

Analysis of Stress, Displacement, and Strain in a UAV Launcher Structure Using the Finite Element Method

Daffa Faris Azmi*, Muhammad Farisan Zhafiri, Dandun Mahesa Prabowoputra

Departement Of Mechanical Engineering, Universitas Jenderal Soedirman, Purbalingga, Indonesia

*Corresponding author: dandun.mahesa@unsoed.ac.id

Abstract. This study aims to thoroughly analyze the behavior of structures in Unmanned Aerial Vehicle (UAV) launcher designs through 3D modeling and using static simulation methods to observe structural behavior when subjected to loading. The launcher model was designed in detail using Computer-Aided Design (CAD) software and evaluated using static simulation features to determine the stress distribution, displacement, strain, and safety factor of the launcher model. The simulation was carried out by applying a load of 1000 N to the rear foot area of the launcher, with a fixed geometry setting on the front and rear feet as boundary conditions. The initial stage of the research included a mesh study using variations in size from 10 mm to 14 mm to obtain optimal computational accuracy. The test results showed a constant stress value of 0.100 MPa in all variations. Therefore, a 14 mm mesh with 5,409 elements was selected for the main simulation because it was the most representative and efficient. Further simulations compared three material variations: Aluminum Alloys (1060 alloy), Alloy Steel, and AISI 321 Annealed Stainless Steel. The results show uniform stress (0.088 MPa) and strain (0.000) values for all three materials. However, the aluminum material produced the highest displacement of 0.008 mm, compared to Alloy Steel (0.002 mm) and AISI 321 (0.003 mm). The safety factor values for aluminum were 333.100, alloy steel 7,485.643, and AISI 321 2,827.741. In conclusion, even though aluminum experienced the greatest displacement, this material is still considered very safe and suitable for use because the safety factor value is well above one.

Keywords: UAV Launcher, CAD, CAE, Material

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1. Introduction

Indonesia, as the world's largest archipelago, faces complex geographical challenges, including a vast territory, limited access to remote areas, and diverse topographical conditions. According to data from the Central Statistics Agency (BPS), Indonesia has more than 74,000 villages spread across a land area of approximately 1.9 million km². Some of these areas are still classified as underdeveloped regions with limited infrastructure and transportation access. Furthermore, not all villages have adequate road access; in fact, some areas can only be reached by air or water. These conditions highlight significant geographical and accessibility challenges, necessitating technological solutions capable of efficiently reaching remote areas, such as the use of UAVs.

UAVs, commonly known as drones, are aircraft that operate without an onboard human pilot (Mendu & Mbuli, 2025). A UAV (Unmanned Aerial Vehicle) is an unmanned aircraft controlled remotely or automatically using a computer system, and is used for various purposes such as monitoring, mapping, and military operations. According to (Laghari et al., 2023) UAVs' military applications are specific for different operations, which provide intelligence about combat. It is used the concept of a swarm of UAVs to collect information about military operations. In Indonesia, UAV technology

development is also driven by competitions such as the Indonesian Flying Robot Contest (KRTI), which serves as a platform for students to design, build, and test UAV performance in various specific missions. In the Indonesian Flying Robot Contest (KRTI), the use of a launcher is a critical aspect in supporting UAV operations, as it functions as a system enabling the launch process to occur efficiently and stably, particularly in areas with limited space. The UAV launcher is a system designed to assist the takeoff process by providing initial thrust, allowing the aircraft to reach minimum flight speed without requiring a long runway. This system is particularly important for fixed-wing UAVs that lack vertical takeoff capability. With a launcher, UAVs can be operated in confined areas or hard-to-reach terrain, such as remote regions or areas lacking runway infrastructure. Additionally, the use of a launcher enhances consistency and safety during launch, ensuring more reliable UAV performance across various operational conditions.

The use of a launcher allows UAVs to be operated flexibly in restricted areas, such as remote regions, areas with minimal infrastructure, or terrain conditions that do not permit conventional runways. One application of the launcher can also be found in competitive settings such as the Indonesian Flying Robot Contest (KRTI), where this system is used to facilitate the optimal launch of UAVs within confined spaces. In addition to enhancing operational flexibility, the launcher also plays a role in maintaining the UAV's initial consistency and stability during takeoff. However, during the launch process, the launcher's structure experiences high mechanical loads that are dynamic in nature over a short period. These conditions can result in complex distributions of stress, strain, and displacement, which have the potential to cause deformation, material fatigue, and even structural failure if not properly designed. Therefore, a thorough structural analysis is required to ensure that the launcher system can operate safely, reliably, and efficiently in supporting UAV operations. To carry out this comprehensive structural analysis, Computer-Aided Engineering (CAE) and Finite Element Analysis (FEA) approaches can be applied. CAE technology enables engineers to virtually design, analyze, and simulate product loads before entering the physical production stage, allowing potential issues and design flaws to be detected and promptly addressed (Hasan et al., n.d.). This simulation method has proven to be crucial and effective in evaluating stress distribution and structural reliability to prevent excessive deformation, as demonstrated in the design analysis of park benches (Ridho et al., n.d.) and living room tables (Hasan et al., 2023). Furthermore, the use of the finite element method (FEA) is highly beneficial for calculating the Safety Factor (Factor of Safety) to ensure the structure can withstand loads without experiencing permanent deformation, as well as facilitating the selection of materials with a superior strength-to-weight ratio (Akhmad Yani Putri Syamara et al., 2026). Through the adaptation of this computational simulation method, evaluations of stress, strain, and displacement in the UAV launcher structure can be accurately predicted, allowing the launch system to be designed as optimally and safely as possible to withstand high dynamic loads.

2. Method

This study employs a numerical approach based on the Finite Element Method (FEM) to analyze the structural response of a UAV launcher to launch loads. The research process begins with the development of a three-dimensional geometric model of the launcher structure based on the design specifications used. The model is then discretized through a meshing process into elements, with element sizes and types adjusted to accurately represent the structural behavior. Next, material properties were defined based on key mechanical parameters such as the modulus of elasticity, Poisson's ratio, density, and yield strength. Following this, boundary conditions were applied to simulate structural constraints or supports, and loads were applied to represent the forces acting during the UAV launch process, including thrust and relevant mechanical interactions. The analysis was performed using FEM-based software to obtain the distribution of structural responses across all parts of the launcher. The parameters observed in this study include the distribution of stress, strain, and displacement as key indicators for evaluating structural performance and integrity. All stages

were carried out systematically to ensure that the developed model adequately represents actual conditions and can be reproduced in similar studies.

The design thinking approach in this study was used to develop a functional and efficient UAV launcher design based on operational requirements. The first stage, empathize, involved understanding the needs for UAV deployment, particularly under operational conditions with limited runway space, necessitating a launch system that is simple, portable, and capable of providing sufficient initial thrust. The second stage, define, focused on formulating the main problem: how to design a launcher structure that is lightweight yet possesses sufficient strength and stiffness to withstand the launch load without excessive deformation. Next, in the ideate stage, various design concepts were developed that led to the use of a pipe-based frame structure with a simple configuration to maximize material efficiency and ease of manufacturing.

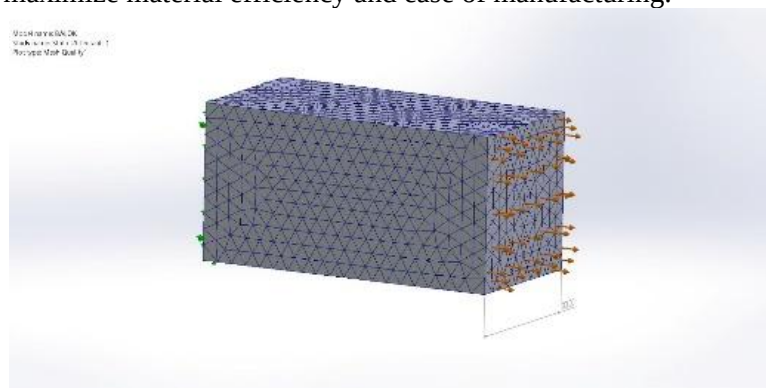


Figure 1. Benchmarking Mesh

To ensure the accuracy of the simulation results, a mesh validation process was conducted using a mesh study approach with a simple benchmarking method to examine variations in element size. The test was performed using several mesh size variations, ranging from 10 mm to 14 mm, to observe their effect on the resulting stress values. Based on the results obtained, the stress values showed consistency across all mesh variations with a relatively small error margin of approximately 1%, indicating that the model had reached a converged state. Therefore, a mesh size of 14 mm was selected for the main simulation to balance computational efficiency without compromising the accuracy of the results. This approach ensures that the model discretization used is capable of adequately representing structural behavior in the analysis using the finite element method (FEM).

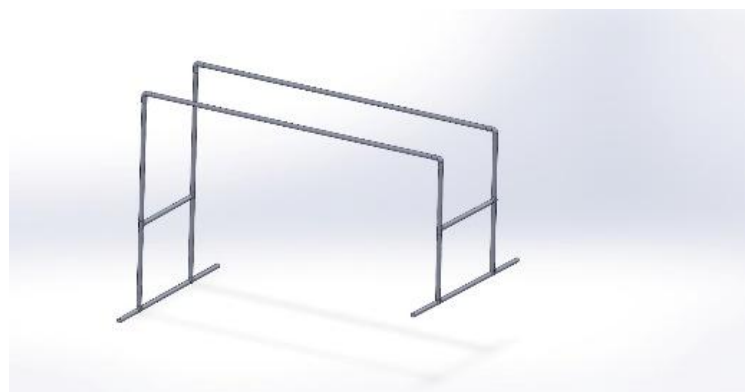


Figure 2. Model Geometry

The UAV launcher's geometry is designed as a simple frame structure consisting of several main components: the front legs, the rear legs, and the ramp serving as the launch track. The front legs are 1.2 m tall and function as the primary supports while providing initial elevation to the launcher

system, whereas the rear legs are 0.8 m tall and play a role in maintaining the overall stability of the structure. The height difference between the front and rear legs creates a 2-meter-long slope on the ramp, allowing the UAV to achieve an optimal launch angle. Additionally, the structure’s width is determined by the leg configuration, with a total width of 1.1 meters. These dimensions are designed to balance structural stability and material efficiency, ensuring the launcher operates effectively under the specified load conditions.

3. Results and Discussion

Based on the methodological steps that have been carried out, a structural analysis of the UAV launcher was performed using the finite element method (FEM) to evaluate the structure’s response to the applied loads. Prior to the numerical analysis phase, the design process was conducted using a design thinking approach, which included a prototyping phase involving three-dimensional design modeling, as well as a testing phase represented by numerical simulations to virtually test the structure’s performance. This simulation aims to obtain the distribution of key parameters, namely stress, strain, and displacement, across all parts of the launcher structure.

Table 1. Result.

Material	Stress	Displacement	Strain
Aluminum Alloy 1060	0,088	0,008	0,000
Alloy Steel	0,088	0,002	0,000
AISI 321	0,088	0,003	0,000

Table 2. Safety Of Factor.

Material	Safety of Factor
Alumunium Alloy 1060	333,100
Alloy Steel	7.485,643
AISI 321	2.827,741

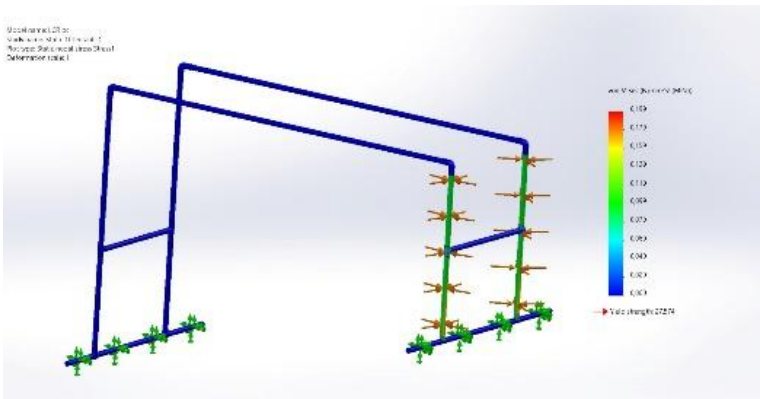


Figure 3. Stress of Materials

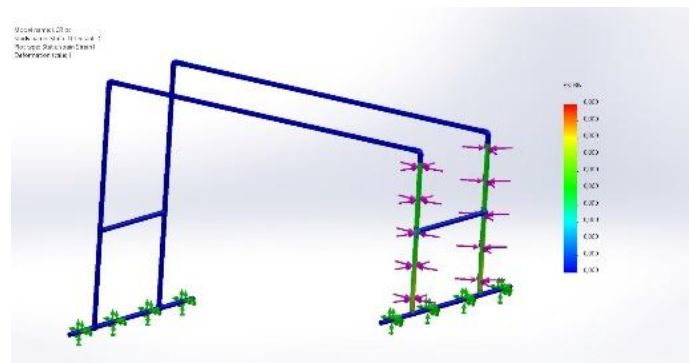


Figure 4. Strain of Materials

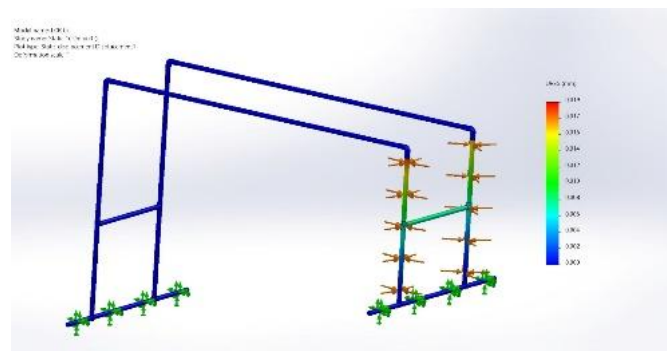


Figure 5. Displacement

Furthermore, the simulation results show the distribution of structural parameters—namely stress, displacement, and strain—in the UAV launcher structure under a load of 1000 N. The maximum stress values obtained were relatively similar for all three material variations, at approximately 0.088, indicating that the load distribution in the structure is not significantly influenced by the material type but is instead determined by the geometry and loading conditions. However, the material differences have a significant impact on the displacement values. The aluminum alloy (1060 alloy) exhibited the largest displacement value of 0.008, compared to 0.002 for alloy steel and 0.003 for AISI 321 stainless steel. This indicates that materials with a lower Young's modulus tend to undergo greater deformation.

In terms of strain, the values obtained are relatively very small and approach zero for all material variations, indicating that the deformation occurring remains within the elastic limit. Further evaluation was conducted through a factor of safety analysis, where all materials showed values above one, so they are generally still considered safe for use. Aluminum has a safety factor of 333.100, while alloy steel and AISI 321 stainless steel have significantly higher values, namely 7485.643 and 2827.741, respectively. These values indicate that although aluminum undergoes greater deformation, the material still meets safety criteria under the given loading conditions.

Overall, the analysis results show that material selection affects the structural deformation response but does not significantly affect stress distribution. Therefore, in the design of a UAV launcher, a balance between material strength and the allowable deformation level must be considered to achieve an optimal and efficient design.

4. Conclusion

Based on the results of the structural analysis using the finite element method (FEM), it can be concluded that the UAV launcher design under study demonstrates good performance in withstanding the applied loads. The results of the mesh study show that variations in mesh size from 10 mm to 14 mm produce relatively constant stress values with a low error rate, so it can be said that the model has reached a convergent state and is suitable for further analysis. In the main simulation stage with a load of 1000 N, it was found that the stress distribution in the structure was not significantly influenced by material variations but was more influenced by the geometry and applied loading conditions. However, the type of material exerts a significant influence on displacement values, with aluminum exhibiting the greatest deformation compared to alloy steel and AISI 321 stainless steel. Nevertheless, all tested materials remain within safe limits based on a safety factor greater than one; thus, in general, all three materials are suitable for use in UAV launcher applications under similar loading conditions. These results indicate that, in addition to considering material strength, the aspect of deformation is also a critical factor in the design process to ensure the stability and performance of the launch system. Therefore, the application of the FEM method in this study has proven effective in evaluating structural response and provides a strong foundation for making more optimal, safe, and efficient design decisions.

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