Indonesian Journal of Contemporary Multidisciplinary Research (MODERN)
Vol. 5, No. 6, 2026: 949-968

Redesign Grappling Hook Guns

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A R T I C L E I N F O

Keywords: Ascender Electric, Body Harness, Chamber Laras, Grappling Hook Guns, Projectile

Received : 15 September
Revised : 20 October
Accepted: 05 November

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A B S T R A C T

This study redesigns a Grappling Hook Guns system by integrating improvements to the projectile, pneumatic chamber-barrel, electric ascender, and body harness to enhance structural capacity and operational performance. The research combines literature review, field observation, engineering calculations, SolidWorks-based structural analysis, prototype development, and experimental testing. The redesigned chamber-barrel uses Aluminum 6061-T6 and operates at an effective working pressure of 17.01 MPa, producing a projectile velocity of 19.8 m/s and reaching an operational height of approximately 15 m. The projectile load capacity increased from 150 kg to 200 kg without permanent deformation. The modified electric ascender, incorporating pulley and transmission improvements, lifted loads up to 110 kg while improving rope movement stability. The redesigned body harness showed a safety factor of 9.2 under a 100 kg load. These results indicate that the integrated redesign improves the mechanical performance, load-bearing capability, and functional reliability of the Grappling Hook Guns system for personnel

INTRODUCTION

The Indonesian Military specifically the tactical assault unit command is an elite unit tasked with carrying out special operations in maritime, coastal and high-risk areas. In carrying out these tasks tactical assault unit personnel are required to have high vertical mobility and tactical climbing capability are important requirements in special operations conducted in difficult-to-access environments (Wood & Swain, 2021). To support successful operations, safe, strong, lightweight equipment is required, capable of operating optimally in a variety of environmental conditions.

One of the tools used to support vertical mobility is the Grappling Hook Guns, a hook launcher that utilizes a pneumatic system to launch projectiles toward the target point so that it can be used as a climbing medium or to pull loads (Jin et al., 2023; Mungan & Lipscombe, 2022). This system consists of several main components such as the chamber, barrel, projectile, rope, ascender and body harness that work in an integrated manner. The success of using Grappling Hook Guns is not only determined by the ability to launch projectiles but also by the ability of the entire system to safely support the personnel's load during the climbing process (Galy et al., 2023).

Based on previous research several limitations remain in the design of grappling hook guns. The chamber and barrel mechanisms lack optimal energy efficiency, limiting the range of the projectile (Lee et al., 2024). Furthermore, the projectile structure, which uses conventional materials, has a relatively low load capacity and is prone to deformation under high loads. The pulley configuration used in electric ascender systems is not yet capable of achieving optimal rope stability when used to lift personnel (Lee et al., 2023). Another critical issue is the lack of a comprehensive analysis of the capabilities of the body harness, the primary safety component that receives direct tensile loads from personnel during the climbing process (Galy et al., 2023; Kumar et al., 2026).

This research conducted a redesign of grappling hook guns by integrating development results on the chamber and barrel, projectile, electric ascender, and analysis of the maximum tensile strength of the body harness. The approach used included software design, engineering mechanics calculations, and testing to obtain a design with a higher level of safety, strength, and effectiveness. The research results are expected to produce a grappling hook gun system that more reliable in supporting the vertical mobility of tactical assault unit personnel and providing data technical aspects regarding the maximum tensile capacity of the body harness as a basis for improving operational safety in the field. Based on these data, there are several research problem formulations, including:

- How to optimize the geometry and material selection of the projectile so that it can withstand static loads of up to 200 kg without experiencing permanent deformation?
- How to determine the pressure required to launch a projectile hook on the barrel and chamber?

- How to design a pulley system configuration that can increase the stability of the rope movement on the electric grappling hook ascender?
- What are the tensile strength characteristics of the selected harness sheath material to ensure the user's strength when receiving dynamic loads?

LITERATURE REVIEW

A grappling hook is a device that utilizes a hook and a tether to secure an anchor point in a hard-to-reach location. Its performance is influenced by launch characteristics, projectile mass, and the tether that remains connected while the projectile is in motion. Mungan & Lipscombe (2022) demonstrated that the presence of a flexible tether affects the launch dynamics of a grappling hook. In pneumatic launchers, the air pressure within the chamber is a key parameter determining projectile velocity. Hartawan et al. (2023) experimentally demonstrated an increase in projectile velocity corresponding to higher chamber pressure, while Jin et al. (2023) showed that pressure, reservoir volume, and airflow channel configuration influence muzzle velocity and launch efficiency. Therefore, the chamber, barrel, and projectile must be designed as an interconnected system.

Upon reaching its target, the projectile functions as a structural element that must withstand tensile loads without failure. A numerical analysis of the hook structure by Cahyadi et al. (2024) indicates that geometry, material, and loading conditions influence stress distribution and the factor of safety. Consequently, the grappling hook projectile requires a balance between the mass necessary for effective launching and the structural strength needed to bear loads. The use of titanium can meet these requirements, as titanium alloys offer low relative density, high specific strength, and excellent corrosion resistance, including in marine environments (Li et al., 2024).

For electric ascenders, load-lifting capability is determined not only by motor power but also by the effectiveness of the transmission system and the interaction between the rope and the pulley. Herdiana & Maulani (2023) identified slip as a key parameter affecting the performance of pulley-based transmission systems. More specifically, in rope-based systems, rope deformation, stress distribution, and friction at the traction sheave can influence slip and the stability of load movement (Lee et al., 2023). Therefore, pulley and groove configurations must be designed to ensure adequate contact with the rope while avoiding binding or slipping during the lifting process.

A body harness serves as the component that transfers the load of a lifting system to the user; consequently, safety is a critical aspect of its design. Herdiana & Maulani (2023) highlight the importance of using a full-body harness as a protection system for work at heights. Regarding structural aspects, Kumar et al. (2026) explain that webbing is the primary load-bearing element of a full-body harness, with its performance influenced by tensile strength, dynamic elongation, energy absorption capacity, and durability. Thus, evaluating a body harness requires considering not only its static load-bearing capacity but also material properties and load distribution within the harness system.

Based on the literature, research concerning pneumatic launchers, hook structures, pulley-rope systems, and full-body harnesses generally evaluates each subsystem in isolation. In Grappling Hook Guns, however, these components function as an integrated unit, meaning that a change to one component can affect the performance of others. Consequently, this study integrates the redesign of the chamber-barrel, projectile, electric ascender, and body harness to enhance launching capabilities, structural capacity, lifting stability, and operational safety.

METHODOLOGY

This research uses a research and development method with an experimental approach and quantitative analysis that integrates four main aspects of grappling hook gun redesign chamber and barrel mechanism redesign, electric ascender system redesign, projectile structural strength analysis, sheath harness tensile strength analysis and overall system performance evaluation. The research method is carried out through the stages of design, simulation, manufacturing, testing and analysis of results.

The first stage begins with identifying tactical assault unit operational needs through field observations, interviews with user personnel and literature studies from journals, books and technical documents related to the grappling hook gun system. The data obtained is used as a basis for determining technical specifications and issues that need to be improved in the previous design. The second stage is the design and modeling of the design using solidworks software. The redesign focused on the chamber and barrel using Aluminum 6061-T6 material, the projectile using titanium material, the electric ascender system with optimized pulleys and drive mechanisms, and nylon 6 material for the sheath harness rope. The created model was then analyzed using the factor of safety method in solidworks software to determine the stress distribution, deformation and safety factor.

The third stage consists of theoretical calculations involving fluid mechanics to determine working pressure, material mechanics to calculate stress and deformation and analysis of motor power requirements and battery capacity in the electric ascender system. The fourth stage is the creation of a prototype based on the design results that have been validated through simulations. Next experimental testing is carried out in the form of chamber and barrel pressure testing, projectile strength testing against loads up to 200 kg, testing the electric ascender's ability to lift loads, testing the harness rope strength capability and testing launch performance at various firing angles.

The final stage is data processing and analysis by comparing the results of theoretical calculations, simulations and actual testing to determine the success rate of the redesign based on structural strength parameters, safety factors, load capacity, system efficiency and operational performance of the Grappling Hook Guns. The analysis results are used as a basis for evaluating and refining the design to obtain a safer, lighter and more effective system to support tactical assault unit operations.

RESEARCH RESULT

This research is an integration of four studies focused on the development of Grappling Hook Guns to support the operational tasks of the Tactical assault unit Command. Redesigns were carried out on the chamber and barrel components, electric ascender system, grappling hook projectile, body harness and optimization of the overall performance of the device. The main objectives of the development were to improve operational capability, load capacity, safety and effectiveness of use in the field.

Design of Hook Projectile

The design is carried out by referring to theoretical concepts and relevant references so that the resulting design has a strong scientific basis. This approach aims to simplify the process of manufacturing, testing and analyzing the entire system. Through this design method each component of the tool can be explained in detail and systematically. The design of the grappling hook gun projectile must consider factors such as safety, work efficiency and ease of application. In general, a grappling hook gun is composed of several main components, each with a specific function. These components include a launch system, a hook and a trigger mechanism, which work in an integrated manner to produce the device's performance in accordance with its design objectives. The interaction between these components determines the effectiveness and results of the device's use as summarized in this table.

Table 1. Grappling Hook Guns Components

No	Component	Function
1	Projectile/Anchor hook	Functions to grip or hook at the target point
2	Rope	Used as a supporting medium to assist user movement or climbing
3	Chamber (barrel, piston rod)	Acts as a channel for transferring energy from the piston to the barrel
4	Trigger	Regulate and control the air flow directed into the barrel
5	Air tube	Functions as a container for storing pressurized air to launch projectiles

Source: Tactical assault unit, 2026

Based on the grappling hook gun used the design focused on the projectile to simplify the manufacturing process and achieve more accurate dimensions and shapes. Therefore a thorough planning and design phase was required utilizing solidworks software as a modeling tool. The application's use aimed to produce a precise grappling hook gun projectile design that met the planned specifications. The visual results of the projectile design can be seen in this image.



Figure 1. Grappling Hook Gun Projectile Design
Source: Author's work, 2026

In the process of planning and designing the design drawings for a grappling hook gun projectile, the main stages include identifying and analyzing each component and its operational function. This process aims to provide a more detailed picture of the projectile's structure, so that the designer can understand the relationships and interactions between the components as a whole. One of the main components that is the focus of identification is the projectile itself, including the trigger system that plays a role in the grappling hook release process. The initial design stage is carried out by compiling a detailed table containing each component and its working function. In this table, the projectile is explained in depth, including its geometric shape, the type of material used and the principle of its working mechanism. In addition, the operational function of each component is also described in detail. For example the trigger mechanism is explained based on how it interacts with the ejection system to initiate the projectile's release. The analysis covers various technical aspects, such as how the load-bearing system and the projectile's release mechanism operate accurately.

This approach not only provides an understanding of the physical structure of the grappling hook gun projectile but also deepens the understanding of the function of each component. This allows designers to make informed decisions regarding material selection, dimensioning, and the necessary tolerances to ensure optimal performance and safety. Through this method, the design of the grappling hook gun projectile can be carried out more precisely and efficiently, thereby achieving the stated design objectives. The function of each component is presented in this table.

Table 2. Functions of the Grappling Hook Gun Projectile Components

No	Component	Function
1	Projectile hook	Functions to grip or hook onto the target media
2	Shaft	Functions as a holder for tying ropes
3	Pen/rivet house	Acts as a connector between the hook and shaft
4	Pen/rivet	Functions as a locking system between components

Source: Author's work, 2026

The manufacturing process for a grappling hook gun projectile involves a series of critical steps that require a high level of precision. The initial stage begins with cutting the material using a cutting grinder, followed by machining of the shaft and hook housing. Each step is meticulously executed to ensure proper dimensions and structural strength. This is followed by material weighing, bolt installation, and a comprehensive finishing process. Connecting the projectile to the piston shaft is also crucial, as it directly impacts the projectile's strength, weight, and functionality. These steps aim to produce a projectile that meets the design requirements and meets the needs and intended use.



Figure 2. Grappling Hook Gun Projectile
Source: Author's work, 2026

Based on the grappling hook gun projectile design, we can then analyze the forces acting on the projectile. This calculation aims to determine the magnitude of the force received by each part of the projectile, thus providing a basis for evaluating its strength and safety.

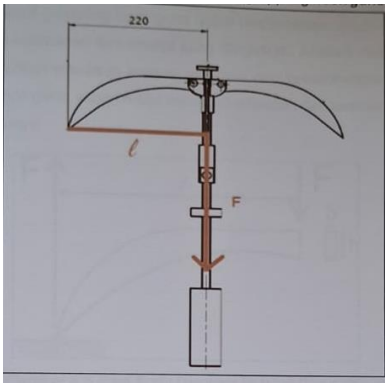


Figure 3. Free Body Diagram of Projectile
Source: Author's work, 2026

In the analysis process of grappling hook gun projectiles, the use of a Free Body Diagram (FBD) is an important method for describing and understanding the forces acting on the system in more detail. The FBD allows for identification of the direction, magnitude, and point of action of the forces affecting the projectile during load acceptance. To determine the force acting on one of the hooks, a force moment calculation approach is used.

The force moment is obtained by multiplying the force applied by the distance of that force from a certain axis of rotation. This method is very effective in analyzing the load distribution on the hook structure. Through the force moment calculation, the magnitude of the force received by the hook can be determined by considering the distance and position of the force. This analysis provides a deeper understanding of the load distribution pattern on the projectile structure. Thus, designers can design the shape and dimensions of the hook that can optimally withstand the workload and are in accordance with the operational function of the grappling hook gun.

Moment of force analysis provides a clearer understanding of how forces act on a component and helps designers make informed decisions. By applying this moment analysis concept, the design of a grappling hook gun projectile can be optimized to meet specified performance and safety requirements. Furthermore, moment of force analysis also provides an overview of the stability and balance conditions of the grappling hook gun projectile, which are critical factors in ensuring successful function and safety during use.

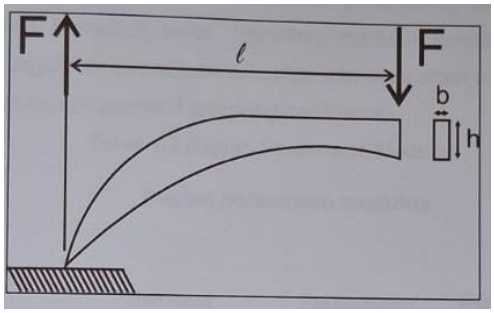


Figure 4. Free Body Diagram of Projectile Hook
Source: Author's work, 2026

A free-body diagram (FBD) of a hook is used to systematically depict the forces acting on the hook structure. This diagram analyzes the relationship between force, distance, and cross-sectional dimensions to determine the magnitude of the moment occurring on the hook. The parameters used in this analysis are as follows: L = 220 mm = distance between the hook support point and the shaft (mm), F = force acting on the hook (N), h = 24 mm = hook length (mm) b = 5 mm = hook width (mm).

Testing is a crucial stage in evaluating a design, which aims to assess the capabilities and performance of the tool after the design and manufacturing process is complete. This stage functions to ensure that all processes that have been implemented are able to produce tools that work in accordance with the specifications and design objectives. The main focus at the testing stage is to verify and validate the design results that have been prepared previously. Through the testing process, it can be identified whether the design meets the specified technical, functional criteria and safety standards. Apart from that, testing also allows potential deficiencies or deviations to be discovered which can be used as a basis for design improvements and refinements.

Test results are an important indicator for assessing the level of success and effectiveness of the design that has been realized. The significance of testing

lies in its ability to determine the accuracy of the function and overall performance of the tool. Through the testing process, it can be proven whether the designed tool has worked according to the initial plan and meets the safety standards that have been set. Apart from that, the data obtained from testing can be used as a basis for validating or improving the designs that have been created. Testing not only focuses on evaluating the technical performance of the tool, but also assesses the extent to which the tool is able to fulfill the expected functional goals. Thus, testing is a crucial stage to ensure that the design is not only technically appropriate, but also effective in meeting predetermined operational requirements.

Based on the test results, the grappling hook gun projectile demonstrated the ability to withstand loads of up to 200 kg without permanent deformation or structural damage. These results indicate that the material used has sufficient tensile strength to withstand the planned workload. Increasing the load capacity from the initial standard of 150 kg to 200 kg also provides a greater safety factor, thereby increasing the device's reliability under operational conditions. The absence of cracks, deformation, or failure in the joints during testing indicates that the projectile's geometric design is able to distribute stress evenly throughout the structure. This demonstrates that the design, material selection, and manufacturing processes have been carried out properly, resulting in a product that meets strength and safety criteria.

Furthermore, the projectile's success in withstanding a maximum load of 200 kg indicates that the device has a sufficient safety margin to anticipate dynamic loads that may occur during operation, such as shocks from rope pulls or user movement. Therefore, the grappling hook gun projectile can be declared suitable for use as operational support equipment because it meets the required strength, reliability, and safety aspects.

Barrel and Chamber Design

The determination of the barrel and chamber dimensions refers to previous research with adjustments for better performance and efficiency. Applies a chamber size of 17 mm inner diameter, 22 mm outer diameter, 2.5 mm wall thickness, 100 mm length, and a barrel of 45.15 mm inner diameter, 50.71 mm outer diameter, 5.56 mm wall thickness, 380 mm length, using Stainless Steel Series 316, which is more resistant to marine environmental corrosion but more expensive and difficult to work with.

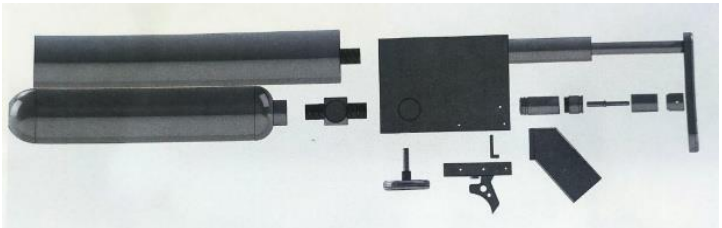


Figure 5. Grappling Hook Guns Design
Source: Author's work, 2026

In this study, the dimensions were taken from previous research to ensure adequate air capacity, but the material was changed to Aluminum 6061-T6. The comparison is:

1. Stainless Steel 316: Yield strength 205–290 MPa, excellent corrosion resistance, but heavy
2. Aluminum 6061-T6: Yield strength 276 MPa, good corrosion resistance, but the specific gravity is only 2.70 g/cm³, so the tool is much lighter and more practical.

The material chosen is Aluminum 6061-T6, with properties:

Table 3. Mechanical Properties of Al 6061-T6

Characteristic	Mark
Yield strength	276 MPa
Maximum tensile strength	310 MPa
Modulus of elasticity	68,9 GPa
Density	2,70 g/cm³

Source: Author's work, 2026

This material was chosen because it is light, rust-resistant (suitable for marine environments), and strong enough to withstand high pressure.

DISCUSSION

Barrel and Chamber Stress

Barrel: Loop voltage = 147,08 MPa

Safety factor $= \frac{276}{147,08} = 1,87$

Chamber : Loop voltage = 141,68 MPa

Safety of factor $= \frac{276}{141,68} = 1,94$

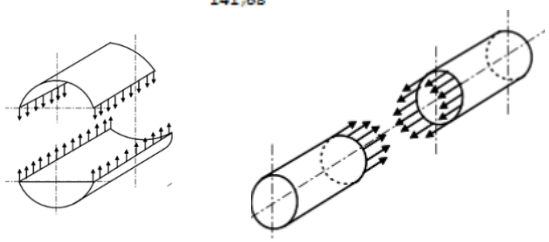


Figure 6. Loop and Longitudinal Stresses
Source: Author's work, 2026

After establishing a fixed working pressure of 17.01 MPa, which results in an initial projectile velocity of 19.8 m/s, an analysis was conducted to determine how variations in the firing angle affect the maximum height that can be achieved. Based on the principle of parabolic motion, the height achieved by the projectile is highly dependent on the magnitude of the elevation angle, because this angle determines how much of the initial velocity component is directed vertically upwards.

The greater the firing angle, the greater the vertical velocity, thus the higher the height that can be achieved. This analysis was conducted with the assumption that the initial velocity is kept constant, so that the difference in height is only affected by changes in the firing angle.

$$H = \frac{V_0^2 \, Sin^2(\theta)}{2g}$$

Table 4. Variations in the Firing Angle

Corner Angle (θ)	Height (H)
30°	4,9 m
45°	9,9 m
60°	14,98 m
90°	19,98 m

Source: Author's work, 2026

At an angle of 60°, the height achieved is 14.98 meters, this value is close to the planned operational height target of 15 meters, so this angle is the most optimal choice for vertical climbing needs or reaching a certain height. Meanwhile, at an angle of 90°, the height achieved reaches the highest value of 19.98 meters, but the projectile does not have horizontal movement, so this angle is only suitable for use if maximum height is needed without requiring horizontal reach. Conversely, angles smaller than 60° only produce lower heights and are not sufficient to meet operational climbing requirements.

Determining the most effective pressure is done by testing the system at several different pressure values, while also considering the resistance conditions around the device during operation. The goal is to find a pressure value that can eject the projectile effectively, safely, and without wasting energy. Explanation of Trial Results:

1. **At a pressure of 14 MPa (Less Effective):** This pressure is actually the pure pressure required at the end of the barrel, but it doesn't take drag into account. When tested, due to air friction and small resistances in the surrounding area, the projectile's power is drastically reduced before it reaches the target. This value is only effective in a vacuum with no resistance at all.
2. **At a pressure of 17.01 MPa (Most Effective):** This value is the sum of the base pressure plus the reserve power to overcome environmental resistance and flow friction. At this pressure, the balance is perfect: air resistance and friction within the duct are completely overcome, so the remaining power is used entirely to propel the projectile. The tool operates smoothly, safely, and produces consistent firing results. This value is designated as the tool's primary working pressure.
3. **At a pressure of 20 MPa (Not Effective):** This pressure is excessive and excessive. Although the high environmental resistance is easily overcome, the excess force does not significantly improve performance. Instead, this pressure puts the tool structure under heavy loads, causes severe vibration, and accelerates component wear. This is considered a waste of energy and is detrimental to the tool's long-term durability. Based on the three results above, it is concluded that a pressure of 17.01 MPa is the most effective, efficient, and safe value to use for all subsequent tests.

Ascender Motor Performance Test

Assuming a working load of 100 kg and a lifting height of 15 meters, the calculation results are as follows:

1. System Acceleration (a) = 0,0083 m/s2
2. Pulling Force (∑F) = 981,83 N
3. Torsi Pulley (T) = 49,091 N·m
4. Rotation Speed (n) = 48 rpm
5. Power Required (P) = 246,02 W
6. Voltage on Housing (σt) = 3,28 N/mm2
7. Allowable stress of material = 59 N/mm2
8. Battery Capacity Requirements:
   a. Minimum per lift = 0,34 Ah
   b. Installed capacity = 22 Ah
   c. Number of appointments = ± 64 time

Testing was carried out with load variations from 100 kg to 110 kg.



Figure 7. Housing Pulley Performance Test
Source: Author's work, 2026

Table 5. Field Test

Burden	Lift Time	Overall System Description
100 kg	60 s	Smooth, not squeezed
105 kg	63 s	Stable, auto release
110kg	69 s	Safe, speed is a bit slow

Source: Author's work, 2026

Based on performance testing, the redesigned pulley performed well in lifting loads on the electric grappling hook ascender system. Calculations showed that the pulley had a diameter of 100 mm, a rotational speed of 48 rpm, and a torque of 49,091 Nm. During testing, the pulley was able to lift a load of 100 kg to a height of 15 meters with a lifting time of 60 seconds under stable conditions. When the load was increased to 110 kg, the lifting time increased to 69 seconds due to the increased tensile force the system had to overcome.

These results indicate that the pulley effectively transmitted motor rotation to the lifting rope without significant slippage during the lifting process. Furthermore, the use of grooves on the pulley helped maintain the rope's stability, allowing for more precise winding. In previous research, the pulley used grooves with a width of 13 mm and a configuration of 6 grooves on

the right side and 6 grooves on the left side. Based on the evaluation and testing results, this configuration still caused problems with the rope getting caught in the groove, disrupting the lifting process and preventing the rope from automatically releasing. To address this issue, this study redesigned the pulley by widening the groove from 13 mm to 16 mm. Widening the groove aims to provide more space for the rope, thereby reducing the potential for rope pinching. However, widening the groove has the potential to reduce traction between the rope and pulley because the contact area in each groove is reduced. Therefore, the number of grooves was increased from 6 to 8 on each side of the pulley. This increase in grooves increased the number of contact points between the rope and pulley, thus maintaining traction even with the increased groove width. With this configuration, the rope can move more freely without pinching, while still providing sufficient friction to support the lifting process.

These results also align with the Capstan Equation principle, which states that the rope's ability to transmit force to the pulley is influenced by the amount of contact between the rope and the pulley surface. Increasing the number of grooves increases the contact and path of the rope on the pulley, resulting in improved traction and reduced slippage. Test results showed that the rope moved more stably, did not get caught in the groove, and was able to release automatically (auto-release). Thus, the redesigned pulley successfully improved the stability of the rope movement and supported the performance of the electric grappling hook ascender system. In addition to improving rope stability, the pulley's service life was also a key consideration. In this study, the pulley was constructed using aluminum, which is lightweight, corrosion-resistant, and strong enough to support lifting operations. During repeated testing at various loads up to 110 kg, no deformation, cracks, or damage was found in the pulley groove. However, this study did not conduct specific fatigue testing to determine the material's fatigue life over a specific number of cycles. Therefore, the pulley's maximum service life cannot be determined with certainty. A more in-depth fatigue analysis requires long-term, repeated loading cycle testing until material failure occurs. Nevertheless, based on the test results, the pulley remains in good condition and is suitable for use in the electric grappling hook ascender system.

Body Harness Tensile Strength Analysis

The redesign of the body armor structure in this study was conducted as an effort to improve the previous design, which was deemed to have limitations in terms of comfort, load distribution, and the strength of its support system, particularly the sheath harness. The redesign not only focused on changing the physical form but also considered mechanical aspects, ergonomics, and structural reliability under operational conditions. Based on observations, literature reviews, and analysis of previous designs, several key issues were identified, including

Suboptimal load distribution. The previous body armor design showed a concentration of load at certain points, particularly the shoulders and back. This condition has the potential to cause user discomfort and increase the risk of

fatigue during long-term use. Ergonomic limitations. The dimensions and configuration of the sheath harness in the previous design did not fully comply with anthropometric principles. This resulted in a lack of flexibility of movement and the potential for excessive pressure on certain body parts. The tensile strength of the sheath harness has limits that are not yet ideal. Potential deformation or structural failure can occur if subjected to dynamic loads or excessive tension. The complexity of the initial structural design was considered relatively complex, which impacted ease of maintenance, assembly, and efficient material use.

In redesigning the body armor structure for Tactical assault unit personnel, the initial step involved identifying risks in the field of operations. The selection of materials, such as Kevlar fiber, considers the balance between protection and mobility. The system is designed with ergonomic aspects in mind, improving user comfort when lifting loads at high altitudes. The overall planning process is based on a thorough understanding of operational needs and user involvement to ensure optimal protection and maximum support for tactical assault unit missions.



Figure 8. Body Armor Redesign
Source: Author's work, 2026

The research results from this redesign demonstrate that the first step, to achieve an ergonomic body armor structure design for Tactical assault unit users, focused on protection without sacrificing mobility and comfort, was successfully implemented. The integration of accurate size adjustments and high flexibility provides optimal ergonomics for the user. Enabling maximum operational efficiency, continuous design development emphasizes efficiency to support movement and handle specific tasks with responsiveness. The selection of Kevlar fiber polymer material proved a strategic decision, producing a lightweight, flexible, durable body armor that achieves optimal balance. Overall, this research confirms that the body armor is a responsive and effective solution, combining protection and operational performance to meet the demands of a dynamic operational environment.

Second, the tensile strength characteristics of the selected sheath harness material were determined to ensure user strength under dynamic loads. This redesign focused on material selection, stitching configuration, and load path distribution. The material used, nylon 6 rope, offers resistance to high tensile forces, energy absorption, and a safety factor against sudden failure. Tensile testing demonstrated a high maximum tensile stress, a relatively high strain

before breaking, and a non-brittle fracture pattern. The increase in tensile strength based on the initial design compared to the current design shows that the changes in structure and material effectively increase the load capacity and this polyester rope material is suitable for use to ensure user safety.

Based on the results of numerical testing with SolidWorks software, the following data was obtained. Tensile Test Results (Yield Strength). After the simulation is complete, the deformation analysis results will be displayed, where the simulation results on the body harness to understand the extent of the tensile test (yield strength) with a load of 100 kg, the maximum stress obtained is 1.146 x 10^8 N/m².

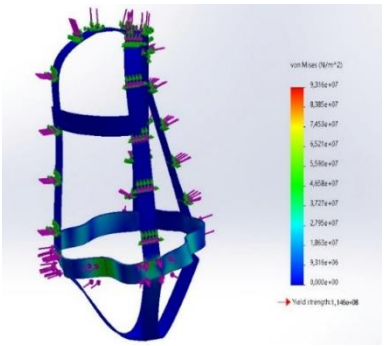


Figure 9. Output Yield Strength
Source: Author's work, 2026

The Safety Factor for the 100 kg load simulation was 9.2, which concluded that at this load the harness used was safe for Tactical assault unit personnel in carrying out operational mobility.

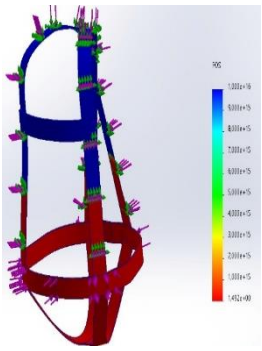
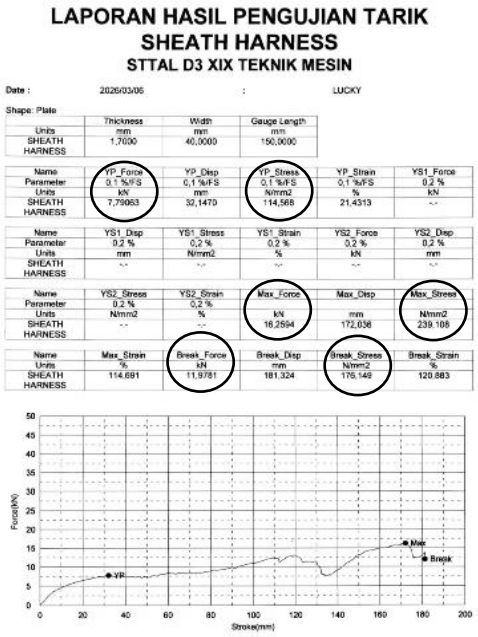


Figure 10. Safety Factor for a 100 kg Load
Source: Author's work, 2026

Based on the simulation results above, the body harness only experiences a tensile load in the downward direction and experiences a normal tensile load of the same size but in the direction upwards to achieve the concept of equilibrium.



LAPORAN HASIL PENGUJIAN TARIK
SHEATH HARNESS
STTAL D3 XIX TEKNIK MESIN

Date : 2026/03/06 : LUCKY

Shape: Plate

	Thickness	Width	Gauge Length
Units	mm	mm	mm
SHEATH HARNESS	1,7000	40,0000	150,0000

Name	YP_Force	YP_Disp	YP_Stress	YP_Strain	YS1_Force
Parameter	0,1 %/FS	0,1 %/FS	0,1 %/FS	0,1 %/FS	0,2 %
Units	kN	mm	N/mm2	%	kN
SHEATH HARNESS	7,79063	32,1479	114,568	21,4313	-.-

Name	YS1_Disp	YS1_Stress	YS1_Strain	YS2_Force	YS2_Disp
Parameter	0,2 %	0,2 %	0,2 %	0,2 %	0,2 %
Units	mm	N/mm2	%	kN	mm
SHEATH HARNESS	-.-	-.-	-.-	-.-	-.-

Name	YS2_Stress	YS2_Strain	Max_Force	Max_Disp	Max_Stress
Parameter	0,2 %	0,2 %			
Units	N/mm2	%	kN	mm	N/mm2
SHEATH HARNESS	-.-	-.-	16,2594	172,036	239,108

Name	Max_Strain	Break_Force	Break_Disp	Break_Stress	Break_Strain
Units	%	kN	mm	N/mm2	%
SHEATH HARNESS	114,691	11,9781	181,324	176,149	120,883

Figure 11. Lab Test Results
Source: Author's work, 2026

Based on these results, it shows that the harness design is in a safe condition and ready to be used by Tactical assault unit personnel in future operational task mobility. Testing a body harness with a grappling hook integration is a critical step in ensuring the device's reliability and optimal performance before use in the field. Some of the commonly performed testing steps include:

1. Mobility Testing

Evaluate the user's mobility while using the body harness and grappling hook to ensure there are no significant limitations to movement. Testing in various terrain conditions to understand the extent to which the body harness can support mobility in various environments.



Figure 12. Mobility Trial
Source: Author's work, 2026

2. Grappling Hook Testing

Testing the reliability of the grappling hook's trigger and locking mechanism. Testing the speed and accuracy of throwing and retracting the grappling hook. Testing the durability and reliability of the DC motor and pulley in repeated operations.

3. Battery Energy and Endurance Testing

Battery endurance testing to ensure it can support operation for the desired duration. Charging testing to ensure the battery can be recharged effectively

4. Safety Testing

Testing of on/off switches to ensure safe power control. Testing of all elements that could pose a risk of injury or operational failure.

5. Field Trial

Field testing that simulates actual operational conditions to verify the equipment's performance in practice.



Figure 13 Field Trial
Source: Author's work, 2026

To obtain the tensile strength characteristics of the selected sheath harness material to ensure user strength when receiving dynamic loads. This redesign focused on material selection, stitch configuration and load path distribution. The material used is nylon 6 rope which has the function of resistance to high tensile forces, energy absorption capacity and safety factor against sudden failure. Based on tensile testing, it shows a high maximum tensile stress, a fairly large strain before breaking and a non-brittle fracture pattern. The increase in tensile strength based on the initial design compared to the current design shows that the changes in structure and material effectively increase the load capacity and this nylon 6 rope material is suitable for use to ensure user safety.

CONCLUSIONS AND RECOMMENDATION

Optimization of the projectile design and material selection increased its tested load capacity from 150 kg to 200 kg without permanent deformation or structural damage. The four-hook configuration provided load distribution across the projectile structure, while the use of titanium resulted in a higher safety factor and lower deformation compared with the previous design.

The redesigned chamber and barrel system using Aluminum 6061-T6 operated at an effective working pressure of 17.01 MPa and produced an initial projectile velocity of 19.8 m/s. The calculated safety factors were 1.87 for the barrel and 1.94 for the chamber, with stresses remaining below the material yield strength. At an elevation angle of 60°, the projectile reached a vertical height of approximately 14.98 m, while a 45° angle produced a maximum horizontal range of 39.96 m under the analyzed conditions.

The redesigned pulley, with a groove width increased from 13 mm to 16 mm and the number of grooves increased from six to eight on each side, reduced the rope-pinching problem observed in the previous configuration. Testing showed stable rope movement and lifting capability for loads ranging from 100 to 110 kg.

The body harness analysis showed that the redesigned configuration remained within the evaluated structural limits under a 100 kg load, with a safety factor of 9.2. These results indicate that the redesigned harness configuration provides sufficient structural capacity under the loading conditions considered in this study.

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