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Modification of counter recoil system in pneumatic counter-tank weapon (CTW) for recoil force reduction

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Abstract

The rapid advancement of defense technology within the Indonesian Army (TNI AD) requires effective, realistic training systems for Counter-Tank Weapons (CTW). Pneumatic CTW trainers have been developed as cost-effective alternatives to live-fire training; however, field tests indicate significant recoil that reduces weapon stability and shooter comfort. Unlike conventional recoil mitigation methods that rely on external dampers, springs, or structural reinforcement, this study proposes an integrated, collision-based counter-recoil mechanism embedded within the valve lever assembly that reduces recoil through internal momentum transfer without adding complex external components. This study aims to design and evaluate the proposed mechanism to reduce recoil force while maintaining firing accuracy and projectile range. Experimental tests were conducted at Politeknik Angkatan Darat under controlled conditions, using three pressure levels (10-30 bar) and three counter pad masses (0.5-1.5 kg), with three repetitions per condition. Recoil force was measured using a calibrated load cell sensor, while projectile range was recorded manually. Data were analyzed using two-way ANOVA to evaluate the effects of pressure and pad mass on recoil behavior. The results show that the proposed internal collision-based counter recoil system significantly reduced recoil force across all pressure levels. At 30 bar, recoil decreased from 81.7 N (without modification) to 65.7 N using a 0.5 kg pad and further decreased to 34.33 N with a 1.5 kg pad. Statistical analysis confirmed that both pressure and pad mass significantly influence recoil force ($p < 0.001$, $R^2 = 98.35\%$). In addition, the maximum firing range increased from 190.7 m to 221.7 m, indicating improved energy transfer and launcher stability. Although the 1.5 kg counterpad had the lowest recoil force, its additional mass may reduce launcher mobility and operator comfort. The 1.0 kg pad provides a balanced compromise between recoil reduction and ergonomic usability, making it more suitable for routine training applications. These findings demonstrate that the proposed internal collision-based counter recoil mechanism offers an effective, passive, lightweight, and practical solution for mitigating recoil in pneumatic CTW training launchers while preserving operational realism and ease of maintenance.

Keywords:
Counter pad; load cell; ANOVA; pneumatic CTW training launcher; recoil force reduction

1 Introduction

The rapid advancement of defense technology has significantly transformed modern military equipment, particularly main weapon systems (Alutsista) utilized by the Indonesian Army (TNI AD). This technological evolution necessitates continuous enhancement of personnel competency to ensure optimal equipment operation in various combat scenarios. Infantry units, as the main element of ground operations, rely heavily on portable weapon systems, including Counter-Tank Weapons (CTW), which are designed to neutralize armored vehicles and fortified positions [1].

Conventional anti-tank weapons such as LRAC (Lance-Roquettes Antichar), Instalaza C90-CR, and Armbrust have proven effective in combat operations. However, their high operational costs, single-use ammunition, and complex logistics limit their applicability for routine training activities [2], [3]. These constraints have encouraged the development of cost-effective training platforms that can replicate operational conditions while reducing expenditure and logistical burden.

Pneumatic propulsion systems have been introduced as sustainable alternatives to CTW training by using compressed gas rather than solid propellants. These systems enable repeated use, improved operational safety, and reduced environmental impact. Nevertheless, preliminary field tests of pneumatic CTW trainers indicate that significant recoil forces remain, reaching approximately 80 N at a working pressure of 30 bar, which negatively affects weapon stability, shooter posture, and firing accuracy.

Existing recoil-mitigation techniques, including mechanical dampers, recoil springs, and buffer systems, were originally designed for solid-propellant weapons characterized by short-duration and high-peak impulse loads. In contrast, pneumatic systems produce longer-duration, lower-peak, but higher-total-impulse profiles. This mismatch causes conventional mitigation devices to provide insufficient damping or to require additional mass and structural reinforcement, thereby reducing portability and operational practicality.

Several previous studies have attempted to improve launcher stability and recoil control through structural reinforcement and mass optimization [6], pressure-loss management [7], airflow regulation using vortex tubes [8], rigid pneumatic launcher designs [9], and lightweight composite structures combined with telemetry systems [10]. However, most of these approaches rely on increased structural stiffness, additional components, or complex flow-control mechanisms, thereby increasing system complexity and maintenance requirements while failing to address dynamic recoil-impulse mitigation in pneumatic CTW trainers directly.

Furthermore, existing studies have primarily focused on propulsion efficiency, structural durability, or material optimization, with limited attention to integrated recoil control mechanisms specifically optimized for training launchers. Quantitative evaluations of recoil reduction via internal momentum transfer mechanisms in pneumatic CTW systems are scarce, indicating a clear research gap in this field.

To address this gap, the present study investigates the design and implementation of a collision-based counter-recoil mechanism integrated into the valve lever assembly. The proposed system employs a counter pad that generates controlled impact with the valve housing during gas release, producing forward momentum to counteract rearward recoil forces. This study systematically evaluates the influence of pressure levels and counter pad mass on recoil behavior using experimental testing and statistical analysis. The novelty of this research lies in the application of an internal collision-based momentum transfer mechanism that provides effective recoil mitigation without requiring additional external components or major structural modifications, while simultaneously maintaining or improving projectile range performance.

The findings of this research advance indigenous defense training technology by providing validated design parameters for safer, more ergonomic CTW trainers. Moreover, this study supports the development of reliable and cost-effective training systems that enhance skill transfer, operational readiness, and long-term sustainability for military personnel.

2 Research methodology

The flowchart shown in Fig. 1 illustrates a systematic research methodology for developing and testing a construction system, beginning with a comprehensive field survey and literature review to establish the theoretical foundation. The process then moves through sequential phases: planning the construction system design, followed by tool making and rigorous testing under varying pressure and firing-angle conditions. After the initial testing phase, a simulation is conducted to evaluate the system's performance, leading to a critical decision point at which the recoil counter's force (F) is compared with the CTW's recoil. If the system fails to meet the required specifications (No path), the process loops back to the planning design phase for refinement and optimization. However, if the system successfully meets the criteria (Yes path), the process advances to result data collection, followed by comprehensive data analysis and conclusion formulation before reaching the final stop point, ensuring a complete validation of the construction system's effectiveness.

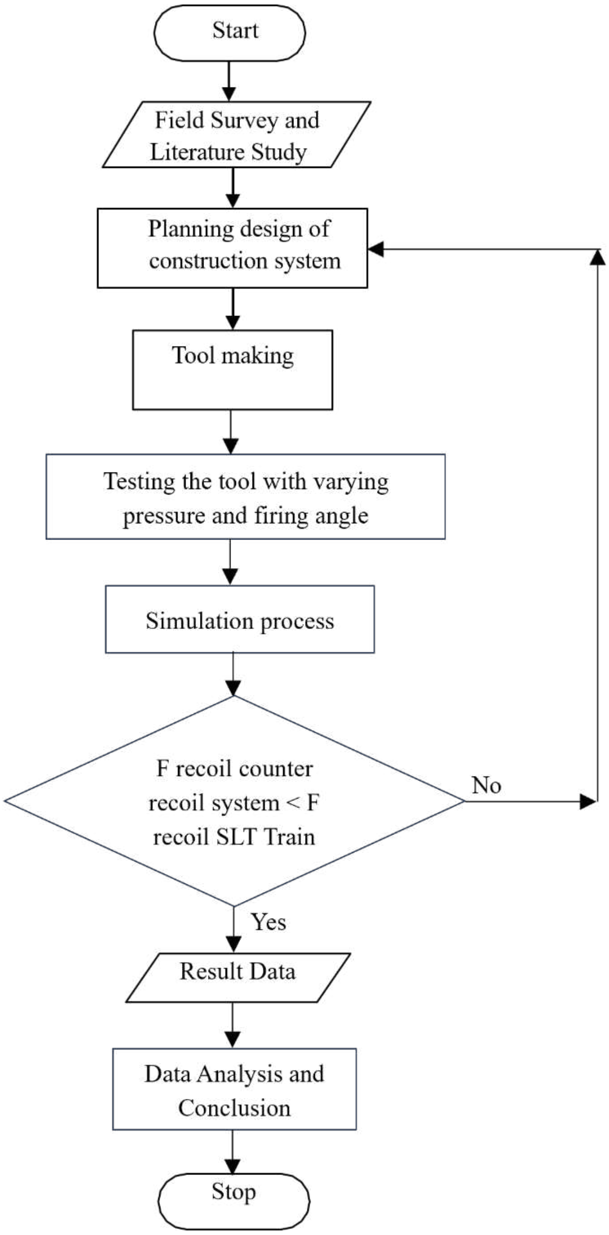


Fig. 1. Flowchart diagram.

Modifications to the CTW Training system in this study focused on the piston housing system circuit, where a counter pad was added to the end of the valve lever as part of the counter recoil mechanism, as shown in Fig. 2. The main purpose of this modification is to create an internal reactive force capable of suppressing the recoil force during firing.

As shown in Fig. 2, the modification was made by adding a counter pad (component number 8) to the valve lever in the piston housing system. Technically, the valve lever controls the flow of pressurized air from the compression cylinder to the barrel/launcher. Through this modification, a recoil pad with a certain weight/mass was added to the end of the valve lever to create a collision effect on the valve housing when the valve opens quickly.

To ensure that the measuring instruments and components function properly and are ready for data acquisition, a functional test of the testing equipment was conducted in advance, covering both mechanical and electronic components. In the operational procedure for the recoil force measuring device, the load cell sensor was first calibrated. After the calibration process, the sensor output was then read and displayed on the LCD. The value shown on the LCD represents the magnitude of the pressure detected by the load cell sensor, which corresponds to the recoil force generated by CTW. The Load Cell Specifications are:

- Model: Bar-Type Load Cell (Single Point Load Cell)
- Material: Aluminum Alloy
- Maximum Load: 20 kg
- Nonlinearity: 0.05% FS
- Hysteresis: 0.05% FS
- Temperature Effect on Sensitivity: 0.05% FS per 10°C
- Temperature Effect on Zero Output: 0.05% FS per 10°C
- Zero Balance: ±0.5% FS
- Repeatability: 0.05% FS
- Excitation Supply Voltage: 5 V

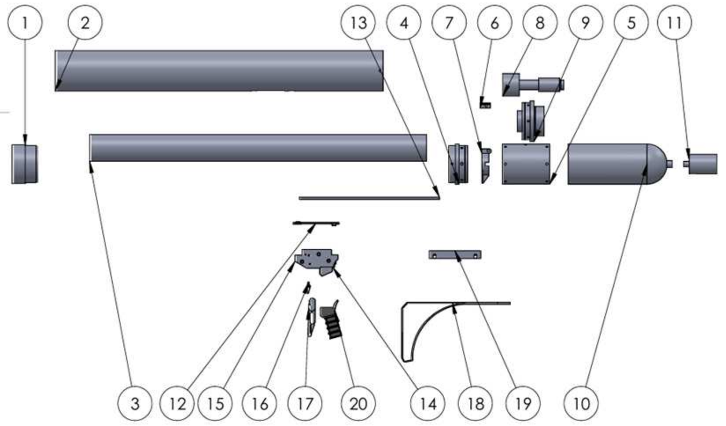


Fig. 2. CTW training design with modified recoil system

1. Muzzle
2. Laras Cover
3. Laras
4. Laras Adapter
5. Piston Housing Cover
6. Lever Hinge
7. Piston Lever
8. Piston
9. Piston House
10. Tube
11. Charging Connector
12. Seatbox Mount
13. As Triger
14. Right Seatbox
15. Left Seatbox
16. Sear
17. Trigger
18. Butt
19. Stock Mount
20. Grip

When firing the Counter-Tank Weapon (CTW) Training, a rearward recoil force is generated. A dual recoil system approximates the force felt during rearward recoil by utilizing the inertial momentum of the counter pad at the base of the lever. The counter recoil system uses the pressure of compressed gas in the compression cylinder to propel the rocket in the CTW's barrel chamber. With this system, when the valve lever is locked by the trigger assembly (as shown in Fig. 3), the base of the valve lever, containing the weight (counter pad), is positioned rearward. When the valve lever is released (as shown in Fig. 4), it simultaneously moves forward due to gas pressure and the weight at its base, which strikes points behind (the counter pad) and in front (the valve housing). This creates a forward inertial momentum, reducing the recoil force of the CTW Training.

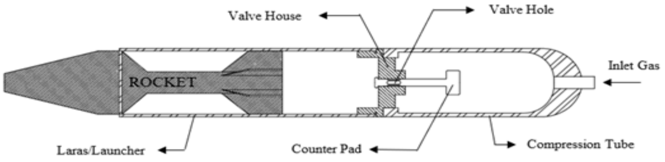


Fig 3. Locked valve system (side/split view)

When the Counter-Tank Weapon (CTW) Trainer is fired, a strong recoil occurs due to the sudden release of gas from the compression tube to propel the rocket out of the barrel. To reduce this recoil, a dual recoil system is used, which creates a forward force, reducing the perceived recoil [14].

This system works by utilizing the gas pressure inside the compression tube. This gas pressure not only pushes the rocket out of the barrel but also moves the valve lever within the mechanical circuit system [10].

Initially, the valve lever is locked in the rear position. When the shot is fired, the valve lever is pushed forward by the gas pressure. At the base of the valve lever is a weight called a counter pad. As the valve lever moves forward, this counter pad strikes the rear of the valve housing.

This impact creates a forward force that helps balance the rearward recoil. This reduces the weapon's recoil, making it more stable and easier to shoot.

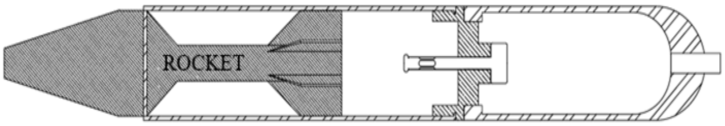


Fig 4. Open valve system (side/split view)

3 Result and discussion

3.1 Design and specifications of modified anti-tank training weapon

The modification to the Anti-Tank Training (CTW) weapon system was implemented by integrating a counter-recoil mechanism that uses impact energy from a recoil pad to push the valve housing. This system was designed to reduce the recoil force generated during projectile launching through controlled pneumatic pressure release.

The working principle begins when pressurized air is released through the main channel toward the launching chamber, propelling the projectile out of the barrel. Unlike conventional systems that fully transfer the reaction to the rear of the weapon, this system redirects a portion of the reactive energy to impact the lever load against the valve housing. The recoil pad installed in the air release path acts as a momentum transfer medium in the opposite direction to the main recoil direction.

When pressure is released, this load accelerates toward the valve housing, producing a controlled impact. This collision creates a reactive force that opposes the weapon's backward movement, generating backward momentum that counteracts the recoil. The valve housing was designed with specific structural strength to withstand impacts without deformation while progressively absorbing impact energy.

Table 1 presents the comparative specifications of the CTW system before and after modification. The primary changes include the addition of a counter-recoil mechanism and a variable counter pad mass (0.5-1.5 kg), with three replications, while maintaining consistent technical parameters such as barrel length (1000 mm), caliber (76 mm), projectile mass (1.025 kg), and pneumatic propulsion system.

Table 1. Comparative Specifications of CTW Weapon System

Component	Before Modification	After Modification
Barrel length	1000 mm	1000 mm
Caliber	76 mm	76 mm
Projectile material	PVC	PVC
Projectile mass	1.025 kg	1.025 kg
Projectile length	46 cm	46 cm
Propulsion system	Pneumatic	Pneumatic
Recoil mechanism	-	Counter recoil
Total weapon mass	18 kg	18 kg ± 1.5 kg (additional counter pad)

3.2 Recoil force analysis

3.2.1 Comparison of recoil forces

The experimental results demonstrate significant differences in recoil forces between the unmodified and modified CTW weapon systems at wind speeds of 0.3-0.7 m/s. Table 2 presents the recoil force measurements at three pressure levels (10-30 bar) with a 15° elevation angle.

Table 2. Recoil force measurements for unmodified CTW system

Pressure (Bar)	Recoil Force (N)	Range (m)
10	28.2	47
20	59.6	98
30	83.2	196

Table 3. Recoil force measurements for modified CTW system

Counter Pad (kg)	Pressure (Bar)	Recoil Force (N)	Range (m)
0,5	10	20.0	60
	20	46.6	122
	30	68.7	215
1	10	19,7	56
	20	34,0	119
	30	50,3	217
1,5	10	21,2	63
	20	25,6	115
	30	35,5	212

The comparison reveals a substantial reduction in recoil force across all pressure levels. At 10 Bar, the recoil force decreased from 27.1 N to 20.3 N (25% reduction). At 20 Bar, the reduction was from 55.9 N to 45.2 N (19% reduction). The most significant absolute reduction occurred at 30 Bar, where recoil force decreased from 81.7 N to 65.7 N (19.6% reduction).

Interestingly, the counter recoil system not only reduced recoil forces but also improved projectile range performance. At 30 Bar, the average range increased from 190.7 m to 221.7 m, indicating enhanced energy transfer efficiency and system stability during launch.

3.2.2 Effect of counter pad mass variation

The influence of counter pad mass on recoil force reduction was systematically evaluated using three mass variants: 0.5 kg, 1.0 kg, and 1.5 kg. Table 4 summarizes the results across different pressure levels.

Table 4. Effect of counter pad mass on recoil force

Counter Pad Mass (kg)	Pressure (Bar)	Average Recoil Force (N)
0.5	10	20.33
	20	45.13
	30	65.67
1.0	10	19.60
	20	32.47
	30	51.73
1.5	10	17.83
	20	22.23
	30	34.33

The results demonstrate an inverse relationship between counter pad mass and recoil force. The 1.5 kg counter pad achieved the most significant recoil reduction, particularly at higher pressures. At 30 Bar, recoil force decreased from 65.67 N (0.5 kg) to 34.33 N (1.5 kg), representing a 48% reduction.

This phenomenon aligns with the principle of inertial damping, in which increased mass provides greater momentum absorption [15]. The heavier counter pad effectively absorbs more impulsive energy from the gas expansion process, thereby reducing the recoil transmitted to the weapon system [16].

The recoil-reduction mechanism provided by the cushion mass is primarily governed by momentum conservation and energy dissipation during firing. When a recoil force is generated, the moving components transfer momentum to the cushion. A heavier cushion has greater inertia, which resists sudden motion and slows down the backward movement of the system. As a result, the recoil impulse is distributed over a longer time interval, reducing the peak force experienced by the structure. In addition, the deformation and friction within the cushion material convert part of the kinetic energy into heat, further dissipating impact energy. The combined effect of increased inertia and energy dissipation results in smoother deceleration of the recoiling components and improved overall system stability.

3.2.3 Range performance analysis

Table 5 presents the projectile range performance across different counter pad masses and pressure levels.

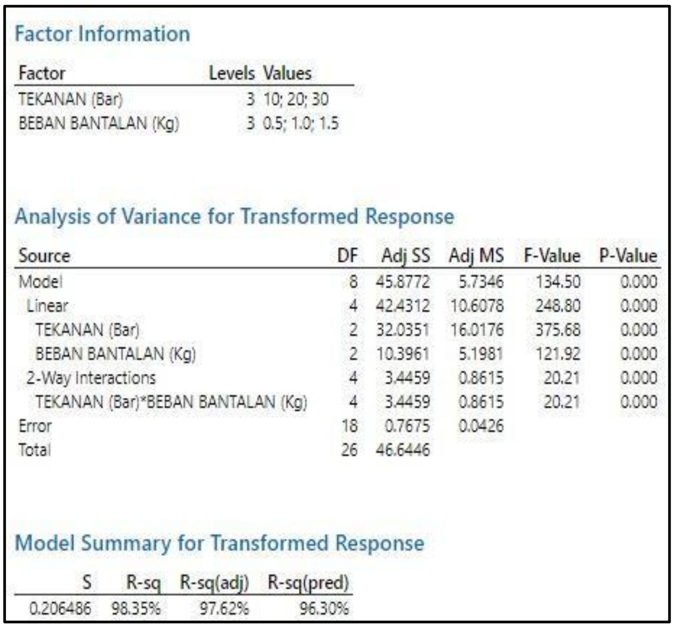
Table 5. Effect of counter pad mass on projectile range

Counter Pad Mass (kg)	Pressure (Bar)	Average range (m)
0.5	10	57.0
	20	121.7
	30	221.7
1.0	10	58.7
	20	121.3
	30	222.0
1.5	10	59.3
	20	124.7
	30	223.3

The range performance remained remarkably consistent across different counter pad masses, indicating that the counter recoil system does not compromise projectile velocity or trajectory. The slight variations observed are within experimental uncertainty and demonstrate that energy absorption by the counter pad primarily affects recoil forces rather than projectile kinetic energy [17].

3.3 Statistical analysis and model validation

A two-way ANOVA was conducted to evaluate the statistical significance of pressure and counter pad mass effects on recoil force. The analysis revealed highly significant effects for both factors (P-value < 0.001) and their interaction (P-value < 0.001). Depend on Fig. 5. The statistical model demonstrated excellent fit quality with $R^2 = 98.35\%$, R^2 adjusted = 97.62%, and R^2 predicted = 96.30%.



Factor Information

Factor	Levels	Values
TEKANAN (Bar)	3	10; 20; 30
BEBAN BANTALAN (Kg)	3	0.5; 1.0; 1.5

Analysis of Variance for Transformed Response

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	45.8772	5.7346	134.50	0.000
Linear	4	42.4312	10.6078	248.80	0.000
TEKANAN (Bar)	2	32.0351	16.0176	375.68	0.000
BEBAN BANTALAN (Kg)	2	10.3961	5.1981	121.92	0.000
2-Way Interactions	4	3.4459	0.8615	20.21	0.000
TEKANAN (Bar)*BEBAN BANTALAN (Kg)	4	3.4459	0.8615	20.21	0.000
Error	18	0.7675	0.0426		
Total	26	46.6446			

Model Summary for Transformed Response

S	R-sq	R-sq(adj)	R-sq(pred)
0.206486	98.35%	97.62%	96.30%

Fig 5. ANOVA result

The high R^2 values confirm that the experimental model effectively captures the relationship between design parameters and recoil performance. The low standard error (S=0.206486) indicates high precision in the measurements and model predictions.

3.4 Three-dimensional response surface analysis

The relationship between pressure, counter pad mass, and recoil force was visualized using three-dimensional surface plotting. The surface plot reveals a clear trend where recoil force increases with pressure but decreases with counter pad mass. The interaction between these variables is non-linear, with more pronounced mass effects at higher pressures.

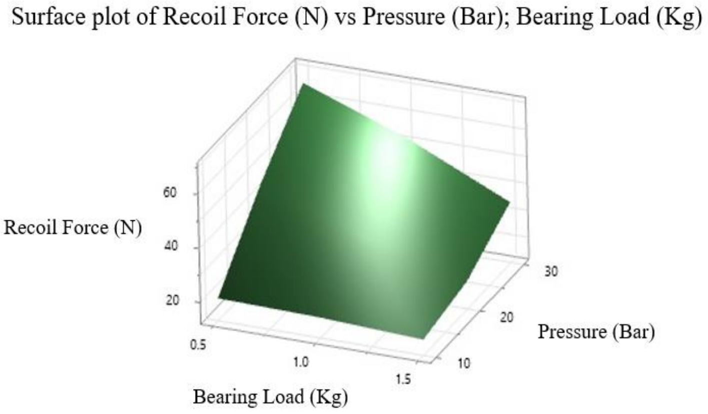


Fig 6. 3D analysis of the relationship between bearing load variation and pressure variation on recoil force

Fig. 6 is a three-dimensional surface plot that illustrates the relationship between air pressure, lever pad mass, and the resulting recoil force in the Counter-Tank Weapon (CTW) training system with a pneumatic mechanism. The experimental model shows that the recoil force increases significantly with rising pressure, particularly when the pad mass is small. At 30 bar, recoil reaches over 60 N with a 0.5 kg pad mass, but decreases sharply when the mass is increased to 1.5 kg. This indicates that the pad mass plays a crucial role in reducing recoil during high-pressure firing. At lower pressures (10 bar), variations in pad mass have little effect, but at medium to high pressures (20-30 bar), the influence becomes more pronounced, demonstrating its effectiveness in dampening recoil energy.

These findings align with dynamic-system principles, in which recoil is proportional to the momentum generated during firing. By adding pad mass, the system passively absorbs part of the impulsive energy, thereby reducing the backward force without disrupting the projectile trajectory or stability. Overall, the surface plot confirms that adding additional pad mass is an effective way to control recoil, especially under high-pressure conditions. Selecting an optimal mass provides a balance between firing performance, operational safety, and user comfort in training applications [18].

3.5 Aerodynamic analysis of warhead design

Computational Fluid Dynamics (CFD) analysis was conducted to evaluate the influence of warhead geometry and material on aerodynamic characteristics. Three warhead shapes (flat, flat radius, and tapered) combined with three materials (rubber, ABS, and polyethylene). The geometry is shown at fig. 7 below.

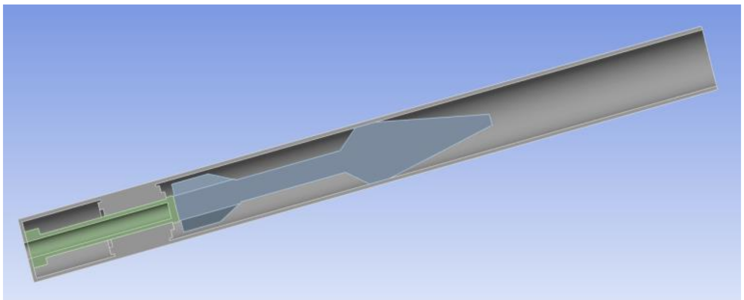


Fig 7. Geometry

Numerical simulations were performed using ANSYS Workbench 2022 R2 coupled with the LS-DYNA explicit dynamics solver to investigate the structural response of the counter recoil mechanism during firing.

The computational model consisted of three main components: the barrel, projectile, and recoil mechanism. Structural steel, aluminum alloy 6063-T6, and rigid PVC were assigned based on material data from the ANSYS material library. Structural steel was defined with a density of 7850 kg/m³ and isotropic elastic properties.

The model was discretized using unstructured three-dimensional tetrahedral elements. The final mesh consisted of approximately 68,954 nodes and 171,004 elements. Local mesh refinement was applied in the valve, counter pad, and housing contact regions to capture high stress gradients and impact behaviour.

Boundary conditions included fixed supports applied to the rear mounting region, representing launcher constraints. A concentrated force of 1140 N was applied to simulate the pneumatic propulsion load. Prescribed displacement conditions were imposed to represent valve motion. Gravitational acceleration of 9.8066 m/s² was applied to all bodies.

Contact interactions between the valve lever, counter pad, and housing were modeled using automatic surface-to-surface contact algorithms. Transient analysis was conducted for a total simulation time of 0.5 s at an ambient temperature of 22 °C.

The final result of the simulation process is shown in Fig. 8. Based on the ANSYS LS-DYNA simulation results, the maximum equivalent stress (σ max=211.28 MPa) occurs at the connection area between the valve lever and the valve housing. This region, highlighted in red on the contour plot, indicates a local stress concentration resulting from a rapid load transfer during the recoil process. The high stress arises from the impulsive force imparted by the sudden release of pressurized air, causing a localized deformation near the joint fillet where geometric discontinuities occur.

Physically, this stress concentration occurs when compressed air from the chamber exerts a strong force on the valve assembly. The counter pad attached to the lever adds inertia during this motion, resulting in a brief impact with the inner wall of the housing. This impact results in a transient load that produces peak von Mises stress in the contact region. The phenomenon demonstrates how mechanical design features, such as sharp transitions or material discontinuities, can amplify stress magnitudes even under controlled pressure increases.

Comparing the simulation and experimental results reveals consistent behavior: as the working pressure increases from 10 to 30 bar, both the recoil force and the stress magnitude increase proportionally. However, the inclusion of the counter-recoil mechanism helps distribute stress more evenly throughout the system, preventing excessive stress accumulation at a single point. Consequently, this configuration effectively reduces recoil energy by approximately 48% at 30 bar, confirming the simulation's reliability and the system's improved structural performance.

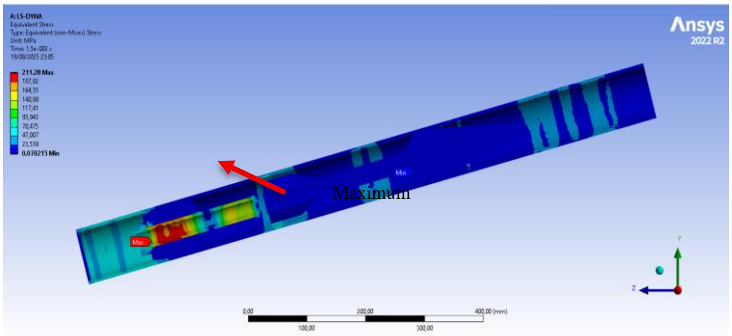


Fig 8. Stress contour resulting from the applied force

3.6 Discussion

3.6.1 Comparison of recoil forces

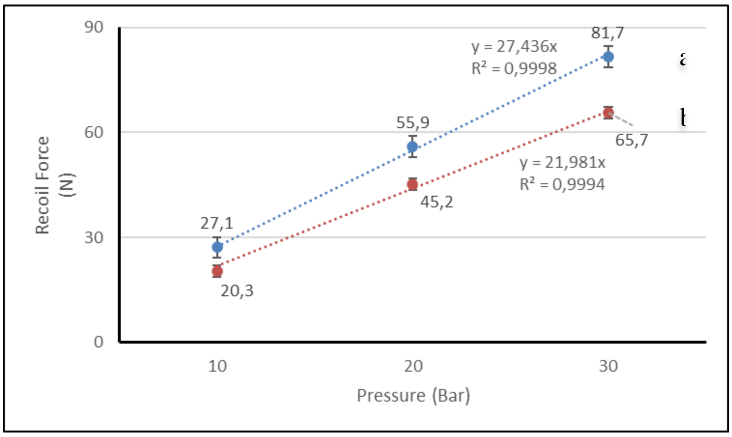


Fig 9. Comparison graph of the amount of recoil force in (a) CTW without a counter recoil system and (b) CTW with a counter recoil system

Fig. 9. presents a comparison of the average recoil forces observed in the CTW system under two operating conditions: without and with the Counter Recoil System. Tests were conducted at working pressures of 10-30 bar using a counter pad mass of 0.5 kg. The primary objective was to assess the effectiveness of the Counter Recoil System in suppressing recoil forces generated during the rocket launching process.

The experimental results demonstrate a proportional increase in recoil force with rising pressure for both configurations. Nevertheless, the Counter Recoil System consistently reduced recoil force across all pressure levels. Specifically, reductions of 25% (27.1 N to 20.3 N) at 10 bar, 19% (55.9 N to 45.2 N) at 20 bar, and 19.6% (81.7 N to 65.7 N) at 30 bar were recorded, indicating significant damping performance across the tested range.

In summary, the Counter Recoil System demonstrates substantial capability to mitigate recoil, thereby enhancing launcher stability, operator safety, and firing accuracy. Its consistent performance across varying pressures underscores its importance for CTW systems, particularly in repetitive and intensive operational scenarios where both structural durability and user comfort are critical [19].

3.6.2 Comparison of rocket reach distances.

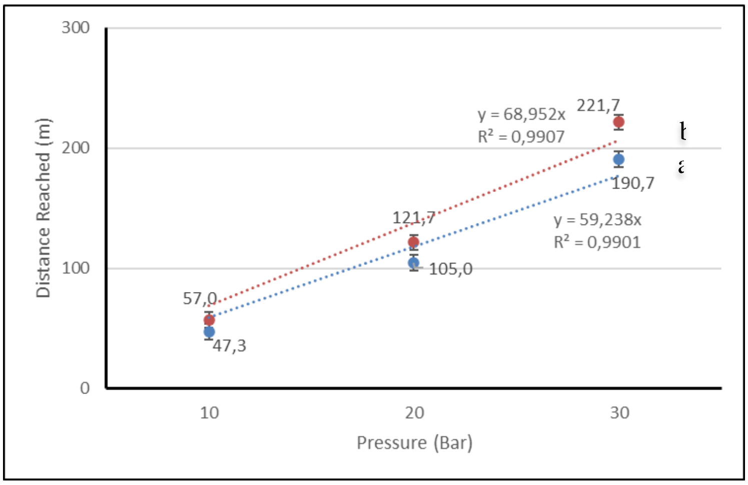


Fig 10. Comparison graph of rocket reach distance on (a) CTW without counter recoil system and (b) CTW with counter recoil system

Fig. 10 compares the average rocket reach distance of the CTW system under two conditions-without and with the Counter Recoil System-at pressures of 10-30 bar using a 0.5 kg counter pad. The results indicate that the Counter Recoil System not only reduces recoil but also improves the efficiency of energy transfer to the rocket, resulting in greater range. At 10 bar, the rocket reached 47.3 m without the system and 57.0 m with the system, while at 20 bar the distance increased from 105.0 m to 121.7 m. The most significant difference was observed at 30 bar, where the reach distance improved from 190.7 m to 221.7 m, a gain of 31 m. These findings confirm that recoil reduction enhances launcher stability and improves kinetic energy transfer during projectile release.

Overall, the Counter Recoil System provides dual benefits: mitigating recoil forces that can compromise operator safety and structural integrity, and enhancing operational performance by extending rocket range. This dual advantage underscores its importance in developing safer and more efficient CTW systems.

3.6.3 Comparison of the effect of counter pad mass on recoil force [20].

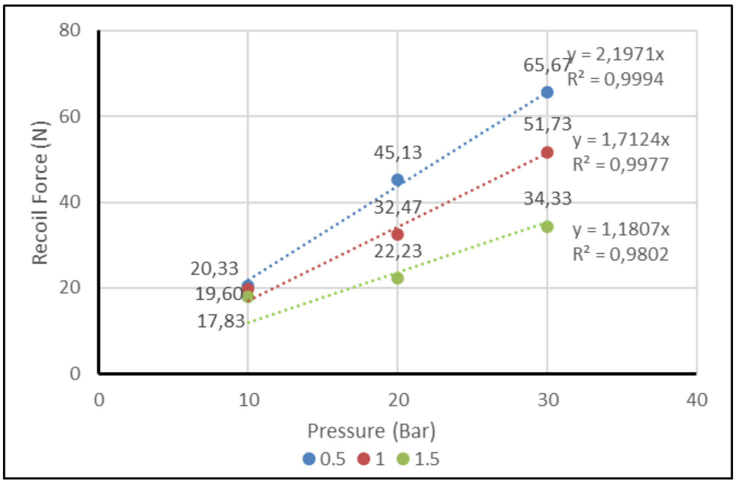


Fig 11. Comparison graph of the effect of variation in counter pad mass on recoil force

Fig. 11 shows the effect of counter pad mass variation (0.5 kg, 1 kg, and 1.5 kg) on recoil force in the CTW system at working pressures of 10-30 bar. The results indicate that increasing counter pad mass consistently reduces recoil force. At 10 bar, recoil decreased from 20.33 N (0.5 kg) to 17.83 N (1.5 kg), while at 20 bar the values dropped from 45.13 N to 22.23 N. The greatest reduction was observed at 30 bar, where recoil decreased from 65.67 N to 34.33 N, demonstrating the effectiveness of counter pad mass as a passive damping mechanism.

This trend can be explained by the increased inertia provided by larger counter pad masses, which absorb part of the reactive force before it is transferred to the launcher structure. However, while heavier pads enhance recoil reduction, they may compromise mobility and field practicality. Therefore, selecting an optimal mass is essential to balance the effectiveness of recoil damping with operational efficiency. Overall, the counter pad mass provides valuable support to the Counter Recoil System, improving safety, comfort, and structural durability [21].

3.6.4 Comparison of the effect of counter pad mass on rocket reach distance.

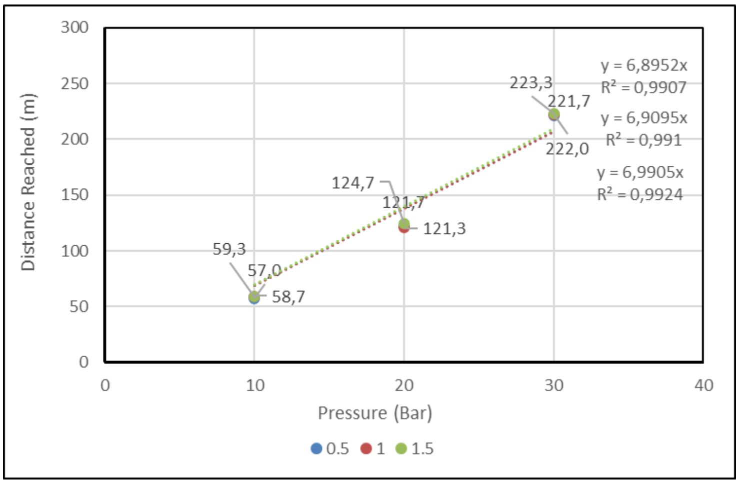


Fig 12. Comparison graph of the effect of variations in counter pad mass on rocket reach distance

Fig. 12. illustrates the effect of counter pad mass variation (0.5 kg, 1 kg, and 1.5 kg) on rocket reach distance at working pressures of 10-30 bar. The results show a strong linear relationship between pressure and projectile distance across all variations, with R^2 values above 0.99. The regression slopes are nearly identical, indicating that each 1 bar increase in pressure extends projectile distance by approximately 6.9 meters, regardless of counter pad mass. This confirms that changes in mass do not significantly affect energy transfer efficiency, but rather influence recoil reduction and launcher stability.

At 10 bar, reach distances were 57.0 m, 58.7 m, and 59.3 m for 0.5, 1, and 1.5 kg, respectively, with negligible differences. At higher pressures, the 1.5 kg mass produced slightly longer ranges (124.7 m at 20 bar and 223.3 m at 30 bar), though the 1 kg configuration achieved nearly equivalent performance (121.3 m and 222.0 m). These results indicate that the Counter Recoil System maintains consistent ballistic performance across varying counter pad masses, allowing operational flexibility while balancing recoil mitigation, stability, and firing range [22].

4 Conclusion

The experimental modification of the Counter-Tank Weapon (CTW) by integrating a counter-recoil mechanism significantly reduced recoil forces while improving launcher performance. The mean recoil force decreased from 27.1 N to 20.3 N at 10 bar and from 81.7 N to 65.7 N at 30 bar. Launch efficiency also improved, with the projectile range increasing from 190.7 m to 221.7 m at 30 bar. Additional inertial tuning using a lever pad mass further reduced recoil, where increasing the pad mass from 0.5 kg to 1.5 kg lowered recoil from 65.67 N to 34.33 N. Two-way ANOVA confirmed that both working pressure and pad mass significantly affect recoil behavior ($p < 0.001$), with the model explaining 98.35% of the variance. While the 1.5 kg counter pad achieved the greatest recoil reduction, its added mass may reduce mobility and operator comfort. The 1.0 kg pad provides a more balanced compromise between damping performance and usability. The proposed counter-recoil mechanism offers an effective passive solution for recoil mitigation while enhancing launch performance. However, this study is limited to short-term testing; future work should address durability, fatigue behavior, ergonomic assessment, and validation under extended and realistic operating conditions to ensure long-term reliability.

References

[1] Rak, L., Zahranicek, P., & Polach, M., “The effectiveness of infantry squad combat and pre-combat formations for warfighting,” International Conference — The Knowledge-Based Organization, vol. 27, no. 1, pp. 106–111, 2021, doi: 10.2478/kbo-2021-0017.

[2] V. M. Khailov, V. Chebotar, and V. Kuzmenko, “Rocket-propelled anti-personnel grenade launchers equipped with different warheads,” Scientific Works of the State Research Institute for Testing and Certification of Weapons and Military Equipment, no. 5, pp. 93–104, Dec. 2020.

[3] A. Silva Da Cruz, “De la robustesse du combattant: le bataillon français de l’ONU en Corée entre 1950 et 1953,” Paris 1, 2023.

[4] E. S. Agustian, “Sistem propulsi roket padat untuk rudal anti tank,” J. Teknol. Kedirgant., vol. 6, no. 2, pp. 23–29, 2021, doi: 10.35894/jtk.v6i2.36.

[5] D. P. Putra, N. Yusman, and M. I. Ali, “Otoranpur aplikasi sistem PCP (Pre – Charge Pneumatic) untuk pendorong anti tank shooting trainer,” J. Otoranpur, 2022.

[6] M. J. Hootman, J. R. Little, and P. D. Smith, “Design and performance analysis of shoulder-launched anti-tank rocket systems,” Def. Technol., vol. 15, no. 4, pp. 512–520, 2019, doi: 10.1016/j.dt.2019.02.004.

[7] E. A. Pane, I. Ismail, F. D. Yudhanto, and B. Suyitno, “Analisis penurunan tekanan aliran udara pada pipa bertekanan,” FLYWHEEL J. Tek. Mesin Untirta, vol. 1, no. 1, p. 13, 2019, doi: 10.36055/fwl.v1i1.3111.

[8] B. Hartono, D. Sugati, and M. Abdulkadir, “Rancang bangun ranque hilsch vortex tube (Rvht),” Cendekia Mek., vol. 01, no. 01, pp. 85–91, 2020.

[9] R. H. Batara, “Rancang bangun meriam pelontar pneumatik 6 bar,” in Proc. Diseminasi FTI Genap 2020/2021, Fak. Teknol. Ind., Institut Teknol. Nasional (Itenas), Bandung, Indonesia, Jun. 14, 2022, pp. 51–57. Available: https://eproceeding.itenas.ac.id/index.php/fti/article/view/680.

[10] Q. Hidayah, U. Salamah, and M. Sasono, “Analysis of water rocket launch test with carbon fiber material using telemetry system,” J. Teori Apl. Fis., vol. 10, no. 1, pp. 81–88, Jan. 2022, doi: 10.23960/jtaf.v10i1.288.

[11] R. Anjani, “Menentukaan Momentum dan koefisien restitusi benda tumbukan menggunakan tracker video analyse,” J. Teach. Learn. Phys., vol. 3, no. 2, pp. 21–25, 2018, doi: 10.15575/jotalp.v3i2.6554.

[12] O. Surya Fanawa and J. Rohman, “Analisa gaya recoil dan desain komponen popor corner shot pada pistol P1 Pindad kaliber 9 mm,” Transmisi, vol. 14, no. 1, pp. 263–273, 2018.

[13] D. E. R. S. Hariadi, F. Sariman, and M. I. Hidayat, “Otomotif kendaraan tempur analisa bahan body roket anti tank latih dengan menggunakan bahan PVC (Polyvinyl Chloride,” J. Otoranpur, 2022.

[14] J. Suprihanto, “Analisis tegangan pada kulit nose cone smoke warhead kaliber 70 mm dengan variasi ketebalan kulit akibat beban jatuh bebas vertikal,” J. Inform. Teknol. dan Sains, vol. 1, no. 2, pp. 21–30, 2023, doi: 10.56244/formateks.v1i2.635.

[15] L. Mccoy, “Analisis pengaruh perubahan massa propelan dan warhead pada roket balistik 122 terhadap titik jatuh roket,” J. TNI Angk. Udara, vol. 2, no. 1, pp. 51–57, 2023, doi: 10.62828/jpb.v2i1.57.

[16] Z. Patrio, “Efektivitas man-portable anti-tank system dalam perang modern : Studi kasus javelin dan NLAW dalam konflik rusia-ukraina,” Hukum, Polit. dan Ilmu Sos., vol. 2, no. 3, pp. 172–182, 2023.

[17] M. Gracia Blanco, “Fuensanta,” La Rev. Nouv., no. 1, pp. 72–77, 2023.

[18] S. Béres and Á. Kovács, “Quality requirements for front and rear support in relation to the precision of a bolt action, big calibre precision rifle,” 2022.

[19] M. Durdevic et al., “Unexpected Hunting Accident: Internal Carotid Artery Dissection Due to Firearm Recoil,” Chest, vol. 164, no. 4, pp. A384--A385, 2023.

[20] L. A. Setiawan, “Assistive technology pada popor senjata ss1-v1 untuk mendukung kestabilan, keseimbangan, keakurasian dan kepresisian menembak bagi prajurit depo pemeliharaan 50 TNI AU,” UNS (Sebelas Maret University), 2022.

[21] M. Y. Kholifudin, “Menentukan koefisien restitusi tumbukan dengan analisis konversi sudut penyimpangan,” J. Penelit. Pembelajaran Fis., vol. 10, no. 1, pp. 64–69, 2019, doi: 10.26877/jp2f.v10i1.3492.

[22] F. A. Rosyadi and A. L. Program, B. Supriadi, “Kajian tumbukan sentral dan tak sentral pada permainan billliards sebagai rancangan bahan ajar fisika sma,” vol. 3, no. 2016, pp. 162–166, 2018.