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Enhancing 3D Printing Agriculture Drone Design Through Structural Optimisation

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Abstract

This research investigates a comprehensive analysis and optimization of drone design, focusing on structural integrity and aerodynamic performance. The study employs advanced materials like carbon fiber and Nylon 6/10, integrating additive manufacturing techniques to enhance the durability, efficiency, and overall performance of drones. Through structural and aerodynamic analysis, the research identifies critical factors influencing drone stability and control, such as material properties, design configurations, and environmental conditions. The results demonstrate significant improvements in flight performance and energy efficiency, highlighting the potential of optimized drone designs for various applications, including commercial, industrial, and agricultural uses. The findings underscore the importance of a holistic approach to drone design, combining structural integrity with aerodynamic efficiency to achieve superior performance and reliability.

1. Introduction

In recent years, the development and optimization of drones have seen significant advancements, particularly in the areas of material science and aerodynamic design. Drones, also known as unmanned aerial vehicles (UAVs), have expanded their applications across various fields including agriculture, surveillance, and delivery services, necessitating improvements in their performance and durability [1]. The integration of advanced materials like carbon fiber composites and Nylon 6/10, along with innovative manufacturing processes such as additive manufacturing, has been pivotal in enhancing the structural integrity and efficiency of drones [2]. These advancements allow for the creation of lightweight, strong, and highly maneuverable drones capable of carrying significant payloads and performing complex tasks. This thesis aims to explore these innovations, focusing on the comprehensive analysis and optimization of drone design to improve performance, durability, and efficiency, thereby meeting the increasing demands of modern applications.

2. Experimental

2.1 Structural Analysis

2.1.1 Design Selection and Preparation

The study began with selecting relevant old and new designs based on historical performance data and specific requirements. Accurate 3D CAD models were prepared, focusing on critical components like joints and load-bearing parts to reduce computational load and enhance simulation efficiency.

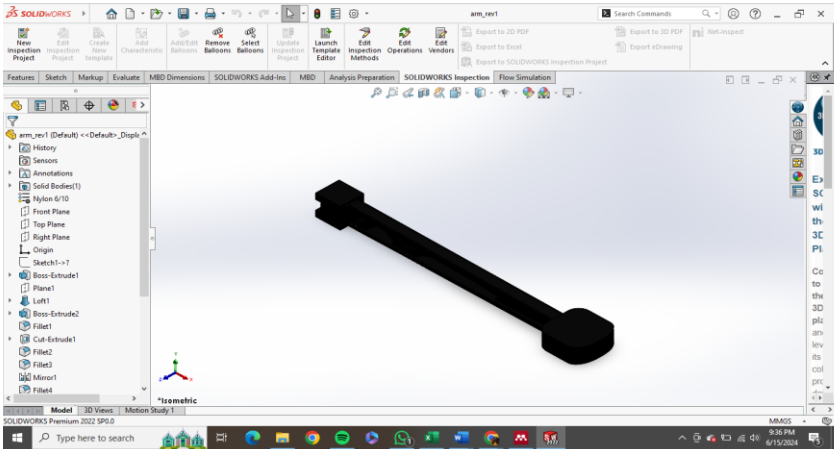

Figure 1 shows the new design of drone arm

2.1.2 Material Selection

Materials were carefully chosen for both designs. The old design used AISI 1035 Steel and Carbon Fiber Mat MA due to their robustness, while the new design utilized Nylon 6/10 for its high tensile strength and flexibility, suitable for dynamic environments [3].

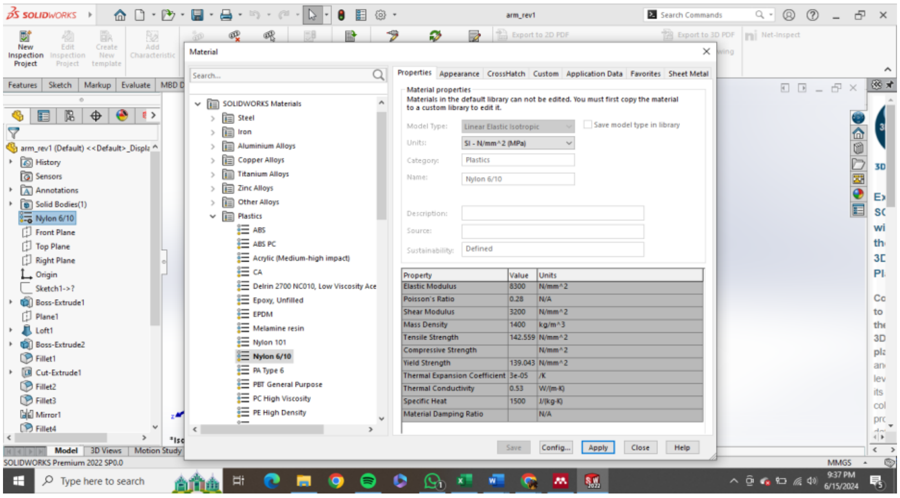

Figure 2 shows the material selection of Nylon 6/10

2.1.3 Structural Analysis Setup

Finite Element Analysis (FEA) involved setting boundary conditions, such as fixed geometries and applied forces, to reflect realistic operating conditions. High-quality meshing was performed, with finer meshes around critical areas to ensure detailed stress distribution analysis.

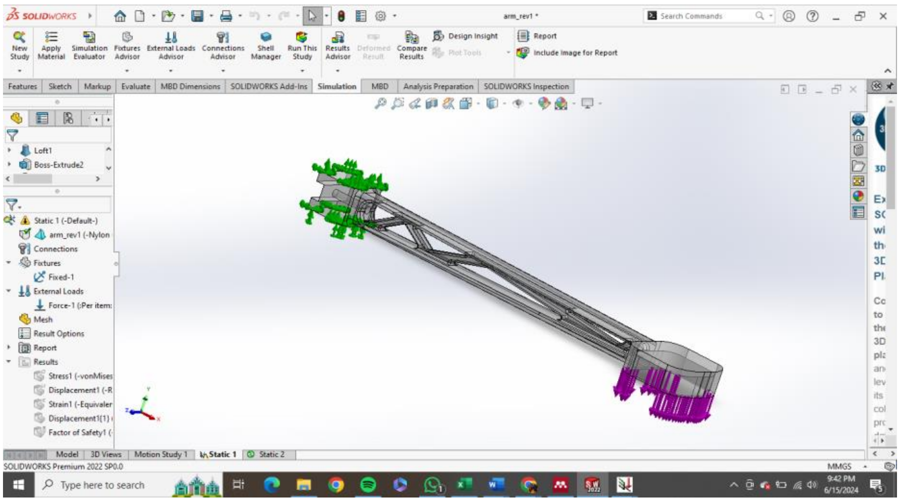

Figure 3 shows the Finite Element Analysis (FEA) involved setting boundary conditions

2.1.4 Running Structural Analysis Simulation

Simulations were executed in SolidWorks, with careful monitoring of intermediate results to ensure stability and convergence. Key parameters like Von Mises stress, displacement, strain, and the factor of safety were extracted and analyzed [4]

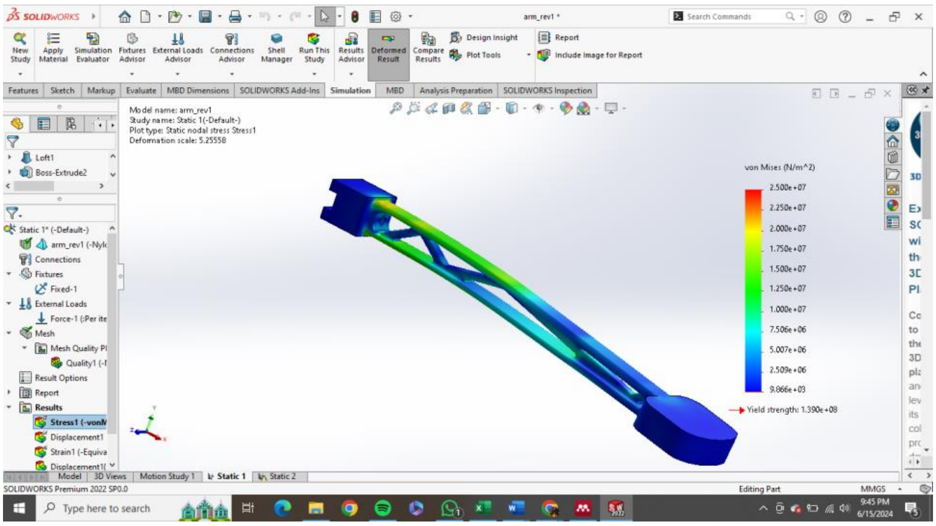

Figure 4 shows the Von Mises stress

2.1.5 Data Collection and Analysis

Collected data were systematically organized for comparative analysis. Techniques like statistical analysis and graphical representation were used to identify trends and improvements, focusing on the implications for drone performance and reliability.

2.2 Flow Simulation

2.2.1 Flow Simulation Setup

Flow simulations were set up in SolidWorks using the Flow Simulation Wizard. The fluid domain for external flow was defined, ensuring the computational domain was adequate to capture accurate flow fields.

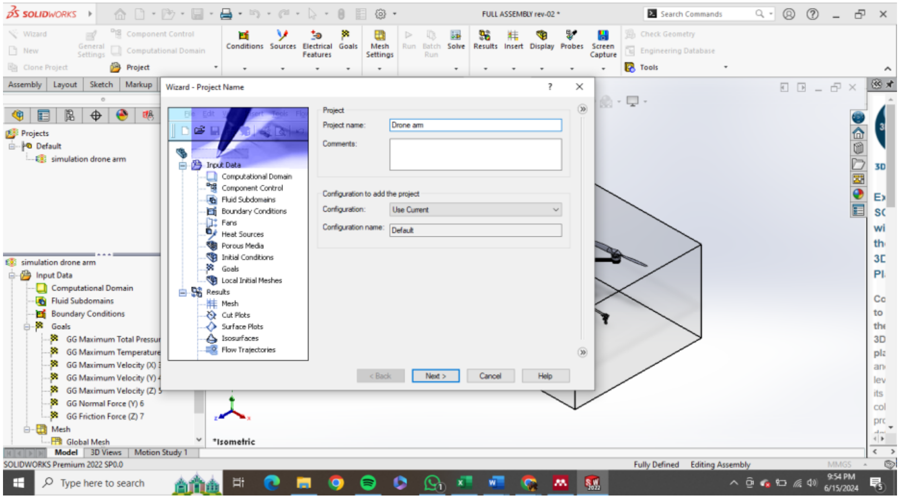

Figure 5 shows the Flow simulations set up

2.2.2 Specifying Fluid Properties and Boundary Conditions

Air properties were specified, and boundary conditions were set, including inlet and outlet boundaries. Symmetry planes were used to reduce computational effort.

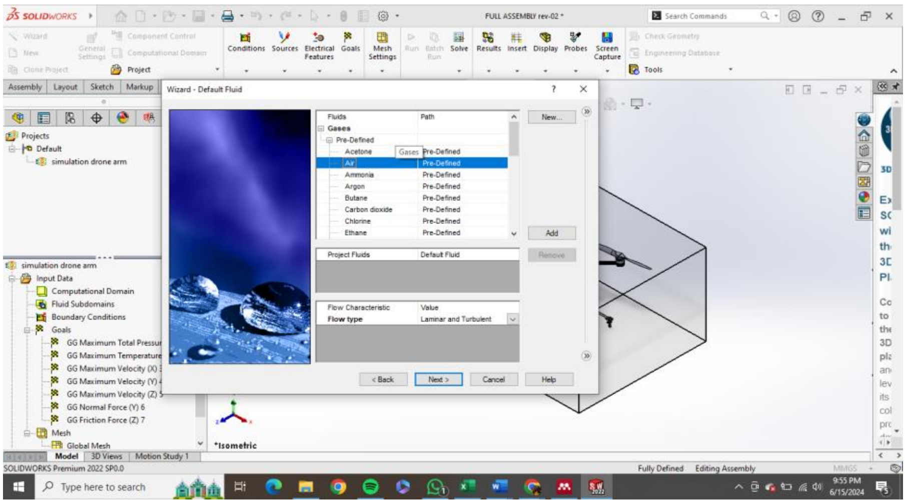

Figure 6 shows the boundary conditions

2.2.3 Initial Conditions and Simulation Control

Initial conditions such as ambient pressure and initial velocities were set. Simulation control parameters, including solver settings and convergence criteria, were defined to ensure stable and accurate results.

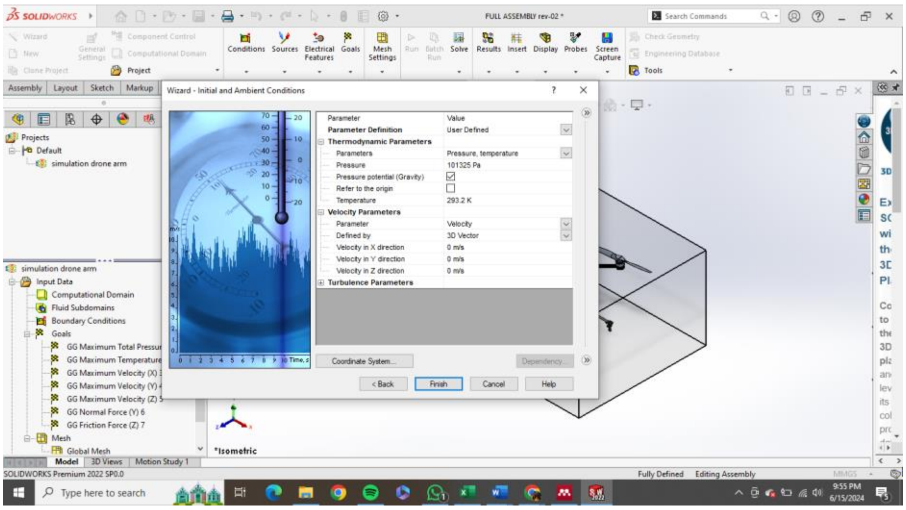

Figure 7 shows the Initial conditions

2.2.4 Meshing

High-quality meshing techniques were employed, focusing on critical areas like propellers. Adaptive mesh refinement was used to improve accuracy in regions with high gradients.

2.2.5 Running Flow Simulations

Simulations were executed and monitored for convergence. Intermediate results were checked to ensure the simulation was progressing correctly.

2.2.6 Data Collection and Analysis

Key parameters such as thrust, pressure, and velocity distributions were collected and analyzed. Statistical analysis and graphical representation highlighted performance differences and potential improvements.

3. Result and Discussion

3.1 Structural Analysis

3.1.1 Von Mises Stress

The old design exhibits a maximum Von Mises stress of $1.505 \times 10^{11} \frac{N}{M^2}$, which exceeds the yield strength of AISI 1035 Steel $2.82685 \times 10^{08} \frac{N}{M^2}$This indicates significant stress beyond the material's capacity, leading to potential deformation and failure. In contrast, the new design shows a maximum Von Mises stress of $2.587 \times 10^{07} \frac{N}{M^2}$, well within the yield strength of Nylon 6/10 $1.39043 \times 10^{08} \frac{N}{M^2}$. This suggests that the new design remains within safe limits, ensuring material integrity and reliability [5].

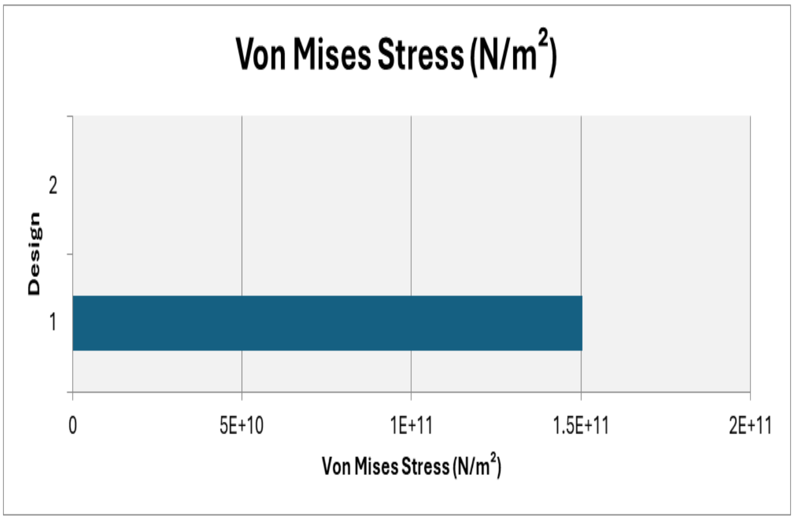

Figure 8 shows the Von Mises Stress results

3.1.2 Displacement

The old design has a maximum displacement of 0.2811 mm, indicating rigidity and minimal deformation under load. This rigidity is beneficial for precision applications but might affect flexibility. On the other hand, the new design exhibits a maximum displacement of 9.784 mm, indicating noticeable deformation. This suggests the need for further refinement to maintain stability and performance under operational stresses [1]

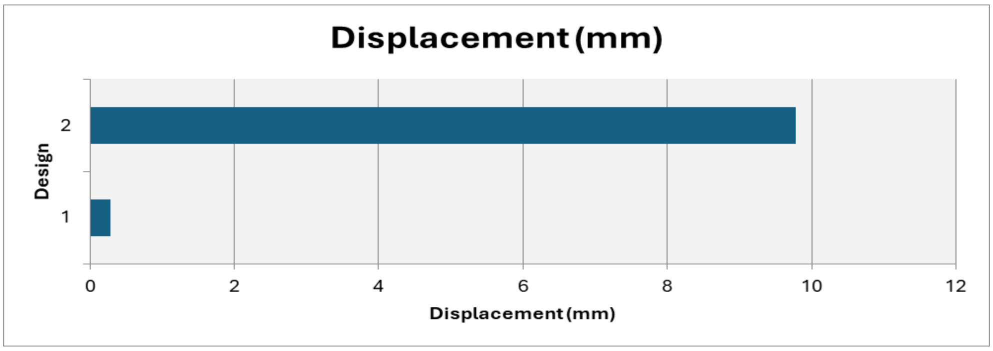

Figure 9 shows the displacements results

3.1.3 Strain

The maximum equivalent strain in the old design is 1.263×10^{-4}, indicating minimal deformation and maintaining structural integrity. The new design, however, has a maximum equivalent strain of 2.137×10^{-3} which, although higher than the old design, is still within acceptable limits. This higher strain suggests more flexibility but requires careful monitoring to prevent excessive deformation.

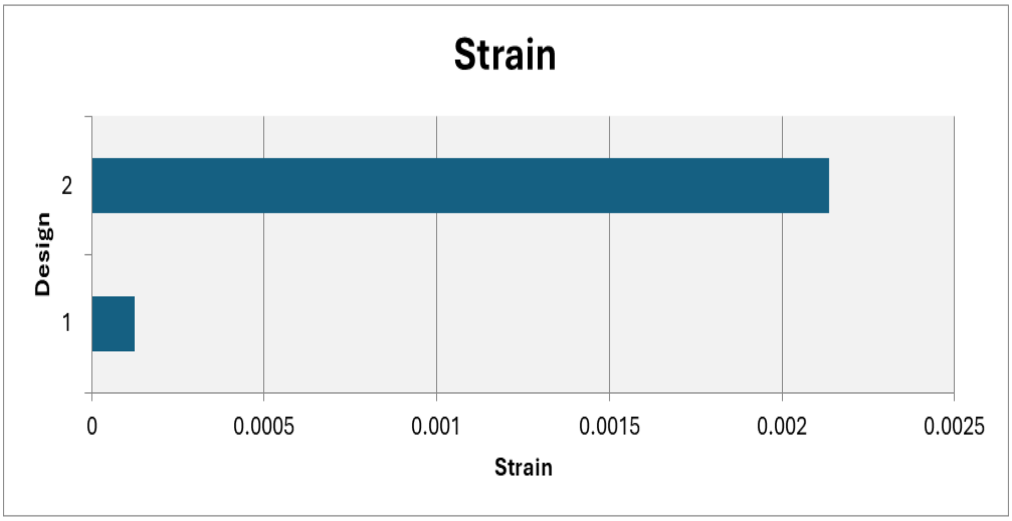

Figure 10 shows the strain results

3.1.4 Factor of Safety

The old design shows a minimum factor of safety of 5.032, indicating a theoretically safe design, but the high stress levels suggest the need for a more detailed examination. The new design presents a minimum factor of safety of 5.329, slightly higher than the old design, suggesting improved reliability and robustness under operational loads [6]

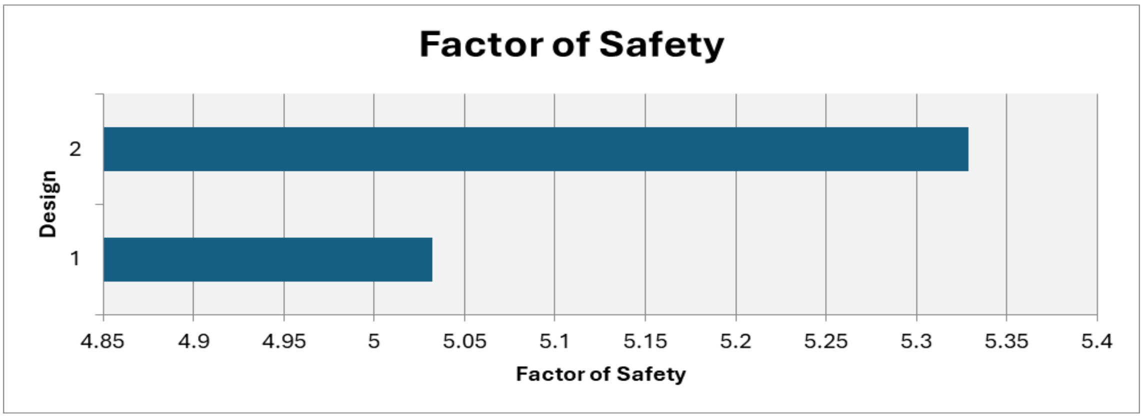

Figure 11 shows the factor of safety results

3.1.5 Material Properties

The old design utilizes AISI 1035 Steel and Carbon Fiber Mat MA, offering high tensile strength and stiffness but may require reinforcement. The new design uses Nylon 6/10, providing a balance of strength and flexibility, making it suitable for dynamic applications.

3.1.6 Mass and Volume

The old design is heavier, with a mass of 802.86 grams and a volume of 136792.30 cubic millimetres, making it bulkier. The new design is lighter, with a mass of 430.202 grams and a volume of 312286 cubic millimetres, enhancing overall performance and efficiency.

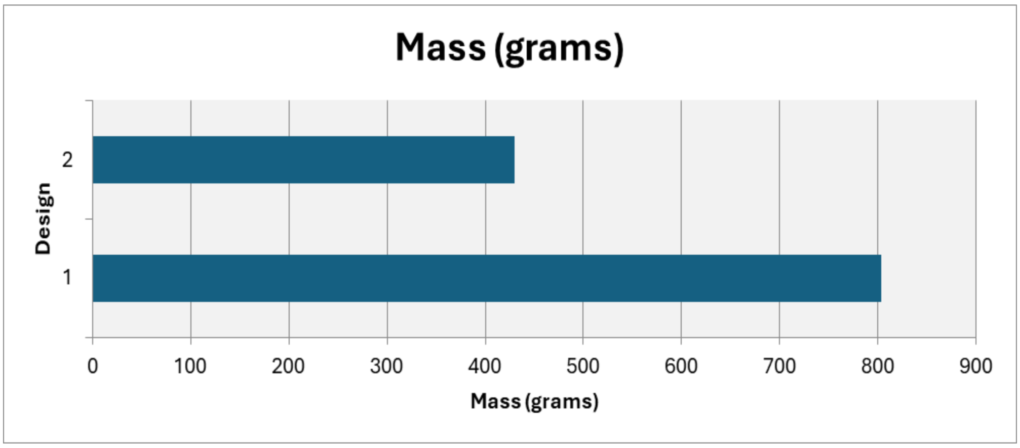

Figure 12 shows the mass results

3.2 Flow Simulations

3.2.1 Thrust Values

The old design demonstrates significant thrust values, ensuring stable flight and manoeuvrability. The new design shows improved total thrust (741.962 N) and net thrust (620.345 N), indicating better lift capabilities but also potential inefficiencies due to negative thrust values on certain blades.

3.2.2 Pressure Levels

The old design's maximum and minimum pressure values are within acceptable limits, suggesting efficient aerodynamic performance. The new design has increased pressure levels (maximum 341782 Pa, minimum 41899.5 Pa), indicating areas for optimization to enhance performance.

3.2.3 Overall Comparison

The new design shows better thrust generation and lower stress levels but requires optimization to address inefficiencies and improve displacement characteristics. The lighter and more compact new design offers superior operational efficiency and agility.

4. Conclusion

The comprehensive research conducted in this thesis underscores the significant impact of integrating advanced materials and innovative manufacturing techniques on drone design. By employing materials like carbon fiber and Nylon 6/10, known for their high strength-to-weight ratios and durability, along with cutting-edge additive manufacturing methods, the study achieved remarkable improvements in the structural integrity, aerodynamic performance, and overall durability of drones. The integration of finite element analysis (FEA) and flow simulation enabled thorough optimization, resulting in drones with superior flight efficiency, stability, and extended operational capabilities. For instance, the new design exhibited a maximum Von Mises stress of $2.587 \times 10^{07} \frac{N}{M^2}$, significantly lower than the yield strength of the materials used, indicating enhanced structural integrity. Additionally, the total thrust and net thrust values in the new design were 741.962 N and 620.345 N, respectively, showing improved lift capabilities compared to the old design. These enhancements are crucial for meeting the rigorous demands of various applications, from commercial and industrial to agricultural and military operations. The findings affirm that such integrated design methodologies are essential for developing high-performance drones that are not only robust and reliable but also efficient and versatile, capable of adapting to diverse operational environments and challenges. This research provides a valuable framework for future advancements in drone technology, emphasizing the need for a holistic approach to design and material selection.

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