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CFD Study on Angle-Dependent Performance of V-Gutter Flame Holders in Ramjet Engines

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Abstract
This study utilizes computational fluid dynamics (CFD) to analyze the impact of various V-gutter flame holder angles on the performance of a ramjet engine combustion chamber. V-gutter angles ranging from 45° to 90° were simulated in ANSYS Fluent to assess their influence on flame stability, recirculation strength, pressure loss, and temperature distribution. Findings suggest that angles between 70° and 80° provide optimal conditions for efficient combustion with strong flame anchoring and moderate pressure losses.

Keywords: Ramjet, V-gutter, flame holder, CFD, optimization, recirculation zone, combustion chamber

1. Introduction
Ramjets rely on stable combustion at high airflow velocities. V-gutter flame holders are crucial in anchoring the flame within the combustor. Their angular configuration significantly influences the fluid dynamics of recirculation zones, flame anchoring, and overall combustion efficiency. This study focuses on CFD-based optimization of the V-gutter angle in a ramjet combustor.

2. Aim and Objective
Aim:

To optimize the angle of a V-gutter flame holder using computational fluid dynamics (CFD) to enhance combustion stability, minimize pressure loss, and improve thermal uniformity in a ramjet engine combustion chamber.

Objectives:

1. **To model and simulate** different V-gutter flame holder angles (e.g., 45°, 60°, 70°, 80°, 90°) in a ramjet combustor using ANSYS Fluent.

2. **To evaluate** the effect of V-gutter angles on flame anchoring, recirculation zone strength, pressure drop, and temperature distribution.

3. **To compare** performance metrics such as combustion efficiency, thermal spread, and aerodynamic drag across different configurations.

4. **To identify** the optimal V-gutter angle that achieves stable combustion with minimal pressure loss and efficient heat distribution.

5. **To support** flame holder design improvements for high-speed propulsion systems based on validated CFD data.

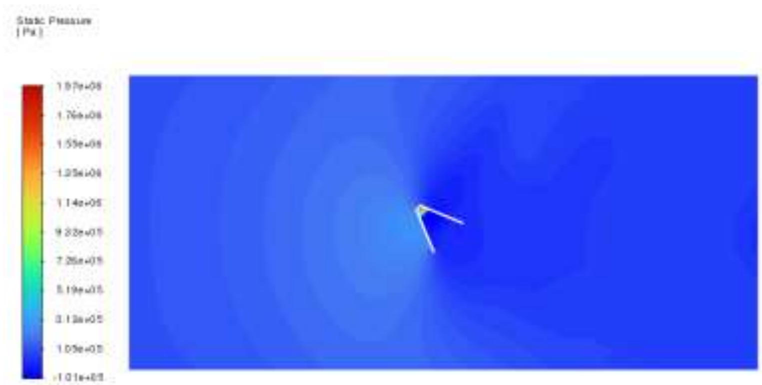
3. Methodology

ANSYS Fluent was used to simulate five V-gutter configurations (45°, 60°, 70°, 80°, 90°) in a 2D ramjet combustor model. The geometry was meshed using a fine grid with refinement near the flame holder. The realizable k-ε turbulence model with species transport and eddy dissipation combustion model was applied. Boundary conditions included an inlet velocity of 100 m/s, a stoichiometric methane-air mixture, and adiabatic walls.

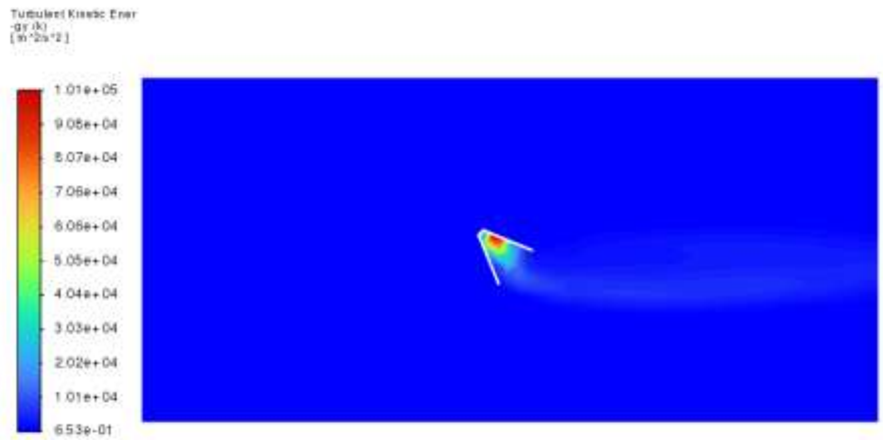
4. Results and Discussion

Results showed weak recirculation and flame instability at 45°, improved vortex strength at 60°, and optimal performance at 70°–80°. The 90° configuration caused excessive drag without further stability gain. Angles between 70° and 80° offered balanced flame anchoring, thermal uniformity, and acceptable pressure loss.

At 45^0 Angle:

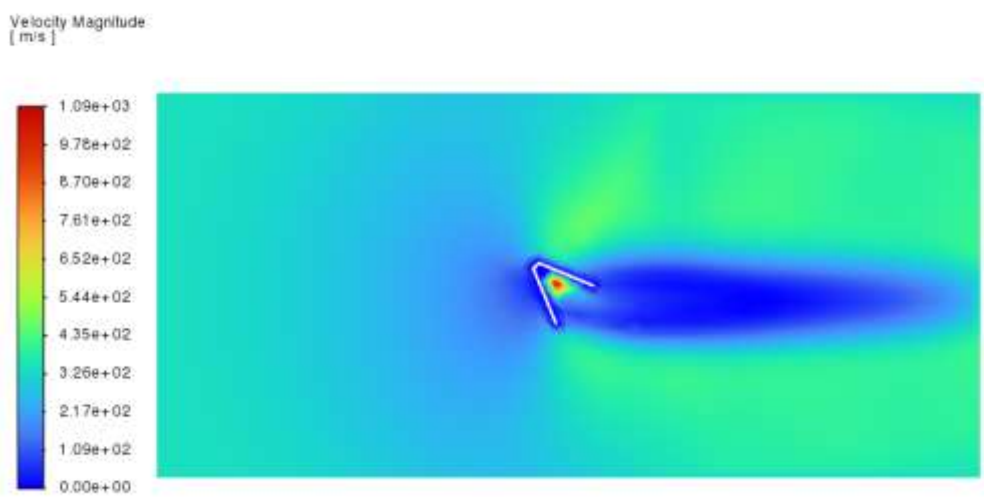


Pressure Contour



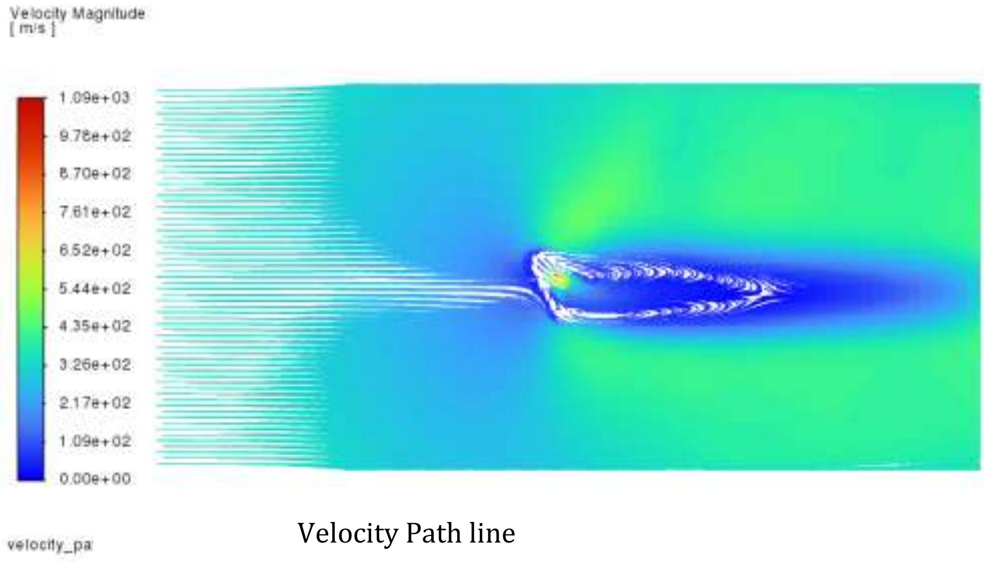
turbulence

Turbulence Contour



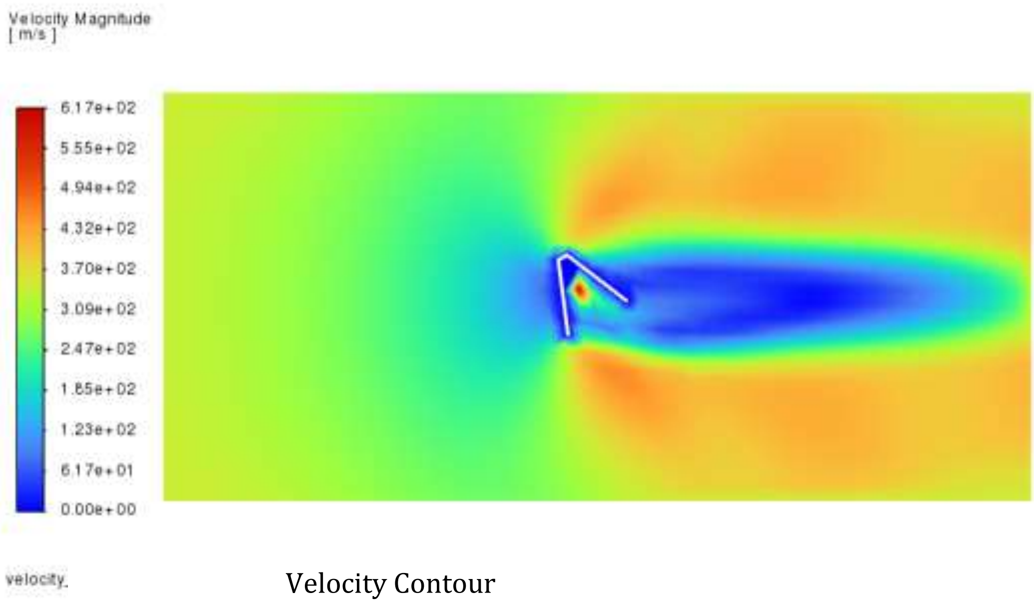
Velocity Contour

velocity_contour



Velocity Path line

At 60º Angle:



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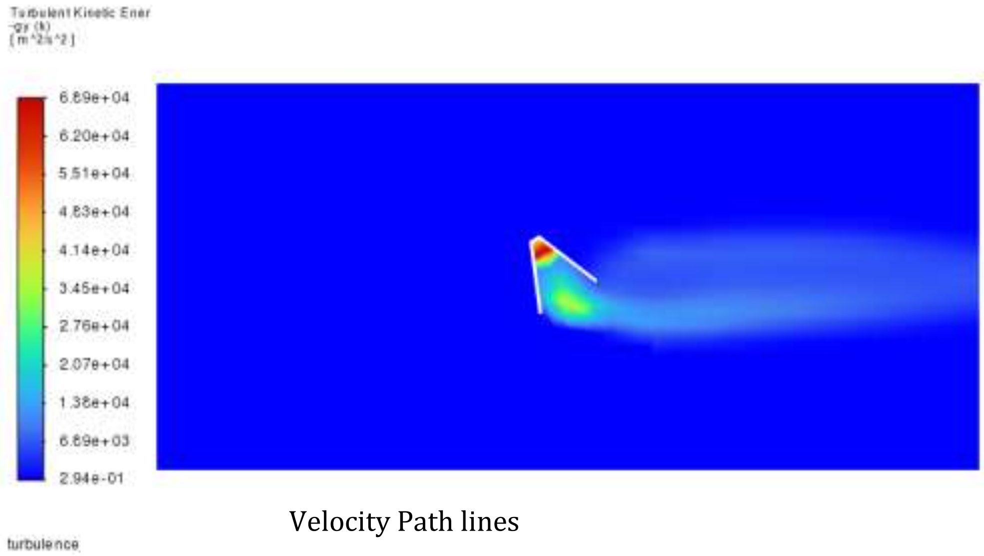
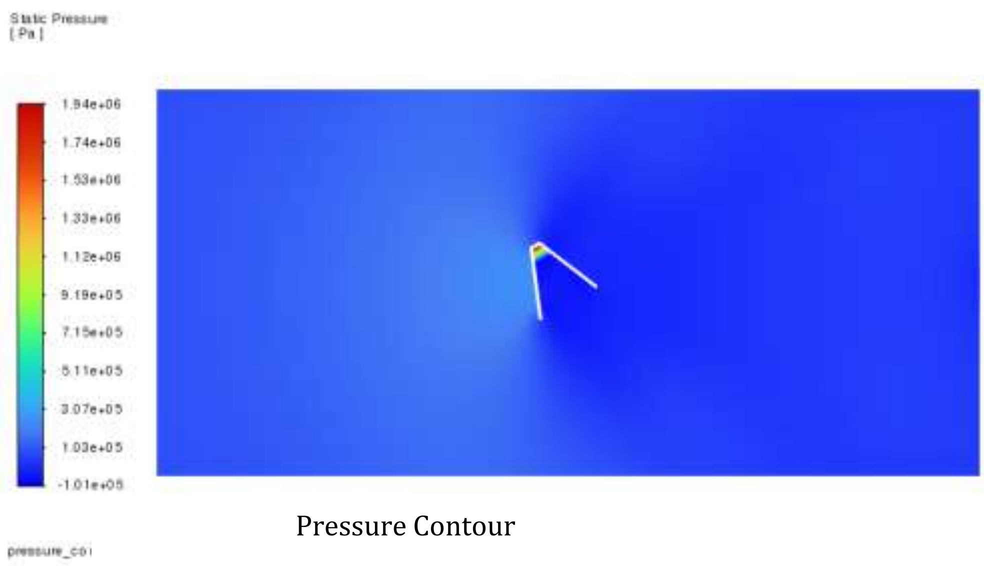
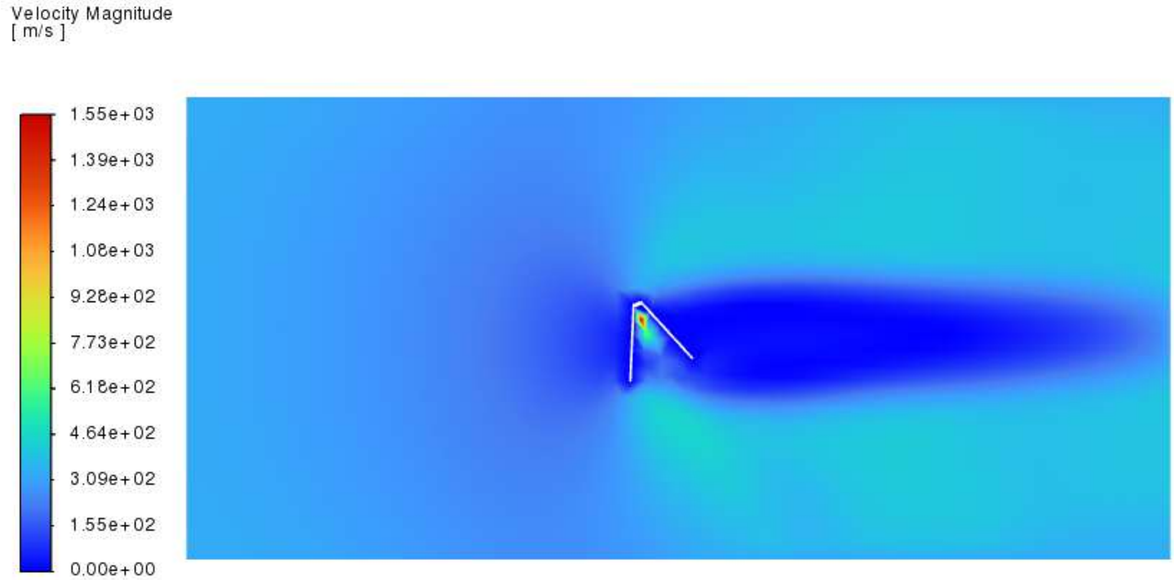


Velocity Path lines



Pressure Contour

At 70^o Angle:



Velocity Contour

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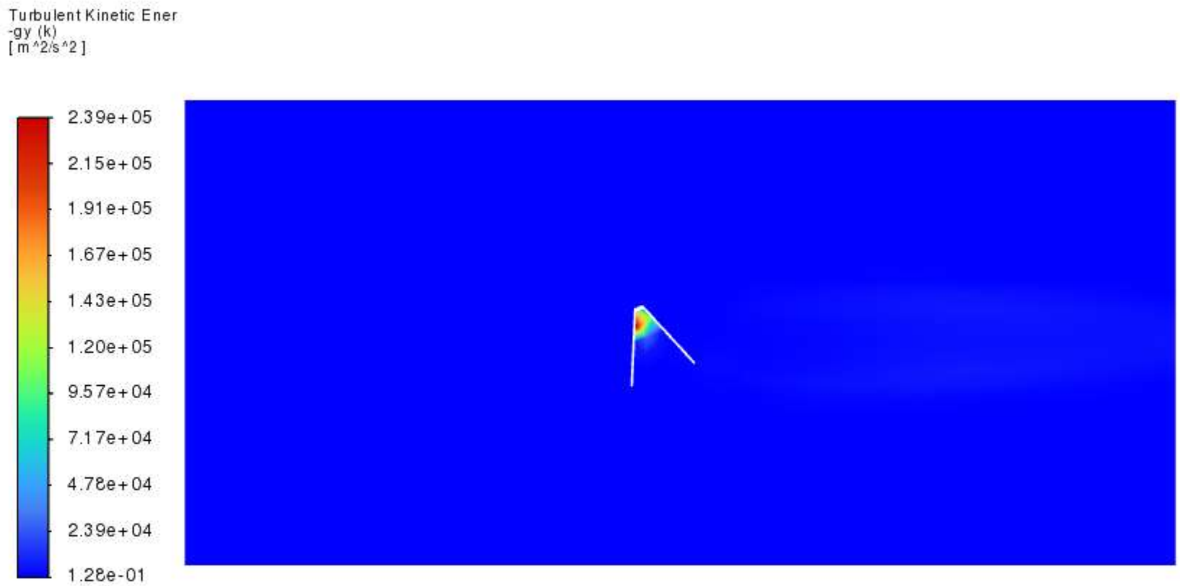
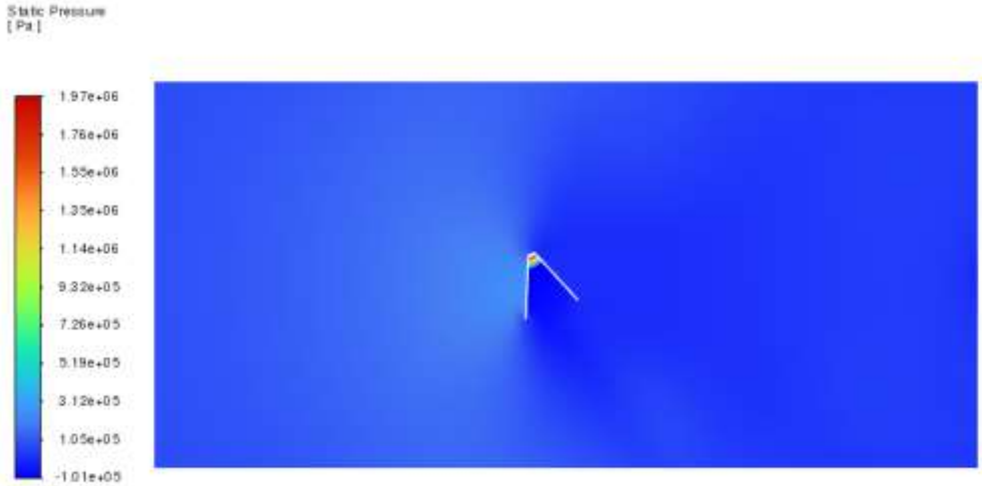


Turbulence Contour

turbulence_contour



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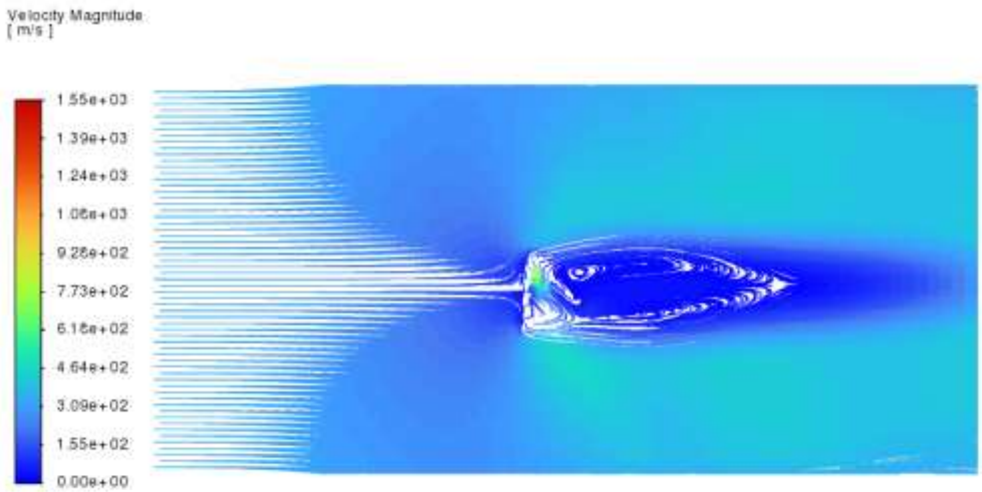
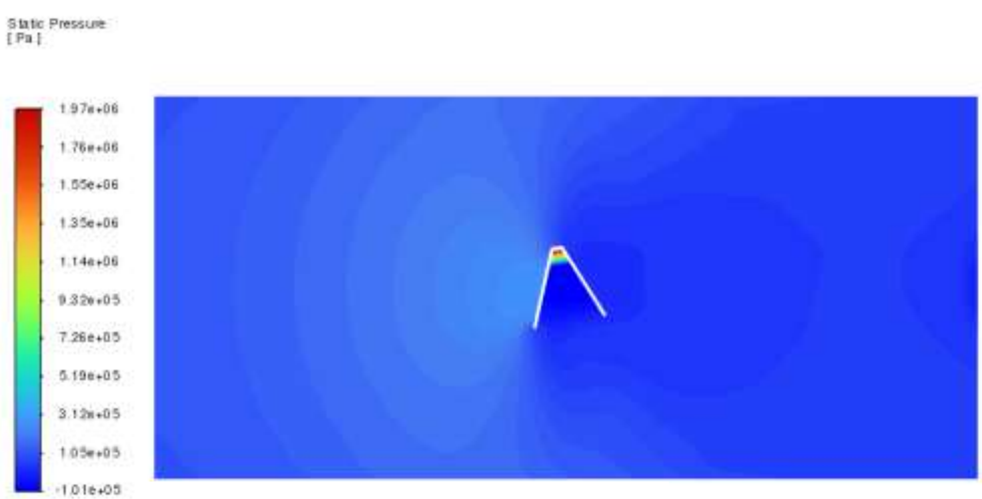
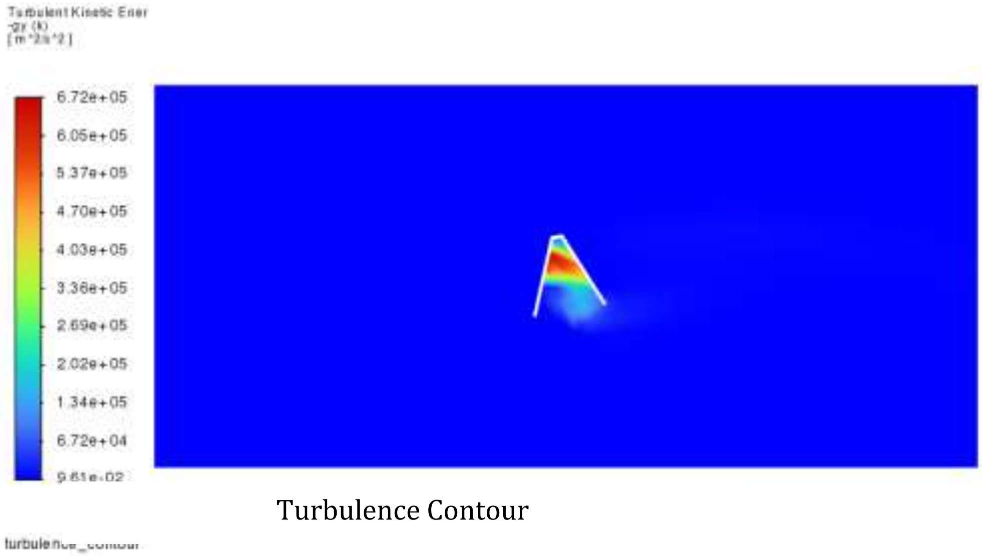


Velocity Pathline

At 80º Angle:



Pressure Contour



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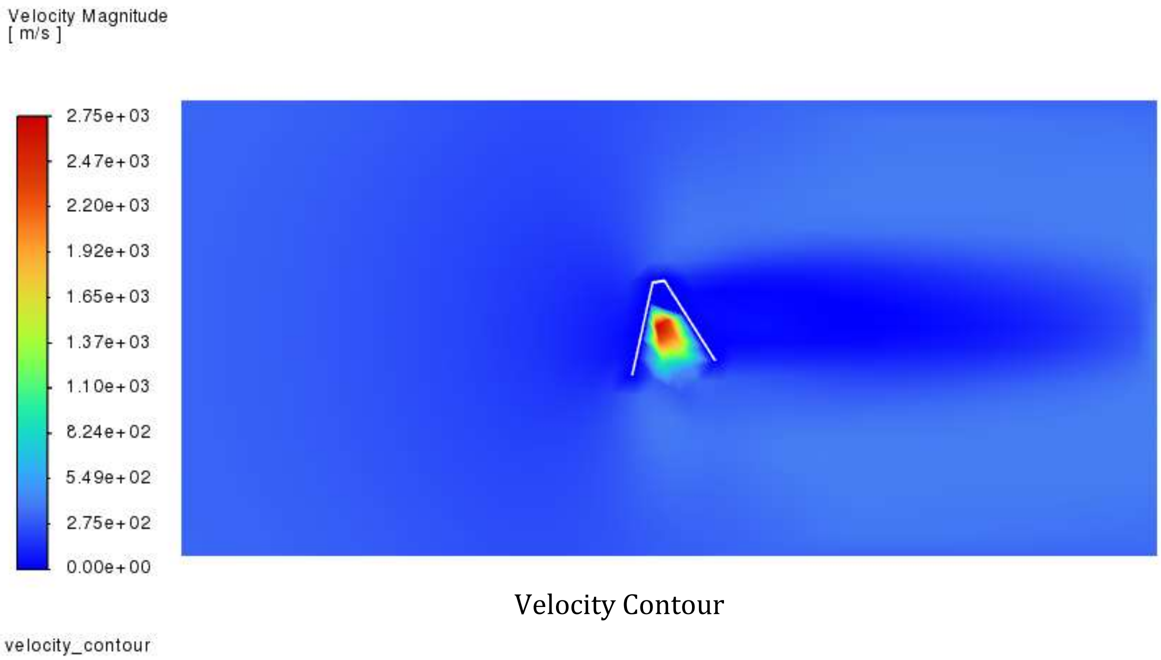

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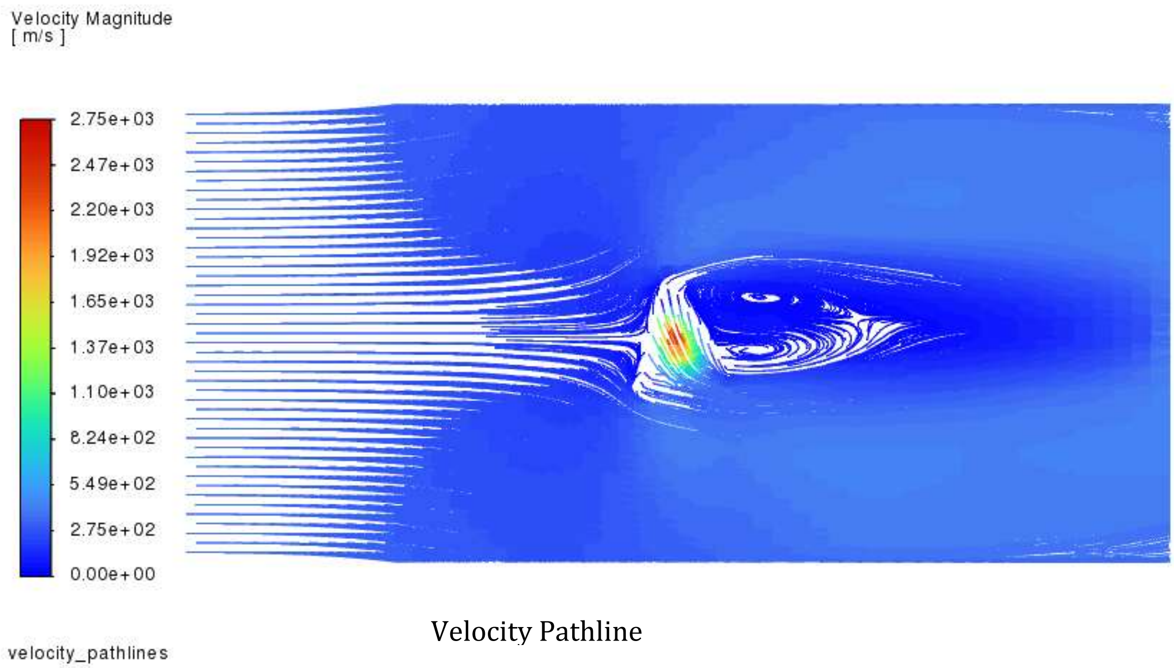
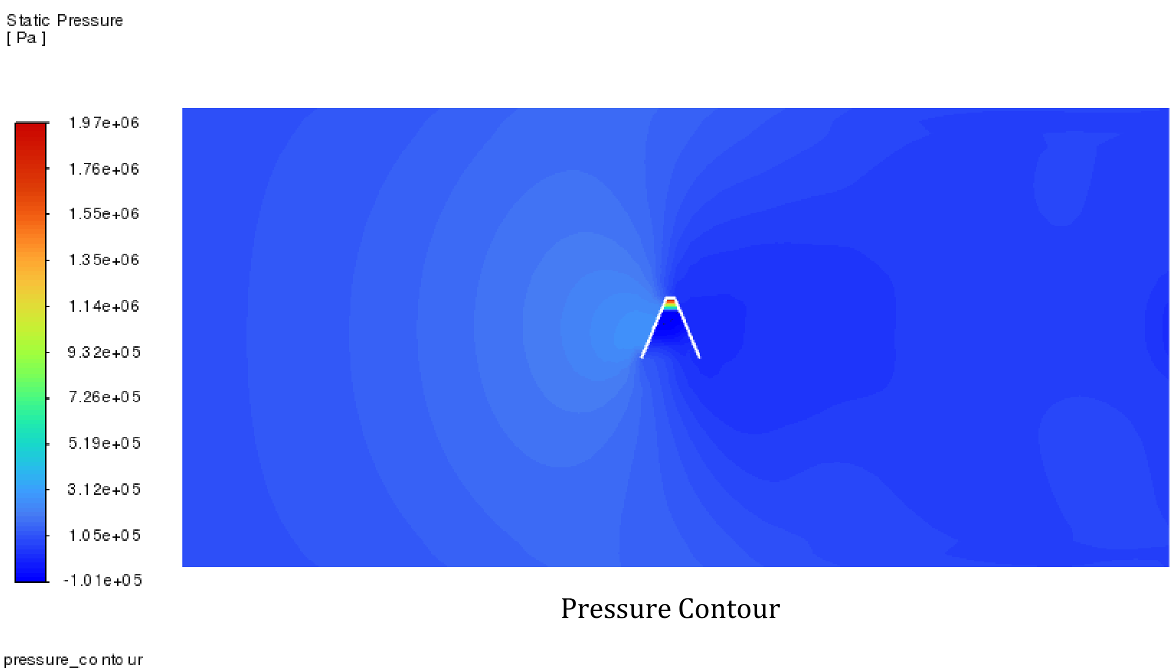
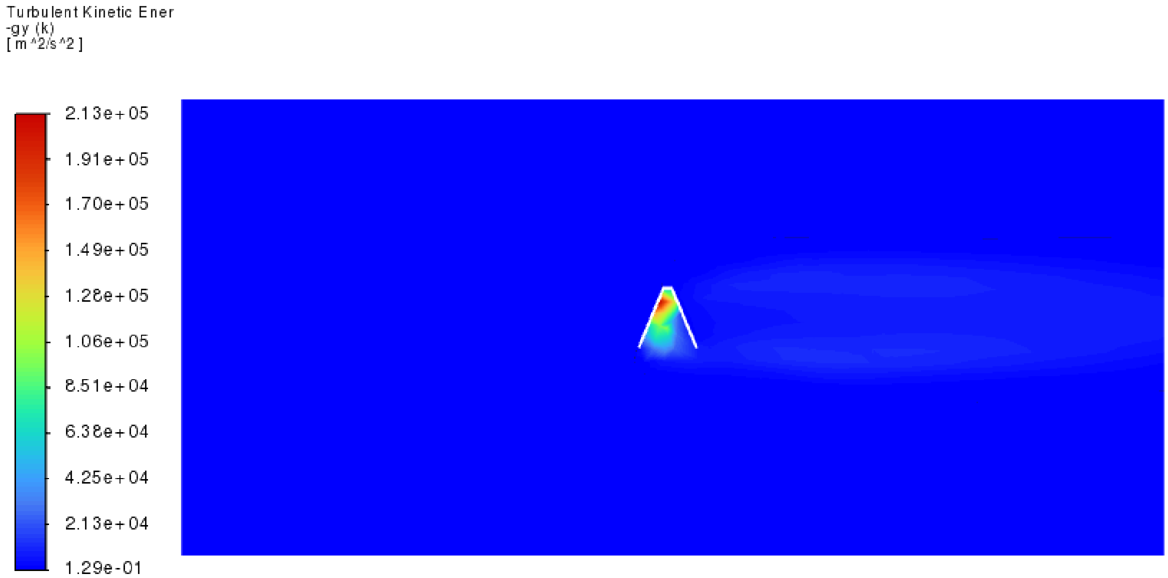


Velocity Pathline

At 90º Angle:

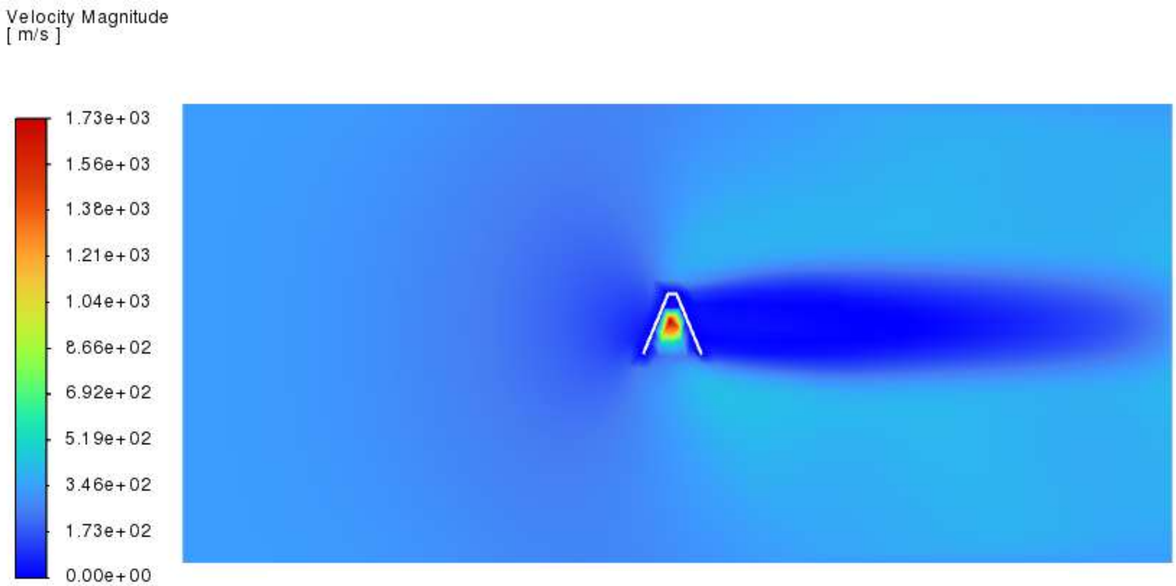


Pressure Contour



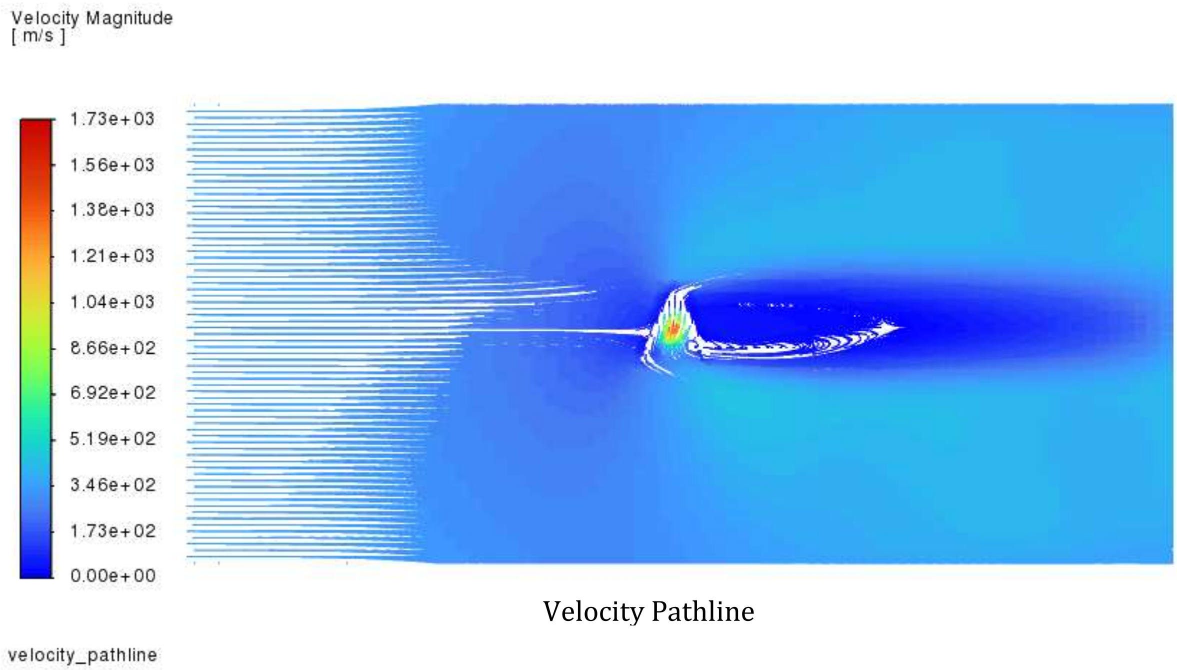
Turbulence Contour

turbulence_contour



Velocity Contour

velocity_contour



Velocity Pathline

Table 1: CFD Analysis of V-Gutter Angles

Angle (°)	Recirculation	Stability	Pressure Drop	Thermal Spread
45	Weak	Poor	Low	Poor
60	Moderate	Fair	Low	Moderate
70	Strong	Good	Moderate	High
80	Very Strong	Excellent	Moderate	Very High
90	Unstable	Fair	High	Low

5. Conclusion

The CFD-based investigation confirms that V-gutter flame holders with angles between 70° and 80° provide the best performance in terms of combustion stability and thermal efficiency. These configurations can significantly enhance ramjet combustor reliability with optimized recirculation and controlled pressure losses.

6. References

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