CFD Analysis of Flow through a 4-Cylinder Exhaust Manifold

1. Introduction

This project focuses on the CFD simulation of a 4-cylinder exhaust manifold to evaluate the internal fluid flow and thermal behavior under steady-state conditions. The manifold geometry was modeled in Autodesk Inventor and analyzed in ANSYS Fluent using a pressure-based solver and the SST k-ω turbulence model.

2. CAD Modeling

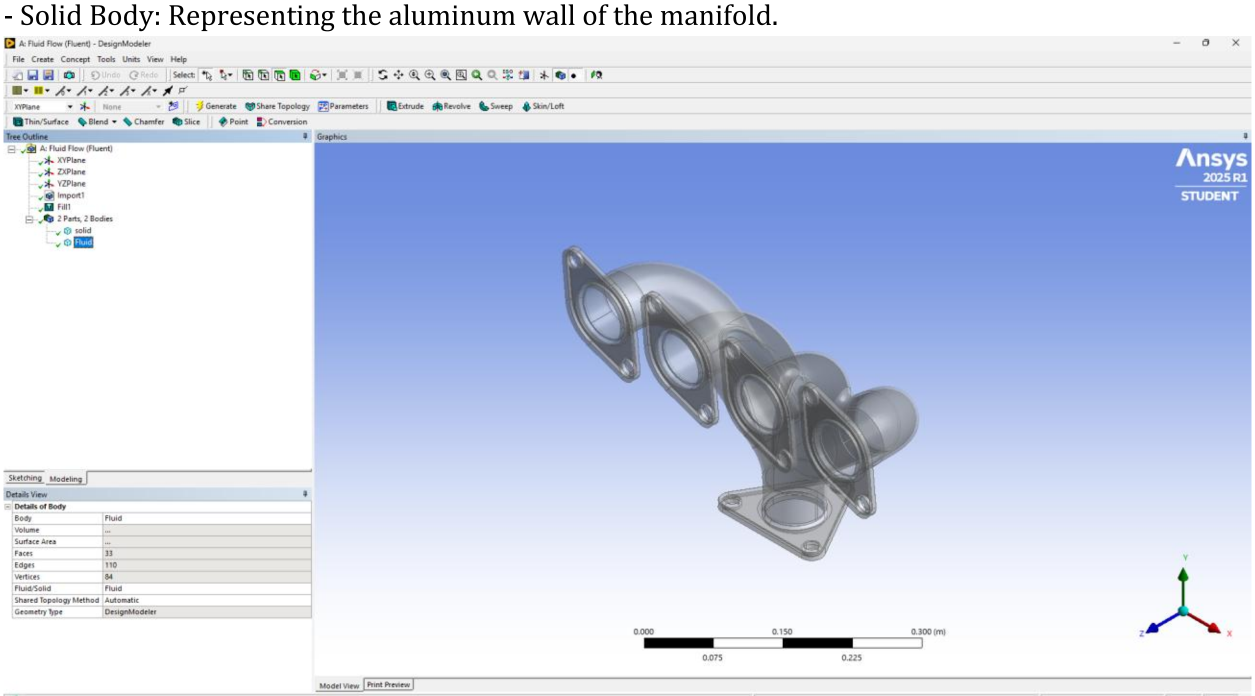
A 4-cylinder exhaust manifold was designed using Autodesk Inventor. The design includes four inlets merging into a single outlet, typical of an inline-4 combustion engine. The model was exported as a STEP file for simulation.

3. Preprocessing in ANSYS Fluent

3.1 Geometry Preparation

The STEP file was imported into ANSYS Geometry. Using the Fill tool, internal surfaces were selected to extract the fluid domain. Two separate bodies were created:

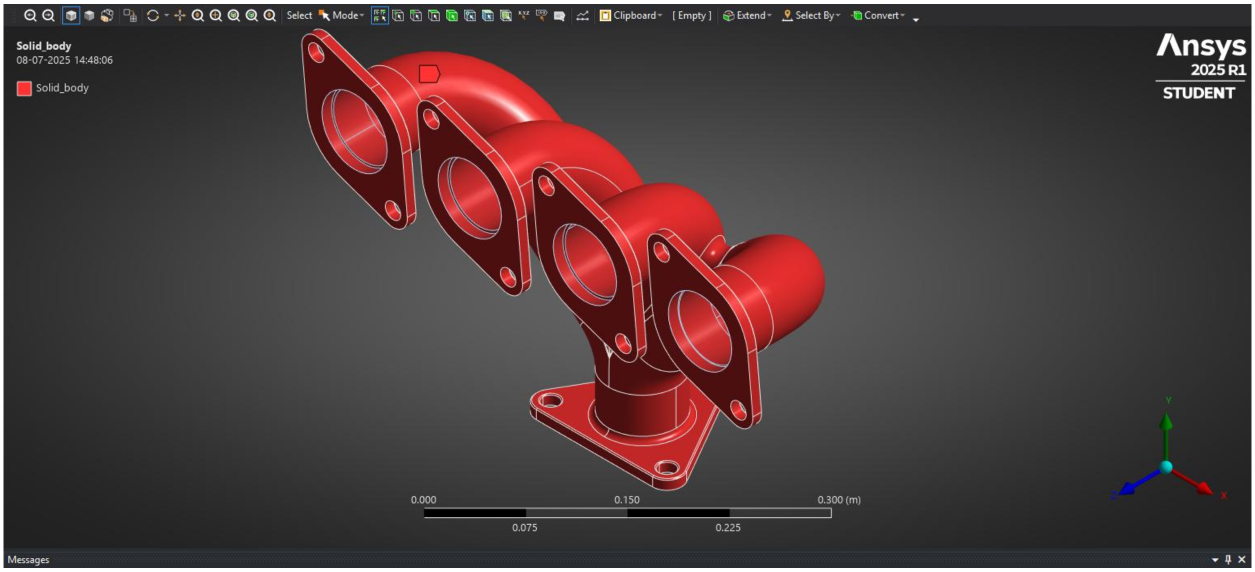
- Fluid Body: Representing the internal volume of the exhaust gases.
- Solid Body: Representing the aluminum wall of the manifold.

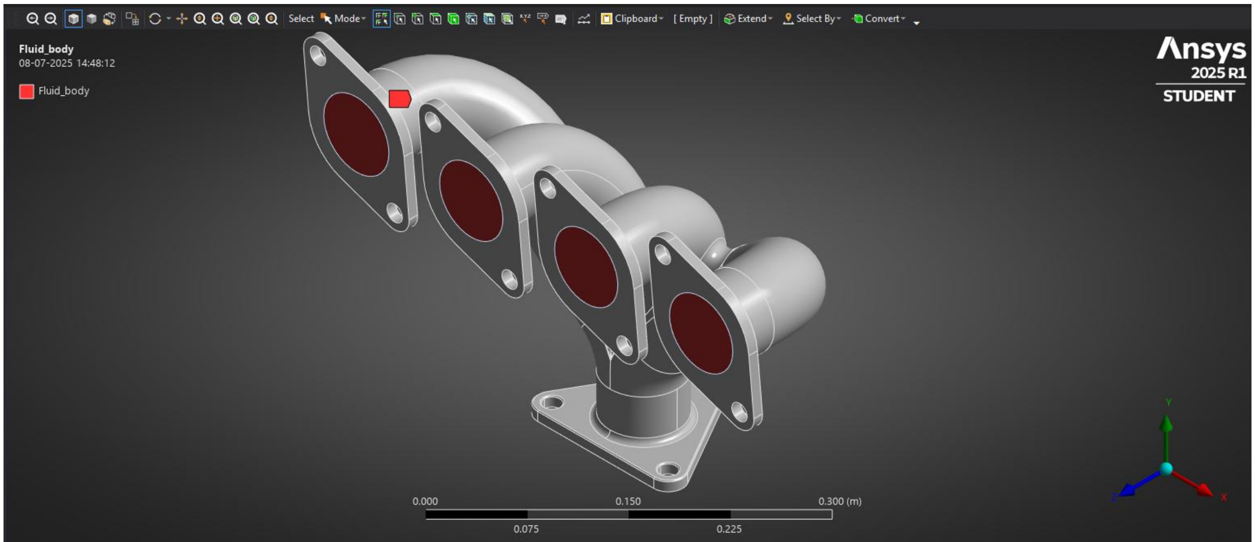


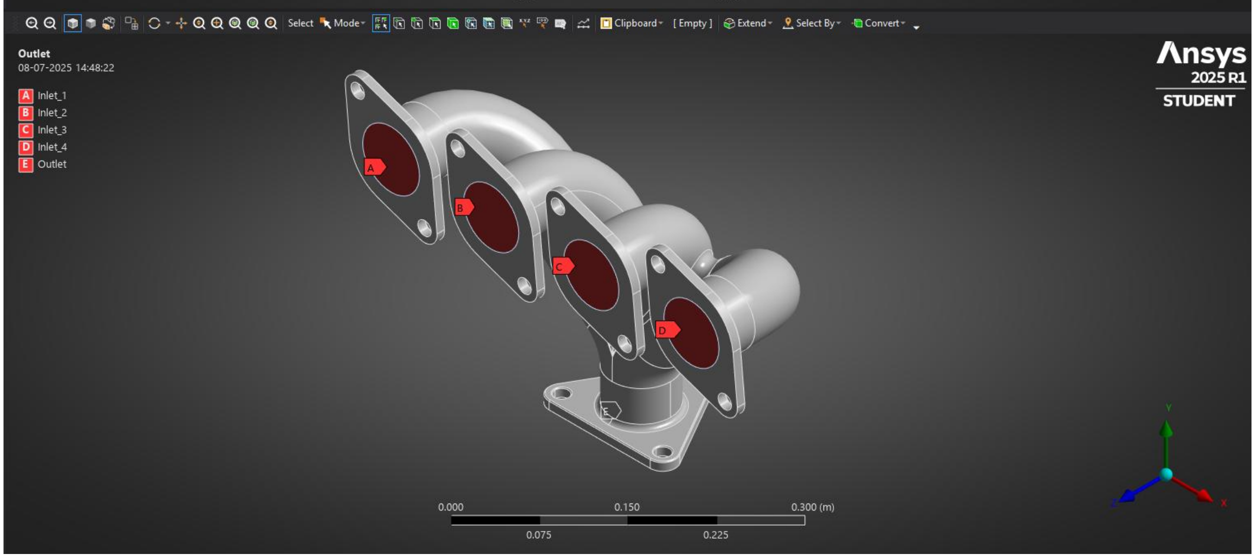
3.2 Named Selections

Named Selections used:

- Inlet_1, Inlet_2, Inlet_3, Inlet_4
- Outlet
- Solid_Body
- Fluid_Body

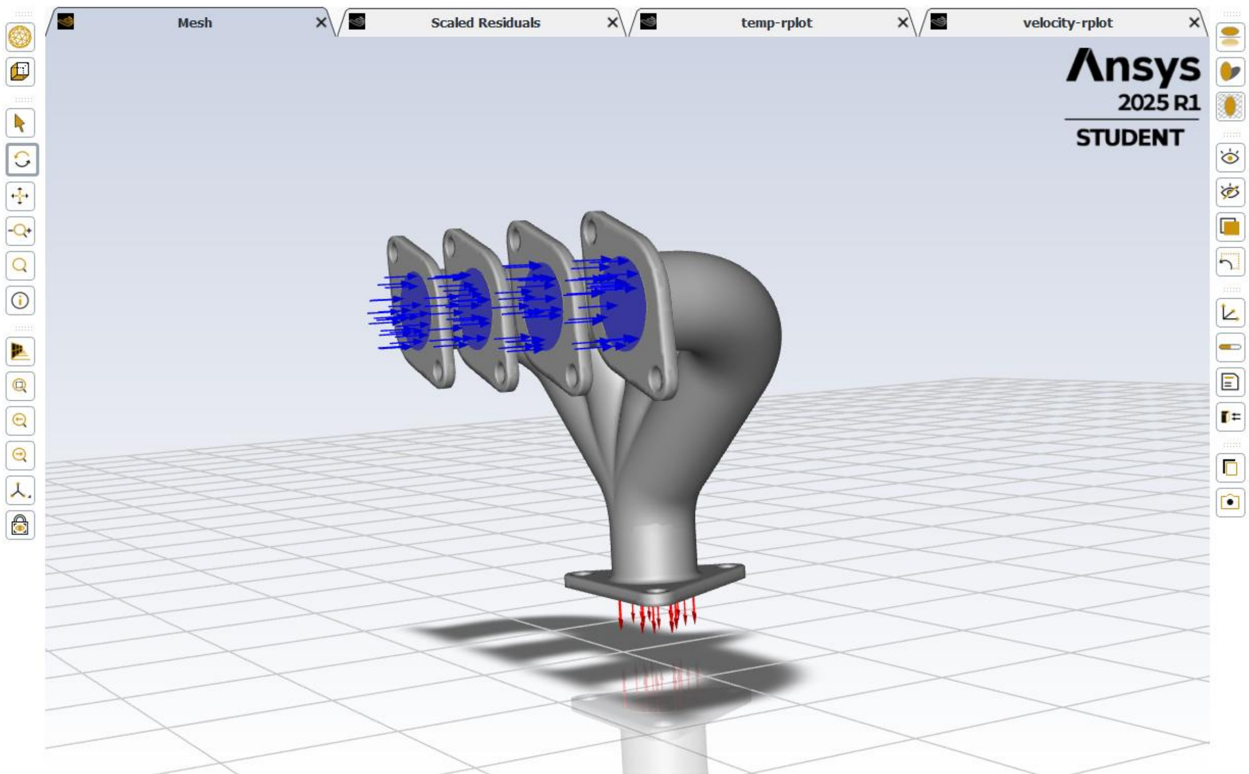


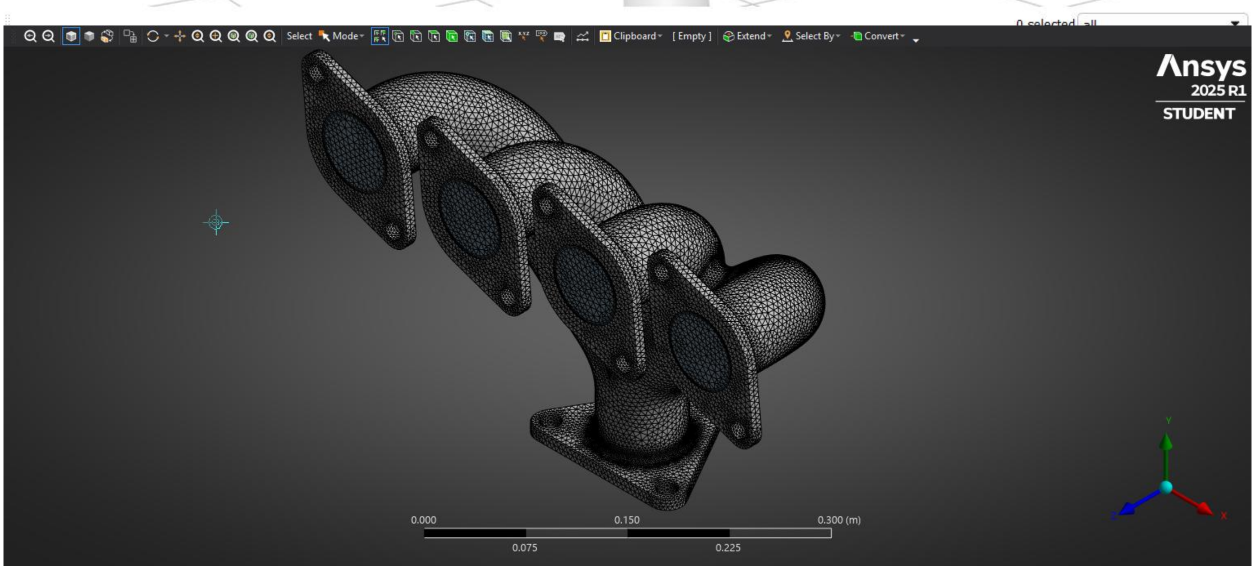




3.3 Meshing

Element Size: 5e-3 m
Mesh Quality: High
Inflation Layers: Applied to Fluid_Body (except on inlets and outlet)
Maximum Layers: 3
The mesh was sufficiently fine to capture flow details and boundary layer effects.





4. Solver Setup

4.1 General Settings

Solver Type: Pressure-based
Velocity Formulation: Absolute
Time: Steady
Precision: Double

Solver Processes: 4
Units: Length (mm), Temperature (°C)

4.2 Models

Viscous Model: SST k-ω
Energy Equation: Enabled

4.3 Materials

Fluid: Nitrogen Oxide Plus (NO^+)
Solid: Aluminium

4.4 Boundary Conditions

Inlets (1–4):
- Velocity Magnitude: 3 m/s
- Temperature: 60°C

Outlet: Pressure outlet (default ambient pressure)
Wall (Solid_Body):
- Thermal Condition: Convection
- Heat Transfer Coefficient: 60 $W/m^2 \cdot K$

5. Solution Setup

5.1 Initialization

Method: Hybrid Initialization

5.2 Pressure-Velocity Coupling

Scheme: SIMPLE

5.3 Report Definitions

Outlet Surface Reports:
- Velocity Magnitude: Facet Maximum
- Static Temperature: Facet Maximum

Convergence Settings:
- Ignore Iterations Before: 20
- Use Iterations: 20

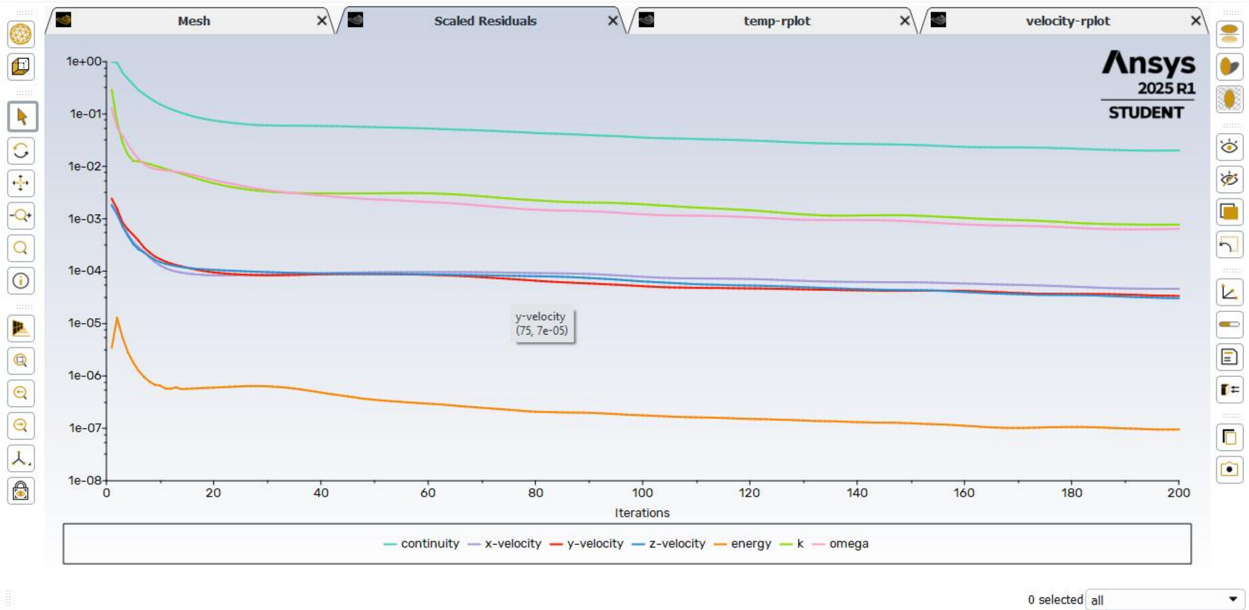
5.4 Run Settings

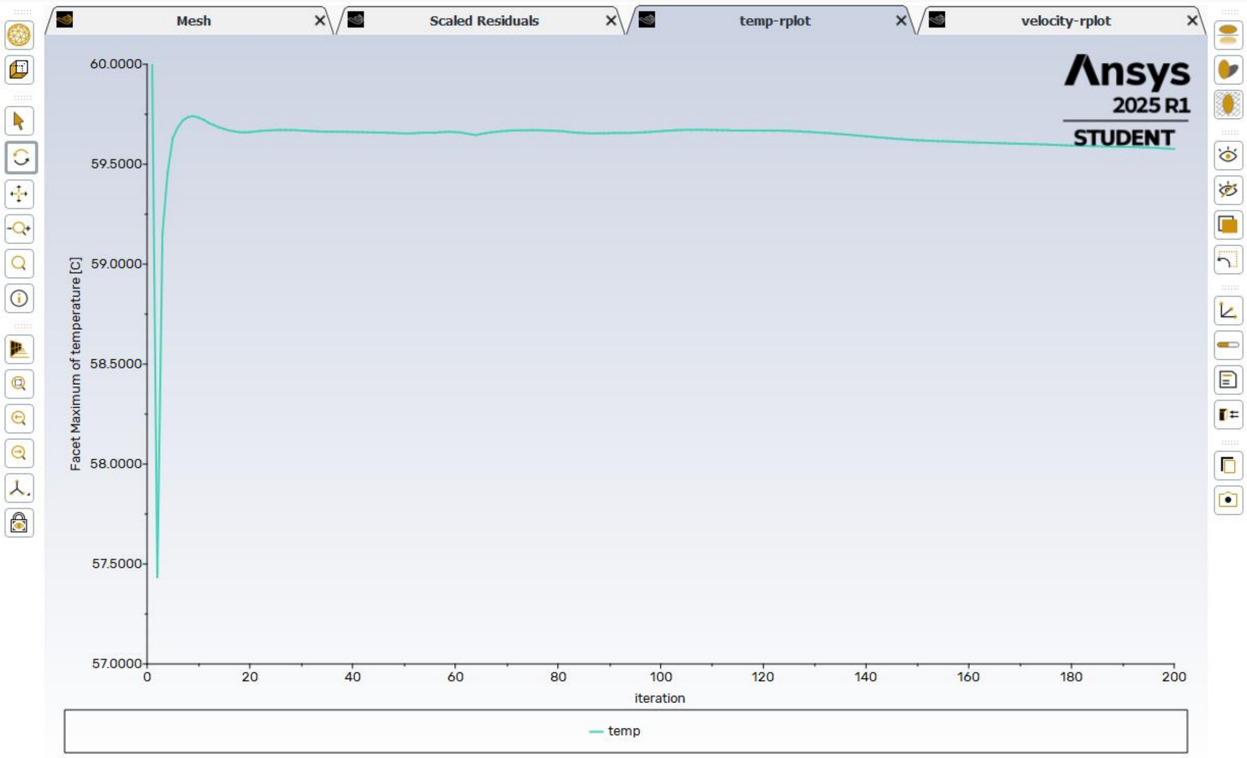
Number of Iterations: 200
Monitored Parameters: Residuals, Velocity, Temperature

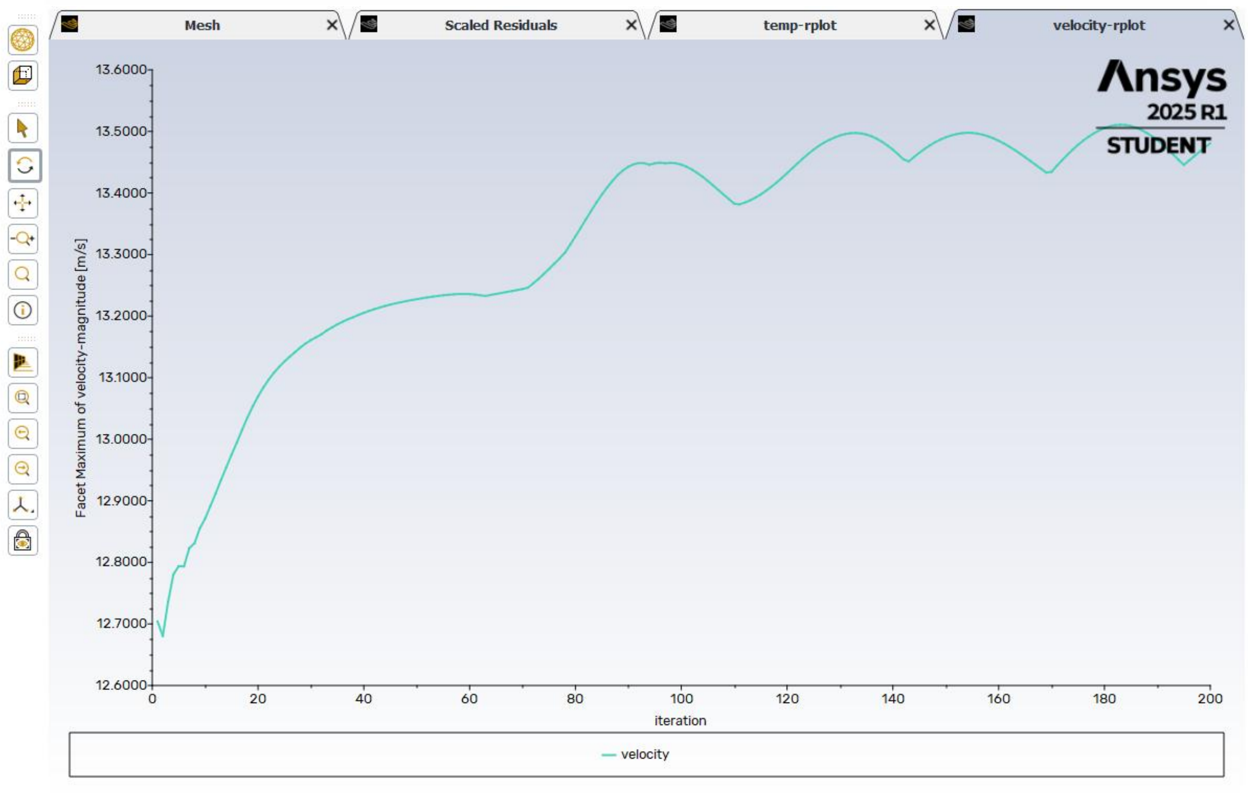
6. Results and Postprocessing

6.1 Convergence

Residuals for continuity, velocity components, energy, and turbulence quantities showed stable decay and convergence.
Report definitions (velocity and temperature at outlet) reached consistent values, validating solution stability.







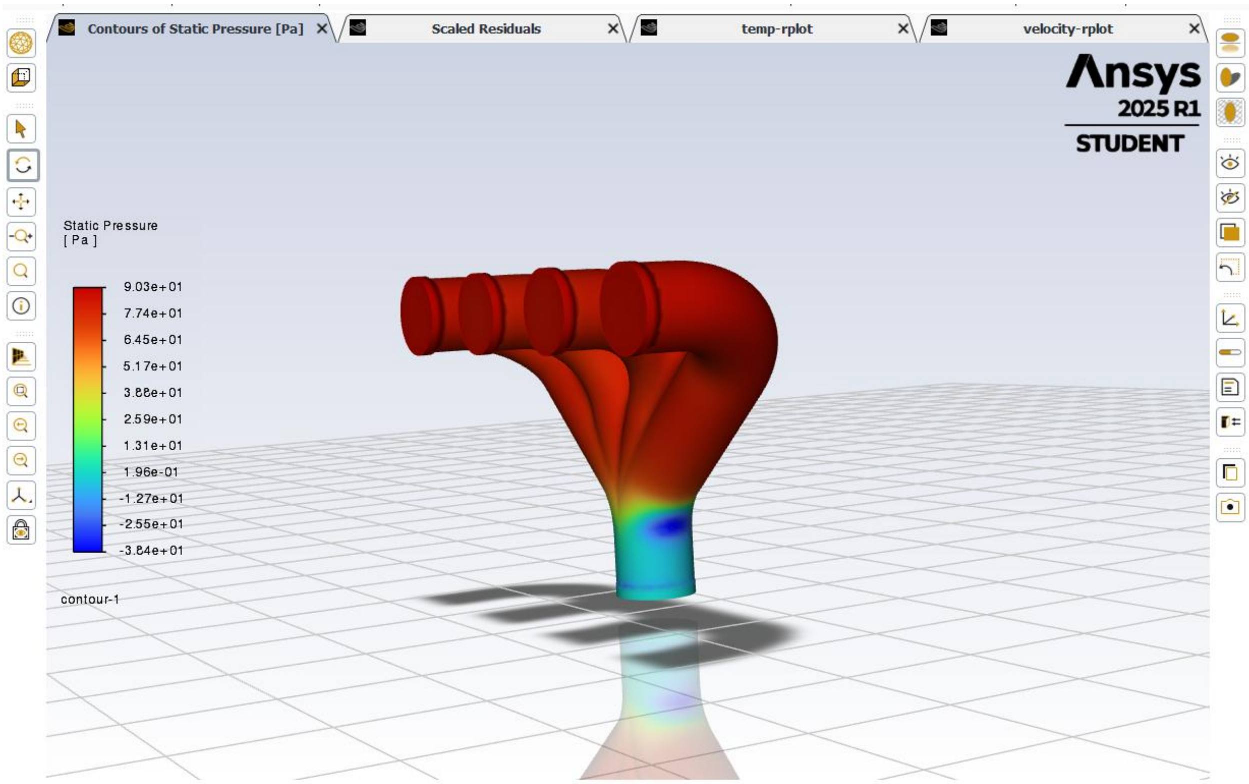
6.2 Visualization

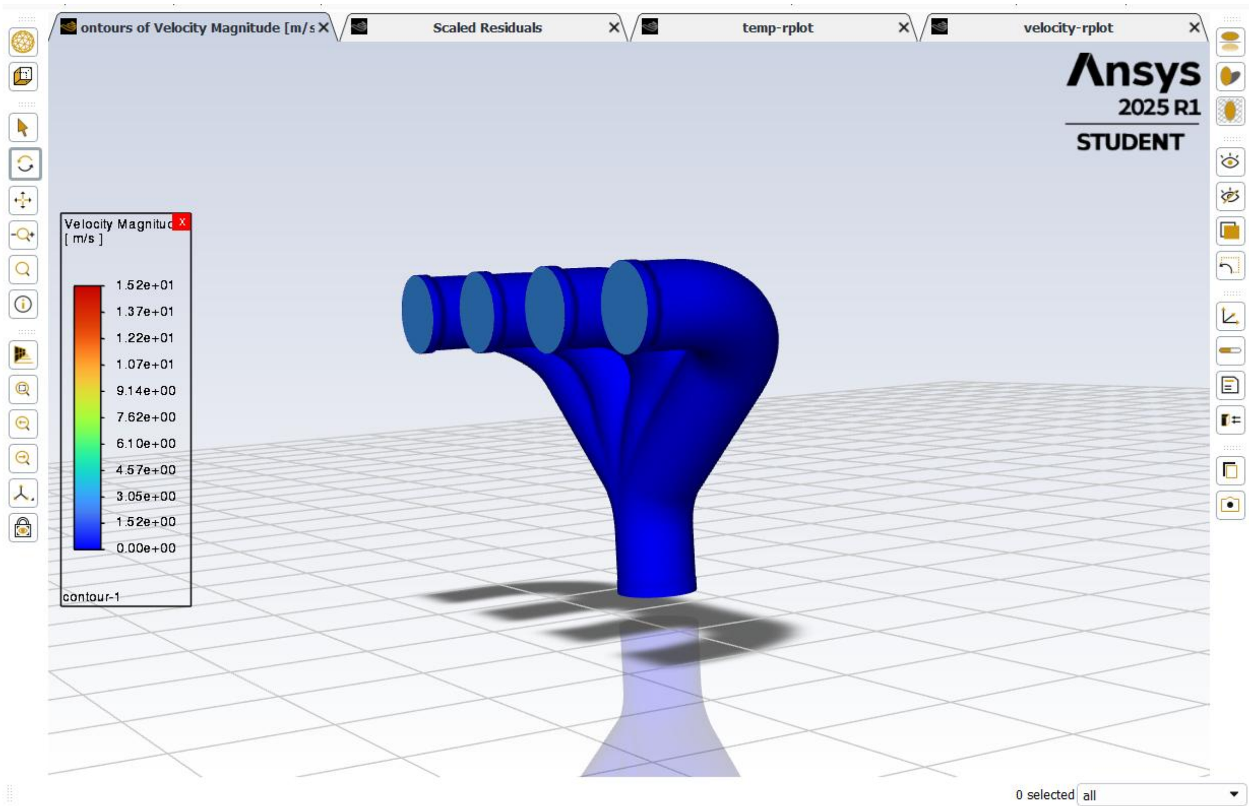
Contours:

- Static Temperature: Tracked thermal distribution from inlets to outlet.

- Static Pressure: Showed pressure loss along flow path.
- Velocity Magnitude: Visualized flow acceleration and distribution.

Velocity Vectors: Indicated merging flow and directionality from all four inlets.
Pathlines: Illustrated streamline behavior, confirming smooth flow convergence and identifying any potential flow separation.

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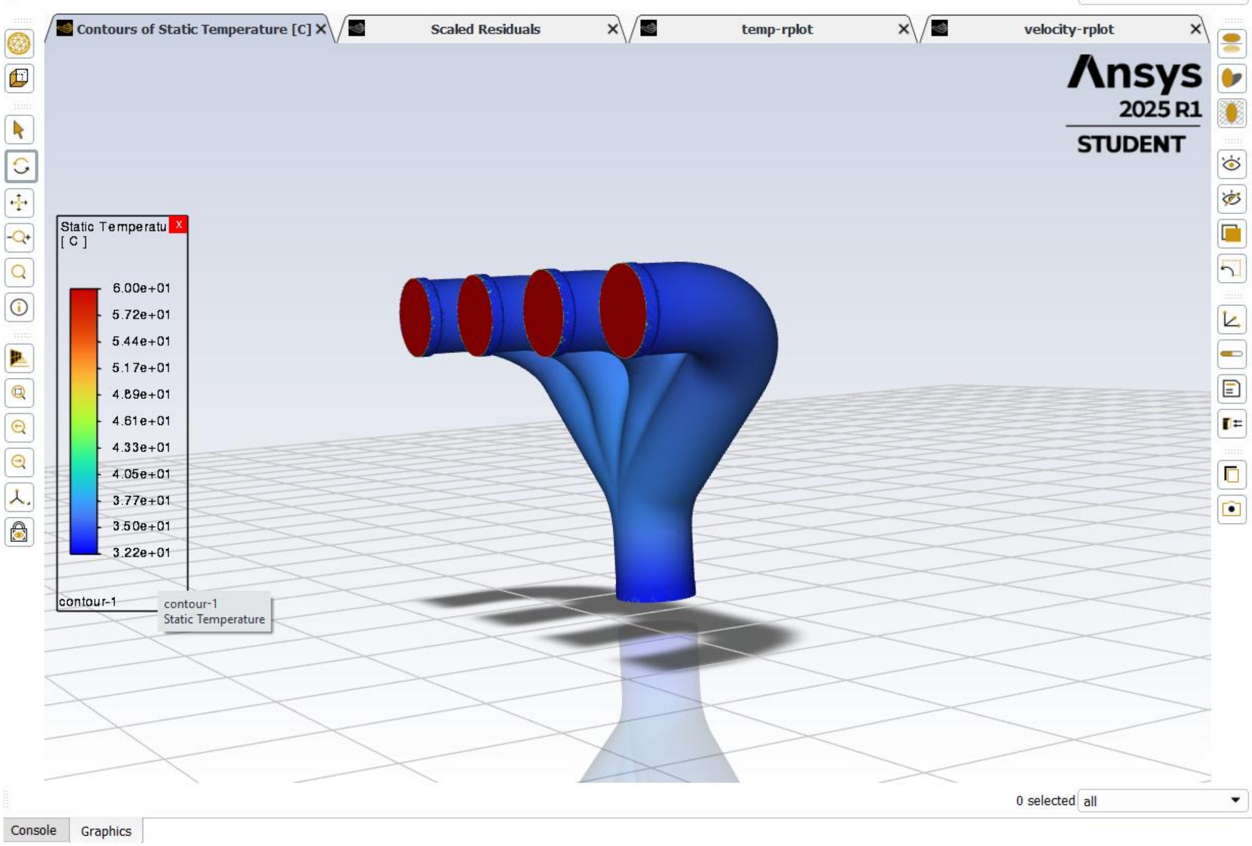
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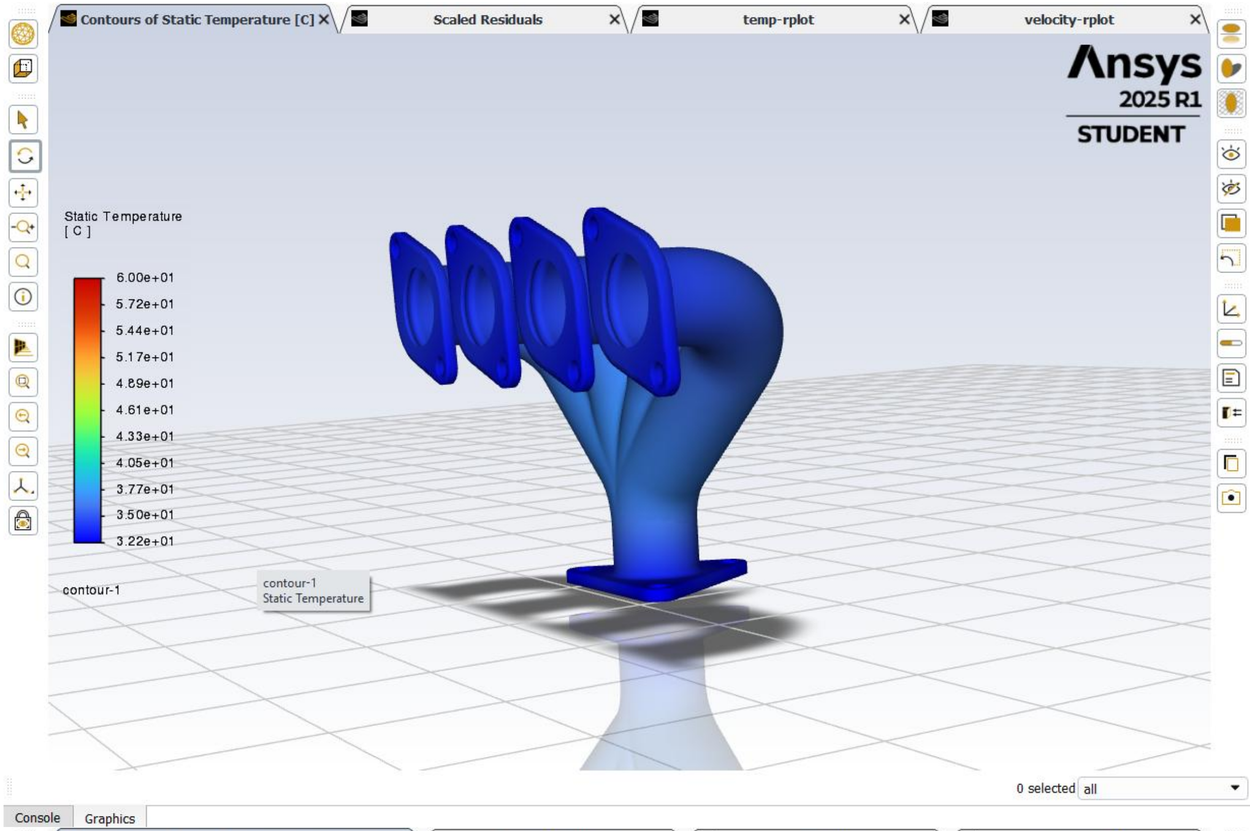
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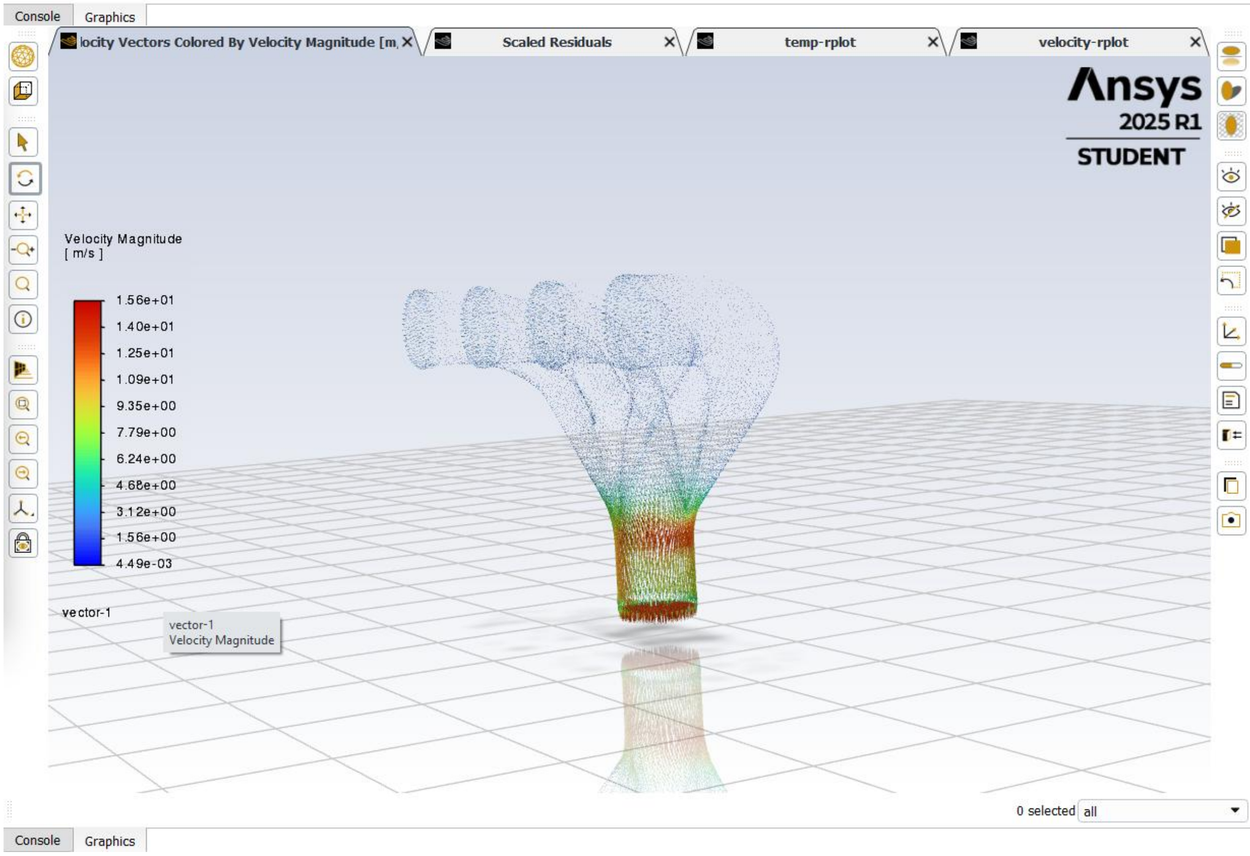
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Velocity Magnitude
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1.09e+01
9.35e+00
7.79e+00
6.24e+00
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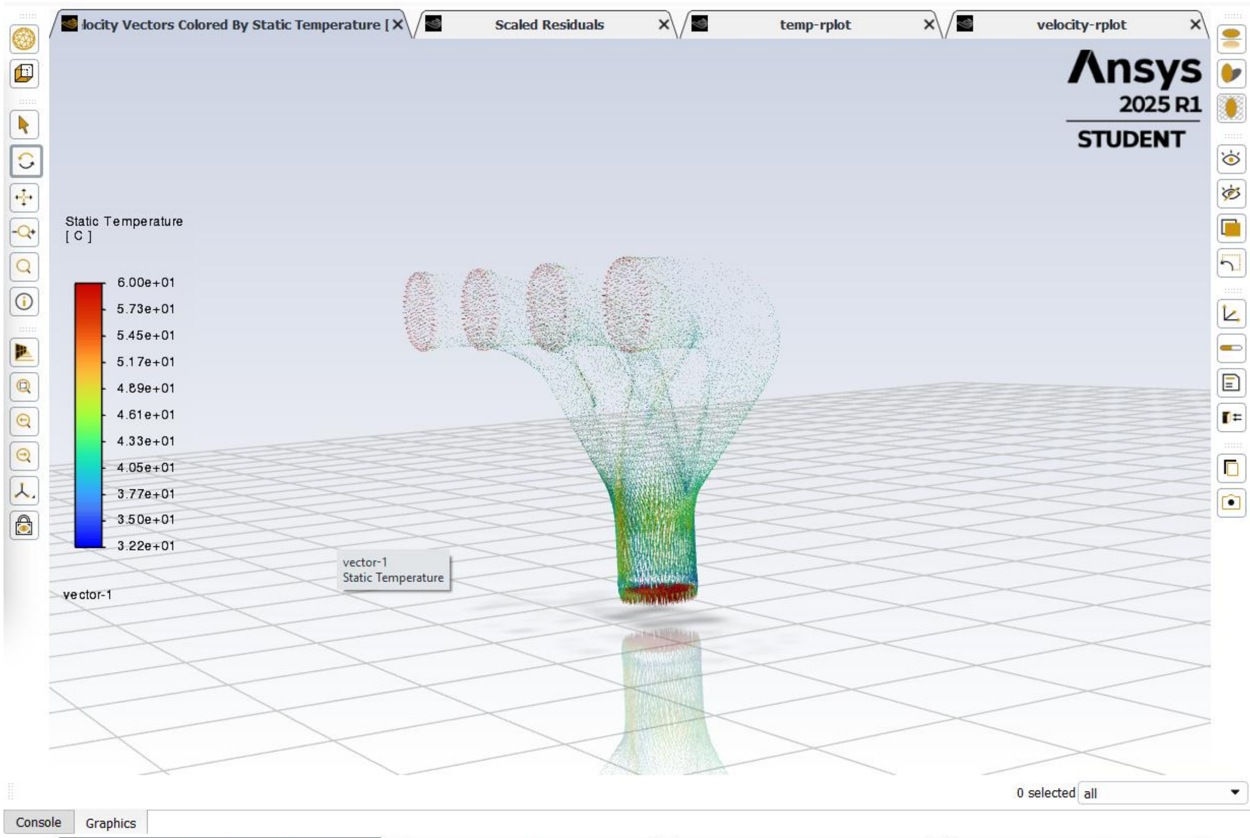
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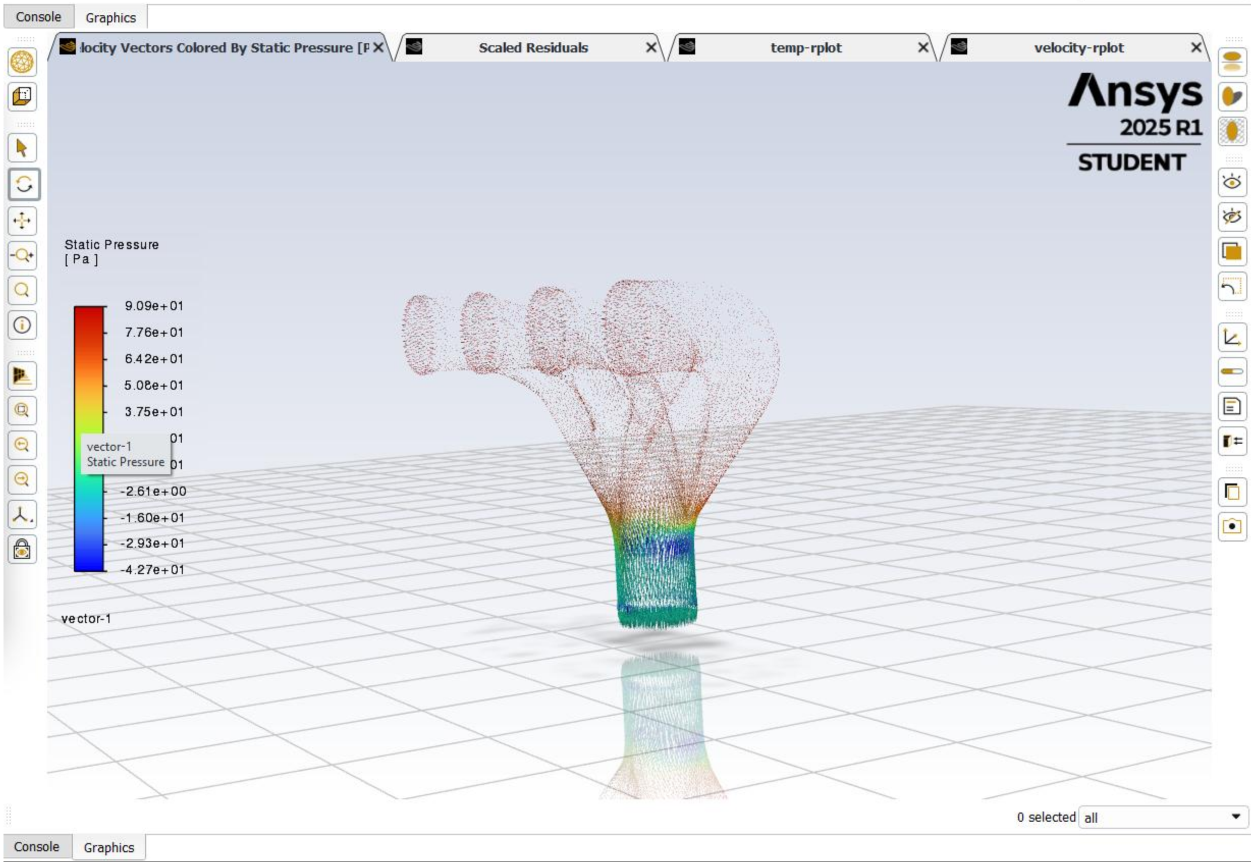
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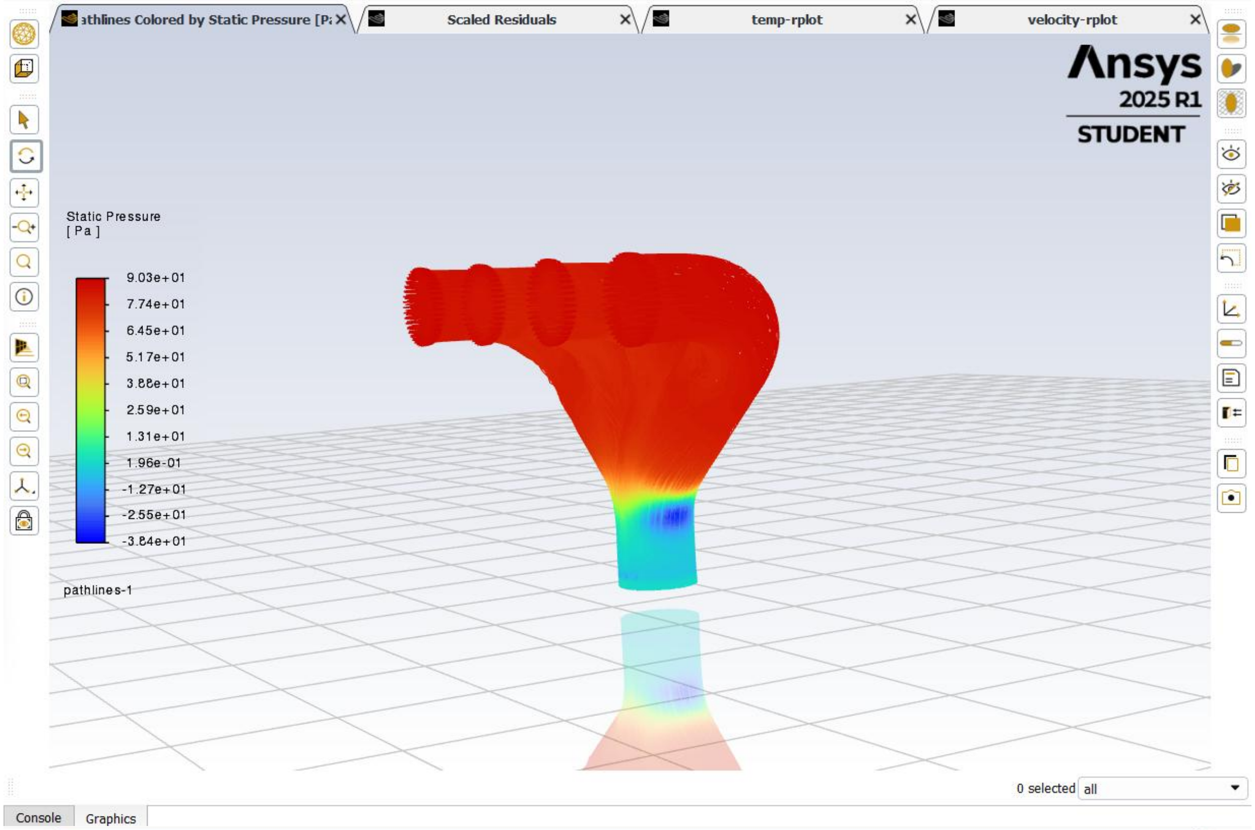
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3.88e+01
2.59e+01
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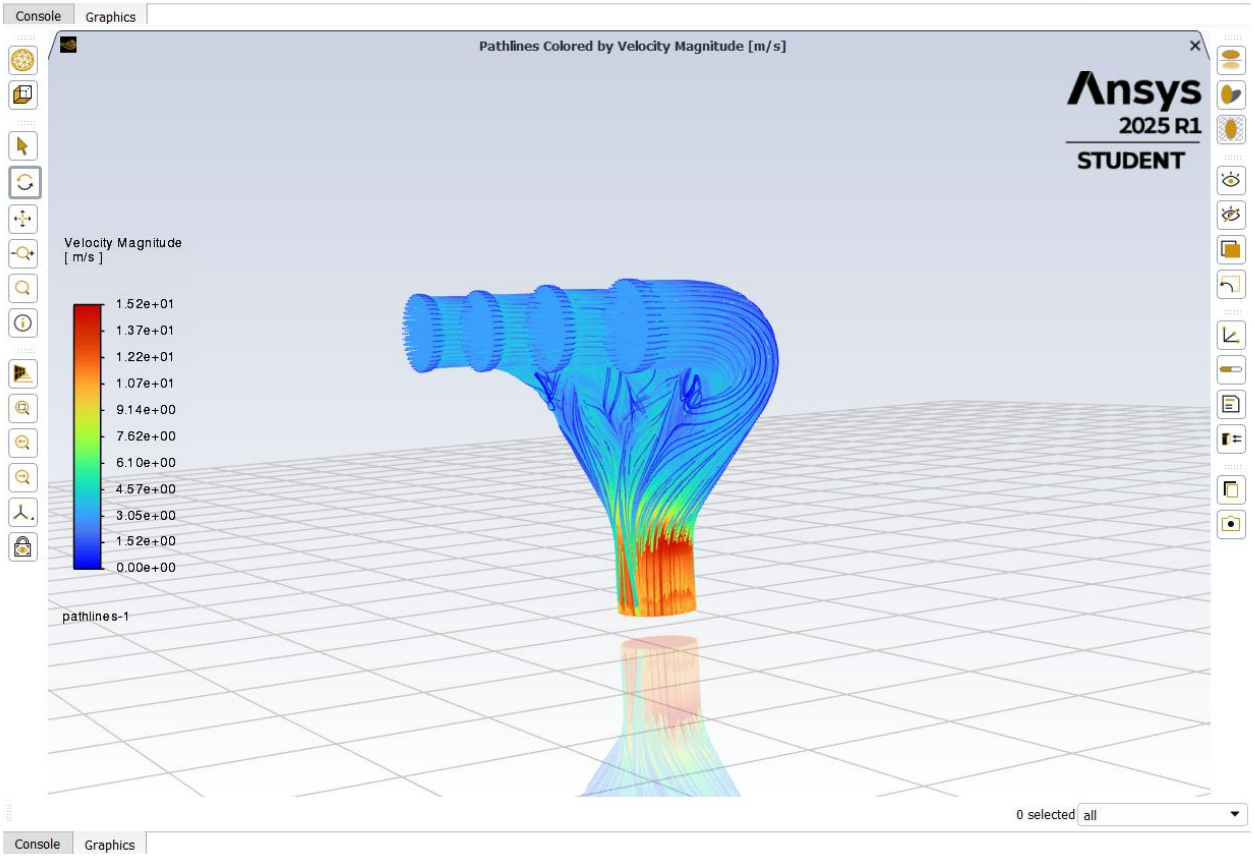
Pathlines Colored by Velocity Magnitude [m/s]
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Velocity Magnitude
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1.07e+01
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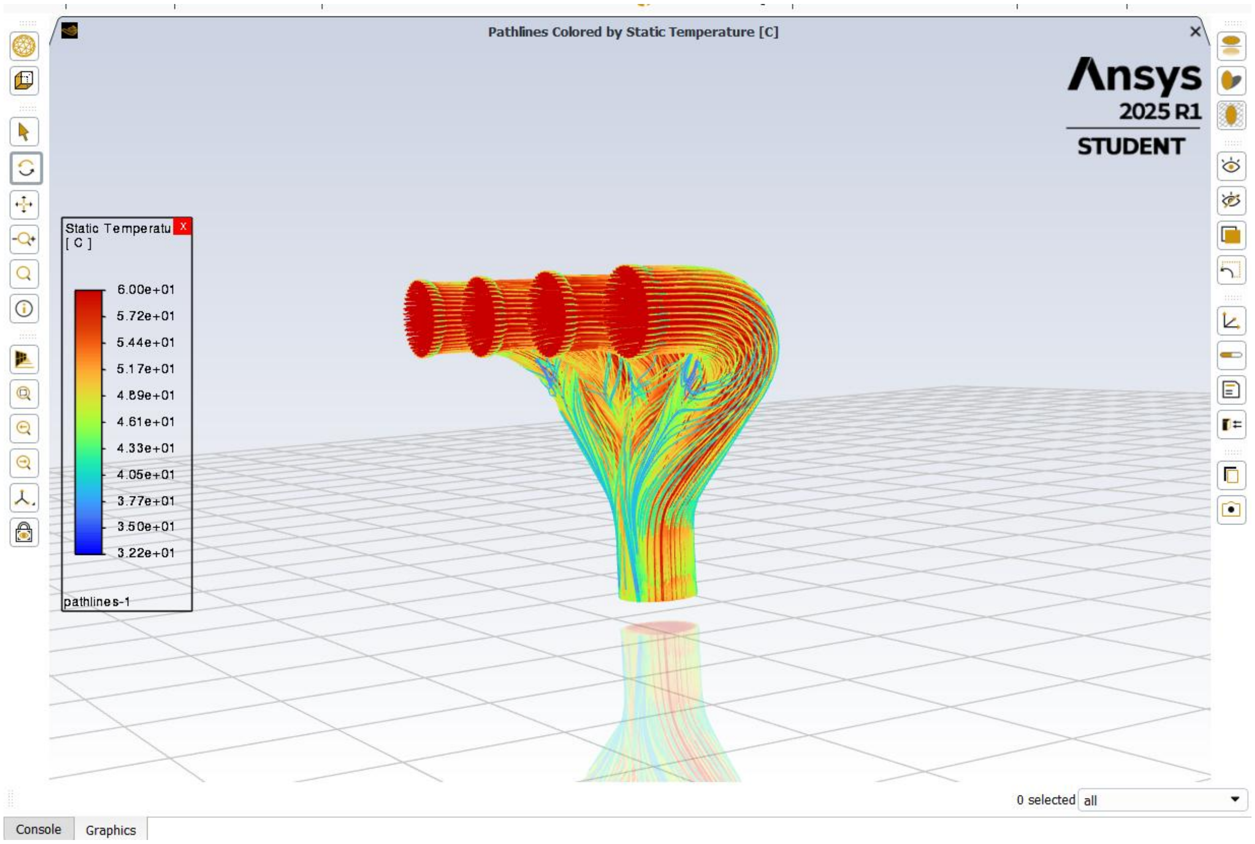

7. Conclusion

The CFD simulation of the 4-cylinder exhaust manifold using Nitrogen Oxide Plus (NO^+) as the working fluid provided key insights into its internal flow characteristics under steady-state conditions. The temperature and velocity distributions were effectively captured using the SST k-ω turbulence model and fine mesh resolution.

Key Takeaways:
- Flow from all four inlets merged uniformly.
- Outlet temperature and velocity stayed within expected bounds.
- The applied thermal boundary condition facilitated realistic heat transfer representation.