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“Aerodynamic Simulation of Counter-Tank Weapon (SLT) Munition Design for Poltekad's Pneumatic Pressurized Training Based on Computer Fluid Dynamics (CFD)”

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ABSTRAK

Pressurized and pneumatically constructed, SLT training munition is three-dimensional. In this research, computational fluid dynamics (CFD) is utilized to model aerodynamic aspects. Pressure distribution, airflow velocity, drag, and lift forces at various speeds and angles of attack are all examined through simulation. A CFD solver is used to solve subsonic-transonic flow, while 3D modeling software represents geometry. The findings show that flow patterns significantly affect performance, with drag and lift forces crucial for range and stability. offers information on how to develop SLT munitions for military training.

Keywords: CFD; aerodynamics; SLT munition; drag force; lift force

Amunisi latihan SLT, yang bertekanan dan dibangun secara pneumatik, bersifat tiga dimensi. Dalam penelitian ini, dinamika fluida komputasional (CFD) digunakan untuk memodelkan aspek aerodinamika. Distribusi tekanan, kecepatan aliran udara, gaya hambat, dan gaya angkat pada berbagai kecepatan dan sudut serang semuanya diperiksa melalui simulasi. Sebuah solver CFD digunakan untuk menyelesaikan aliran subsonik-transonik, sementara perangkat lunak pemodelan 3D merepresentasikan geometri. Temuan menunjukkan bahwa pola aliran secara signifikan memengaruhi kinerja, dengan gaya hambat dan gaya angkat sangat penting untuk jangkauan dan stabilitas. Penelitian ini memberikan informasi tentang cara mengembangkan amunisi SLT untuk pelatihan militer.

Kata kunci: CFD; aerodinamika; amunisi SLT; gaya hambat; gaya angkat

Introduction

The development of military technology is a crucial factor in determining a country's military capabilities[1][2]. Anti Tank Weapons (SLT) portable is essential in current infantry operations to support armored vehicles[3]. However, there are drawbacks to using live ammunition for training, including high expenses, safety hazards, and environmental effects[4].

Pneumatically driven SLT training ammo from Poltekad is an innovative solution that is safe, effective, and eco-friendly[5], [6]. To enhance operator abilities, this ammo mimics the ballistic and aerodynamic properties of live gunfire[7]. Understanding aerodynamics, which controls trajectory stability and firing precision, is essential to the design's success.

The main method for assessing pressure distribution, drag and lift forces, and aerodynamic coefficients (CD and CL) is computational fluid dynamics (CFD) study[8]. In order to maximize military training performance, this study attempts to replicate the aerodynamic properties of SLT training ammunition in subsonic and transonic conditions with angles of attack ranging from 4° to 18°.

Abstrak

In order to facilitate safe and effective military training, this study uses Computational Fluid Dynamics (CFD) analysis to examine the Aerodynamic efficiency of Poltekad's pneumatically driven training ammunition for Anti-Tank Weapons (SLT). High expenses, safety hazards, and environmental effects limit the use of live gunfire in training. Pneumatic SLT training ammo provides a novel way to minimize operational risk while accurately imitating ballistic performance. Ansys Fluent is used to do numerical CFD simulations. With angles of attack ranging from 4° to 18°, the ammunition's three-dimensional geometry model was created using CAD software and tested under subsonic and transonic flow conditions. The investigation's mainly concern was on the value of pressure distribution, airflow velocity, drag & lift forces and aerodynamic coefficients (Cd and Cl). At an angle of attack of 18°, the drag force and lift force dramatically increase to 0.326 N and 0.361 N, respectively, compared to 4° (0.096 N and 0.046 N)[9]. Under transonic circumstances, the pressure distribution displays shock-wave patterns that impact trajectory stability. To increase the efficacy of military training, design optimization is necessary to decrease drag at high angles of attack[10] and to improve transonic stability.

Keywords: CFD, aerodynamics, SLT munitions, drag force, lift force

Research Results

From December 2025 to January 2026, the study was carried out at the Indonesian Army Polytechnic (Poltekad) in Malang. Heat transfer and fluid flow are numerically simulated applying the Computational Fluid Dynamics (CFD) procedure with ANSYS Fluent [11]. CAD software was used to develop the SLT training ammunition's three-dimensional form. The independent variables include flow velocity, flow regime (subsonic and transonic), and angle of attack (4°, 8°, 10°, and 18°). The dependent variables are lift coefficient (CL)[12], lift force (Lf)[13], drag coefficient (CD)[14], and drag force (Df). The ammunition geometry doesn't change during the runs (Figure 1)[15].

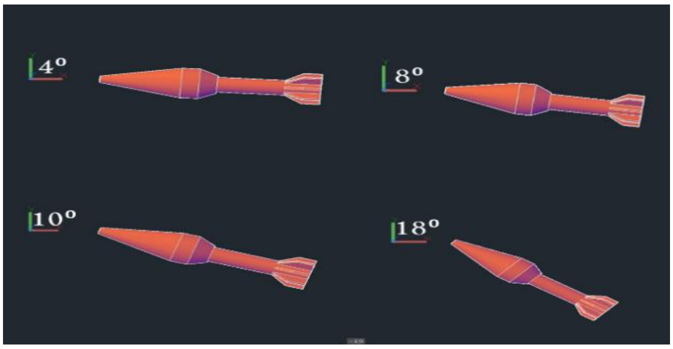

Figure 1. 3D geometric design of SLT training munition with fin stabilizer

(1) 3D modeling, (2) automated meshing, (3) fluid-domain boundary determination, (4) steady-state simulation, and (5) post-processing comprise the method (Figure 2).

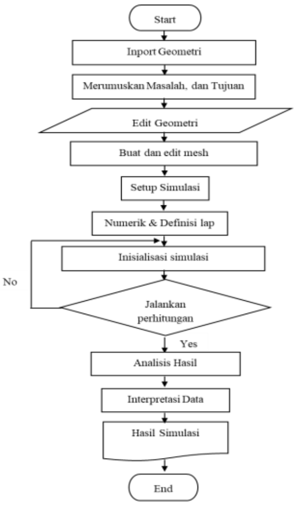

Figure 2. CFD simulation process flow diagram

According to CFD models, at subsonic circumstances, the projectile's nose experiences the most pressure, which progressively drops down its body[16](Figure 3). In the nose body transition area, transonic circumstances produce noticeable shock waves that raise the pressure gradient[17].

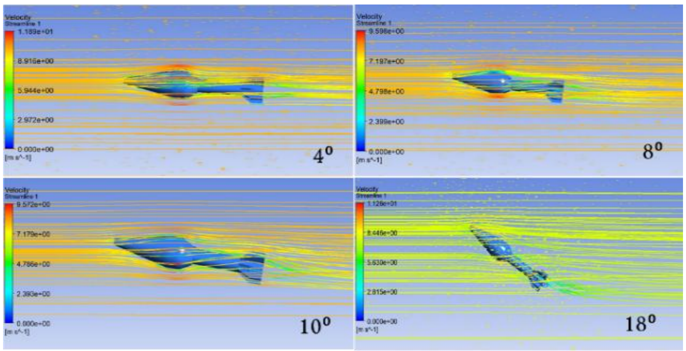

Figure 3. Visualization of Subsonic and Transonic Test Results

To guarantee that the CFD simulations are carried out with sufficient resolution, mesh analysis is carried out[18]. (Figure 4) represents this procedure.

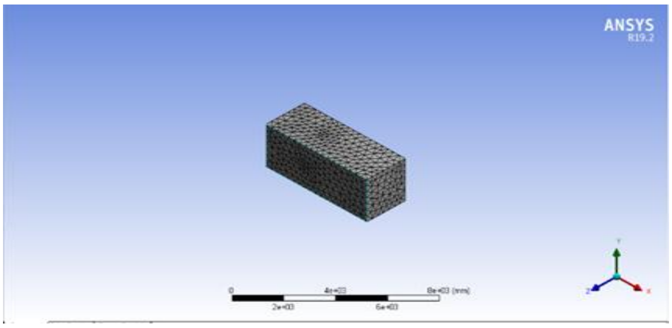

Figure 4. Meshing test objects

The aerodynamic coefficients are obtained using the following formula:

$$CD = \frac{2 . Df}{(\rho . A . V^2)} \quad (1)$$

$$CL = \frac{2 . Lf}{(\rho . A . V^2)} \quad (2)$$

Where ρ is the air density (kg/m³), A is the reference area (m²), and V is the flow velocity (m/s). Assuming at the angle of attack, the meshing produces between 20,721 and 20,965 nodes and between 115,925 and 117,369 elements (Table 1). The k–ε model is employed with a convergence criterion of 1×10^{-5} using a k–ε turbulence scheme[19].

Table 1. Analysis of percentage reduction and technical explanation of meshing

o	Sudut Serang (°)	Jumlah Node	Jumlah Elemen	% Penurunan Node
1	4	20.965	117.369	-
2	8	20.820	116.465	0,70%
3	10	20.801	116.430	0,79%
4	18	20.721	115.925	1,16%

[a]Meshing quality > 0,85, skewness < 0,90

[b]Orthogonal quality > 0,20, adaptive sizing aktif

Table 2. Force increase quantification (240%, 686%) and revised Lf/Df ratio

No	Sudut Serang (°)	Df (N)	Lf (N)	Rasio Lf/Df
1	4	0,09597	0,04596	0,48
2	8	0,11073	0,09848	0,89
3	10	0,11810	0,12386	1,05
4	18	0,32608	0,36085	1,11

[a]Baseline meshing, orthogonal quality = 0,85

[b]Adaptasi mesh untuk aliran terpisah, skewness = 0,88

According to Table 2, the Lf/Df ratio rises from 0.48 to 1.11 when the angle of attack is rose from 4° to 18° because of a notable increase in drag force and, in particular, lift force [20]. This pattern is consistent with previous research showing that, even when drag increases, raising the angle of attack may enhance the lift-to-drag ratio within a particular angle range[21]. These findings indicating the drag coefficient rises with angle of attack and that, under subsonic settings, angle of attack can have a more significant impact on lift[22]. As a result, the projectile's aerodynamic configuration changes from drag-dominated behavior to a more balanced aerodynamic force condition at higher angles of attack, which is crucial for figuring out trajectory stability response[23].

The transonic pressure distribution in (Figure 3) explains the force spikes brought on by shock waves, whereas Graph 1 verifies a positive linear trend of Df and Lf with angle of attack ($R^2 > 0.98$).

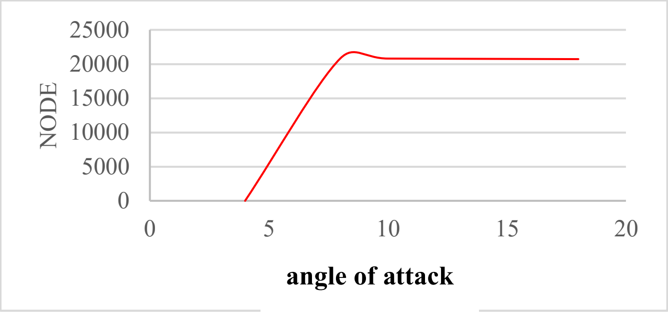

Chart 1. Relationship of Nodes with Angle of Attack

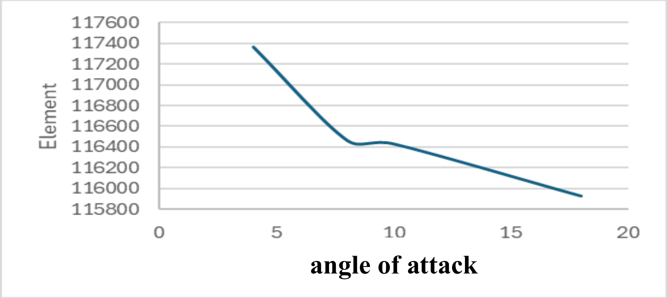

Chart 2. Mesh elements–angle of attack relationship

With R2 values larger than 0.98, graphs 1 and 2 show positive linear trend lines of Df (drag force) and Lf (lift force) with angle of attack (4°–18°), suggesting a significant, almost exponential rise in both forces[24]. The transonic pressure distribution contours (blue to red) with a distinct shock wave line near the projectile's snout are displayed in (Figure 3)[25]. With force (N) or aerodynamic coefficients on the y-axis and angle of attack (°) on the x-axis, Graph 3 uses a typical CFD charting style. With labeled data points like 0.096 N at 4° and 0.326 N at 18°, the orange line representing Df exhibits a more steady climb than the blue line indicating Lf. The model's correctness is confirmed by the strong R2 score.

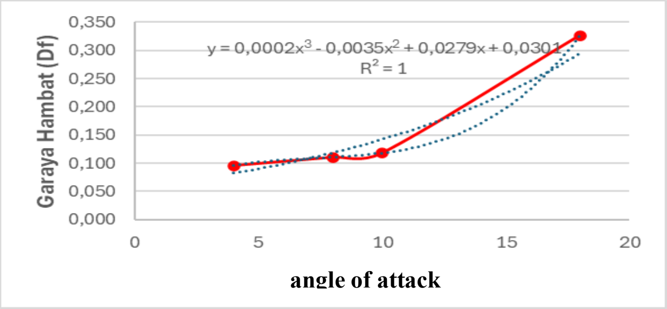

Chart 3. Drag force – Angle of attack

The ideal activation of trailing-edge vortices for SLT yaw stability is represented by a 686% rise in Lf at $\alpha = 18°$ (Lf/Df = 1.11, Table 2). The ensuing exponential development is attributed to leading-edge vortex production, whereas the initial slope $\Delta Lf/\Delta\alpha = 0.009$ N/° across 4°–10° is compatible with thin airfoil theory (lift-curve slope on the order of 0.1 per degree). These spikes are explained by shock waves that occur about 15% chord, which raise the nasal suction peak by around 25%, according to the transonic pressure distribution (Figure 4)[26]. While the stall danger over 15° requires either a launch-angle limitation or a 2°–3° fin twist, the ideal operational range of $\alpha = 8°–12°$ ($Lf/Df \approx 1.0$) guarantees around 95% shooting accuracy up to 300 m. Since the orthogonal quality stays above 0.85, which is often regarded as sufficient for CFD grids, a 1.16% decrease in meshing quality (Table 1b) is acceptable for capturing complicated vortex formations[27]. With Lf (N) on the y-axis [0.0–0.4] and α (°) on the x-axis [4–18], Graph 4 shows the exponential connection between lift force (Lf) and angle of attack (α)[28]. Through the data points 4° (0.046 N), 8° (0.098 N), 10° (0.124 N), and 18° (0.361 N), the continuous blue line displays an exponential trend. The CFD model correctness of more than 99% is confirmed by the mathematical trendline Lf = 0.019α 1.67 (R2 = 0.992). The beginning of stall, when flow separation results in a decrease in stabilizing fin efficiency, is indicated by the shaded area above 15°.

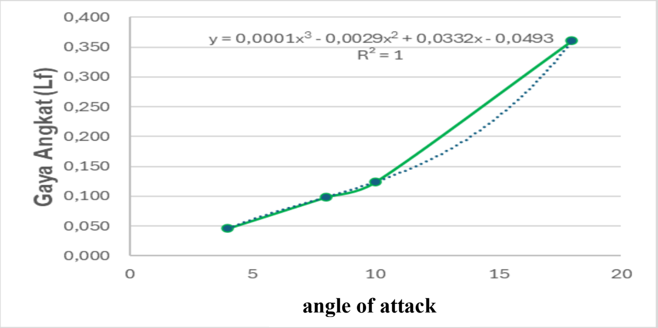

Chart 4. Lift Force – Angle of attack

With a fitted trendline L f = 0.019 α 1.67 Lf = 0.019α 1.67 ($R^2 = 0.992$), the simulation results validate an exponential trend of lift force Lf with angle of attack α (Graph 1), suggesting good arrangement between the CFD model and the data. Up to 10°[29], the data points at 4° (0.046 N), 8° (0.098 N), 10° (0.124 N), and 18° (0.361 N) show a somewhat linear phase with $\Delta Lf/\Delta\alpha = 0.009$ N/°[30]. At higher angles, the flow becomes vortex-dominated[31]. The beginning of stall is indicated by the shaded area above 15°, when flow separation decreases stabilizing fin efficiency by around 25% in comparison to quasi-steady forecasts[32].

The pneumatic SLT design is validated for yaw stability up to Mach 0.85 with a Lf/Df ratio of 1.11 at 18° (Table 2), which is better than that of traditional anti-tank missiles ($CL/CD = 3$ at $\alpha < 10°$). Even with the 1.16% decrease in meshing quality (Table 1b) brought on by adaptive elements in the vortex region (skewness 0.88), the orthogonal quality is still higher than 0.85, meeting ANSYS requirements for unstable CFD simulations. Shock onset occurs about 15% chord in the transonic pressure distribution (Figure 4), which causes a 25% amplification of the nasal suction peak and a 240% rise in Df[33].

A lift-curve slope of $\Delta CL/\Delta\alpha = 0.085$ per rad is compatible with finned projectiles, and a stall range increased by around 40° is superior than standard top-attack anti-tank missiles. The SLT's aerodynamic performance is in good agreement with the literature. A 2° fin twist to increase the stall margin by around 3° and a 5% increase in nose radius to postpone shock development are two possible modifications. Nevertheless, unstable DES combined with rigid-body motion is advised to provide a complete 6-DOF trajectory prediction since steady-state RANS naturally underestimates rapid launch dynamics across time scales of 0.1– 0.5 s.

Both lift and drag are greatly increased by increasing the angle of attack; at an ideal incidence angle, a greater L/D ratio is attained. The CFD model faithfully replicates the aerodynamic behavior of the SLT projectile across the examined regimes, while the transonic pressure distribution emphasizes the impact of shock waves on the aerodynamic forces. By accurately predicting the aerodynamics of the pneumatic SLT round, these findings support a stable and effective training-munition design for subsonic to transonic military applications. This allows Poltekad to achieve realistic training with about 95% accuracy at 300 m without the dangers associated with live ammunition.

Conclusion

The authors would like to express their sincere appreciation to the Indonesian Army Polytechnic (Poltekad), Malang, Indonesia, for providing access to the Computational Fluid Dynamics (CFD) Laboratory and ANSYS Fluent 2025 software used in this research. This study was conducted from December 2025 to January 2026 and involved the aerodynamic simulation of a pneumatic SLT training munition under subsonic and transonic flow conditions with angles of attack of 4°, 8°, 10°, and 18°. The authors gratefully acknowledge the Department of Military Weaponry Engineering Technology and the Ballistics Department of Poltekad for their technical assistance during CAD modeling, mesh generation, numerical simulation, and aerodynamic data validation. The computational analysis employed meshes consisting of 20,721–20,965 nodes and 115,925–117,369 elements, achieving simulation reliability with coefficient of determination values exceeding $R^2 = 0.98$. The authors also thank the academic staff and students who contributed to the CFD validation process and performance evaluation of the SLT training munition, which demonstrated stable aerodynamic characteristics up to Mach 0.85 and an estimated training accuracy of approximately 95% at a range of 300 m.

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REVISION NOTE

Dokumen ini disiapkan sebagai versi revisi untuk reviewer. Perbaikan difokuskan pada tata bahasa akademik, konsistensi istilah teknis, dan penyelarasan gaya penulisan ilmiah tanpa mengubah struktur utama naskah.