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Investigation of the Influence of Warhead Shape and Type of Missile Weapon Material Counter-Training Tank Weapons Simulation Approach

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ABSTRACT

This study analyzes the effect of warhead shape and material variations on pressure, temperature, and lift on training missiles using CAD-based simulation methods. The variations of warhead shapes tested include flat, flat radius, and tapered, while the materials used are rubber, ABS, and PE. The simulation results show that the tapered warhead shape with PE material produces the lowest pressure (50.3 MPa) due to more efficient pressure release and low friction properties. Conversely, the Flat shape produces the highest pressure (69.1 MPa) on all materials due to flow stagnation. In terms of temperature, the Flat Radius warhead with PE and Rubber materials has the lowest temperature (~335.56 K) due to flow expansion and low thermal conductivity, while the Tapered warhead with PE has the highest temperature (336.07 K) due to increased fluid velocity, which causes an adiabatic effect. In terms of lift, the tapered warhead with rubber shows the highest value (72.397) due to interaction with the turbulent boundary layer, while the flat radius warhead with rubber has the lowest lift (67.420) due to faster flow separation. These results can be applied in the optimization pf training missile design, jet warhead systems, and aerodynamic vehicles. Further development can include the exploration of alternative materials and the integration of advanced simulation technologies to improve the aerodynamic efficiency and durability of materials.

Keywords: *Material, simulation, training weapon, warhead shape.*

I. Introduction

Missile-based weapons play a vital role in modern military training and defense strategies [1]. The effectiveness of such weapons depends largely on their aerodynamic properties and material composition [2]. This research focuses on analyzing the impact of various warhead geometries and materials on missile performance, especially in a simulated training tank environment. By utilizing simulation techniques, this research aims to provide recommendations for improving missile design.

Recent studies have explored the influence of shape and material on tool performance [3]. Conical and ogive-shaped missile heads found that the conical missile head increased the lift coefficient by 2-11% compared to the ogive design [4]. Missile geometry optimization using multiobjective genetic algorithms, increasing the lift-to-drag ratio by 11-17% at supersonic speeds [5]. Thrust warhead design for scramjet-powered vehicles, noting that longer warheads perform better at higher Mach numbers [6]. Single expansion ramp warhead (SERN) geometry, comparing thrust-optimized parabolic contours and minimum-

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length warhead ramp contours. They found that the thrust-optimized parabolic contour increased the thrust coefficient by 29.2% at (Nuclear Posture Review) NPR 3, while the minimum-length warhead showed an improvement of 56.3% at NPR 3.5. These studies collectively demonstrate the significant impact of shape optimization on missile and warhead performance across a range of flight regimes [7].

Materials play a critical role in missile design and performance. Aluminum alloys are used in impulse thrusters for guidance systems because of their favorable strength-to-weight ratio, but require careful thermal analysis to ensure structural integrity [8]. Microwave absorbing materials are essential for reducing radar cross-section and achieving stealth capabilities on missiles and other air platforms [9]. The choice of warhead filler material has a significant impact on fragmentation characteristics, with axially strengthened designs showing improved fragment quality and distribution over traditional cylindrical warheads [10]. In solid propellants, polymers serve as binders for oxidizer and fuel particles in composite propellants, with ongoing research focused on improving performance and developing “insensitive ammunition” that is resistant to accidental ignition [11].

Missile simulation research covers various aspects of the missile system, including trajectory modeling, guidance systems, and equipment support. Six-degree-of-freedom digital simulation is used to verify design indicators and performance parameters, reducing the time and cost of field testing [12]. A real-time hardware-in-the-loop (HIL) simulation platform has been developed for television guidance (TG guidance) systems, offering high precision and a compact structure [13]. The parameterization dynamics visual design platform enables seamless transfer between geometric and dynamics models for missile launch systems, facilitating efficient design and analysis processes [14].

A mission-oriented modeling framework for missile equipment support systems, taking into account failure events and health degradation, has been proposed to improve equipment availability and optimize support resources throughout the life cycle [15]. These advances in missile simulation contribute to more efficient design, testing, and maintenance of missile systems [16].

This research is important because it provides insight into how the design of the missile warhead and materials affect effectiveness in military training scenarios. Using a simulation approach, this study identifies optimal design parameters that can improve the aerodynamic stability of the missile [17]. The result can be used to develop more efficient, realistic, and safe weapon technology in military training. In addition, this research helps reduce the reliance on expensive and risky live trials by offering a more cost-effective and flexible simulation-based solution.

II. Material and Methods

This study uses a simulation method using the CAD (Computer Aided Design) program, SolidWorks 2022 flow simulation. This simulation begins by designing a training missile with a variety of warhead shapes, as shown in Figure 1, then using the flow simulation feature available in SolidWorks 2022 to determine the pressure, resistance and lift on the training missile, after that inputting parameters as conditions during training using weapons against training tanks whose tools, are shown in Figure 2. The simulation results are automatically shown when the simulation is complete; an example of the results is shown in Figure 3. The results used are the simulation results with the highest values.

The warhead of a missile or projectile is a critical area for ballistic performance and measurement. The warhead can be used for self-velocity testing on small-caliber [18]. The study uses a variation in missile warhead designs, namely: flat, flat radius, and pointed as in Figure 1, and the variations in the types of materials used are: rubber, ABS (Acrylonitrile Butadiene Styrene), and PE (Polyethylene) which have mechanical properties as in Table 1, the mechanical properties of the material are based on the data available in SolidWorks 2022 software. Variations in missile warhead designs and variations in the types of materials were chosen because they are commonly found on the market [19], [20].

Fig. 1. Warhead shape variations: (a) Flat warhead, (b) Flat warhead with radius, and (c) Tapered warhead

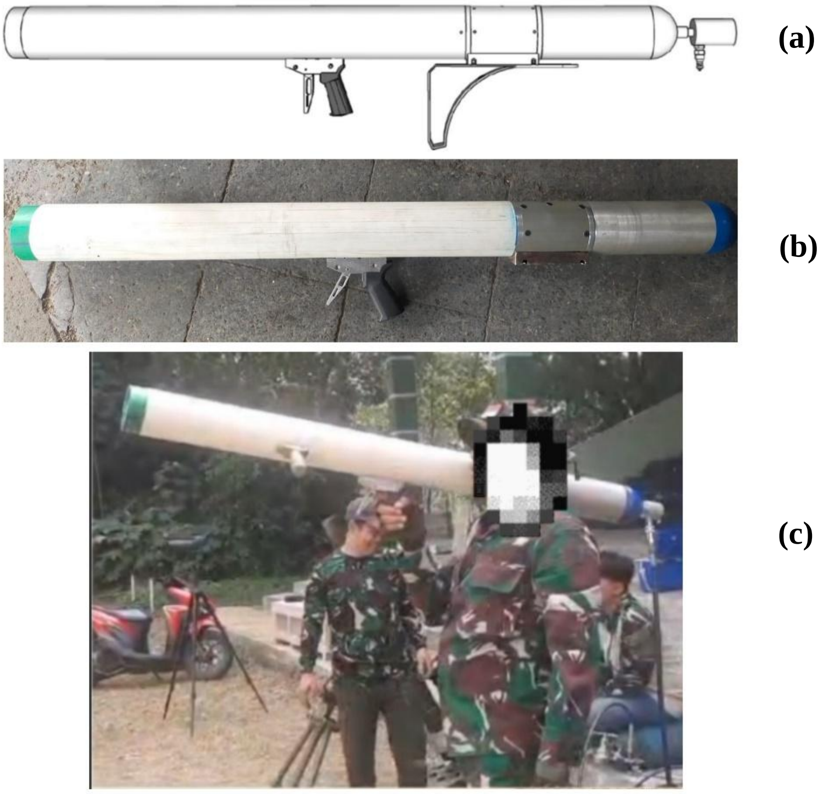
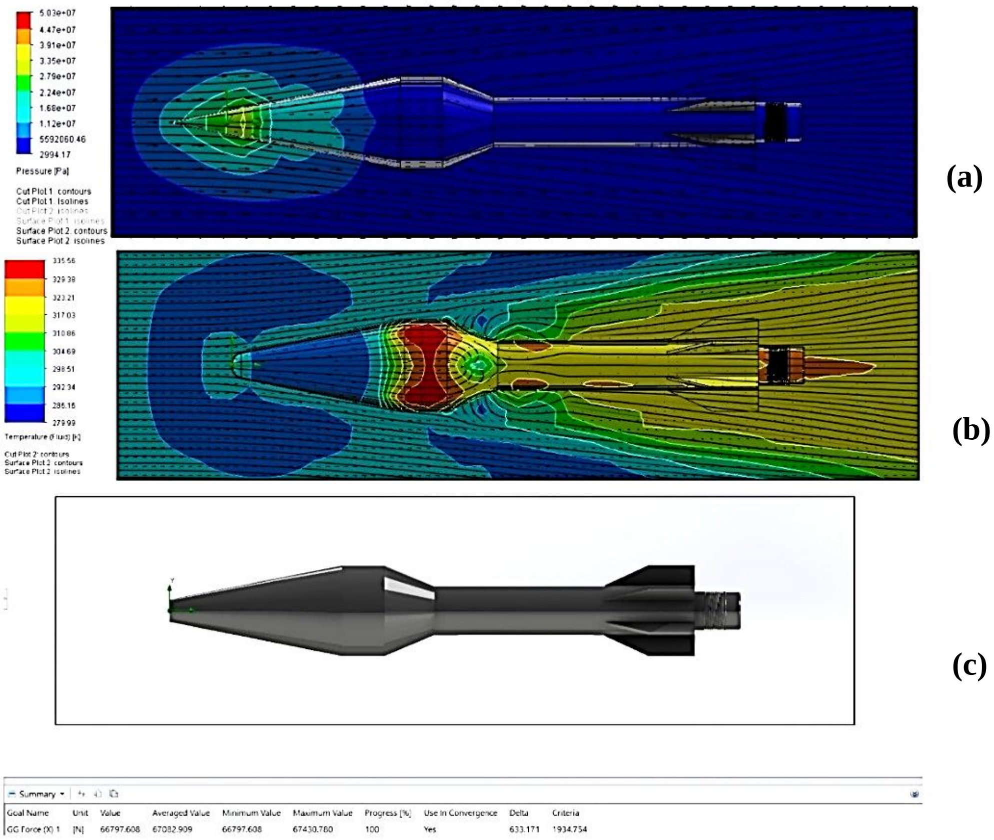


Fig. 2. Counter-training tank weapons: (a) Design of counter-training tank weapons, (b) finished form of counter-training tank weapons, and (c) implementation form of counter-training tank weapons.



Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Force (X) 1	[N]	66797.608	67082.909	66797.608	67430.780	100	Yes	633.171	1934.754

Fig. 3. Examples of simulation results: (a) Result pressure from tapered warhead made of PE, (b) Result temperature from flat warhead with radius made of PE, and (c) Result lift force from flat warhead made of PE.

Table 1. Mechanical properties of materials based on the SolidWorks software

	Rubber	ABS	PE
Elastic modulus (N/m^2)	6100000	2E+09	1.86E+09
Poisson's ratio	0.49	0.394	-
Shear modulus (N/m^2	2900000	3.19E+08	-
Mass density (kg/m^3)	1000	1020	950
Tensile strength (N/m^2)	13787100	30000000	31000000
Yield strength (N/m^2)	9237370	-	-
Thermal expansion coefficient (/K)	0.00067	-	-
Thermal conductivity (W/(m·K))	0.14	0.2256	0.48
Specific heat (J/(kg·K)	-	1386	-

This research uses SolidWorks software, whose missile design is based on the design of the original training missile used for training, as shown in Figure 4.

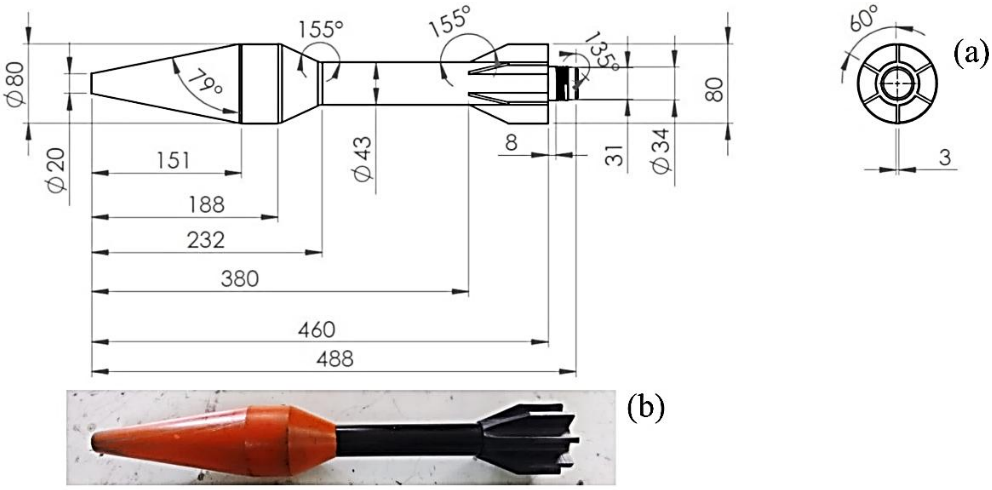


Fig. 4. General design of the missiles used: (a) Missile dimensions, (b) Original missile.

The research uses the parameters that have been set as in Figure 5 and Table 2. In this parameter, the mesh size uses the size recommended by the SolidWorks software and has been automatically set by the system.

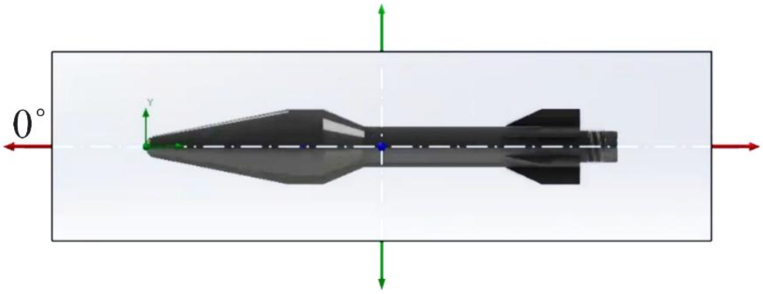


Fig. 5. Simulation elevation angle

Table 2. Parameters of simulation

Parameters of simulation	
Specimen size	Ø80× Ø80 ×488
Elevation angle	0˚
Constant speed	565.46 m/s
Warhead shape type	Flat, flat radius, and tapered
Initial temperature	293.2 K
Initial pressure	101325 Pa
Mesh size	3 mm
Warhead material type	Rubber, ABS, and PE

III. Results and Discussions

The simulation process to determine the pressure was carried out 9 times based on the parameters specified in Table 2, and the simulation results are shown in Table 3. Based on Table 3, it can be seen that the highest pressure value of 69100000 Pa occurred in the flat warhead with ABS, Rubber, and PE material types, and the lowest value of 50300000 Pa occurred in the tapered warhead with PE material type, this shows that the most effective parameters in reducing pressure are the tapered warhead shape and PE material type because they have the lowest pressure.

Table 3. Pressure simulation results

Warhead	Material	Pressure (Pa)
Flat Radius	ABS	62600000
	Rubber	62600000
	PE	62900000
Flat	ABS	69100000
	Rubber	69100000
	PE	69100000
Tapered	ABS	50900000
	Rubber	50800000
	PE	50300000

Based on Figure 6, the decrease in pressure value occurs in the tapered warhead shape with PE material, This is because the tapered shape allows for more efficient pressure release, while the PE material, with its flexible properties and low friction coefficient, further optimizes the pressure reduction [21], [22]. Therefore, the combination of the tapered shape and PE material produces the smallest pressure compared to other combinations. In the warhead flat radius shape, the PE material experiences increased pressure due to the stagnation effect, increased gas flow contact area, and greater aerodynamic resistance compared to the Tapered shape. While PE has elastic properties that help reduce pressure, the shape effect still dominates, so the pressure remains higher than a more aerodynamic design, such as a tapered [23]. While in the form of a flat warhead with different material variations, the pressure that occurs is constant. Constant pressure on the flat warhead for PE, ABS, and rubber occurs because the flat shape causes uniform pressure stagnation, where variations in material properties are not significant enough to affect the pressure pattern. [24]. In this case, geometry is more dominant than material characteristics in determining the pressure distribution.

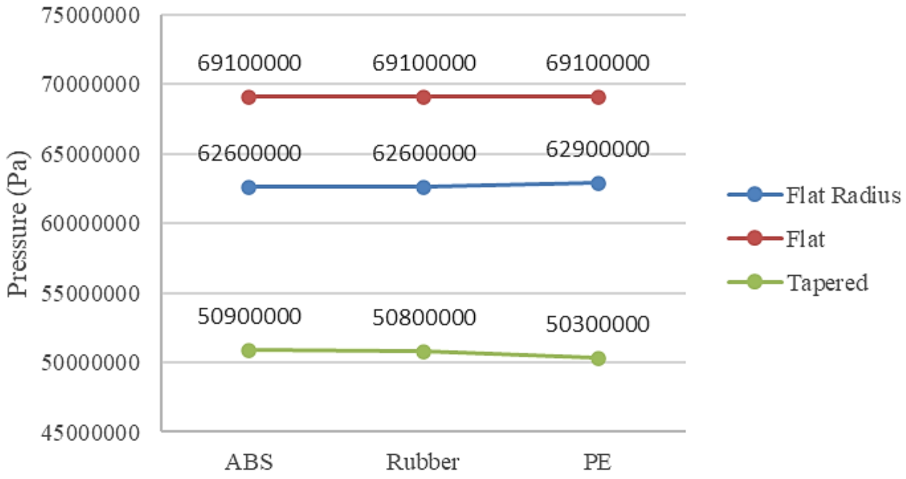


Fig. 6. Pressure simulation results graph

Table 4 shows the simulation results on missile temperature. The tapered warhead shape with PE material has the highest temperature of 336.07 Kelvin (K) and the lowest flat radius warhead shape with rubber and PE material of 335.56 K, this shows that the most effective parameter in reducing temperature is the flat radius warhead shape with PE and Rubber material because it has the smallest temperature.

Table 4. Temperature simulation results

Warhead	Material	Temperature (K)
Flat Radius	ABS	335.7
	Rubber	335.56
	PE	335.56
Flat	ABS	335.63
	Rubber	335.63
	PE	335.63
Tapered	ABS	336.05
	Rubber	336.06
	PE	336.07

Based on Figure 7, there is a decrease in temperature in the warhead flat radius form, namely in rubber and PE materials, which is caused by a combination of flow expansion which reduces pressure and temperature, low thermal conductivity, high specific heat capacity, and lower friction compared to ABS [21]. This causes heat to be more difficult to accumulate in the system, so the temperature is lower than other combinations. In a flat warhead with constant temperature material variations, uniform flow stagnation, the conversion of kinetic energy into heat is the same, and the minimal influence of thermal conductivity and material friction [25]. In this case, the warhead geometry is more dominant in determining the temperature than the material characteristics. While the tapered warhead shape experienced an increase in temperature, with the highest being 336.07 K from PE material, due to a combination of several physical and thermal factors that affect the fluid flow in the warhead. The tapered shape causes a narrowing of the flow, which increases the fluid velocity when passing through the section [26]. When the fluid velocity increases in a narrowed space, there is a decrease in pressure [27]. However, in adiabatic conditions, this pressure drop is often accompanied by an increase in temperature to maintain the energy balance in the system. In addition, the thermal properties of polyethylene (PE) play an important role in this process. PE has low thermal conductivity, so that the heat generated due to friction and flow acceleration cannot be quickly conducted to other parts or released into the environment [28]. As a result, heat energy tends to be trapped in the system, causing temperatures to rise higher than with other warhead shapes. Additional contributing factors are internal friction and fluid viscosity. At high velocities in a tapered warhead, there is increased interaction between the fluid and the warhead walls, which generates additional heat due to frictional effects [39]. In contrast to the flat radius shape, which allows for flow expansion and natural cooling, the tapered shape actually accelerates the flow without providing an opportunity for expansion, so the natural cooling mechanism is reduced, causing the temperature to increase [30].

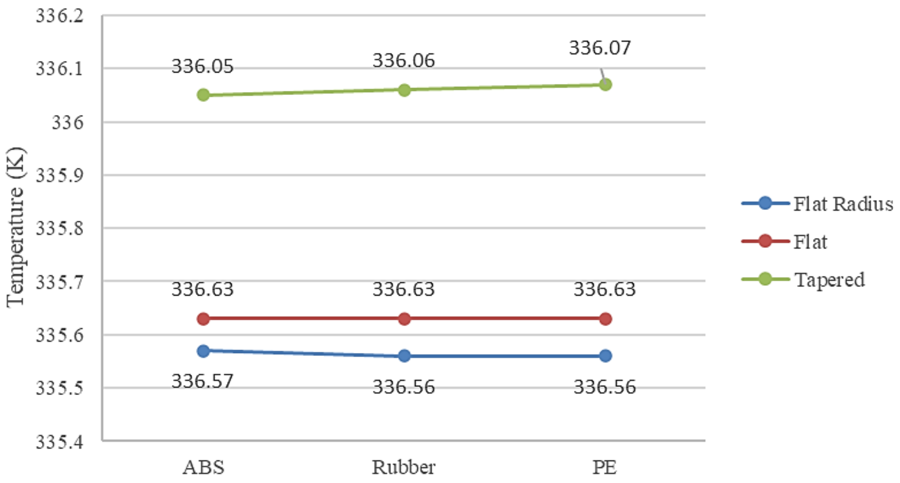


Fig. 7. Temperature simulation results graph

Table 5 shows the simulation results on the missile lift force. The tapered warhead shape with rubber material has the highest lift force of 71.397 N and the lowest is the flat radius warhead shape with rubber material of 67.420 N, this shows that the most effective parameter in reducing the lift force is the flat radius warhead shape with rubber material because it has the smallest lift force.

Table 5. Lift force simulation results

Warhead	Material	Lifting Force (N)
Flat Radius	ABS	67.539
	Rubber	67.571
	PE	67.560
Flat	ABS	67.450
	Rubber	67.420
	PE	67.431
Tapered	ABS	71.388
	Rubber	71.397
	PE	67.560

As shown in Figure 8, there is an increase in lift force in the tapered warhead shape with rubber material, but it decreases in PE material due to differences in material characteristics that affect the interaction with the air flow and the distribution of aerodynamic pressure around the warhead. Rubber material has viscoelastic properties and a rougher surface than PE, so it is able to create a more stable turbulent boundary layer [31]. This boundary layer helps maintain optimal airflow around the warhead, increasing the pressure difference between the upper and lower sides, which ultimately results in greater lift. In addition, the elastic properties of rubber allow for micro deformations that can adjust the pressure distribution more efficiently, thus supporting increased lift [32]. In contrast, in PE materials, the smoother surface causes a more laminar boundary layer, which reduces the turbulence effect needed to maintain higher lift [33]. In addition, because PE is lighter and stiffer than Rubber, this material is more susceptible to aerodynamic disturbances and oscillations due to unstable airflow [34]. As a result, the aerodynamic pressure acting on the warhead decreases, so that the lift force becomes smaller. In addition to surface and viscosity factors, the difference in density between the two materials also has an effect. Rubber has a higher density than PE, so the mass distribution on the warhead is more stable, helping to maintain greater lift [35]. On the other hand, because PE is lighter, this material is less able to withstand air pressure fluctuations, which results in reduced lift efficiency [36].

The flat radius warhead shape also experiences a similar thing but with a lower lift value than the tapered warhead shape. The decrease in lift on the flat radius warhead compared to the tapered warhead is caused by differences in pressure distribution and airflow characteristics formed around the warhead. In the tapered warhead, the tapered shape causes a narrowing of the airflow, which increases the fluid velocity as it passes through the warhead [37]. This increased velocity creates a greater pressure difference between the top and bottom of the warhead, resulting in higher lift. In addition, the tapered shape helps maintain a turbulent boundary layer, which keeps the airflow stable and supports increased lift [38]. In contrast, with the flat radius warhead, its blunter shape causes more gradual changes in air flow [39]. As a result, the airflow does not experience significant acceleration, so the resulting pressure difference is smaller compared to the tapered warhead. In addition, the flat radius shape also causes flow separation to occur faster, which reduces the low-pressure zone at the rear of the warhead and reduces overall lift. In terms of material, rubber still shows higher lift than PE, because it has better interaction with the turbulent boundary layer. However, although rubber still maintains a better pressure difference than PE, the resulting lift value remains lower than the tapered warhead, due to limitations in maintaining optimal aerodynamic pressure distribution [40].

Meanwhile, on a flat warhead, the opposite occurs, on rubber material, the lifting force decreases, and on PE material, the lifting force increases. In the flat warhead, there is an opposite phenomenon compared to the tapered or flat radius warhead, where the rubber material experiences a decrease in lift force, while the PE material experiences an increase in lift force. This difference is caused by the interaction between the characteristics of the material and the air flow pattern formed around the warhead. The flat warhead shape causes flow separation to occur faster after the air passes through the tip of the warhead [41]. This reduces the effect of pressure differences, which are usually the main factor in producing lift.

With this condition, the material properties become a more dominant factor in determining the change in lift. In rubber materials, which have a more elastic and rough surface, the interaction with the air flow becomes less stable. The roughness of the rubber surface causes disturbances in the air flow, accelerates the flow separation, and causes the pressure distribution to be more balanced between the upper and lower sides of the warhead pressure distribution to be more balaced between the upper and lower sides of the warhead [42]. As a result, the pressure difference is reduced, so the lift force decreases. In contrast, PE material, which has a smoother and stiffer surface, is able to maintain a more stable flow boundary layer around the warhead [43]. Because the surface is smoother, the air flow tends to remain laminar longer, so that the flow separation occurs more controlled. This causes a greater pressure difference between the upper and lower sides of the warhead, which ultimately increases the lift force on the PE material compared to the rubber material. In addition, the density and elasticity of the material also have an effect. The heavier and more flexible rubber material can experience micro deformation due to aerodynamic pressure, which causes the pressure distribution to be less stable [44]. In contrast, lighter and stiffer PE retains its shape, so aerodynamic pressure can work more effectively to increase lift. [43].

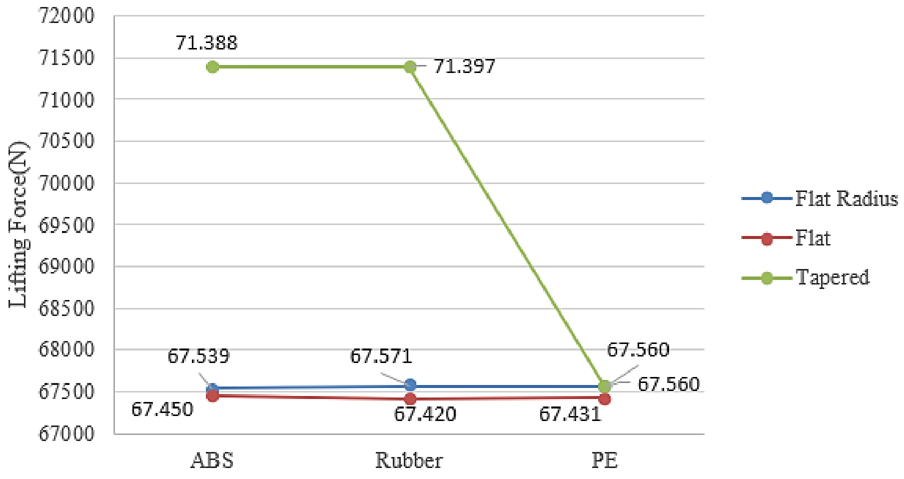


Fig. 8. Lift force simulation results graph

IV. Conclusions

Based on the simulation results, it can be concluded that the warhead shape and the type of material used have a significant effect on the pressure, temperature, and lift generated. Overall, the selection of warhead shape and material type must be adjusted to the desired aerodynamic and thermal needs. If the main goal is to reduce pressure, then the tapered warhead shape with PE material is the best choice. If the priority is to reduce temperature, the flat radius shape with PE or rubber material is more effective. Meanwhile, if what is desired is to increase lift, then the tapered shape with rubber material is more optimal, while the flat radius shape is less recommended because it produces the lowest lift. Thus, the combination of the right warhead design and material will greatly depend on the specific needs of the application used.

In terms of further development, this research can be directed at optimizing the warhead design by combining the characteristics of the tapered and flat radius shapes to obtain a balance between pressure reduction and increased aerodynamics. In addition, exploration of alternative materials, such as polymer composites reinforced with carbon fiber or glass fiber, can provide more optimal mechanical and thermal properties, increasing resistance to high pressure and temperature. In terms of future applications, this research has great potential in various industries, especially in defense and military, where a more optimal warhead design can improve the accuracy of projectiles and training missiles, as well as reduce wear due to high pressure. In addition, in the aerospace industry, the result of this research can be applied to the design of jet warheads and small rocket exhaust to improve thrust efficiency and reduce heat generation.

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