.