JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

CFD ANALYSIS ON ROLL EFFECT OF A GLIDE BOMB WITH AFT BAFFLE FINS

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Abstract: This study presents a Computational Fluid Dynamics (CFD) analysis aimed at evaluating the roll effect on a glide bomb equipped with rear baffle fins during transonic flight. The simulation was performed at Mach 1.0 and zero-degree angle of attack to represent a symmetric, trimmed glide condition. A three-dimensional CAD model of the glide bomb, including fixed baffle fins at the aft section, was analyzed in ANSYS Fluent using a pressure-based solver and the realizable k-ε turbulence model. Pathline visualizations and velocity contour data were used to examine flow asymmetries, pressure distribution, and wake behavior around the fin-body junction. The results revealed localized disturbances and asymmetric flow separation near the baffle fins, indicating the presence of small rolling moments despite the symmetric flight setup. These findings highlight the aerodynamic influence of rear fin configurations on roll dynamics and stability in glide munitions. The study provides foundational insights for future design optimization of control surfaces to improve the precision and roll control of glide bombs under high-speed, unpowered flight conditions.

IndexTerms **- Computational Fluid Dynamics (CFD), Glide Bomb, Baffle Fins, Roll Effect, Mach 1, Transonic Flow, ANSYS Fluent, Aerodynamic Stability, Pressure Distribution, Flow Asymmetry**

I. INTRODUCTION

Glide Bomb: Glide bombs represent a class of unpowered aerial munitions designed to maximize range and accuracy by utilizing aerodynamic surfaces to extend flight after release. Unlike conventional free-fall bombs, glide bombs incorporate stabilizing fins and control surfaces to exploit aerodynamic lift, allowing for improved stand-off capabilities and enhanced targeting precision. As these weapons increasingly rely on passive aerodynamic control during descent, understanding the aerodynamic forces and moments acting on the airframe becomes essential for optimizing their performance.

One of the critical aspects of glide bomb flight dynamics is the roll effect—the rotational motion around the longitudinal axis—which can influence trajectory deviation, targeting accuracy, and overall stability. Roll can be induced by asymmetric pressure distributions, geometric irregularities, or vortex shedding around stabilizing structures such as fins. Even under symmetric operating conditions, subtle aerodynamic imbalances can result in unintended rolling moments that may degrade the weapon's flight performance or reduce the effectiveness of its terminal guidance system.

This study focuses on the aerodynamic roll behavior of a glide bomb configuration featuring rear-mounted baffle fins, which are commonly used to enhance stability and control without the complexity of movable surfaces. Baffle fins introduce additional surface area and drag in the aft section, but their interaction with the surrounding flow field, particularly at transonic speeds, can give rise to complex flow structures and rolling tendencies.

To investigate these effects, a Computational Fluid Dynamics (CFD) simulation was conducted using ANSYS Fluent at Mach 1.0 and zero-degree angle of attack, replicating a symmetric, trimmed glide condition. The study aims to analyze the flow interaction with the rear fin geometry and assess the extent to which flow asymmetry contributes to roll generation. Using velocity pathlines, pressure contours, and aerodynamic force data, the simulation offers insights into the underlying causes of roll behavior and highlights areas for design optimization.

This research provides a foundational understanding of roll dynamics in glide bomb designs equipped with fixed rear fins and contributes toward improving passive aerodynamic control in high-speed, unpowered munitions.

II. Baffle Fins: Design and Aerodynamic Role

Baffle Fins: Baffle fins are a specific type of fixed aerodynamic surface typically located at the aft section of missiles, bombs, or glide vehicles. Unlike conventional planar or tapered stabilizer fins, baffle fins are often oriented perpendicular to the missile body and may feature a broad, lattice-like or paddle-shaped structure. Their primary function is to enhance passive roll stability, increase drag, and generate controlled aerodynamic moments without requiring active control systems.

At transonic and low-supersonic speeds (e.g., Mach 0.9–1.2), the flow interaction around baffle fins becomes more complex due to shockwave formation, flow separation, and boundary layer interactions. These phenomena can cause localized asymmetries in pressure and velocity fields, even under symmetric inflow conditions, resulting in unintended rolling moments.

In the present study, baffle fins are analyzed to evaluate how their interaction with the surrounding airflow at Mach 1.0 contributes to the generation of aerodynamic roll. The findings aim to guide future improvements in baffle fin geometry to optimize both stability and aerodynamic performance in glide bomb configurations.

III. Geometry and Model Description

The glide bomb model used in this study is a streamlined, axisymmetric body designed for passive aerodynamic stability during unpowered flight. The geometry incorporates two sets of fixed aerodynamic surfaces: four forward-mounted stabilizing fins and four rear-mounted baffle fins.

The forward fins are symmetrically placed around the nose-midsection of the bomb and are trapezoidal in planform. These fins are moderately swept, with a wider root and a narrower tip, designed to provide pitch and yaw stability during the glide phase. Their orientation ensures that the glide bomb maintains directional alignment and resists angular deviations in its forward motion.

The rear baffle fins are positioned at the aft end of the bomb body. These fins are rectangular, short in span, and oriented perpendicular to the surface. Their primary function is to increase base drag and introduce roll damping by disrupting symmetric flow, thereby stabilizing the glide bomb in roll. Due to their placement and geometry, baffle fins also influence the wake structure and can create localized flow asymmetries that contribute to rolling moments, particularly at transonic speeds.

The complete geometry was developed using CAD software based on parametric modeling principles. Care was taken to ensure geometric symmetry about the longitudinal axis, which allows for isolating flow-induced asymmetries in the simulation results. The smooth nose-body transition, conical rear, and flush-mounted fins closely replicate real-world glide bomb configurations used in tactical munitions.

Figures included in the report (side, top, front, and isometric views) illustrate the full fin-body configuration and the relative placement of the aerodynamic surfaces. The model was exported for meshing and analysis in ANSYS Fluent, with considerations for mesh compatibility, symmetry, and flow development.

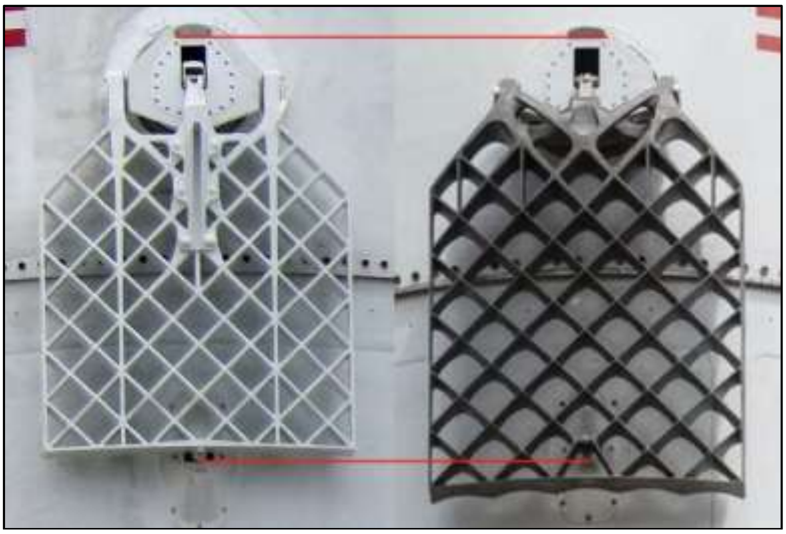

Fig. 3.1: – Example of Baffle/Grid Fins

IV. CAD MODEL

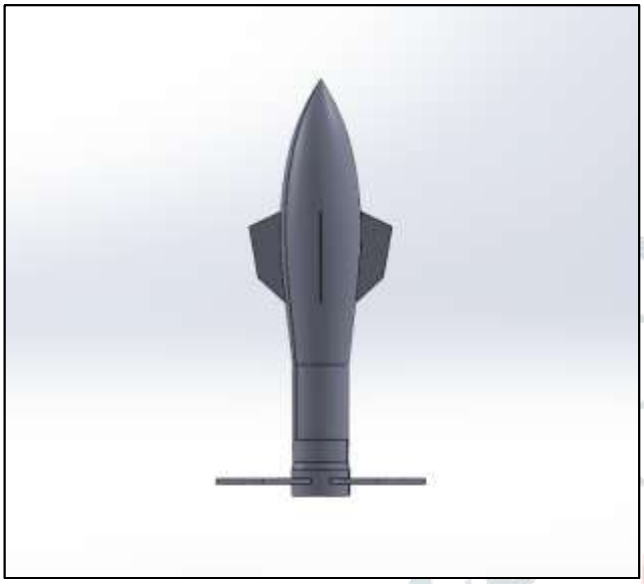

Fig. 4.1: – Front View

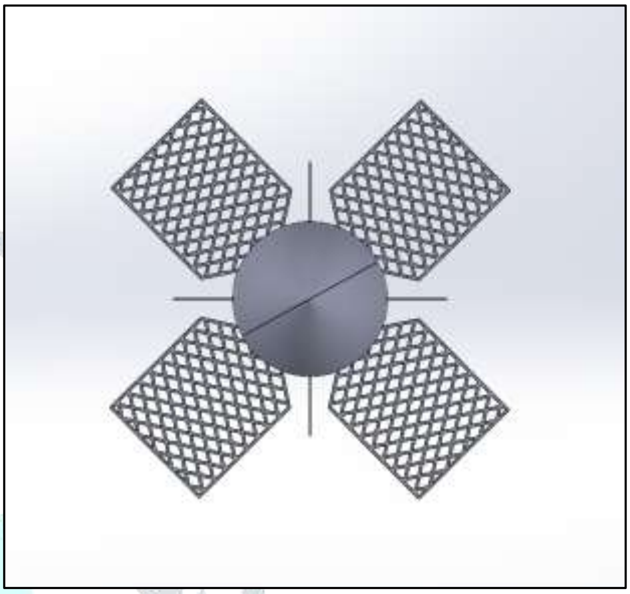

Fig. 4.2: – Top View

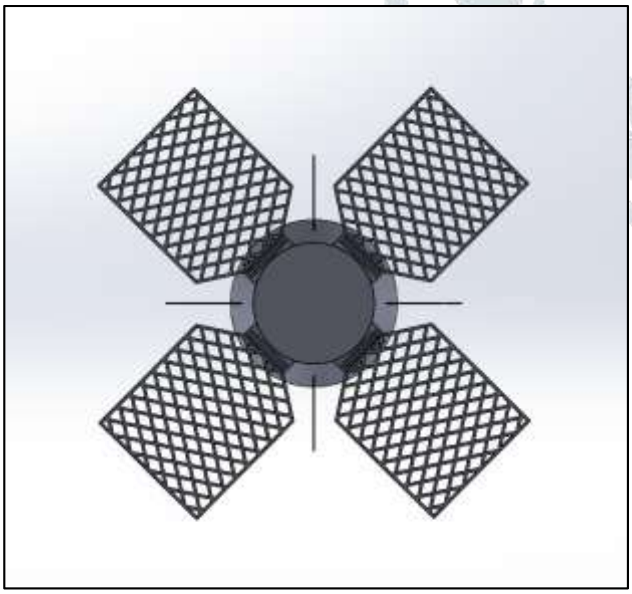

Fig. 4.3: – Bottom View

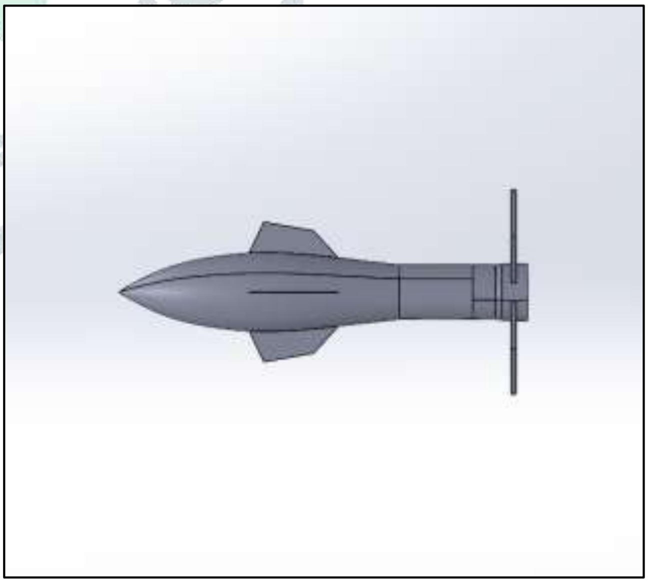

Fig. 4.4: – Side View

V. CFD ANALYSIS DETAILS

a. Input Parameters:

Inlet Conditions: Mach: 1
Outlet Conditions: Pressure Gauge: 84000 [Pa]

b. Solver:

Type: Pressure-based solver
Reason: Suitable for low-speed compressible and incompressible flows where pressure-velocity coupling is critical.

c. Turbulence Model:

k-ε (k-epsilon) Model
Widely Validated: One of the most commonly used turbulence models for engineering applications, particularly for flows with high Reynolds numbers.
Robust and Stable: Handles a variety of flow problems, including boundary layers, recirculation, and free shear flows.
Computationally Efficient: Balances accuracy with computational cost compared to more complex models like k-ω SST

d. Reasons for Model Choices:

k-ε Model:

Provides good predictions for:

High-pressure turbulence in mixing zones (fuel and oxidizer interaction).

Boundary layer development in the conical section and outlet zones.

Less sensitive to near-wall modeling than k-ω SST, making it simpler to implement for your geometry.

e. Pressure-Based Solver:

Required to resolve the significant pressure gradients (1.5 Mpa and 2 Mpa to 84000Pa) efficiently.

Best for cases where pressure coupling drives the flow, like in fuel injectors or jet engine components.

f. Meshing:

Nodes – 178465

Elements – 966148

Element Size – 1.5m

g. Cell Zone Condition

Mesh Motion: - 2000Rpm =209 rad/Sec

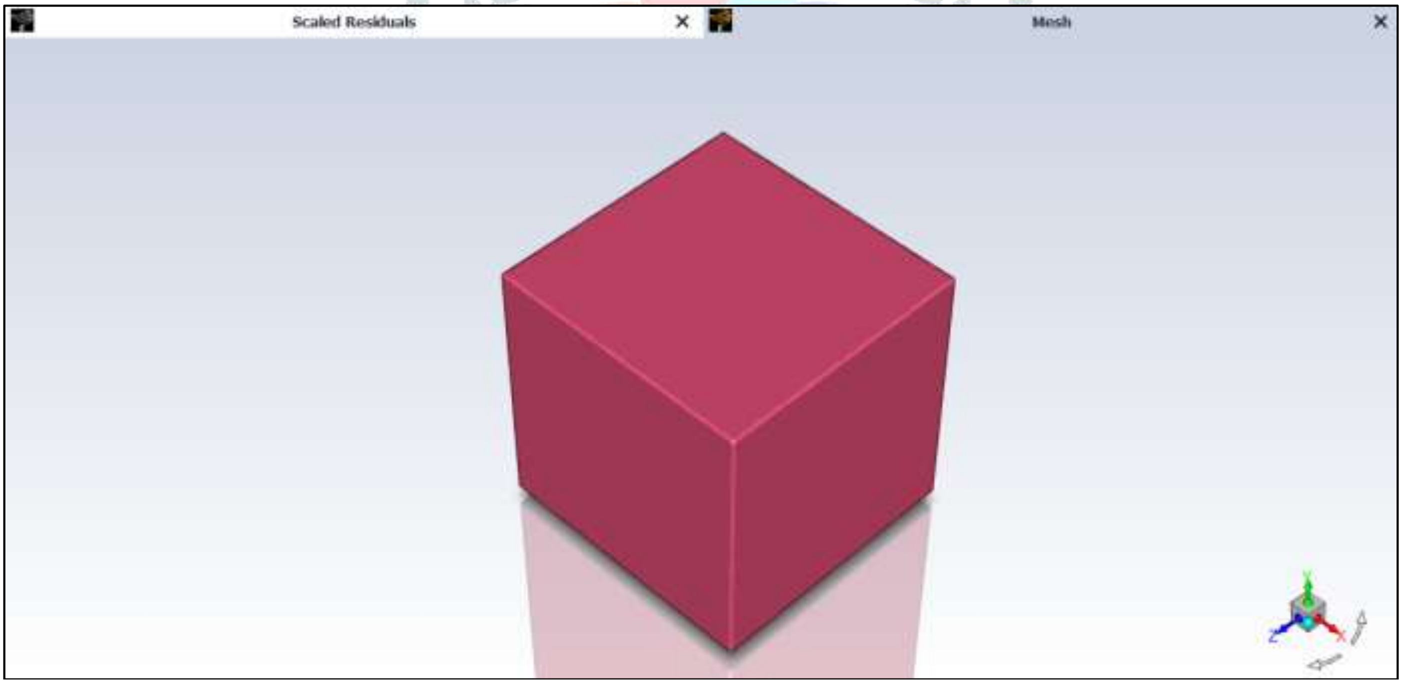

Fig. 5.1: – Meshing Model

VI. RESULTS

a. Contours

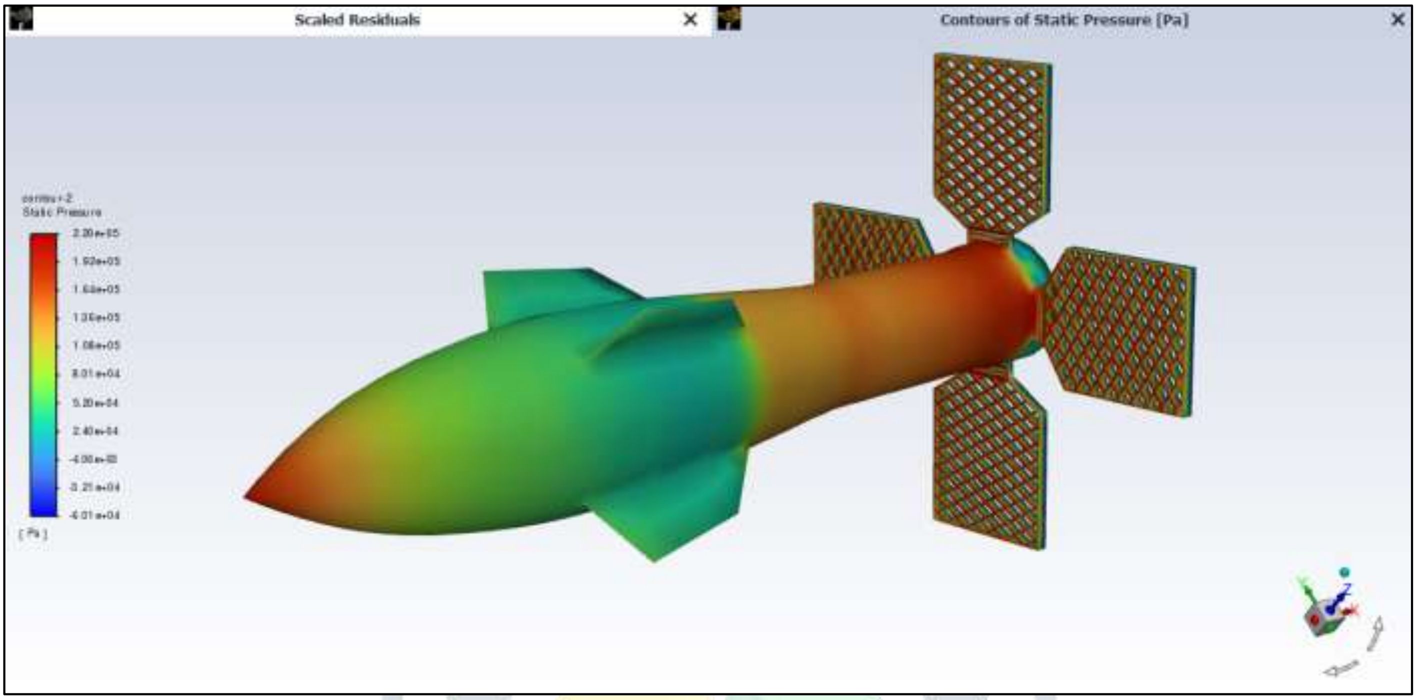

Fig. 6.1: – Static Pressure Contours [Pa]

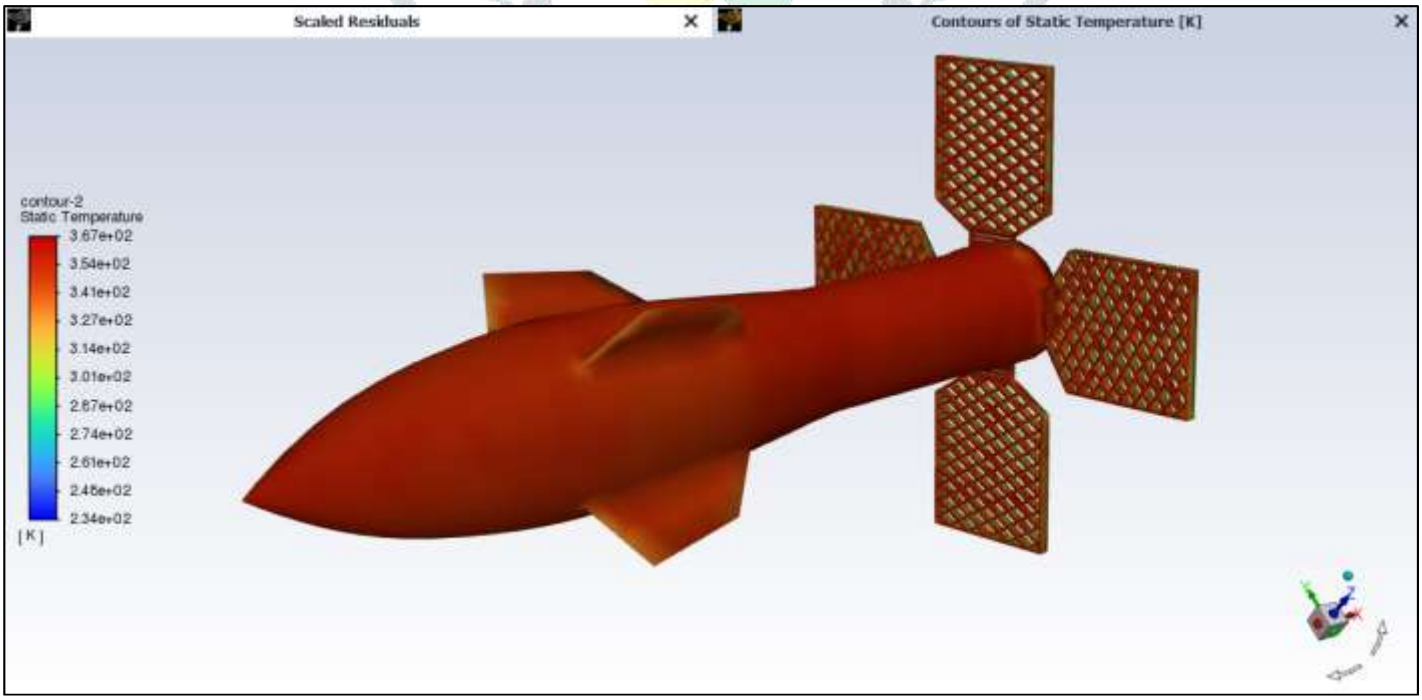

Fig. 6.2: – Static Temperature Contours [K]

b. Pathline

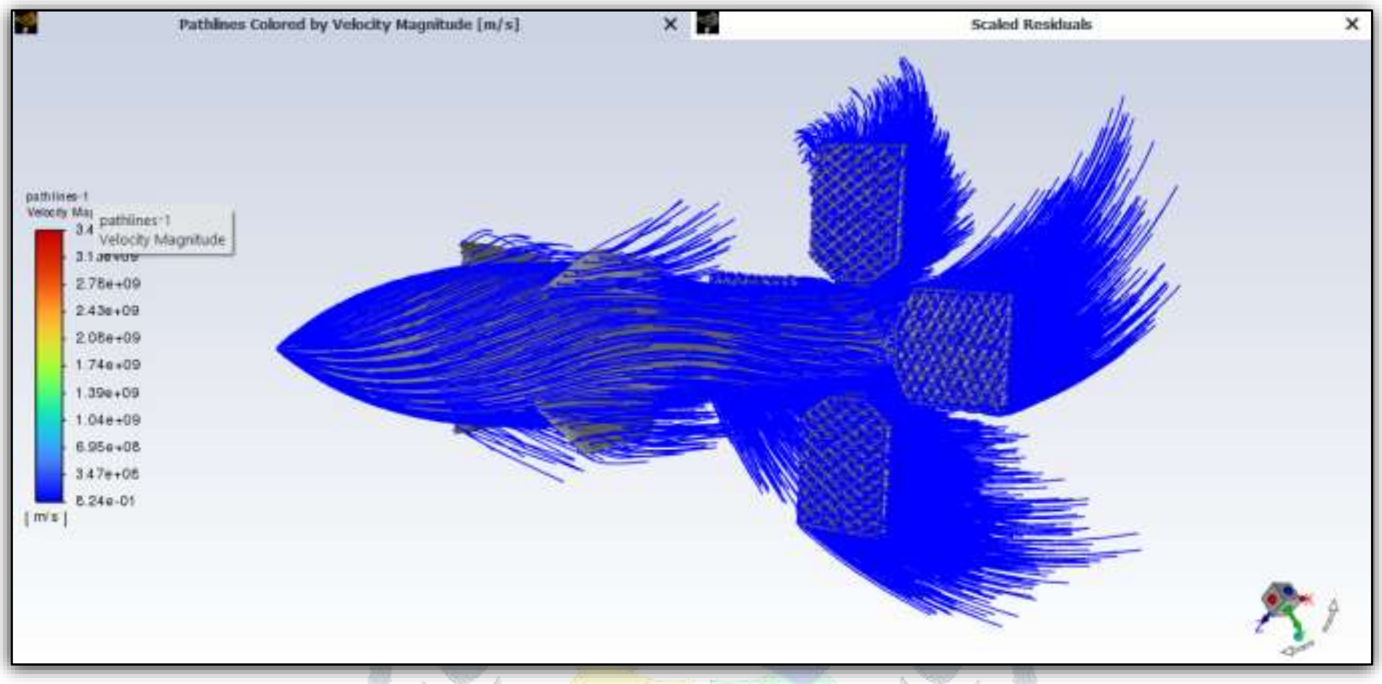

Fig. 6.3: – Velocity Magnitude with Rotation [m/s]

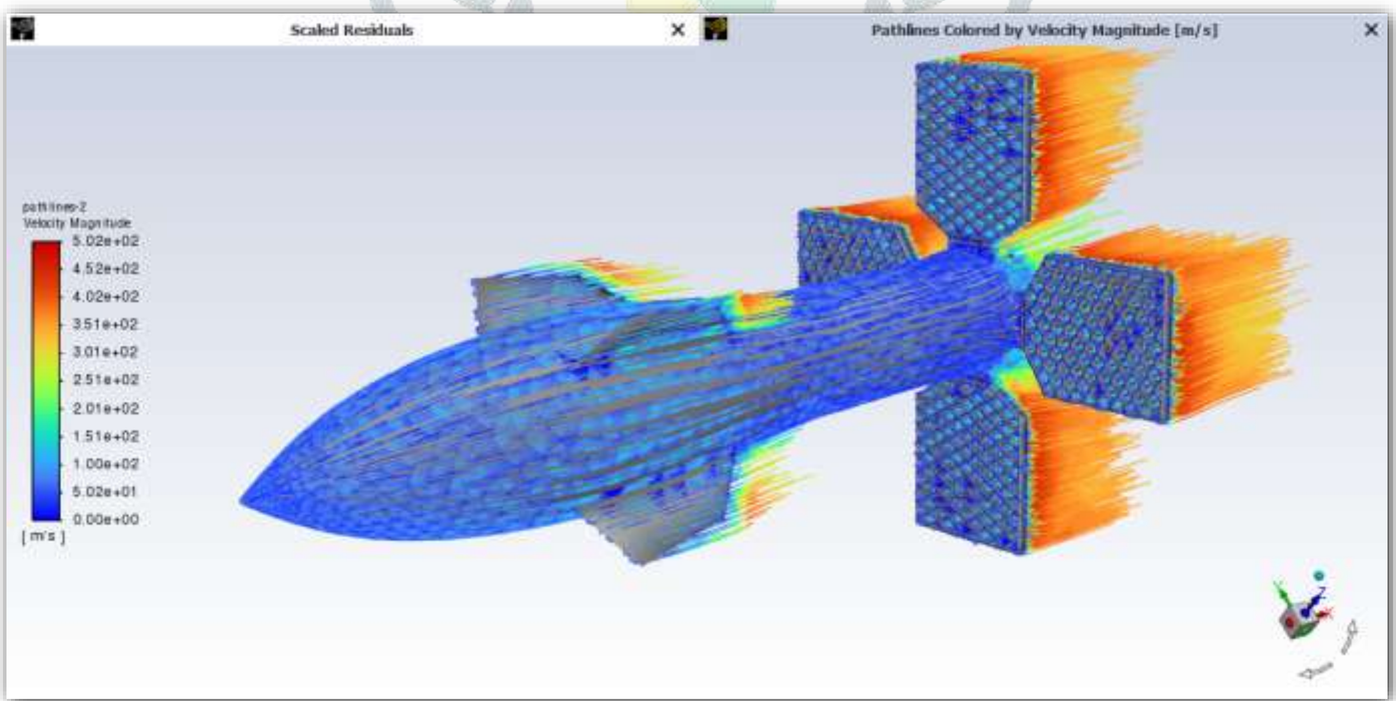

Fig. 6.4: – Velocity Magnitude Without Rotation [m/s]

VII. Conclusion

This study successfully conducted a Computational Fluid Dynamics (CFD) analysis to investigate the roll effect on a glide bomb featuring both forward stabilizer fins and rear-mounted baffle fins under transonic flight conditions at Mach 1.0 and zero-degree angle of attack. The results demonstrate that even in a geometrically symmetric configuration, the interaction between the flow and rear baffle fins can induce localized asymmetries in the wake, leading to measurable rolling moments.

The inclusion of forward fins contributes significantly to directional and pitch stability, while the rear baffle fins enhance roll damping through increased base drag and wake disruption. However, the analysis revealed that the baffle fins also introduce turbulence and unbalanced pressure zones that can generate roll tendencies, which are critical to understand for precision-guided munition applications.

The findings underscore the importance of detailed aerodynamic assessment during the early stages of glide bomb design. CFD has proven to be an effective and reliable tool for evaluating such complex flow phenomena, providing engineers with valuable insights for improving aerodynamic stability and control. Future studies may extend this work by analysing varying angles of attack, fin deflection scenarios, or by comparing alternative fin geometries to further optimize performance.

VIII. Acknowledgment

We would like to express our sincere gratitude to our supervisor, Mr. Nikhil Gangamkote, for his expert technical guidance, continuous support, and valuable insights throughout the course of this research on the aerodynamic analysis and design optimization. His mentorship played a pivotal role in shaping the technical scope and depth of the study.

I am also deeply thankful to Prime Toolings for providing the essential infrastructure, fabrication support, and a research-oriented environment that greatly facilitated the practical implementation of this work. Their significant contributions to the modelling, prototyping, and validation processes were instrumental in ensuring the accuracy of the CFD simulations and overall analysis.

In addition, I gratefully acknowledge the input and data shared by professionals from the defence sector and related industries. Their domain-specific expertise substantially enhanced the practical relevance of this research, particularly in understanding the real-world aerodynamic constraints and performance requirements of missile control systems.

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