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Material Optimization for Structural Strength of Hexacopter Landing Skid Using Finite Element Method

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Abstract—Hexacopter is a type of UAV that has six propellers with a load of 147 N in this study. Then, to support the landing of the hexacopter and to support it while being on the ground, landing skid is needed. The landing skid is designed using 3D printing from selected materials to find out which material is best used for the landing skid, including PLA, PETG, and ABS. 3D-printing supports the production of lightweight and high-strength parts. This research method uses finite element to compare several materials and uses SolidWorks to simulate static load and drop test by landing skid. The results show that PETG material is the best material with the highest safety factor in the static load and has the lowest strain value in the drop test.

Keywords— Finite Element Method; Landing Skid; Material; Unmanned Aerial Vehicles

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), better known as drones, have become an increasingly popular technology with a wide range of applications in various sectors, including military, mapping, surveillance, and delivery [1]. Hexacopter, which has six rotors, is one of the commonly used UAV types [2], [3]. The importance of sustainability and reliability of UAVs in operation has led to improved performance and durability of key components that comprise the UAVs, including the landing skid. The landing skid on a UAV serves as a component that supports the weight of the UAV when landing. In addition, it also protects the sensitive electronic components contained within the UAV. Therefore, the strength and reliability of the landing skid are important in ensuring the structural integrity of the UAV and preventing damage that can occur during the take-off and landing process [4], [5].

One factor that has a major influence on the strength of the landing skid is the selection of materials used in its construction. The right material must have sufficient strength to withstand the weight of the UAV and be resistant to deformation or damage that may occur due to the pressure exerted during landing [6]. In addition, the stiffness and toughness of the material should also be considered to deal with situations that may affect the landing skid, such as strong impact or vibration [7], [8]

There are three materials that were simulated in this study, including PLA (Polylactic Acid), PETG (Polyethylene Terephthalate Glycol-Modified), and ABS (Acrylonitrile Butadiene Styrene). Therefore, it is possible to print and shape them using the Fused Deposition Modeling (FDM) technology method for 3D-printing [9]–[12]. Other similarities are dimensional stability after printing, relative resistance to weather and UV light, and good biocompatibility [13]–[18]. Although there are similarities in the three materials, it is still important to know the characteristics and properties to select the best material from the simulation results.

PLA (Polylactic Acid) is one of the most popular and easiest-to-use 3D printing materials [19], [20]. It is made from natural polymers derived from plant sources such as corn or sweet potato starch, making it more environmentally friendly than other materials [21], [22]. PETG (Polyethylene Terephthalate Glycol-Modified) is a popular material for 3D printing as it offers a good mix of properties between PLA and ABS [23], [24]. It is resistant to high temperatures, moderate strong, and has better physical durability than PLA [25], [26]. ABS (Acrylonitrile Butadiene Styrene) is one of the commonly used plastic materials in the manufacturing industry and popular in 3D printing [27]. This material is resistant to impact, high degree of rigidity, lightweight, high durability [28], [29].

Regarding the previous simulations that have ever been done by other researchers, there was Yildirim [17] who aimed to analyze crash landing simulations of a rotary wing unmanned air vehicle with skid landing gear using both experimental and computational methods. Experimental drop tests recorded the impact loads, the stresses, the strains, and the deformations, while a numerical simulation was recorded with free falling and crash landing. Four skid landing gear specimens with different shapes were tested, evolving based on feedback. The fourth specimen, made of 6061 T6 aluminum alloy in a hollow semi-circle form, proved the best at absorbing impact energy and withstanding crashes.

In addition, there was Wibawa [30] who investigated the impact of material selection on the strength of UAV aircraft's main landing gear frame using finite element analysis. Different materials, including Aluminum 5052-H38, Aluminium 5083 87 Cold Formed, Aluminium 6061, and CFRP, were examined. The simulation considered an 85 kg UAV with a landing speed of 10 m/s and impact time of 0.5 seconds. The results ranked the frames by weight from the lightest to the heaviest: CFRP, Al 5083 87 Cold Formed, Al 5052-H38, and Al 6061. In term of safety factor, CFRP, Al 5083 87 Cold Formed, Al 6061, and Al 5052-H38 were found to be the most secure materials.

Next, there was Vashi [31] who focused on improving the performance of small Group 1 category UAVs by designing and analyzing lightweight 3D-printed wheels. The goal was to reduce weight by 50% using 3D-printing materials like ABS, PLA, Nylon, and Carbon fiber mix. The study followed an iterative design approach, considering wheel configurations with 4, 5, and 6 spokes. SolidWorks and Ansys software were used for modeling and Finite Element Analysis to assess static and dynamic strength, ignoring bending and torsion. A Charpy impact test was also performed to study crack propagation upon impact.

The finite element method, which is a numerical approach used to model structures and analyze their response to loads, has proven to be an effective tool in analyzing the strength and structural performance of various machine and vehicle components [32], [33]. Therefore, the use of the finite element method can provide a deeper insight into the structural response of the hexacopter landing skid and assist in the selection of optimal materials. In this context, this research was done under the aim of conducting an appropriate material selection analysis to improve the strength of the landing skid of a hexacopter using the finite element method with bending and drop test loads. By conducting this research, it is expected to find the most suitable material that can increase the strength and reliability of the hexacopter landing skid, and contribute to the development of more reliable UAVs.

II. Research Method

This research uses the finite element method with SolidWorks 2022 software to analyze the selection of appropriate materials to increase the strength of the landing skid on the hexacopter. This method is a numerical approach used to model structures and analyze their response to applied loads. The following are the steps that were carried out in this research. SolidWorks is a parametric-based CAD (Computer-Aided Design) software used to design products in three dimensions. Developed by Dassault Systèmes, it provides a wide range of features and tools to model, draw, and simulate objects or components in a virtual environment. With parametric modeling methods, designers can easily change the size, shape, and other detail of objects, and the changes will be automatically applied to the entire design. SolidWorks allows engineers and designers to comprehensively visualize and analyze products before they are physically manufactured, saving time and cost, and improving accuracy and efficiency in the design process [34], [35].

The finite element method is a numerical technique used to analyze and solve structural or physical problems by dividing the domain of an object or system into smaller elements that are easier to calculate [36], [37]. Each element has physical characteristics expressed in mathematical equations by connecting the elements, it can accurately model and simulate the structural response of the whole system [38], [39]. The finite element method allows analysis of changes in conditions, loads, or other parameters on the system [40], [41]. It helps understand and predict complex behavior under various conditions to optimize designs and solve engineering problems. Fig 1, is a UAV hexacopter with six propellers.

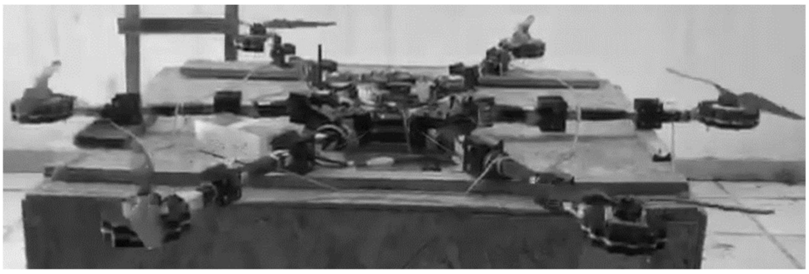


Fig 1. Hexacopter

Literature study, the initial stage of this research involved a comprehensive literature study on material selection for UAV landing skids and the finite element method. The literature study will includes sources, such as scientific journals, conferences, and related publications that address material selection and structural analysis on UAVs and their components.

Modeling the structure, once sufficient understanding of material selection and finite element method had been achieved, the next step was designing the landing skid structure using simulation software based on finite element method. The modeling included the landing skid geometry in precise detail, including dimensions and shape.

Material selection, this stage involved selecting the three materials to be analyzed, as previously described. The materials in this research simulation were PLA, PETG, and ABS which were used in the analysis. In Table. I, characteristics of PLA, PETG, and ABS materials from matweb.com are presented [42]–[44].

TABLE I. MATERIAL PROPERTIES (MATWEB.COM)

Material	Density (g/cc)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elastic Modulus (GPa)	Total Elongation (%)
PLA	1.30	41.9	59.5	2.34	76.2
PETG	1.27	51.4	44.8	3.03	123
ABS	1.07	44.8	40.7	2.35	28.7

Selection of constraints was used for fixed constraints at the foot end of the landing skid. Fig 2, is the location of fixed constraint of hexacopter landing skid.

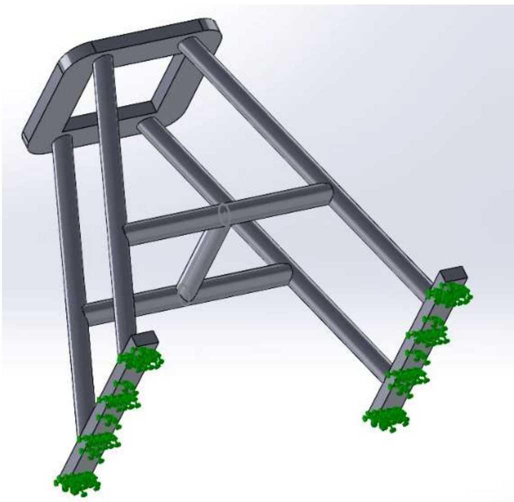


Fig 2. Location of fixed constraint of landing skid

The next step was doing the meshing process. The meshing process is a step in numerical simulation in which a geometric object is divided into small elements or vertices. Each element/node represents a discrete part of the object with geometric and physical properties. The goal is to convert continuous geometry into a mesh of discrete elements so that the simulation software can perform numerical analysis and approach accurate solutions to complex physical problems.

Load analysis, the next step was determining the loads that were applied to the landing skid in the analysis. These loads included static loads and drop tests. These loads were applied at points on the landing skid structure. Fig 3, is the location of the sloading point as the point of receiving the load.

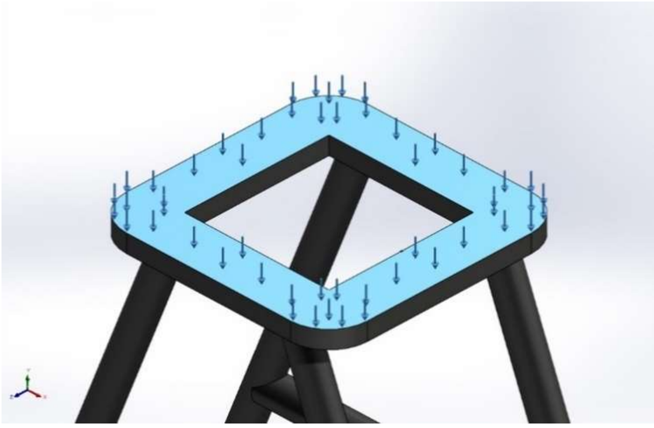


Fig 3. Location of loading point

Numerical analysis. In this stage, numerical analysis using the finite element method will be performed on each of the selected materials. The analysis included a simulation of the loading and structural response of the landing skid. Factors to be analyzed included stress, deformation, factor of safety, and overall structural performance.

Evaluation and comparison, after the numerical analysis was completed, the results were evaluated and compared. The analysis results enabled researchers to compare the performance of different materials in meeting the strength and reliability requirements of the landing skid. The material that provided the best results was be identified as the optimal material to improve the strength of hexacopter landing skid.

Conclusions and recommendations, the last step was drawing conclusions based on the results of the analysis and provide recommendations on the most suitable materials to be used in the hexacopter landing skid. Table II, represents the parameters for conducting test with simulation.

TABLE II. PARAMETERS FOR THE TEST

Material	PLA, PETG, dan ABS
UAV mass	15 kg
Jacobian point	16
Load	147 N
Minimum element size	0.193928 in
Maximum element size	0.581789 in
Mesh quality	High
Number of nodes	29217
Number of elements	16376
Gravitational force	9.81 m/s^2
Aspect ratio < 3	98.5 %

III. Result and Discussion

After the researcher did the simulation. The simulation has results with linear static analysis. Linear static analysis is an analysis method used to analyze the behavior of a structure or system when given a certain load, without considering significant deformation changes or material non-linearity. The purpose of analysis with the finite element method in this study was to estimate the structural response of an object by dividing the object domain into small elements and applying mathematical equations to each element to obtain a solution that is close to the exact solution. The safety factor is the ratio between the maximum load that a structure or component can handle to the real applied load. The von Mises stress is a measure of the pressure or stress resulting from the combination of normal and shear stresses at a point in the material. Deformation refers to the change in shape or shift of an object or component due to the application of a load. The drop test is a simulation used to analyze how an object will survive and behave when dropped or impacted. The purpose of a drop test here was to virtually test and verify the performance and reliability of a product prior to physical testing, saving time and money in the product development process.

The von Mises stress is a stress parameter in materials mechanics used to evaluate the stress level that can potentially cause failure in a material subjected to a combination of normal and shear stresses. The von Mises stress combines the normal and shear stress components at a point in the material by considering the interaction relationship between the two types of stress. This method is based on the assumption that material failure might occurs when the von Mises stress reached a specified critical value. The von Mises stress is often used in structural analysis to identify areas of possible failure and to estimate the material's resistance to mechanical loads.

Fig 4, Fig 5, and Fig 6 are the results of the Von Mises stress of the landing skid against the material with static load. The Von Mises stress value of the landing skid with PLA, PETG, and ABS materials has the same value of 2.56 MPa. The Von Mises stress is still below the yield strength of the PLA, PETG, and ABS materials, which are 4190 MPa, 4480 MPa, and 4070 MPa, respectively. The maximum Von Mises stress is located on the outer side of the four corners of the quadrilateral of the top mount section which indicates the most critical point of the landing skid.

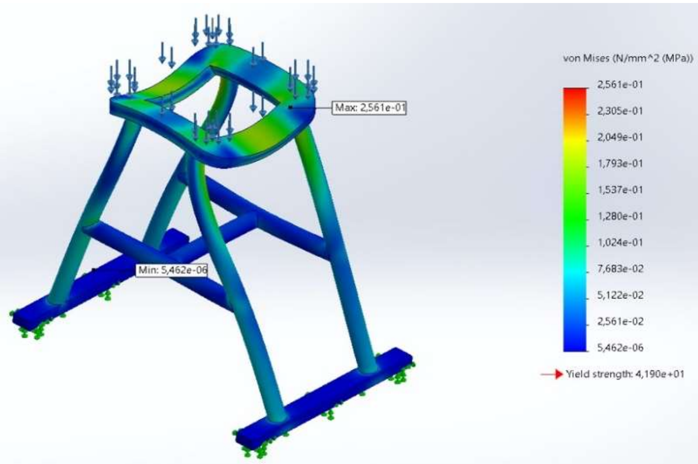


Fig 4. Von mises stress using PLA (left)

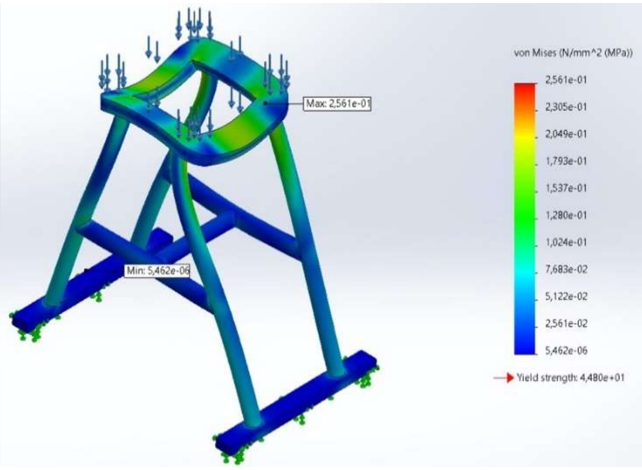


Fig 5. Von mises stress using PETG (right)

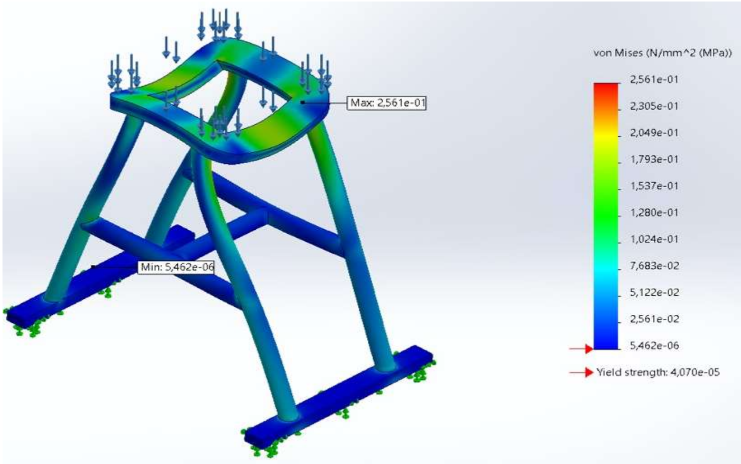
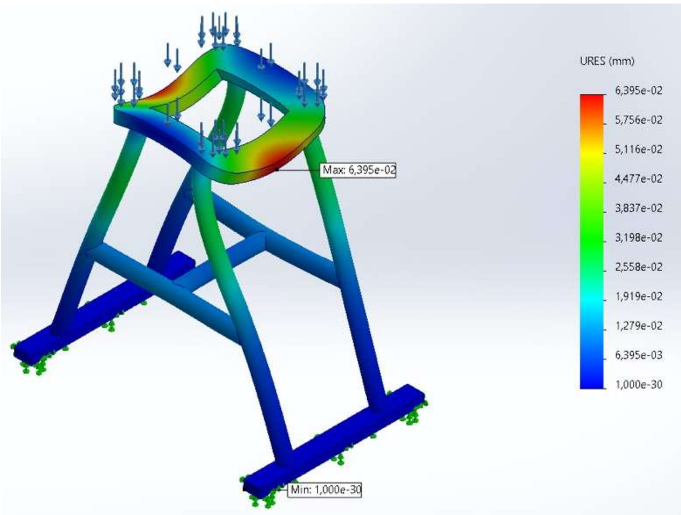


Fig 6. Von mises stress using ABS

Deformation is a change in the shape or dimensions of an object or material due to the application of an external force or load. In mechanics, deformation can occur as an elastic or plastic response of a material to an applied load. Elastic deformation is a temporary change in shape that can recover back to its original shape once the load is removed, while plastic deformation is a permanent change in shape that occurs when the elastic limit of the material is exceeded. Deformation is measured as the change in relative length, angle, or shape between points on the object. Deformation analysis is important in understanding the behavior of structures and materials and is often used in simulation and product design to ensure reliability and resistance to a given load.

Fig 7, Fig 8, and Fig 9, show the deformation values of the landing skid against the material variations. The displacemen values of the landing skid with PLA, PETG, and ABS materials are 6.4 mm, 4.9 mm, and 6.4 mm, respectively. The maximum displacement is located on the left and right outer sides of the top mount.



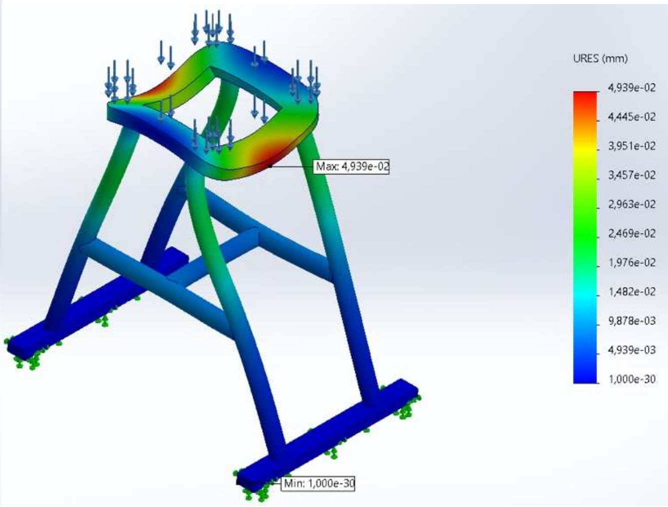


Fig 7. Deformation using PLA (left)

Fig 8. Deformation using PETG (right)

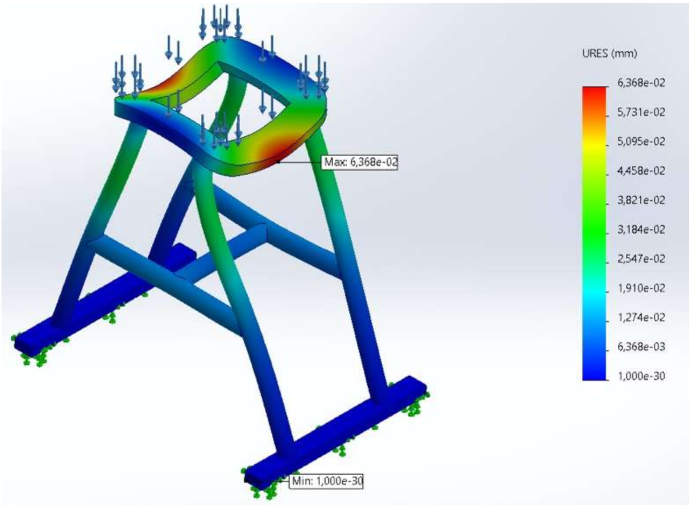


Fig 9. Deformation using ABS

The safety factor is the ratio between the maximum capacity of a structure or component to the load that is actually applied. In structural mechanics, the safety factor is used to assess the extent to which a structure is able to withstand external loads and forces without failure or damage. The greater the value of the factor of safety, the greater the margin of strength and resistance of the structure to the loads received. The factor of safety is very important in structural design and engineering, as it ensures that the structure has sufficient strength to safely withstand loads and meet safety requirements and applicable technical standards.

Fig 10, Fig 11, and Fig 12 show the safety factor values of the landing skid against the material variations. The minimum safety factor values of the landing skid with PLA, PETG, and ABS materials are 7.6, 8.2, 7.4, respectively. The smallest safety factor value is located on the outer side of the four corners of the quadrilateral of the top mount section, indicating the most critical point of the landing skid.

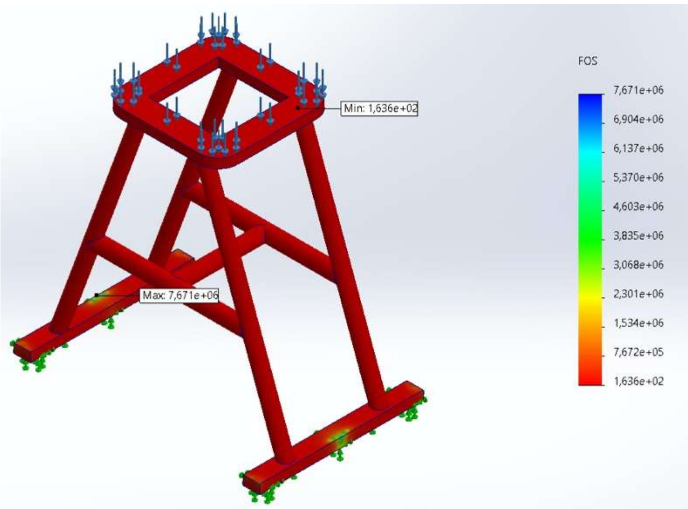


Fig 10. Safety factor using PLA

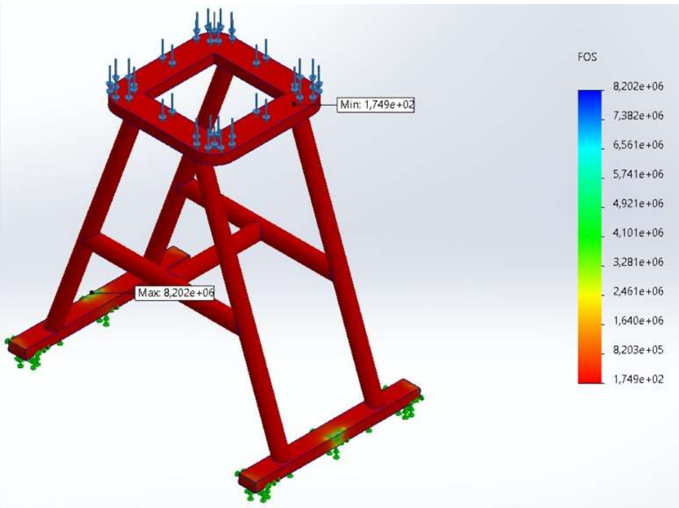


Fig 11. Safety factor using PETG

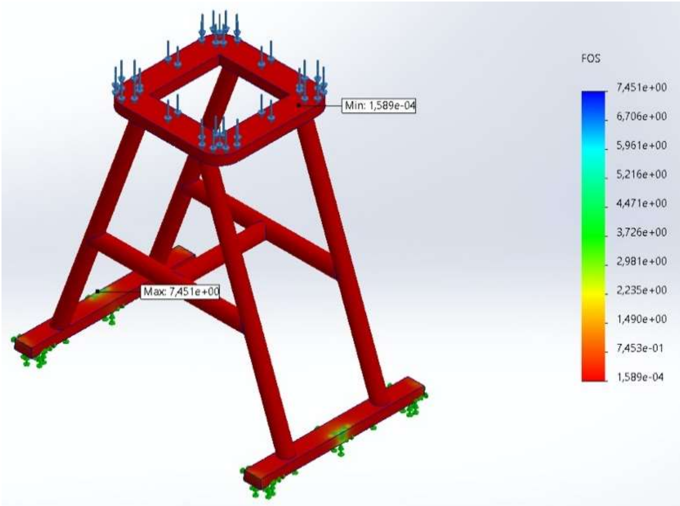
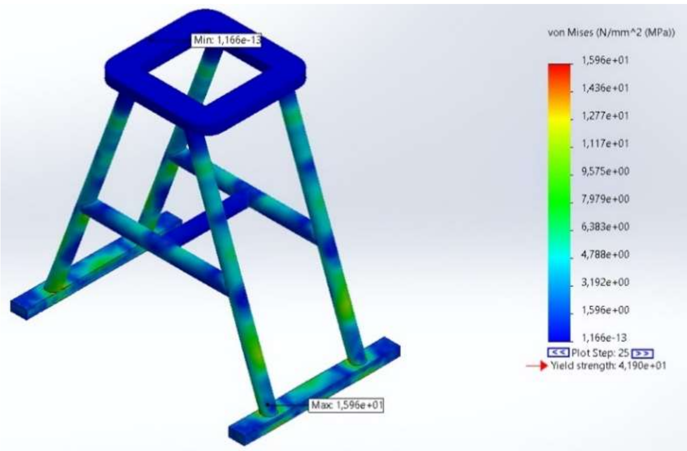


Fig 12. Safety factor using ABS

The drop test simulation is a numerical simulation method used to model and analyze the behavior of a product or object when subjected to a fall or impact. In this simulation, a geometric model of the object was fed into software that broke it down into discrete elements and applied physical equations to predict its structural response. This process, in fact, helps to understand how the object will survive and behave upon impact, thus enabling the evaluation of reliability and impact resistance without the need to conduct expensive and complicated physical tests. This method is important in the design and engineering industry to improve product quality and identify areas that require improvement in design to reduce the risk of damage or failure to the product. The drop test was performed from a height of 500 mm in this simulation.

Fig 13, Fig 14, and Fig 15 show the drop test values of the landing skid against the material variations. The von mises stress values of the landing skid drop test with PLA, PETG, and ABS materials are 1.6 MPa, 1.2 MPa, and 1.6 MPa, respectively. The smallest drop test value is located at the lower structural end of the landing skid main leg.



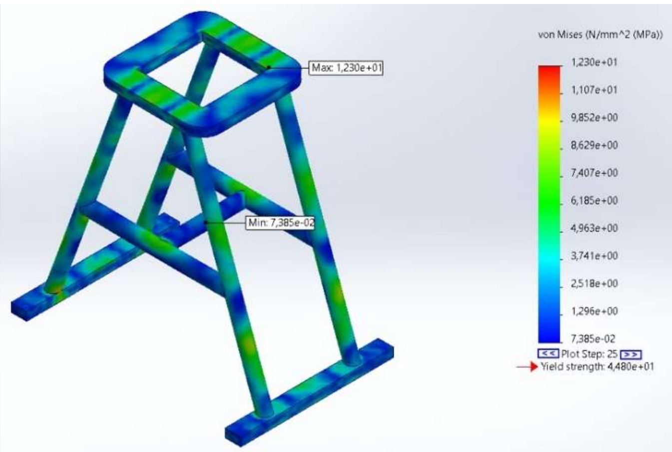


Fig 13. Von Mises stress result of PLA in drop test (left) Fig 14. Von Mises stress result of PETG in drop test (right)

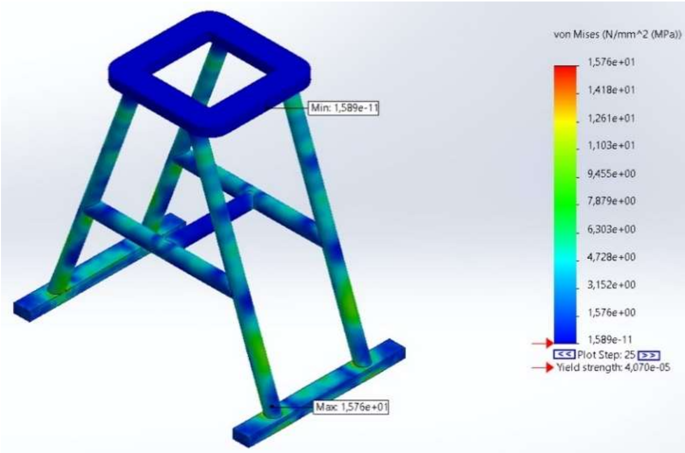
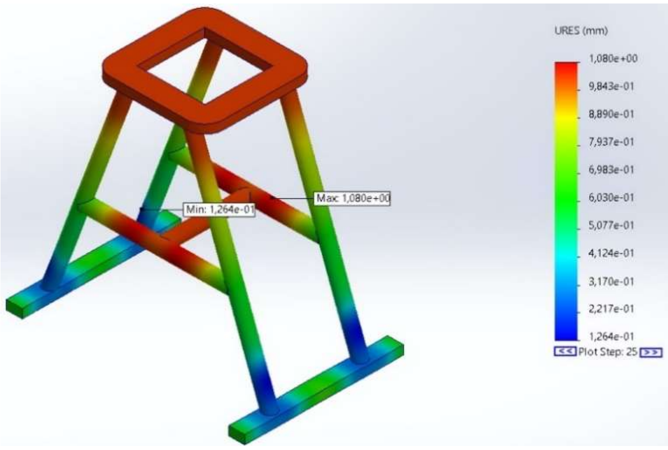


Fig 15. Von Mises stress result of ABS in drop test

Fig 16, Fig 17, and Fig 18 show the deformation values of the landing skid with various materials from the drop test. The displacement values of the landing skid with PLA, PETG, and ABS materials are 1.1 mm, 1.2 mm, and 1.1 mm, respectively. The maximum displacement is located at the connecting part of the two landing skid legs.



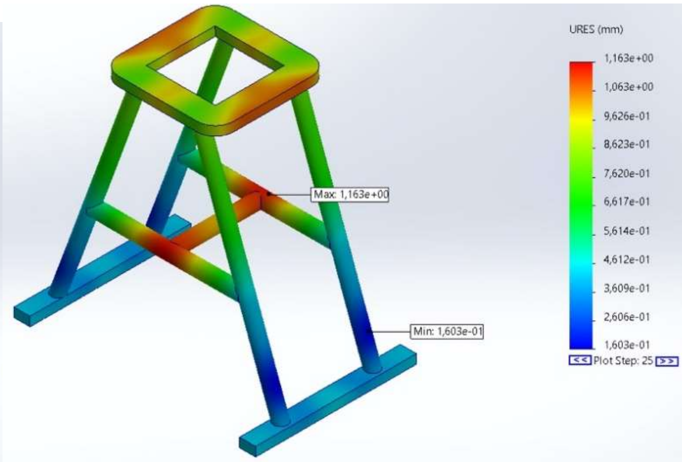


Fig 16. Displacement result of PLA in drop test (left) Fig 17. Displacement result of PETG in drop test (right)

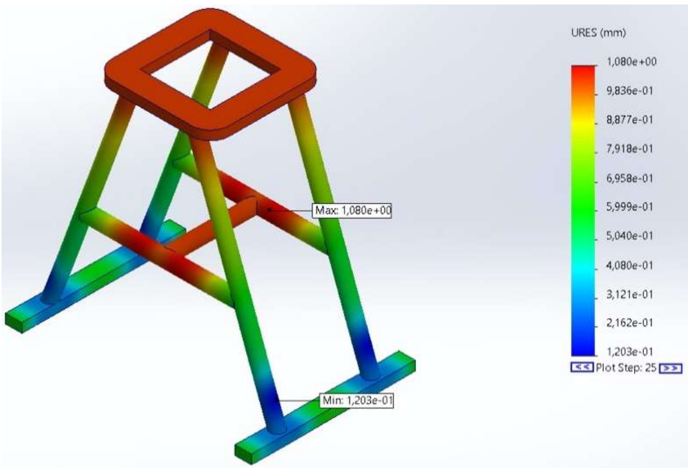
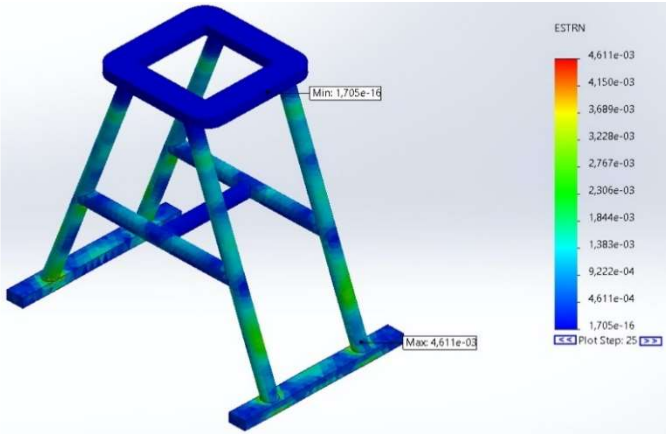


Fig 18. Displacement result of ABS in drop test

Fig 19, Fig 20, and Fig 21 show the equivalent strain values of the landing skid with various materials from the drop test. The equivalent strain values of the landing skid with PLA, PETG, and ABS materials are 4.6, 2.4, and 4, respectively. The maximum equivalent strain is located at the lower structural end of the landing skid main leg.



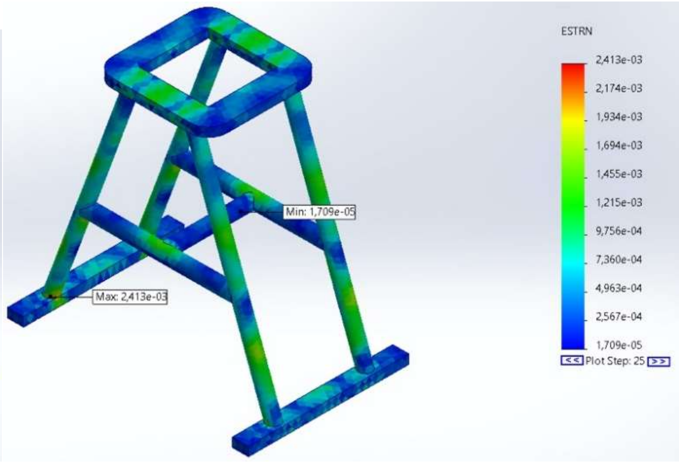


Fig 19. Equivalent stress result of PLA in drop test (left) Fig 20. Equivalent stress result of PETG in drop test (right)

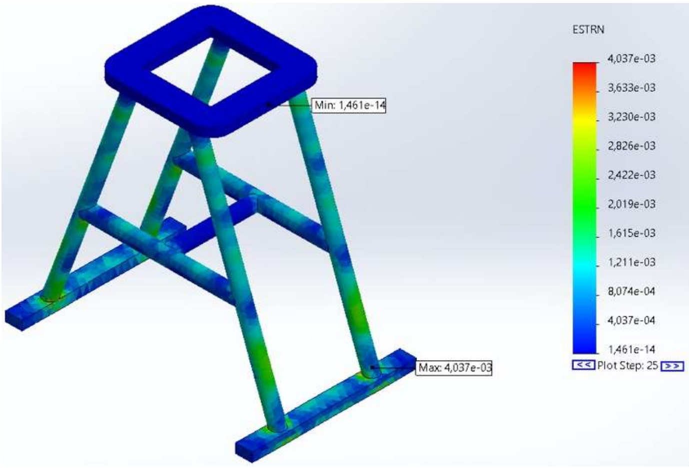


Fig 21. Equivalent stress result of ABS in drop test

Simulations that were performed on PLA, PETG, and ABS materials obtained from static loading can be seen in Fig 22, and it shows the results of von Mises Stress, displacement, and safety factor. The von Mises Stress and displacement values are the same for all three materials. The safety factors obtained by PLA, PETG, and ABS are 7.6, 8.2, and 7.4, respectively. Fig 23, shows the results of the drop test simulation with the von Mises Stress values of PLA, PETG, and ABS of 1.6, 1.2, and 1.6. The displacement values are 1.1, 1.2, and 1.1. The stain values are 4.6, 2.4, and 3.

From this study, it can be observed that PETG material is the best as it has the highest safety factor in the static load and has the lowest strain value in the drop test. It can be seen that the least damage from the simulations used on the landing skid is with PETG material thus supporting the credibility of the landing skid.

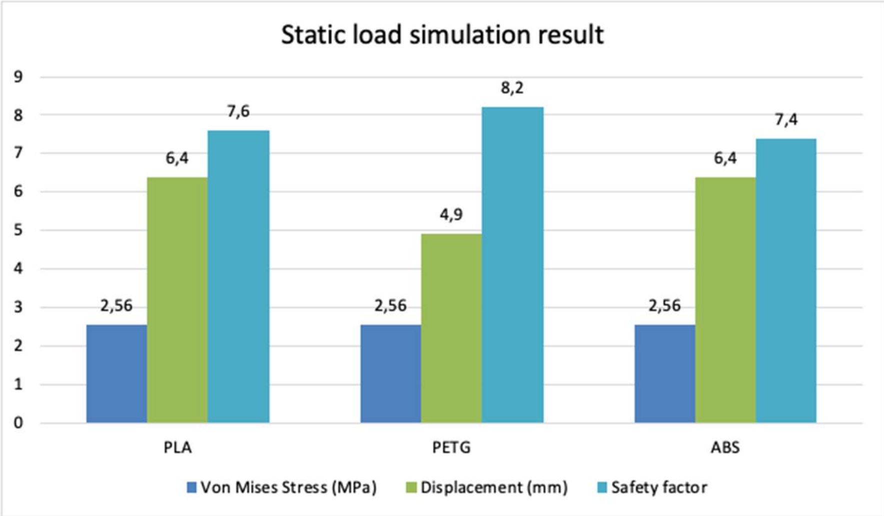


Fig 22. Static load simulation result

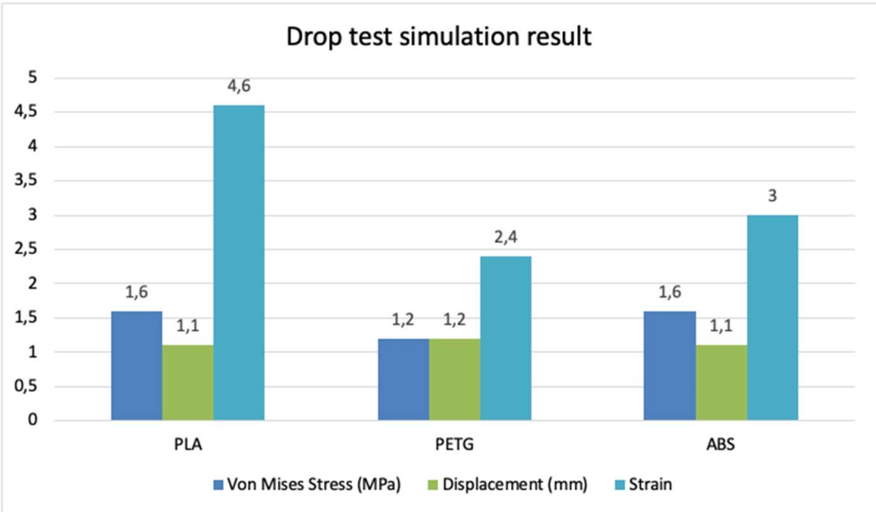


Fig 23. Drop test simulation result

IV. CONCLUSION

Recently, UAVs are widely used and continue to increase their use in various fields. Hexacopter is one of the most widely used UAV types. The most important part of the UAV is the landing skid as a place to rest and to support the UAV to be able to land on the ground. This research aims to explore and try various materials in hexacopter landing skid design. The materials for 3D printing used are PLA, PETG, and ABS because these materials are commonly used. CAD structural modeling was done using SolidWorks to analyze and simulate the landing skid design under static load and drop test. The analysis includes von Mises Stress, deformation, and strain. The static load simulation analysis results show that the largest safety factor and smallest displacement is PETG. The results of the drop test obtaining the lowest strain is PETG. This shows that the best material in the landing skid simulation is PETG, which indicates the reliability of the landing skid design.

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