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Design Improvement and Finite Element Analysis of a Drone Frame

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Abstract

In response to the growing operational demands placed on Unmanned Aerial Vehicles (UAVs), this research focuses on improving the structural design of micro-drones, such as the DJI Mini 3, which are often hindered by fractured arms and body-frame failures. These failures frequently arise from the use of unsuitable materials and non-optimised frame geometries designed strictly to meet sub-250 g weight regulations. The main goal of this study is to design and analyse a drone frame to achieve an improved strength-to-weight ratio using 3D Computer-Aided Design (CAD) software and Finite Element Analysis (FEA). FEA evaluates important parameters, including stress levels, degrees of deformation, and the Factor of Safety (FOS). Moreover, this project involves analysing key material properties to compare and select the most suitable materials for creating structures that are not only effective but also affordable.

1. Introduction

Unmanned Aerial Vehicles (UAVs) represent a significant technological advancement in modern aerospace and mechanical engineering [1]. The drone's frame acts as the primary skeleton, providing essential support for all critical subsystems, including motors, propellers, batteries, and payload modules. As the utility of UAVs expands, the demand for highly efficient, powerful, yet exceptionally portable drones has surged. Consumer micro-drones designed specifically to comply with sub-250 g aviation regulations, such as the DJI Mini 3, are particularly sought after for their ease of transport and reduced regulatory oversight [2].

However, in real-world operations, arm breakages around hinges, cracked motor mounts, and shattered body structures are common following minor accidents. Balancing mechanical strength, lightweight material constraints, and manufacturing costs remains a paramount challenge in drone design. Advanced engineering thermoplastics such as Polycarbonate (PC) and Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blends offer promising alternatives to brittle carbon composites, providing a highly favourable balance of stiffness, impact resistance, ductility, and cost-effectiveness [3]. Computational engineering tools like Finite Element Analysis (FEA) are crucial in this context, allowing engineers to systematically identify stress concentrations, simulate structural behaviour under applied forces, and calculate Factors of Safety (FoS) in a virtual environment before physical fabrication.

The primary objective of this research is to improve the design of a lightweight drone frame using advanced 3D CAD modelling software (SolidWorks) to create an improved structure capable of withstanding extreme operational forces. The study employs FEA in SolidWorks Simulation to rigorously evaluate the frame's structural performance, explicitly analysing stress distributions, deformation patterns, and crashworthiness during static bending and dynamic drop tests. By analysing suitable engineering plastics and implementing targeted geometric modifications, this study aims to provide a systematic engineering approach to overcome

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common structural failures. Ultimately, this research ensures the development of a highly durable, cost-effective aircraft that achieves an optimal strength-to-weight ratio while strictly adhering to the sub-250 g regulatory framework.

2. Methodology

This chapter outlines the methodology for the Final Year Project, which is fundamentally based on a Simulation-Driven Design Process. By utilising computational analysis, the drone frame will be rigorously evaluated and improved for both high strength and lightweight design. This virtual approach relies on established principles in mechanics to assess structural performance metrics, such as stress and strain, without needing physical prototypes. The project's implementation involves several key stages, starting with selecting a multirotor configuration and creating a 3D model in SolidWorks 2024. The core of the study then relies on Finite Element Analysis (FEA) via SolidWorks Simulation. This involves defining material properties, specifying boundary conditions, and simulating realistic loading scenarios, such as direct impacts and payload stresses. Crucially, this relies on an iterative loop: simulation results are continuously used to refine geometric shapes and material choices.

2.1 Project Flowchart

The project methodology is executed through a structured, step-by-step lifecycle. Based on Figure 1, it begins with identifying a specific engineering problem to establish clear research objectives, followed by submitting a project proposal for supervisor appraisal. The research phase then focuses on a systematic literature review to build a theoretical foundation and justify the project's technical goals, alongside the definition of the implementation methodology, including CAD and FEA processes. Once planning is complete, the design phase involves conceptualisation, 3D modelling, and material selection to create a virtual prototype. This prototype is subsequently subjected to FEA testing to simulate real-world stress and deformation scenarios, and the supervisor validates the results. Finally, the project concludes with the compilation of a comprehensive report detailing all activities from problem formulation to simulation outcomes.

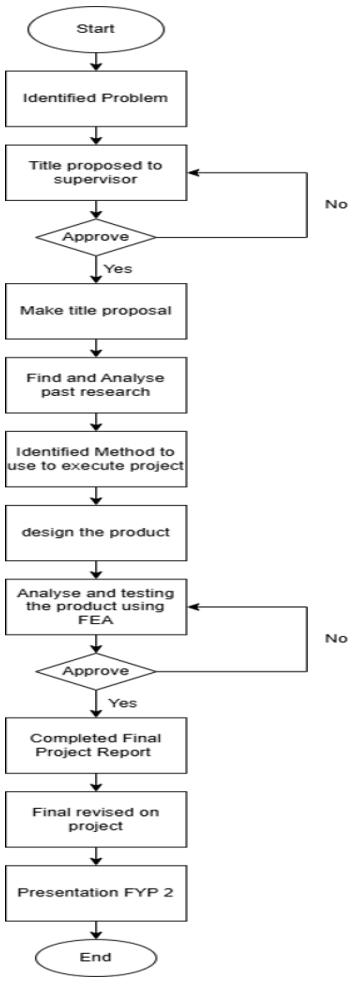


Fig.1 Flow Chart of Project Methodology

2.2 Conceptual and Final Design

The drone was modelled using a Quadcopter-X configuration, selected for its high propulsion efficiency, mechanical simplicity, and optimal power-to-weight ratio. This symmetric arrangement enables an even distribution of thrust, which helps maximise aerodynamic efficiency and manoeuvring performance. The core architecture features a stiff central cylinder that serves as a protective hub housing the flight control and power distribution boards. Based on Figure 2, the drone has four lifting arms extending from this hub in a cross formation, specifically designed with high torsional stiffness to support the powertrain assemblies reliably. The overall dimensions of the frame serve as the fundamental architecture and are strictly constrained to an overall length of 120 mm, a width of 90 mm, and a drone arm length of 70 mm. To ensure operational stability and ground clearance, the landing system comprises two Forward Touchdown Struts and two Aft Fuselage Nodes integrated into vertical struts, providing a stable takeoff and landing platform across varied terrain.

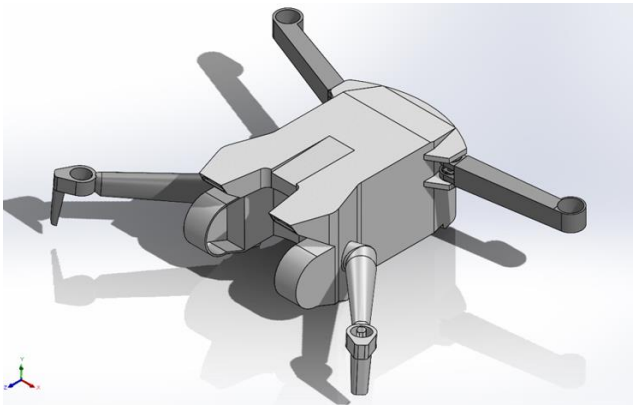


Fig. 2 The design of the Drone Frame

2.3 Material Selection

The drone's material selection process focuses on improving the strength-to-weight ratio to enhance flight performance and durability while employing "Value Engineering" to ensure cost-effectiveness. The airframe design prioritises mechanical rigidity, with landing gear assembly requiring high fracture toughness and energy-absorption capabilities to protect the structure from impact forces. Ultimately, the chosen materials must balance these structural and safety requirements with manufacturing feasibility and material availability to maintain project viability.

2.3.1 Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend

The drone frame will utilise a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, selected for its optimal balance of performance, cost-effectiveness, and manufacturing simplicity. Based on Table 1, with a density of 1.14 g/cm^3, a yield strength of 50MPa, and a Young's Modulus of 2.4 GPa, the material provides the necessary rigidity and structural integrity to withstand flight forces while improving the thrust-to-weight ratio. Furthermore, the alloy's high ductility (40–60% elongation at break) ensures that the frame undergoes controlled deformation rather than brittle failure, significantly reducing maintenance needs and long-term costs.

Table 1 *Mechanical Properties of Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend*

Property	Value
Tensile Strength	55 MPa
Yield Strength	50 MPa
Young's Modulus	2.4 GPa
Density	1.14 g/cm^3
Elongation at Break	40-60%
Cost & Manufacturability	Low cost

2.3.2 Polycarbonate

Based on Table 2, Polycarbonate (PC) is selected for the drone frame due to its exceptional impact strength of 800 J/m and high ductility (80–150% elongation at break), which allows the structure to absorb significant energy and flex during crashes rather than shattering. To support operational performance, the material offers a Young's Modulus of 2.3 GPa to minimise vibrations and a yield strength of 60MPa to prevent deformation during aggressive manoeuvres. While its density of 1.2 g/cm^3 necessitates careful geometric improvement to meet mass constraints for micro-drones, PC's combination of structural rigidity and damage tolerance ensures both sensor stability and long-term durability for payload-heavy applications.

Table 2 *Mechanical properties of Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) Blend*

Property	Value
Tensile Strength	65 MPa
Yield Strength	60 MPa
Young's Modulus	2.3 GPa
Density	1.2 g/cm^3
Elongation at Break	80-150%

2.4 Finite Element Analysis (FEA)

SolidWorks Simulation will be utilised for Finite Element Analysis (FEA), serving as a virtual prototyping tool to assess the frame's structural integrity rigorously. By simulating real-world forces, this analysis will map von Mises stress distributions and deformation patterns to identify potential failure points and ensure the design remains within safe elastic limits. The process involves precise model preparation, the application of loading constraints, and the calculation of a Factor of Safety (FOS) through both static and dynamic simulations. These findings will provide the necessary data to refine the geometry, ultimately ensuring the final airframe achieves an optimal balance between a lightweight profile and the robustness required for demanding operational flight.

2.4.1 FEA Analysis and Testing

The accuracy of the FEA depends on precisely defining boundary conditions and loading scenarios to mimic real-world operational behaviour, with a target Factor of Safety (FoS) of 1.2 [5]. Based on Table 3, the structural verification will employ both static structural analyses to assess maximum deformation and stress under peak operational loads and drop test analysis to ensure durability. For the design to be considered sound, these simulations must demonstrate that the induced von Mises stress remains well below the material's yield strength, confirming that the structure can withstand expected loads without failure or excessive elasticity.

Table 3 Analysis type that will be carried out in the FEA analysis

Analysis Type	Objective	Critical Result and Validation Criteria
Static Structural Analysis	Determine the frame's ability to withstand maximum operational loads without failure or excessive deflection.	Von Mises Stress: Must be significantly below the material's yield strength ($\sigma_{max} \ll \sigma_{yield}$). Minim FOS across frame is 1.2
Drop Test	Determine the frame's ability to withstand the maximum stress when dropped from a height without failing or exhibiting excessive deflection.	Von Mises Stress: Must be significantly below the material's yield strength ($\sigma_{max} \ll \sigma_{yield}$). Minim FOS across frame is 1.2

3. Result and Discussion

The mechanical and structural integrity of the drone frame was validated through rigorous testing and detailed finite element analysis (FEA) simulations in SolidWorks Simulation 2024. This comprehensive analysis demonstrates how specific geometric refinements and engineered material selections allow improved, lightweight designs to significantly outperform heavier, traditional By observing stress distribution, deformation effects, and strain concentration zones under anticipated operational forces, this study aims to definitively

confirm that the frame remains well within safe material limits, without ever exceeding the yield point. Ultimately, these testing efforts will yield an approved, simulation-tested conceptual framework that is purposefully designed to be both lightweight and economical, whilst still providing the high degree of strength, safety, and dependability required to support optimal flight performance fully.

3.1 Bending Test

Bending tests are basic mechanical tests performed to determine a structure's response to bending forces. For this study, this principle is applied computationally to evaluate the structural integrity of the improved DJI Mini 3 drone arm. During flight and impact scenarios, the drone arm functions structurally as a cantilever beam, anchored securely to the main chassis, while subjected to external forces at the motor mounts. The design's viability is evaluated against the selected material's yield strength.

3.1.1 Bending Test on Rear Arm

To evaluate the structural integrity of the rear arm, a bending simulation was configured to replicate an extreme localised stress event, such as forces acting on the arm. A static downward load of 180 N was then applied uniformly across the top surface of the rear arm. To improve, as shown in Table 4, the shell thickness of the rear arm increases from 1mm to 1.4 mm to provide greater strength and withstand the bending force acting on it. The rear arm is also being improved by adding a 0.5mm-thick rib along its length. The rear arm material changed from polycarbonate (PC) to a Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS) blend to improve its strength-to-weight ratio.

Based on Table 4, the comparative bending test results demonstrate a critical structural improvement between the original and upgraded rear arm designs. Based on Figure 3, the initial design utilising pure Polycarbonate (PC) was structurally unviable; it experienced a maximum stress of 158.89 MPa, exceeding its yield strength of 60.0 MPa, resulting in a failing Factor of Safety (FOS) of just 0.38. Based on Figure 4, the upgraded design increased the shell thickness from 1 mm to 1.4 mm and incorporated an internal rib structure [6]. Although the material was changed to a slightly weaker PC/ABS blend with a yield strength of 50.0 MPa, the geometric stiffness provided by the new ribs and thicker walls drastically reduced the maximum stress down to 38.57 MPa, successfully elevating the FOS to a safe 1.2.

Table 4 *Comparative Results of Bending Test Between Original Design and Improved Rear Arm*

Parameter	Original design	Improved design
Material	Polycarbonate (PC)	PC/ABS Blend
Material Yield strength	60.0 MPa	50.0MPa
Shell thickness	1 mm	1.4mm
Internal Structure	none	rib
Maximum Stress	158.89 MPa	38.57 MPa
Factor of Safety	0.38	1.2

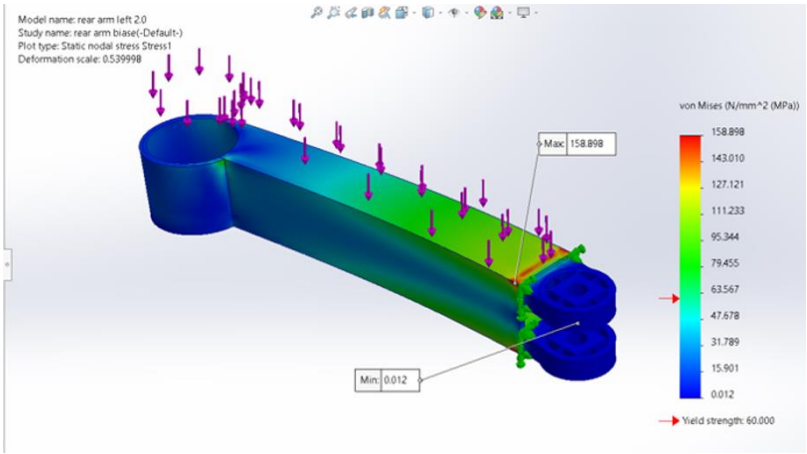


Fig. 3 Result of FoS for bending test on rear arm

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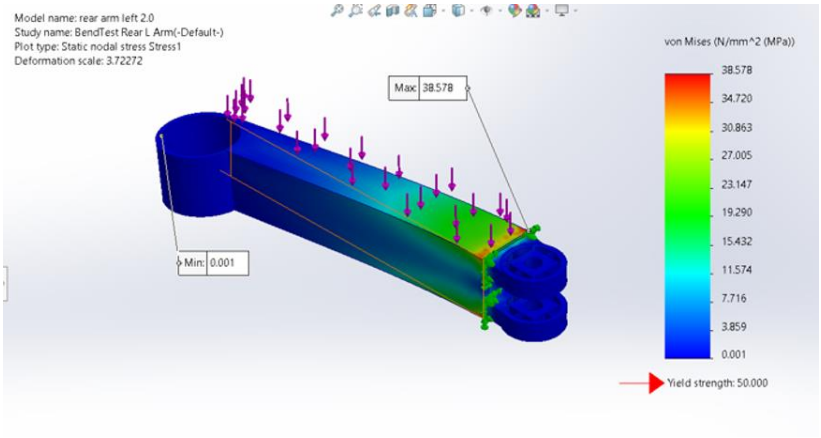


Fig. 4 Result of stress distribution bending test on the improved rear arm

3.1.2 Bending test on Front Arm

To evaluate the structural integrity of the drone frame under operating loads, a static structural bending test was conducted on the front arm design using SolidWorks Simulation. An external downward force of 197 N was applied normal to the top face of the arm. This simulates an extreme load case, such as a hard landing or severe aerodynamic stress during flight. To improve, as shown in Table 5, the shell thickness of the rear arm increases from 1mm to 1.2 mm to provide greater strength and withstand the bending force acting on it. The rear arm is also being improved by adding a 0.5mm-thick rib along its length. The rear arm material changed from polycarbonate (PC) to a Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS) blend to improve its strength-to-weight ratio.

Based on Figure 5, the original front arm design, despite utilising a stronger pure Polycarbonate (PC) with a 60.0 MPa yield strength, was structurally inadequate for the applied loads. Under the bending test, it experienced a maximum stress of 71.94 MPa, resulting in a failing Factor of Safety (FOS) of 0.83, meaning the part would yield or break. To correct this, the upgraded design expanded the internal structure from localised ribs to continuous ribbing along the entire arm and increased the shell thickness from 1 mm to 1.2 mm. Based on Figure 6, even with a switch to a slightly weaker PC/ABS blend (50.0 MPa yield strength), the maximum stress was reduced nearly by half to 41.94 MPa, successfully raising the FOS to a safe 1.2.

Table 5 Comparative Results of Bending Test Between Base Design and Improved Front Arm

Parameter	Original design	Improved design
Material	Polycarbonate (PC)	PC/ABS Blend
Material Yield strength	60.0 MPa	50.0MPa
Shell thickness	1 mm	1.2mm
Internal Structure	Rib certain position	Rib along the arm
Maximum Stress	71.94 MPa	41.94 MPa
Factor of Safety	0.83	1.2

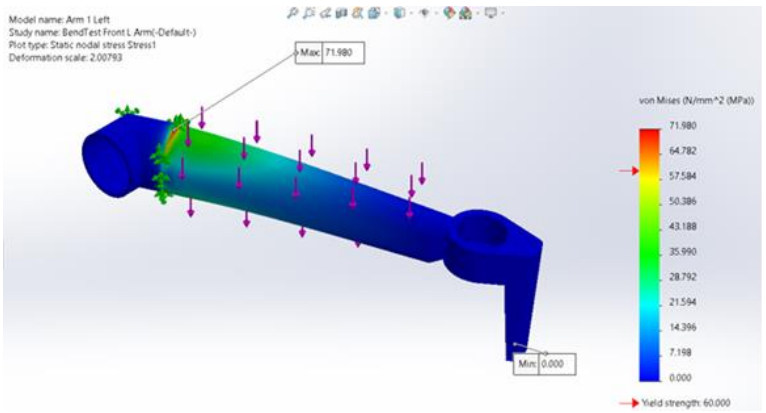


Fig. 5 Result of the stress for the bending test on the front arm

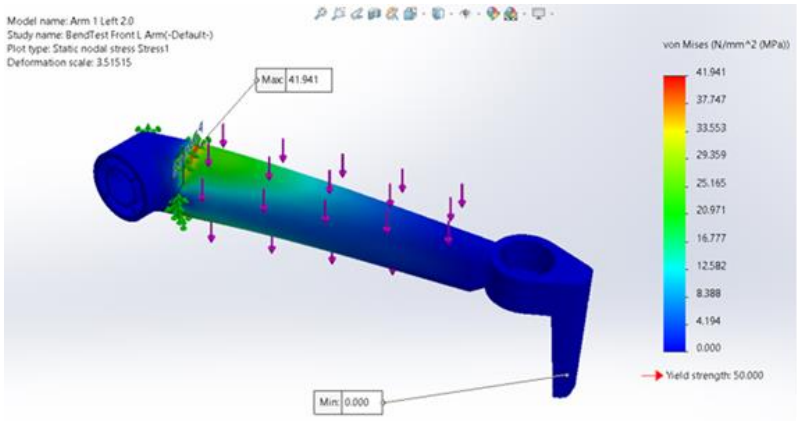


Fig. 6 Result of the stress for the bending test on the improved front arm

3.2 Drop Test

A drop test is an important dynamic test used to assess a part's ability to withstand strain and impact under high-strain conditions. Unlike a static structural assessment, a drop test recreates realistic kinetic situations by converting the falling object's gravitational potential energy into kinetic energy, which is then dissipated on impact [7]. For uncrewed aerial vehicles (UAVs), these impact forces are a primary cause of mechanical failure. In this study, drop-test simulations are applied to the DJI Mini 3 drone's arm. As the primary structural member connecting the propulsion system to the main chassis, the drone arm is highly vulnerable to stress concentrations during a crash. The primary metric extracted from these drop simulations is the maximum equivalent stress (von Mises stress) experienced by the drone arm upon impact. To evaluate whether the design can survive, the level of stress is compared with the material's yield strength; if the stress exceeds this limit, the part may bend or fracture, but if it stays within the allowable limit, the arm will not be deformed.

3.2.1 Drop Test on the Top Surface of the Whole Drone Frame

The simulation was configured to replicate a free-fall drop from a height of 9 meters, with the initial point of impact localised on the top surface of the drone casing. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, utilising a uniform shell thickness of 1 mm. The key findings from the static stress analysis (Plot type: von Mises Stress) at the critical part of the drone. To improve the drone frame, the material was changed from a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend to Polycarbonate. The drone frame's shell thickness is being reduced from 1mm to 0.9mm to improve the length-to-weight ratio.

Based on Table 5, the comparative drop-test results for the drone frame's top surface highlight a successful material-driven improvement strategy. As shown in Figure 7, the original design, modelled with a PC/ABS blend (yield strength of 50.0 MPa) and a 1 mm shell thickness, was structurally insufficient for the impact; it experienced a maximum stress of 52.51 MPa, resulting in a failing Factor of Safety (FOS) of 0.95. To resolve this without adding bulk, the improved design transitioned to pure Polycarbonate (PC), which provides a higher baseline yield strength of 60.0 MPa as shown in Figure 8. Counterintuitively, the shell thickness was reduced to 0.9 mm. Yet, the maximum stress under the drop test decreased to 45.19 MPa, successfully raising FOS to a safe 1.2.

Table 5 Comparative drop test results on the top surface of the Drone frame.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Shell thickness	1 mm	0.9 mm
Maximum Stress	52.51 MPa	45.19 MPa
Factor of Safety	0.95	1.2

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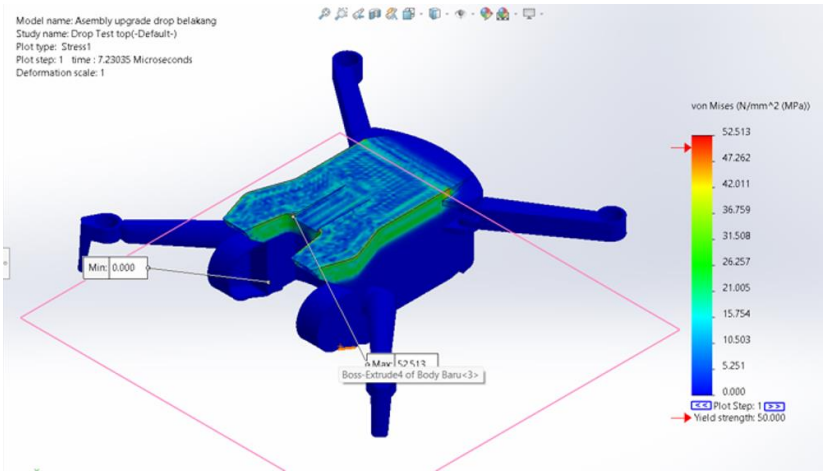


Fig. 7 Result of drop test on the top surface of the Whole Drone Frame

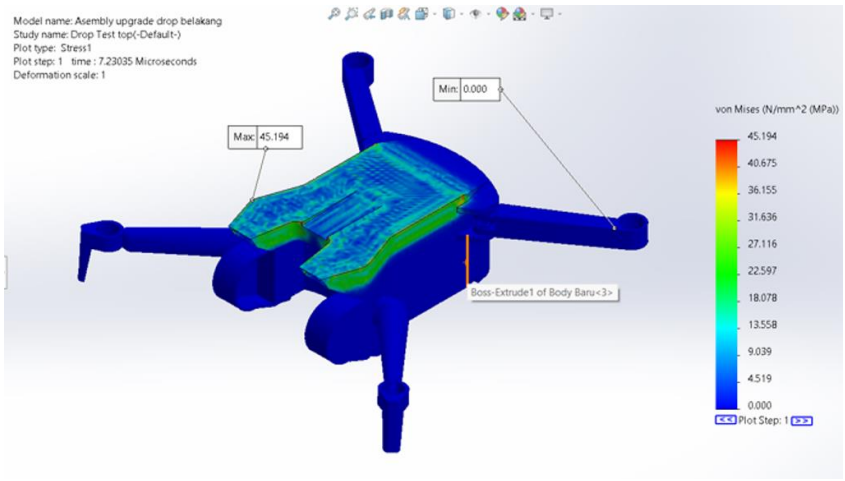


Fig. 8 Result of drop test on the top surface of the Whole Drone Frame

3.2.2 Drop Test on Base Surface of Whole Drone Frame

A drop test simulation was conducted on the drone frame assembly to evaluate its structural integrity during a free-fall impact with a height of 1m. The drop orientation was set to impact the drone's bottom, simulating a hard landing or a direct impact with the landing gear. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, utilising a uniform shell thickness of 1 mm. To improve the drone frame, the material was changed from a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend to a Polycarbonate blend to improve overall toughness and impact resistance. The drone frame's shell thickness is being reduced from 1mm to 0.9mm to improve the length-to-weight ratio. The primary design modification was expanding the landing gear's geometric footprint (making it wider and longer) to increase the surface area for impact distribution.

Based on Table 6, the 1-meter drop test simulation reveals a highly effective, two-pronged improvement strategy targeting the drone frame's bottom impact resistance. As shown in Figure 9, the original design, which utilised a PC/ABS blend (50.0 MPa yield strength) with a 1 mm shell thickness, was structurally insufficient for a hard landing; it recorded a maximum stress of 52.96 MPa, resulting in a failing Factor of Safety (FOS) of 0.94. To resolve this without adding unnecessary mass, the improved design introduced both material and geometric upgrades. The material was switched to pure Polycarbonate (PC), elevating the baseline yield strength to 60.0 MPa. Geometrically, the landing gear's footprint was expanded, made wider and longer to distribute the impact force over a larger area [8]. As shown in Figure 10, this broader energy distribution was so effective that it enabled the primary shell thickness to be reduced from 1 mm to 0.9 mm, improving the length-to-weight ratio while maintaining a maximum accumulated stress of 49.52 MPa. This combination of superior force distribution and stronger base material successfully elevated the design from a failing state to a safe FOS of 1.21.

Table 6 Comparative drop test results on the top surface of the Drone frame.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Shell thickness	1 mm	0.9 mm
Maximum Stress	52.96 MPa	49.52 MPa
Factor of Safety	0.94	1.21

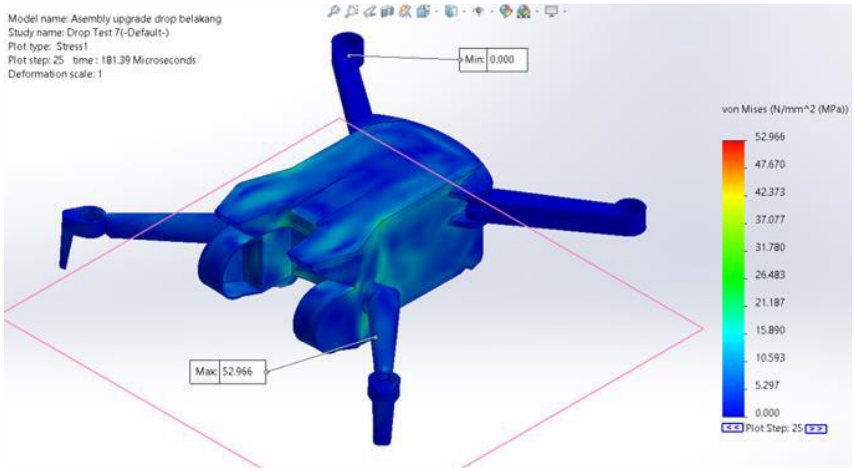


Fig. 9 Result of drop test on the base surface of the Whole Drone Frame

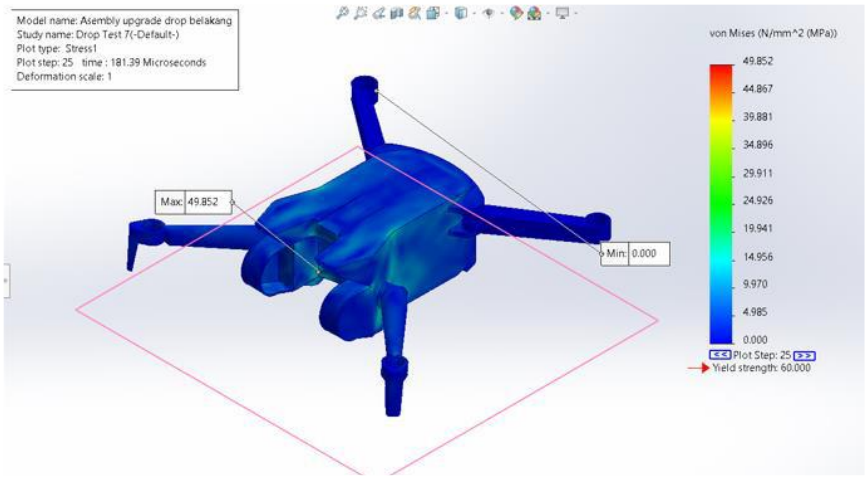


Fig. 10 Result of drop test on the base surface of the improved Whole Drone Frame

3.2.3 Drop Test on Front Surface of Drone

The simulation was configured to model a free-fall drop from a height of 3.8 meters, with the point of impact localised on the drone's casing. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend. To improve the drone frame, the material was changed from a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend to a Polycarbonate blend to improve overall toughness and impact resistance. The drone frame's shell thickness is being reduced from 1mm to 0.9mm to improve the length-to-weight ratio.

Based on Table 7, the comparative results from the severe 3.8-meter drop test on the drone's front surface demonstrate the need for a structural intervention to prevent impact failure. As shown in Figure 11, the original design, utilising a PC/ABS blend (yield strength of 50.0 MPa) with localised internal ribbing and a 1 mm shell thickness, failed to withstand the high kinetic energy of the impact. Resulting in stress 67.46 MPa, resulting in a failing Factor of Safety (FOS) of 0.88. To mitigate this, as shown in Figure 12, the improved design adopted a

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stronger base material, pure Polycarbonate (PC), which increased the yield threshold to 60.0 MPa. More importantly, substantial geometric reinforcements were applied: the table data indicates the shell thickness was increased to 1.2 mm, and the internal structure was upgraded to feature continuous ribbing along the entire front arm. These modifications drastically improved the frame's structural stiffness and impact force distribution, reducing the maximum stress to just 39.86 MPa and raising the FOS to a highly secure 1.25.

Table 7 Comparative drop test results on the front surface of the Drone frame.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Area of impact	Front Arm	Front Arm
Shell thickness	1 mm	1.2 mm
Internal Structure	Rib at a certain position	Rib along the front arm
Maximum Stress	67.46 MPa	39.86 MPa
Factor of Safety	0.88	1.25

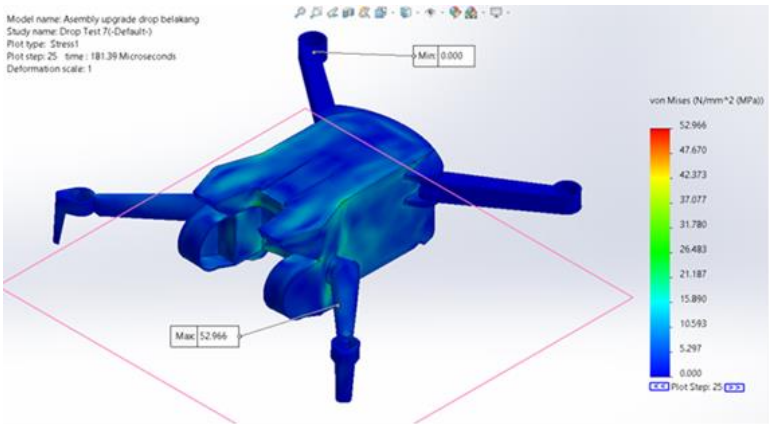


Fig. 11 Result of drop test on the front surface of the Whole Drone Frame

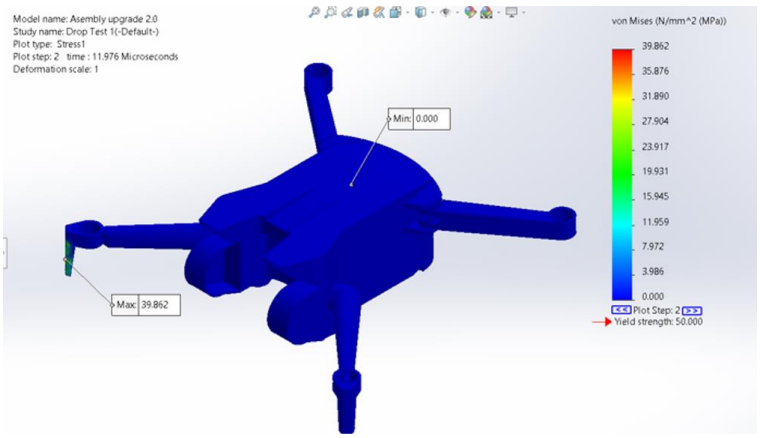


Fig. 12 Result of drop test on the front surface of the improved Whole Drone Frame

3.2.4 Drop Test on Back Surface of Whole Drone Frame

The simulation was configured to simulate a free-fall drop from a height of 5 meters, with the initial point of impact localised on the back surface of the drone casing. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, utilising a uniform main body shell thickness of 1 mm and an arm shell thickness of 1 mm.

To improve the drone frame, the material was changed from a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend to a Polycarbonate blend to improve overall toughness and impact resistance. The drone frame's shell thickness is being reduced from 1mm to 0.9mm to improve the length-to-weight ratio. The key findings from the static stress analysis (Plot type: von Mises Stress) at the critical part of the drone. To

improve the rear, the shell thickness of the rear arm increases from 1mm to 1.4 mm to provide greater strength and withstand the bending force acting on it. The rear arm is also being improved by adding a 0.5mm-thick rib along its length. The rear arm material changed from polycarbonate (PC) to a Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS) blend to improve its strength-to-weight ratio.

Based on Table 8, the original design using a PC/ABS blend with a 50.0 MPa yield strength and a uniform 1 mm shell failed under the severe 5-meter impact. Figure 13 shows that the front arm region absorbed a maximum stress of 61.67 MPa, resulting in an inadequate Factor of Safety (FOS) of 0.97. To resolve this, the improved design employs a localised strengthening approach: the front arm shell thickness was increased to 1.2 mm, the internal structure was upgraded to feature a continuous rib along the arm, and the material was switched to a stronger pure Polycarbonate (60.0 MPa yield capacity). This specific geometric and material stiffening in the impact zones effectively halved the accumulated stress in the front arm, such as in Figure 14, reducing it to 31.32 MPa and catapulting the FOS to a highly robust 1.59. This is a classic, effective methodology for unmanned aerial vehicle structural simulation: bulking up the critical load paths to ensure survivability in a hard landing while shaving material elsewhere to prevent unnecessary mass penalties [9].

Table 8 Comparative drop test results on the back surface of the Drone frame.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Area of impact	Front Arm	Front Arm
Shell thickness	1 mm	1.2 mm
Internal Structure	Rib at a certain position	Rib along the front arm
Maximum Stress	61.67 MPa	31.32 MPa
Factor of Safety	0.97	1.59

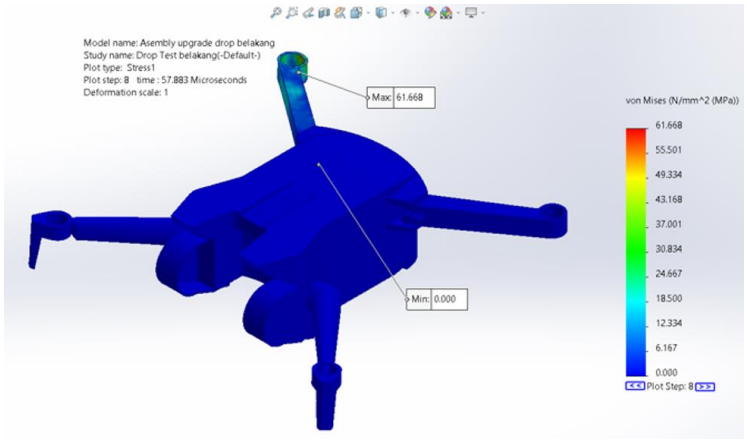


Fig. 13 Result for the drop test on the back surface of the drone

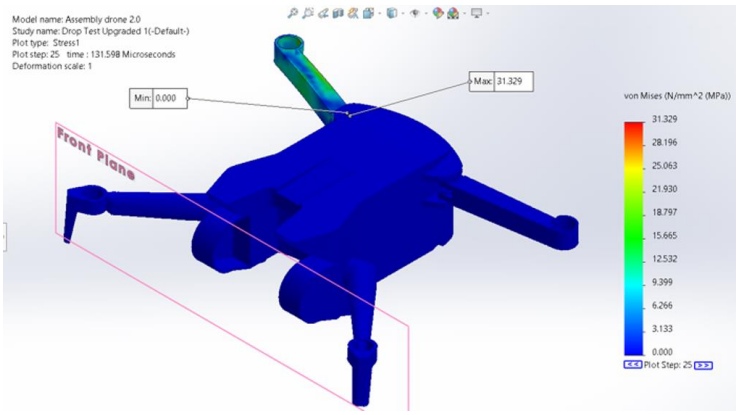


Fig. 14 Result drop test on the back surface of the improved drone

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3.2.5 Drop Test on Right Side Surface of Whole Drone Frame

The simulation was configured to replicate a free-fall drop from a height of 6 meters, with the initial point of impact localised on the right side of the drone's frame. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, utilising a uniform shell thickness of 1 mm. The front and rear arms have a 1 mm wall thickness. To improve the drone frame, the material was changed from a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend to a Polycarbonate blend to improve overall toughness and impact resistance. The drone frame's shell thickness is being reduced from 1mm to 0.9mm to improve the length-to-weight ratio. To improve the front arm, the shell thickness is increased from 1mm to 1.2 mm to provide greater strength and withstand the bending force acting on it. The rear arm is also being improved by adding a 0.5mm-thick rib along its length. The rear arm material changed from polycarbonate (PC) to a Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS) blend to improve its strength-to-weight ratio.

Based on Table 9, the results from the extreme 6-meter drop test simulation demonstrate a highly targeted and successful structural improvement strategy. Under the immense kinetic energy of a 6-meter free-fall, the original drone frame design's structure failed. Based on Figure 15, the front arm recorded a maximum von Mises stress of 67.43 MPa, resulting in an inadequate Factor of Safety (FOS) of 0.88. The base material was upgraded to pure Polycarbonate (PC) to increase the yield threshold to 60.0 MPa. Furthermore, the shell thickness of the highly stressed front arm was specifically increased to 1.2 mm, and its internal structure was fortified with continuous ribbing along the arm's entire length. As shown in Figure 16, this targeted geometric stiffening drastically improved the arm's ability to absorb and distribute severe impact forces, reducing the maximum stress to just 33.98 MPa. As a result, the FOS surged to a highly secure 1.47.

Table 9 Comparative drop test results on the back surface of the Drone frame.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Area of impact	Front Arm	Front Arm
Shell thickness	1 mm	1.2 mm
Internal Structure	Rib at a certain position	Rib along the front arm
Maximum Stress	67.43 MPa	33.98 MPa
Factor of Safety	0.88	1.47

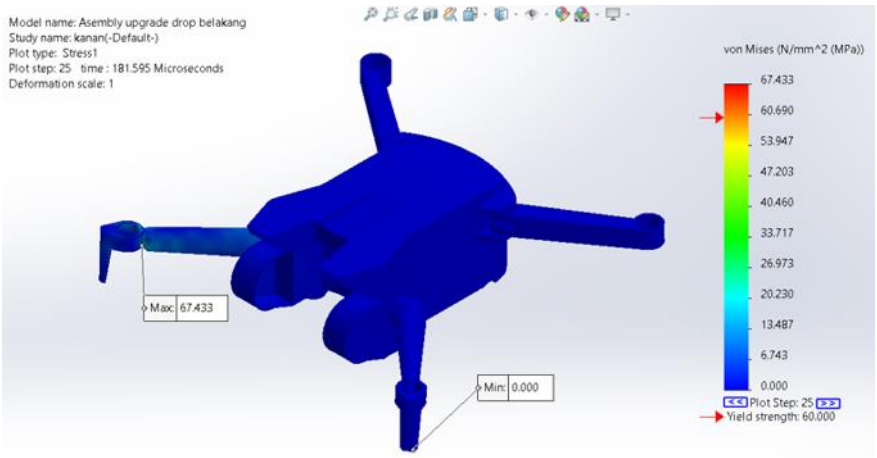


Fig. 15 Result of the drop test on the right side of the whole drone frame

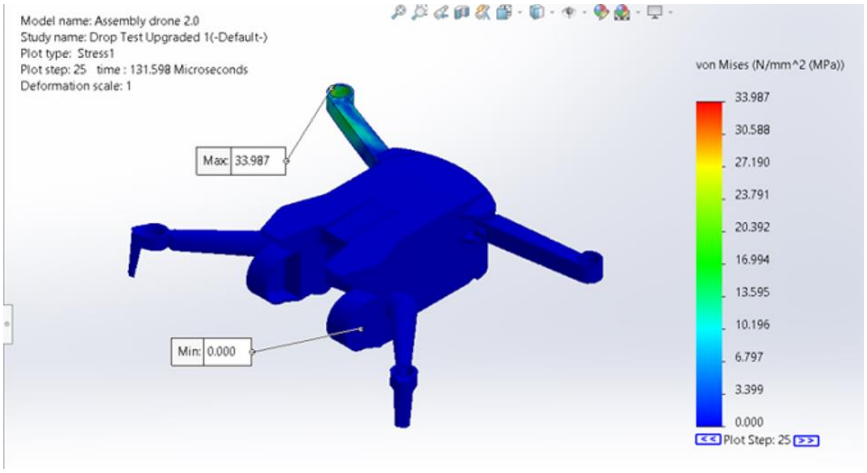


Fig. 16 Result of the drop test on the right side of the whole improved drone frame

3.2.6 Drop Test on the Left Side of the Main Drone Body

The simulation was configured to replicate a free-fall drop from a height of 1 meter, with the initial point of impact localised on the left surface of the drone casing. The primary material assigned to the frame was a Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, utilising a uniform shell thickness of 1 mm

Based on Table 10, the comparative drop test results for the drone frame's top surface demonstrate a highly effective, material-driven improvement strategy that increases strength while simultaneously reducing weight. As shown in Figure 17, the original design, utilising a PC/ABS blend with a yield strength of 50.0 MPa and a 1 mm shell thickness, was structurally inadequate for the impact; it registered a maximum von Mises stress of 59.71 MPa, resulting in a failing Factor of Safety (FOS) of 0.83. The improved design transitioned to pure Polycarbonate (PC), elevating the baseline yield strength to 60.0 MPa. Notably, to improve the frame's length-to-weight ratio, the shell thickness was reduced from 1 mm to 0.9 mm. Despite this thinner wall, the maximum accumulated stress during the impact dropped significantly to 47.35 MPa, indicating that the stiffer PC material more effectively absorbed and distributed the kinetic energy, as shown in Figure 18.

Table 10 Comparative drop test results on the left side of the Main Drone Body.

Parameter	Original design	Improved design
Material	PC/ABS Blend	Polycarbonate (PC)
Material Yield strength	50.0 MPa	60.0MPa
Shell thickness	1 mm	0.9 mm
Maximum Stress	59.71 MPa	47.35 MPa
Factor of Safety	0.83	1.26

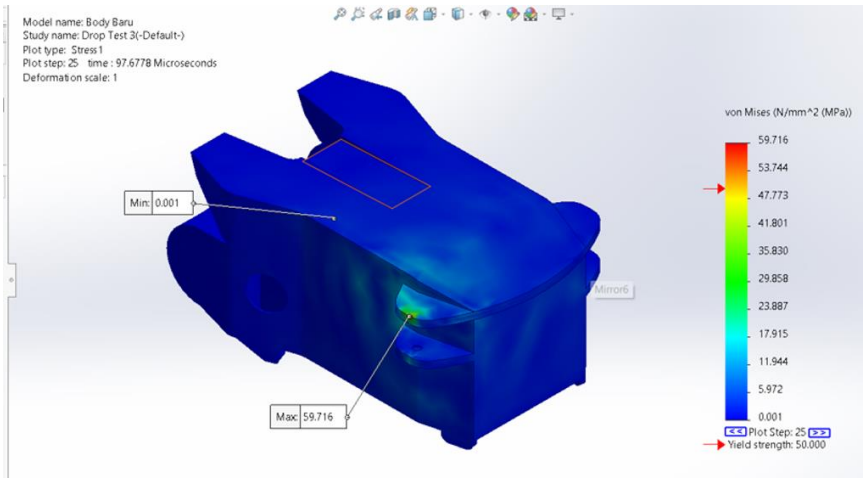


Fig. 17 Result drop test on the left side of the main body of the drone

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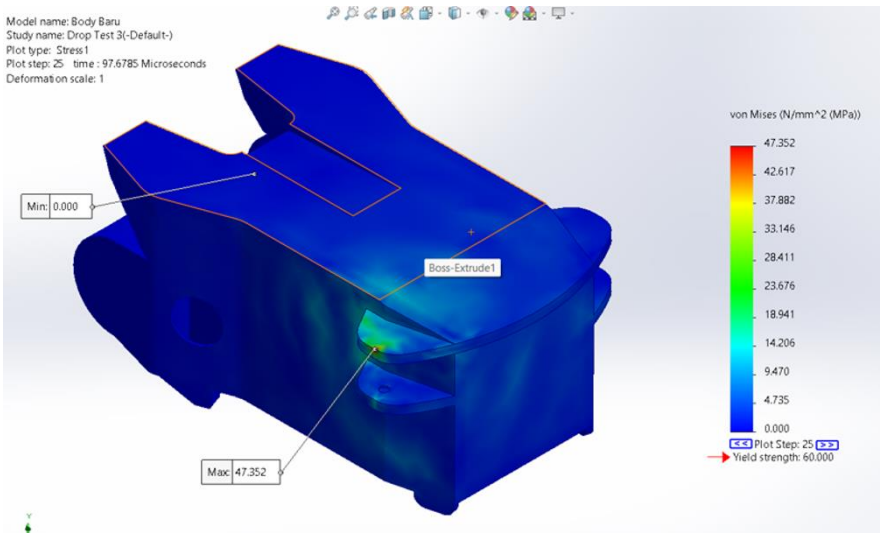


Fig. 18 Result of the drop test on the left side of the improved main drone body

3.2.7 Comparative Original and Improved Design

Comparative data summarises the critical geometric, material, and physical property shifts applied to the complete drone assembly following the iterative Finite Element Analysis (FEA) testing. The material used for the drone body has been changed from PC/ABS blend to pure Polycarbonate. Based on Table 12, by choosing pure PC with a higher yield strength of 60.0 MPa instead of 50.0 MPa in the PC/ABS blend, the frame can become more crashworthy in the chassis's central area while maintaining a nominal 1mm shell thickness. Furthermore, pure PC has been replaced with PC/ABS blend for both front and rear arms. For the front arm, the shell thickness was increased from 1 mm to 1.2 mm, and the internal support ribbing was extended continuously along the entire length of the arm, rather than being limited to specific localised sections. The rear arm saw an even greater increase in shell thickness, moving from 1 mm to 1.4mm, and integrated a continuous internal rib structure, replacing the original design's hollow, unreinforced cavity. Specifically, the former design of 66.51 g would never meet the requirement for a Factor of Safety of 1.2 or greater in any bending or impact tests conducted under various conditions. In contrast, this more massive but better-designed 71.76 g drone perfectly resolves all existing structural issues while comfortably staying within the necessary weight constraints for a sub-250g drone.

Table 12 Comparative Original and Improved Design

Parameter	Original design	Improved design
Material Drone Body	PC/ABS Blend	Polycarbonate (PC)
Thickness of the Drone Body	50.0 MPa	60.0MPa
Material of Front Arm	1 mm	0.9 mm
Feature on the Front Arm	52.51 MPa	45.19 MPa
Thickness of the Front Arm	0.95	1.2
Material of the Rear Arm	Polycarbonate	PC/ABS blend
Feature on the Rear Arm	none	Rib along the arm
Thickness of the Rear Arm	1mm	1.4mm
Weight	66.51 g	71.76 g
Cost of Material	RM0.53	RM0.6

4. Conclusion

This research successfully resolved the engineering challenge of balancing mechanical strength with lightweight requirements for sub-250g UAV payload structures. Using SolidWorks, an optimised quadcopter frame was designed by upgrading a thin-walled baseline model with a widened landing gear and 0.5 mm-0.6 mm internal ribs. Finite Element Analysis (FEA) was then used to evaluate the frame under static bending loads (180 N and 197 N) and dynamic drop tests (1-9 meters). These initial simulations identified critical vulnerabilities in the baseline design, exposing localised plastic deformation and dangerously low Factor of Safety (FoS) values of 0.38 at the arm roots and 0.81 at the landing gear.

To enhance structural integrity, strategic material and geometric upgrades were implemented to redirect impact energy away from vulnerable zones. The frame arms were transitioned to a PC/ABS blend (50.0 MPa yield strength) for maximum ductility, while the central chassis utilised pure Polycarbonate (60.0 MPa) for exceptional impact resistance, alongside an increased shell thickness of 1.4 mm. This FEA-guided approach drastically reduced stress and elevated the minimum FoS to safe margins of 1.2 during extreme bending and 1.17 to 1.59 across high-impact drops, ultimately proving that these modifications can yield a highly durable, lightweight platform for payload missions.

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