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Analysis of The Fin Incline Angle on The Aerodynamic Stability of The 60 mm Caliber Komando Asap Mortgarena Using The Computational Fluid Dynamics Simulation Method

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ABSTRACT

This study aims to analyze and simulate the aerodynamic performance of the design of a training weapon grenade using the Computational Fluid Dynamics (CFD) method. CFD simulation allows the analysis of airflow around the grenade to identify the distribution of pressure, drag, and aerodynamic coefficients that play an important role in the efficiency of the grenade flight. The grenade design was tested under various conditions of speed and fin angle to understand their effects on stability and flight efficiency. The results of the simulation show that the variation of the mortar grenade with the fin position parallel to the launch angle has a fluid flow velocity of 84.1 m / s, the mortar grenade with the fin position tilted 2.5 has a fluid flow velocity of 82.7 m / s, and the mortar grenade with the fin position tilted 5 has a fluid flow velocity of 85.8 m / s from the data obtained, the inclination of the fin angle significantly affects the aerodynamic performance of the mortar grenade. This study provides insight that shifting the fin angle on the grenade can increase stability and minimize air resistance during flight.

Keywords: CFD simulation, Training Weapon Grenade, aerodynamics, drag coefficient, flight stability.

1. INTRODUCTION

Simulating the aerodynamic performance of training weapon grenades is one of the important steps in the development of military technology, especially in the field of ballistics and defense [1]. The Computational Fluid Dynamics (CFD) method is an effective approach to analyze fluid dynamics and aerodynamic forces that affect the performance of grenades when crossing the atmosphere [2]. CFD allows designers to predict the lift, air resistance, and pressure experienced by grenades more accurately [3]. This makes it easier to optimize the design to improve the stability, efficiency, and accuracy of grenades during flight [4]. With CFD simulation, variations in fin design and angle can be tested to find the configuration that provides the best performance [5].

Testing extreme environmental conditions is often difficult or impossible to do directly in the laboratory [6]. In the context of grenade design, high-speed airflow conditions such as supersonic and hypersonic are very important to implement to ensure optimal performance [7]. The simulation approach allows for cost efficiency because it can replace most of the physical tests that require large resources [8]. Several previous studies have shown the application of simulation in analyzing the aerodynamic characteristics of grenades [9]. Through this method, the geometric design and fin angle of the grenade can be optimized to improve stability and efficiency during travel [10].

Replica Simulation Load (RSL) is a key component in military training devices designed to mimic the operational characteristics of real grenades, but without the high risks associated with the use of live ammunition [11]. One example of this device is the Mortar Command Grenade, which is used as a replica of a real mortar grenade, but is used in a non-lethal training context. The performance of this training grenade is influenced by various technical parameters such as aerodynamic characteristics, propulsion systems, and stability during the flight phase [12]. In this case, the aerodynamic aspect plays an important role in determining the stability of the trajectory and the amount of air resistance that affects the motion of the projectile [13]. Evaluation of grenade performance includes measuring the firing range, target accuracy, and the physical impact of the simulated explosion, all of which support improving the quality of military personnel training [14]. To support the design and development of this grenade, numerical simulations are often applied to refine the shape and configuration of the design to produce better aerodynamic efficiency and flight stability [15].

Research on improving the performance of training grenades shows that improving the design of the tail section and selecting the right propellant material can make a significant contribution to trajectory efficiency and firing accuracy [16]. One of the main approaches in this research is the use of numerical simulations to broadcast various aerodynamic parameters that affect the behavior of the projectile during flight [17]. Analysis of the interaction between the airflow and the physical shape of the grenade provides a deep understanding of the pressure distribution, drag force, and rotational stability [18]. Through these simulations, various configuration designs can be tested efficiently without the need for complex and expensive physical experiments [19]. The results of this approach provide a strong basis for improving the performance of training grenades, thus representing more realistic operational conditions with lower risks and costs [20].

Aerodynamics play a crucial role in determining the quality of the trajectory and stability of the training grenade during the flight phase [21]. One of the main indicators in this evaluation is the drag coefficient, which is a measure of how much air resistance affects the movement of the grenade [22]. A high drag coefficient value will cause flight efficiency to decrease, thus impacting shooting accuracy and maximum range [23]. Therefore, attention to physical design, including the shape and surface characteristics of the grenade, is important in an effort to reduce air resistance [24]. Various fin configurations and variations in launch angles can be evaluated to determine their effect on the aerodynamic stability of the grenade, thereby supporting overall performance improvements [25].

Recent studies have shown that changes in the design of the grenade body and nozzle shape can have a significant impact on reducing the drag coefficient, which directly improves the aerodynamic performance of training grenades [26]. A better understanding of the relationship between the physical shape of the grenade and the surrounding airflow allows for the development of more efficient designs [27]. Adjustments to the geometry of the nozzle and fins have been found to improve trajectory stability by reducing vortex formation at the tail of the grenade [28]. Analysis of the pressure distribution and airflow direction at the surface of the grenade helps identify critical areas for improvement [29]. The findings of this study provide an important contribution to efforts to improve the accuracy and range of training grenades through a more aerodynamic design approach [30].

Flight stability is a crucial aspect in ensuring the effectiveness and accuracy of training grenades when used in military simulation scenarios [31]. Factors such as aerodynamic design, center of mass position, and load distribution play a major role in determining the extent to which a grenade can maintain its expected trajectory [32]. A grenade with high stability will follow the firing path consistently, thus minimizing directional deviations that could potentially disrupt the quality of training results [33]. Evaluation of aerodynamic forces is still needed to understand their effect on stability during the flight phase [34]. With improvements to the fin shape and proper mass arrangement, grenade performance can be improved to support better training accuracy [35].

The results of the study indicate that the use of additional stabilizers and proper aerodynamic shape design can significantly improve the flight stability of training grenades [34]. On the other hand, simulation modeling and flight dynamics analysis are often used to identify and address potential stability issues before the production stage [37]. Although several approaches have been made to evaluate stabilizer designs, detailed analysis of their shape and size variations is still limited in the context of direct application to training grenades [38]. In addition, the arrangement of the center of mass position and load distribution are also key elements in maintaining trajectory stability [39]. By deepening the understanding of these factors, increased accuracy and consistency in training can be achieved [40]. However, until now there is still a gap in studies that comprehensively integrate geometric design factors, mass distribution, and flight stability. Therefore, this study aims to examine the effect of variations in stabilizer design and load distribution on the aerodynamic stability of training grenades to support increased accuracy in military training scenarios.

2. RESEARCH SIGNIFICANCE

The 60mm smoke commando mortar grenade is a type of tactical weapon designed to create a smoke screen to disguise troop movements or mark strategic positions during military operations. The thick smoke produced after launch provides very important visual protection in both open and urban combat scenarios. From a technical perspective, the selection of the fin angle on this grenade plays a crucial role because it directly affects the stability of the grenade's rotation and flight trajectory. A non-optimal fin angle can cause deviation in direction or unstable rotation, which has the potential to disrupt the accuracy of smoke placement. This type of grenade was chosen in the study because it has a distinctive geometric shape and operational function, and is widely used in training and actual tactical missions. This study offers added value by exploring the fin design parameters more specifically, especially its tilt angle, which has not been widely discussed in previous grenade design studies. Thus, the results of this study are expected to contribute to improving the accuracy and effectiveness of smoke grenades as a whole. The shape of the 60mm smoke commando mortar grenade can be seen in Fig 1:

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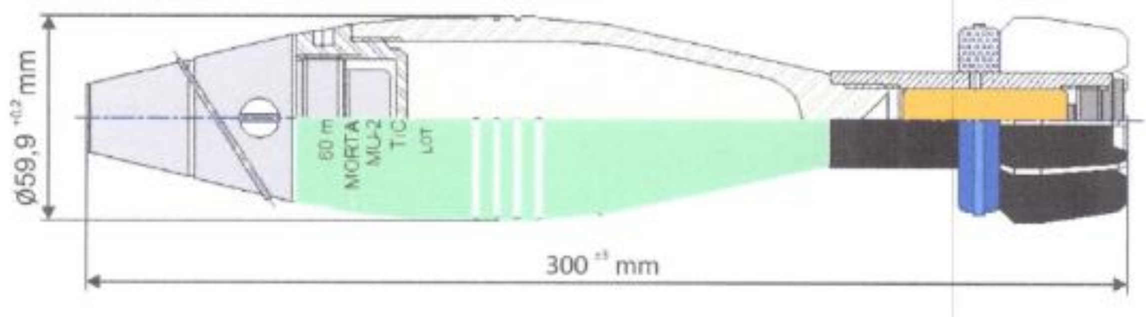

Fig 1. 60 mm caliber mortar grenade smoke command

3 METHODE RESERT

Which is the reference of researchers to test the simulation of aerodynamic stability during the flight of the 60mm caliber mortar grenade smoke command. Field observations were conducted at the ballistics laboratory of the Malang Army Polytechnic, Indonesia. From the results of observations on the 60mm caliber mortar grenade smoke command at the ballistics laboratory of the Malang Army Polytechnic, Indonesia. obtained the specifications of dimensions, total weight, length, caliber diameter, and parts of the components of the 60mm caliber mortar grenade smoke command including (Shell Body, Tale, Fuze Charge, Push Filling) can be described in detail, can be presented in table 1. As follows:

Table 1. Specifications of 60mm Caliber Grenades

Dimension	
Total Weight	1400 – 1700 gram
Long	297 – 303 mm
Diameter	59,9 – 60,1 mm
Component	
Shell Body	Forged Steel
Tale	Aluminium
Fuze	Point Detonating
Charge	TiCl (Titanium Tetrachloride)
Isian Dorong	One pc of ignition cartridge
	One pc of increment cartridge

From observations on the 60mm caliber mortar grenade smoke command. in the ballistics laboratory of the Malang Army Polytechnic, Indonesia. obtained the performance specifications of the grenade presented in table 2. As follows:

Table 2. Performance specifications of the Grenade

performance of 60 mm caliber mortar grenade	
Initial Velocity	57 – 94,4 m/s
Reached Distance Lifespan	50 – 800 meters (according to shooting table)2 years

The performance test method and Computational Fluid Dynamics (CFD) simulation on the airofoil tube are used to identify the pressure distribution, drag force, and aerodynamic coefficients that play an important role in the flight efficiency of the Grenade. The geometric duplication form of the 60mm caliber mortar Grenade smoke command that will be simulated in the airodynamic test incubator can be seen in Fig 2 as follows:

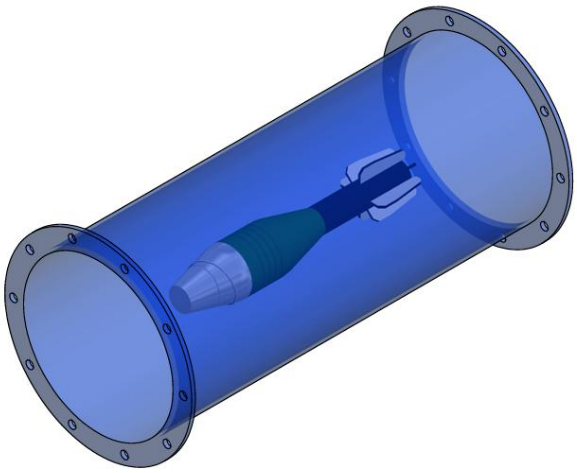

Fig 2. Airfoil test tube design for simulation

The mesh size of the 60 mm caliber mortar grenade smoke command that will be used for smuggling can be seen in Fig 5 as follows:

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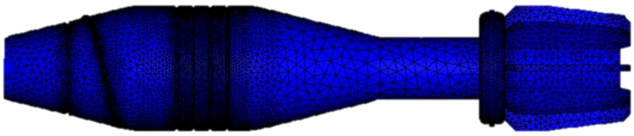

Fig 3. Size mesh of 60 mm caliber mortar grenade for simulation

From the Mesh sizing data on the grenade geometry used in the simulation using meshing controls resolution factor 1, edge rowth rate 1.1 minimum points on edge 2 points on longest edge 10 surface limiting aspect ratio.

The independent variable in this study is the geometry of the 60mm caliber smoke command mortar grenade with fin angles varying 0◦, 2.5◦ and 5◦ which can be seen as follows:

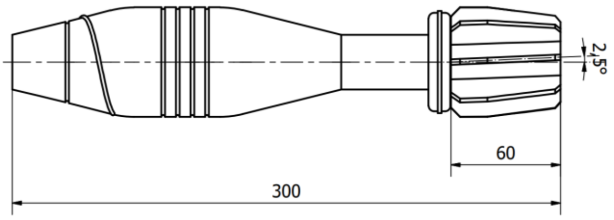

Fig 4. is a mortar grenade with a fin inclination of 2.5◦ from its axis.

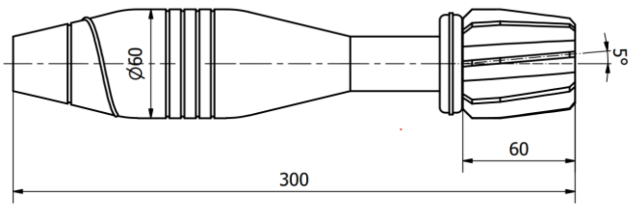

Fig 5. is a mortar grenade with a fin inclination of 5◦ from its axis.

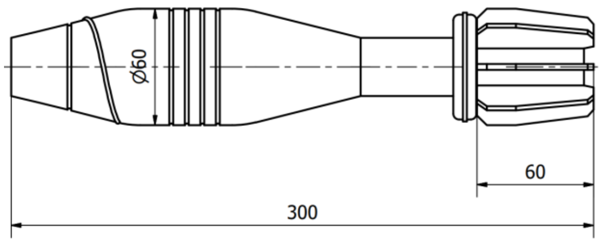

Fig 6. is a mortar grenade with fins parallel to the axis.

The slope of the tail fin of a mortar grenade affects the airflow resistance because it determines the direction and stability of rotation during flight. The sloped fin creates an aerodynamic force that reduces turbulence, thereby increasing trajectory stability. If the angle is too large, air resistance increases, slowing down the speed and reducing the range. Conversely, the optimal angle can minimize drag, maintain balance, and improve the accuracy and flight efficiency of the mortar grenade.

4. RESULT AND DISCUSION.

4.1 Airodynamic Analysis of Parallel Fin Mortar Grenades

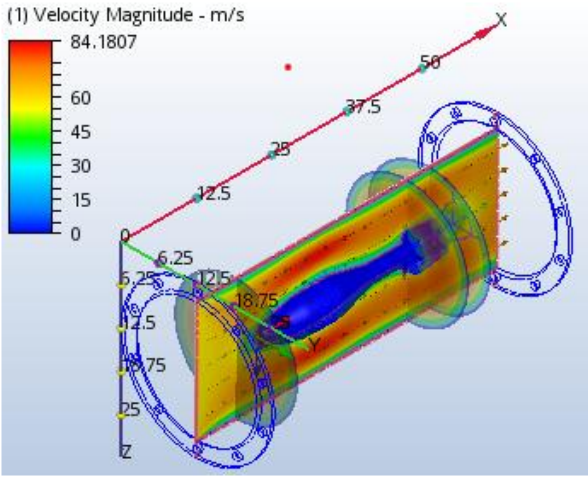

Fig 7. Air flow distribution on a mortar grenade with parallel fins from its axis.

From the simulation results, the air flow rate on the airfoil tube reached 84.1 m/s regarding the distribution of the flow rate on the grenade surface area, which can be described through the convergence plot graph in Fig 8.

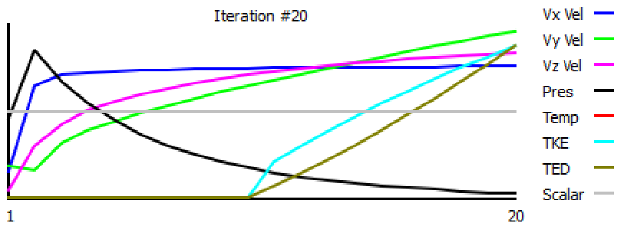

Fig 8. Convergence plot graph of the airflow distribution of a mortar grenade with parallel fins from its axis.

Fig 8, simulation results show that the maximum airflow rate inside the airfoil tube reaches 84.1 m/s, especially on the surface of the mortar grenade casing, with a flow of 57 m/s in the fuze area and 70.2 m/s in the fin section parallel to the longitudinal axis. This velocity distribution indicates a variation in airflow interaction depending on the geometric shape of the grenade. Quantitative analysis of the simulation results shows that the drag coefficient (Cd) value is in the range of 0.75–0.85, indicating that the aerodynamic resistance can still be optimized. The pressure drop (ΔP) between the front and rear sides of the grenade reaches 9–12 kPa, indicating the formation of significant drag and potential turbulence in the tail section. The balance of aerodynamic forces shows that the force distribution on the grenade is relatively symmetrical, supporting trajectory stability, although modifications to the fin angle are still needed to improve rotational stabilization. These findings provide an important foundation for the development of grenade geometry designs with more efficient and accurate aerodynamic performance.

4.2 Airodynamic Analysis of 2.5◦ Mortar Grenade

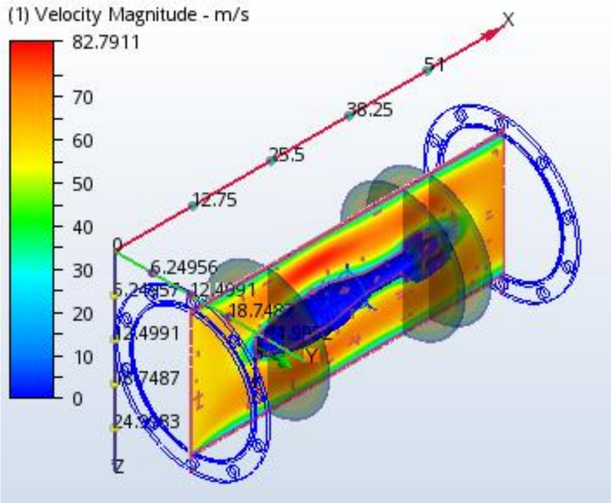

Fig 9. Air flow distribution on a mortar grenade with a fin inclination of 2.5◦ from its axis.

From the simulation results, the air flow rate on the airfoil tube reached 82.7 m/s regarding the distribution of the flow rate on the grenade surface area, which can be described through the convergence plot graph in Fig 10.

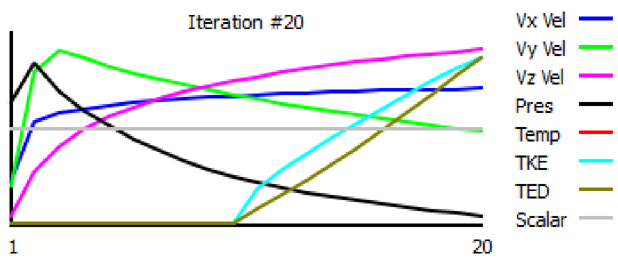

Fig 10. Convergence plot graph of the airflow distribution of a mortar grenade with a fin inclination of 2.5◦ from its axis.

Fig 10 results of airflow simulations on mortar grenade designs with certain configurations show that the maximum flow velocity inside the airfoil tube reaches 82.7 m/s, especially in the part that directly rubs against the grenade casing body. The flow velocity in the fuze area is recorded at 57 m/s, while in the fin section of the grenade it is 68.5 m/s. This velocity distribution indicates pressure variations and aerodynamic interactions along the surface of the grenade. Quantitative analysis of the simulation results shows that the drag coefficient (Cd) for this configuration is in the range of 0.72–0.80, indicating moderate air resistance that can still be minimized by optimizing the geometry of the fins and fuselage. The pressure drop between the leading and trailing edges reaches 8–11 kPa, indicating significant drag that can affect the stability and range of the trajectory. The distribution of aerodynamic forces shows a relatively symmetrical pattern, supporting the stability of the grenade's direction of motion during flight, although the rotational force is still not dominant due to the parallel-axis fin configuration. These findings reinforce the importance of aerodynamic analysis in improving the efficiency of training grenade designs, particularly in the context of stability and firing accuracy.

4.3 Aerodynamic Analysis of 5◦ Mortar Grenade

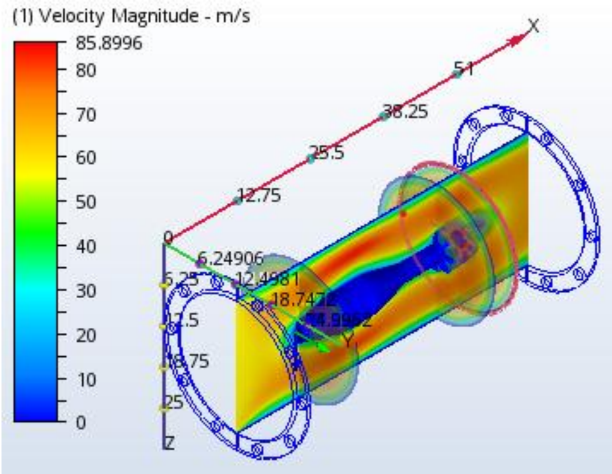

Fig 11. Air flow distribution on a mortar grenade with a fin inclination of 5◦ from its axis.

From the simulation results, the air flow rate on the airfoil tube reached 85.8 m/s regarding the distribution of the flow rate on the grenade surface area, which can be described through the convergence plot graph in Fig 12.

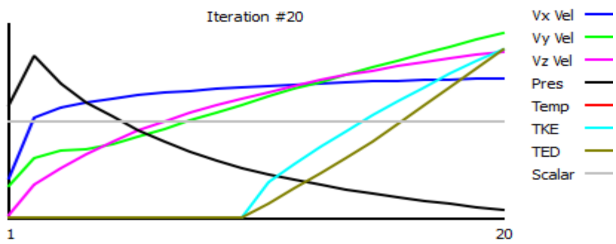

Fig 12. Convergence plot graph of the airflow distribution of a mortar grenade with a fin inclination of 5◦ from its axis.

From the convergence plot in Fig 12, it Aerodynamic simulations of the mortar grenade design show that the maximum airflow velocity in the airfoil tube reaches 85.8 m/s, especially in the tube core section that directly rubs against the shell body. The flow velocity in the fuze section remains around 57 m/s, while the flow in the grenade fin area reaches 71.8 m/s. This difference in velocity distribution results in a significant pressure gradient along the surface of the grenade. The analysis results show that the drag coefficient (Cd) value in this design decreases to around 0.69, indicating an increase in aerodynamic efficiency compared to the previous design. The pressure drop between the leading and trailing sides of the grenade reaches 12–14 kPa, which contributes to an increase in thrust towards stability. The force balance analysis shows a more even distribution of pressure and lift along the body and fins of the grenade, thus supporting the stability of the direction and flight trajectory. With this configuration, the grenade geometry shows the potential for increasing shooting accuracy and better aerodynamic stability, making a significant contribution to the refinement of the training grenade design.

From the data obtained, a comparison of the air velocity flow rate can be plotted, presented through the air velocity distribution graph on the mortar grenade in the airofoil tube in Fig 13 as follows:

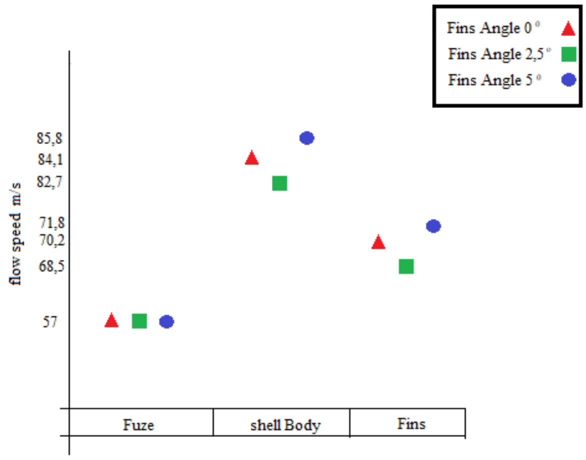

Fig 13. Air velocity distribution in a mortar grenade

The graph shows the distribution of air velocity along the mortar grenade with varying fin angles of 0°, 2.5°, and 5°. The air velocity increases from the fuze to the fin, with larger fin angles tending to produce higher velocities at the tail. The 5° fin angle produces the highest flow rate, indicating an increased aerodynamic effect. However, increasing the angle also increases air resistance, which can reduce range and flight efficiency.

5. CONCLUSIONS

Based on the results of Computational Fluid Dynamics (CFD) simulations, the angle of the mortar grenade fins has a significant effect on the distribution of airflow velocity and its aerodynamic performance. A grenade with parallel fins has a fluid flow velocity of 84.1 m/s, while a 2.5° inclination produces 82.7 m/s, and a 5° inclination reaches 85.8 m/s. Changes in the fin angle affect the drag force and flight stability of the grenade. A larger angle can increase the airflow velocity, but also increase drag. Therefore, optimal fin angle settings are needed to achieve a balance between the stability and aerodynamic efficiency of the mortar grenade.

This study shows that the fin angle of a mortar grenade plays a significant role in its aerodynamic performance. Grenades with parallel fins have a relatively high flow velocity, but a certain fin inclination can affect flight stability and efficiency. A 5° inclination results in the highest speed, but can increase aerodynamic drag. Thus, the fin angle needs to be adjusted to provide an optimal balance between speed, stability, and air resistance. These findings provide important insights into grenade design to improve aerodynamic performance and trajectory accuracy during launch.

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7. AUTHOR CONTRIBUTIONS

- Conceptualization: Lazuardi Lazuardi, Maryono Maryono.
- Data curation: Lazuardi Lazuardi , Maryono Maryono.
- Formal analysis: Muhammad Ali, Sugeng Hadi Susilo.
- Examination: Muhammad Ali, Sugeng Hadi Susilo.
- Methodology: Muhammad Ali, Sugeng Hadi Susilo
- Project administration: Maryono Maryono
- Source: Muhammad Ali, Sugeng Hadi Susilo.
- Software: Lazuardi Lazuardi.
- Supervisor: Sugeng Hadi Susilo.
- Validation: Muhammad Ali, Sugeng Hadi Susilo.
- Visualization: Lazuardi Lazuardi, Maryono Maryono.
- Writing – original draft: Lazuardi Lazuardi , Maryono Maryono.
- Writing – review & editing: Muhammad Ali, Sugeng Hadi Susilo.

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