

Pretest Simulations of a Supersonic Mixing and Combustion Validation Experiment to Assess Sensitivities

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- **Background/Motivation**
- **Computational approach**
 - Automated solution adapted workflow
- **Verification of the adapted anisotropic tetrahedral grid workflow**
 - Jet flow configuration from the 6th AIAA Propulsion Aerodynamics Workshop
- **Details of the planned validation experiment**
 - Geometry
 - Conditions
- **Description of the geometric sensitivities investigated**
- **Discussion of results**
- **Summary**



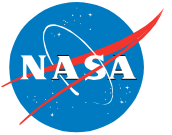
- **An outcome of the High Speed Code Credibility Workshop series emphasized the need for high quality model validation databases.**
 - Fundamental fuel/air mixing and combustion data in a relevant scramjet engine flow environment was one of the high priority gaps identified.
 - Databases exist but lack rigor required to isolate model form discrepancies.
 - Incomplete geometry and BC information
 - Insufficient measurements available to isolate model performance
 - Limited documentation on experimental uncertainties
 - Design and execution of the experiment should follow accepted guidelines for tests intended for CFD validation, e.g., Oberkampf and Smith [2014].
 - Facility artifacts fully documented so their effects can be accounted for in the simulations.
 - Flowfield characterization for CFD boundary condition specification (or verification) must be a top priority.
 - Use of multiple redundant diagnostics to address diagnostic method bias errors.
 - Replicate tests at a different facility to address facility bias errors.

Computational Approach

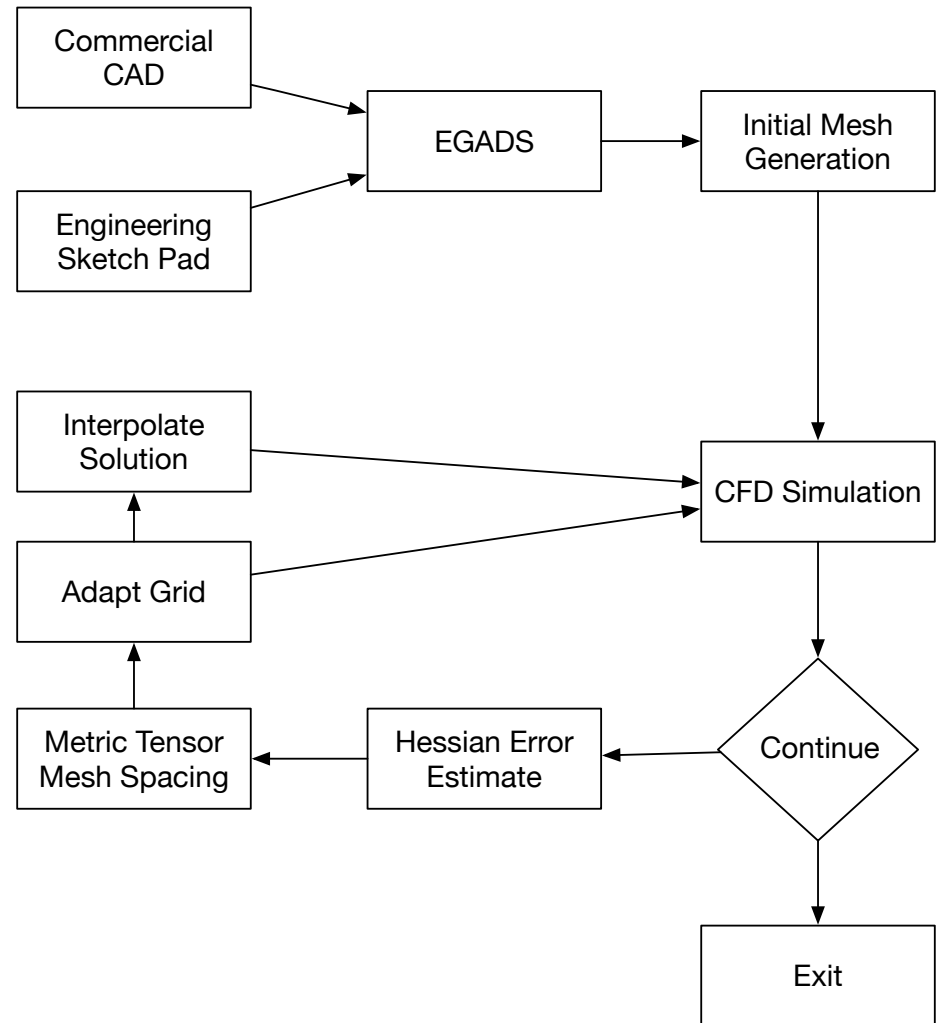


- **All results obtained using the VULCAN-CFD unstructured solver**
 - Menter SST Model, $Pr_t=0.9$, $Sc_t=0.7$
- **Anisotropic tetrahedral adaptive gridding workflow based on *refine* [Park et al. 2019].**
- **Several positive attributes of this workflow:**
 - No human-in-the-loop grid generation.
 - Grids are adaptively refined based on an estimate of numerical error.
 - Completely automated simulation workflow.
 - Numerical error naturally tracked as part of the simulation workflow.
- **The one downside is the reliance on pure tetrahedral meshing.**
 - Solution quality is compromised in the near wall region of boundary layers.
- **The *refine* approach was particularly attractive given the focus here on simulation sensitivities to variations in geometry.**

Automated Adaptive Grid Workflow Process



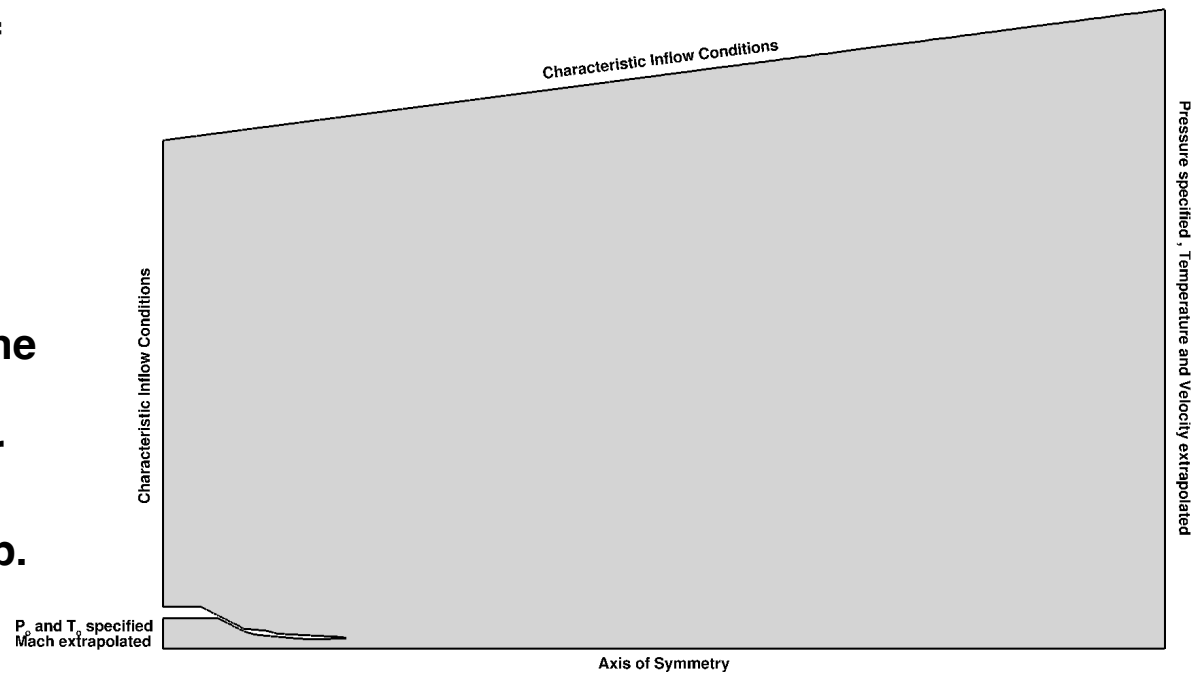
- 1) Start with CAD description.
- 2) Generate an initial mesh with no human intervention.
- 3) Obtain an initial CFD solution.
- 4) Estimate the error.
- 5) Determine new mesh spacing based on the error estimate.
- 6) Adapt the mesh to conform to these mesh characteristics.
- 7) Interpolate previous solution onto new mesh (optional).
- 8) Repeat steps 3-7.



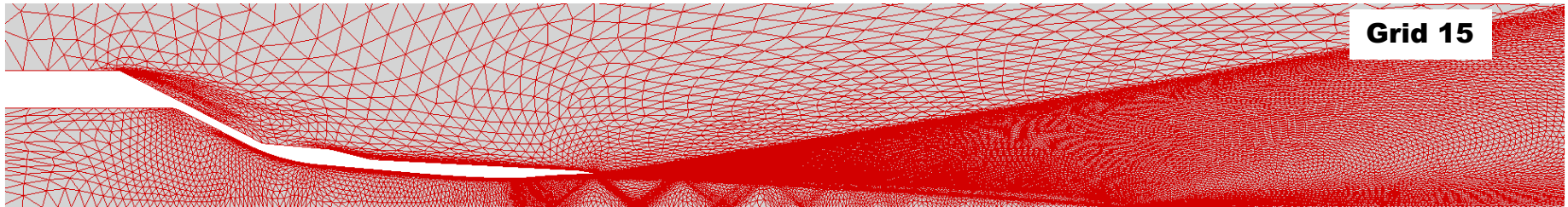
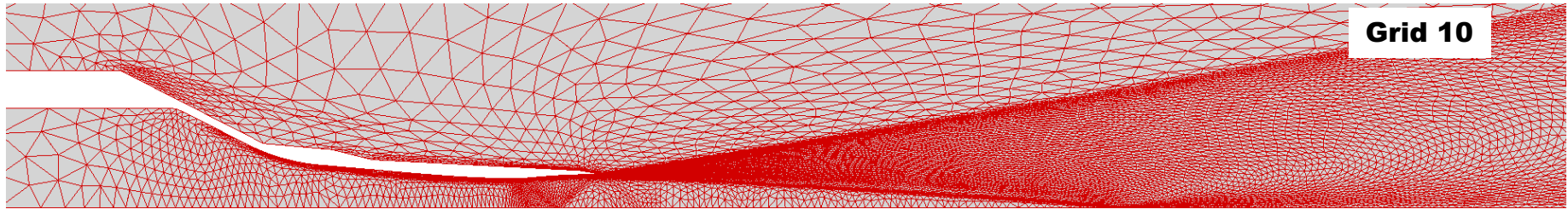
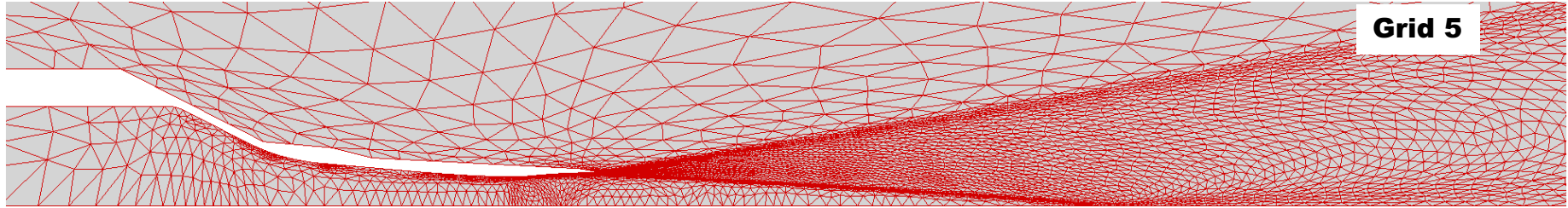
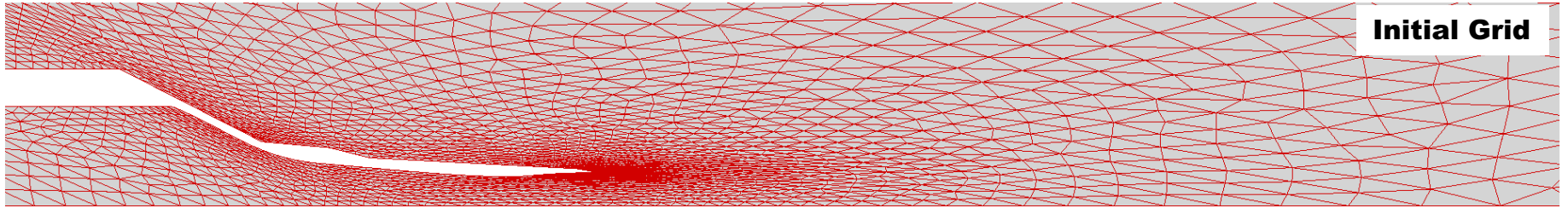
Verification of the Adaptive Grid Workflow



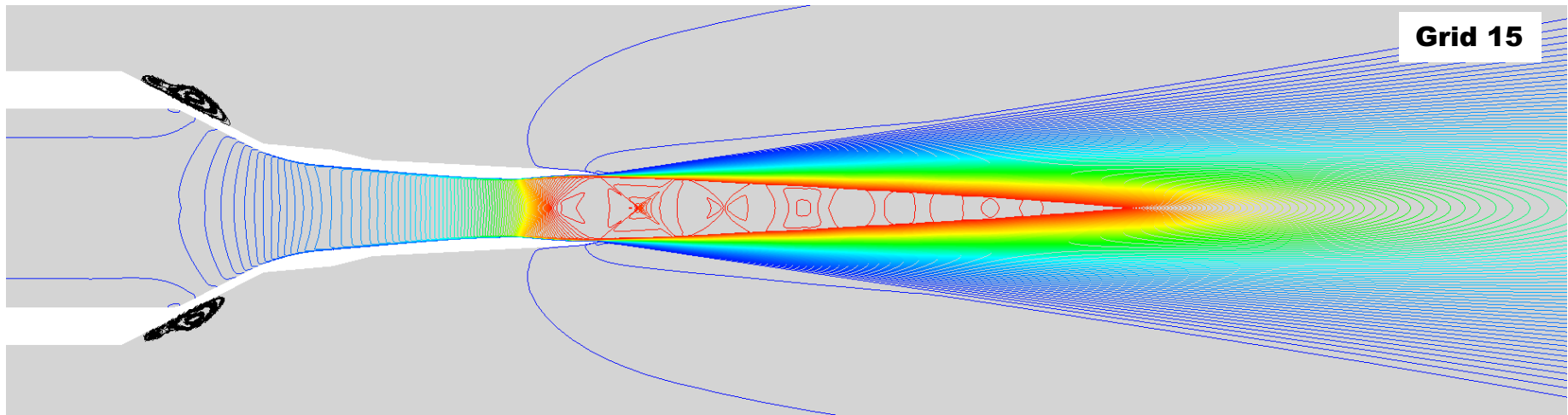
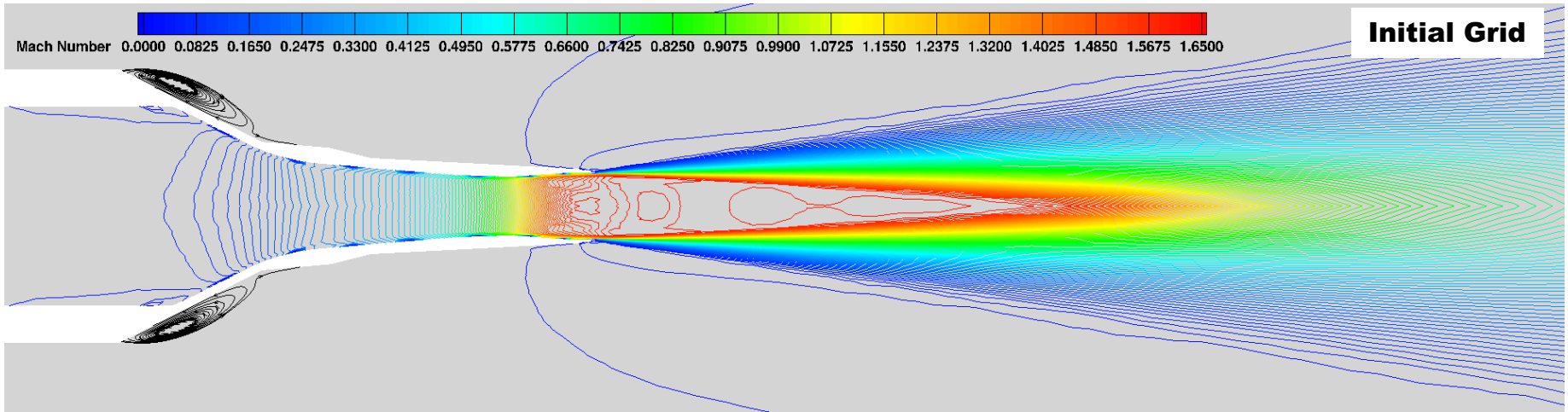
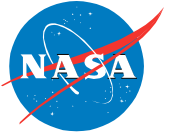
- **Tetrahedral grid are known to be problematic in many scenarios**
 - Difficult to grid align flow features to triangular cell faces
 - Reduced accuracy in boundary layer near wall region is well documented.
 - Even free shear flows have been shown to be problematic, e.g., Dippold [2018].
- **Given the prominence of jet/wake shear mixing in the proposed validation experiment, verification tests were performed to assess the adequacy of the *refine* workflow for the supersonic jet flow configuration chosen for the 6th Propulsion Aerodynamics Workshop.**



Verification of the Adaptive Grid Workflow



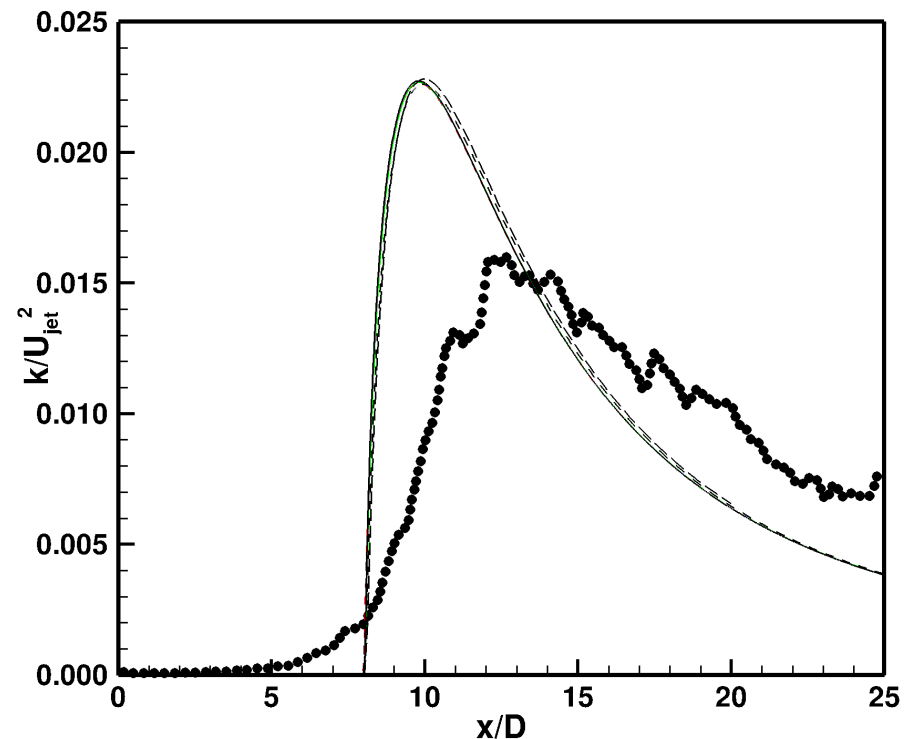
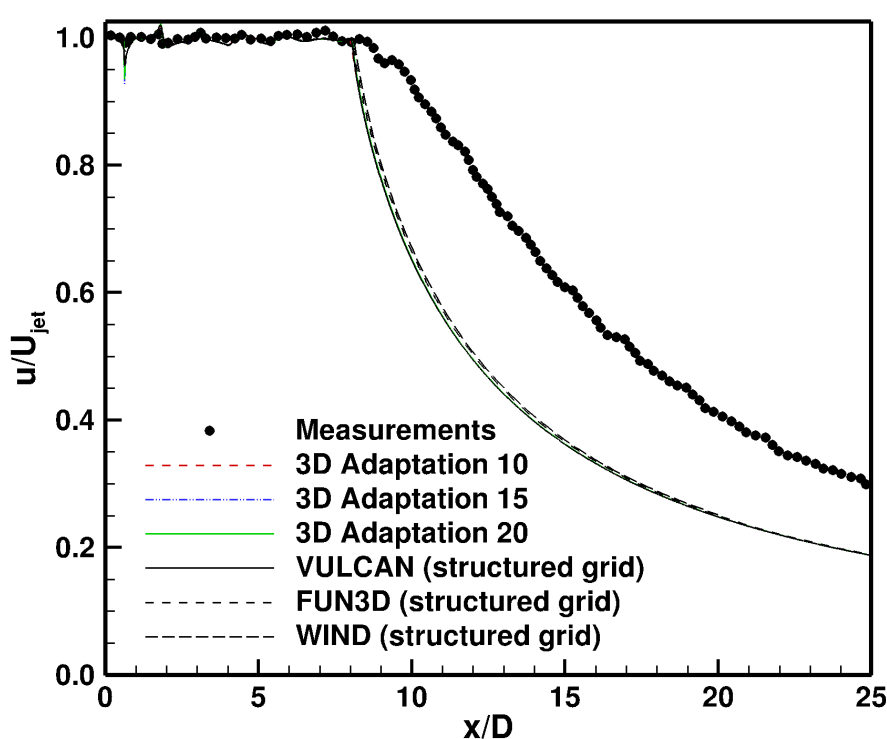
Verification of the Adaptive Grid Workflow



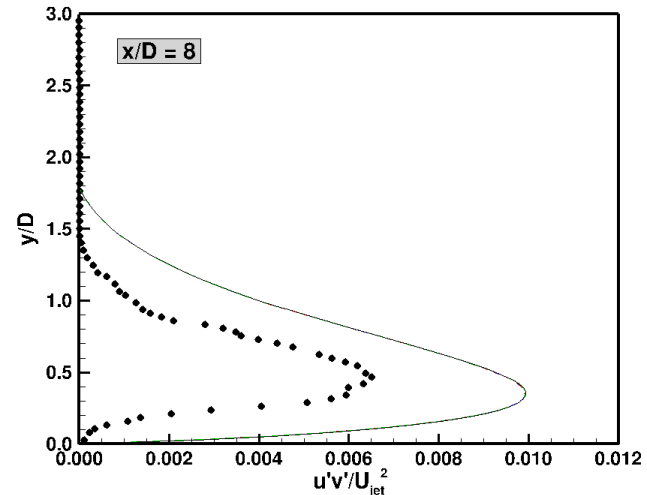
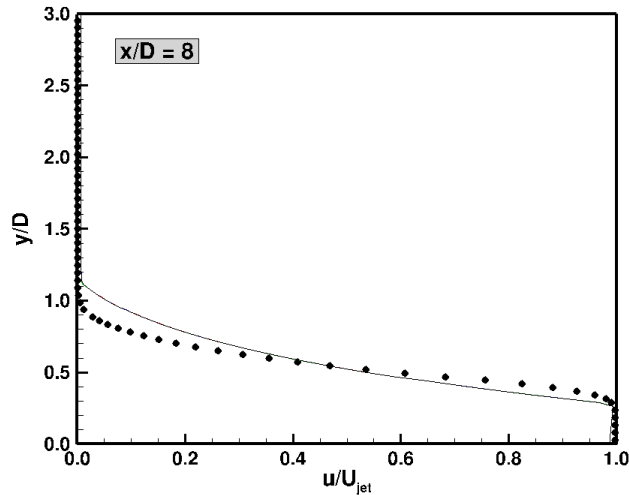
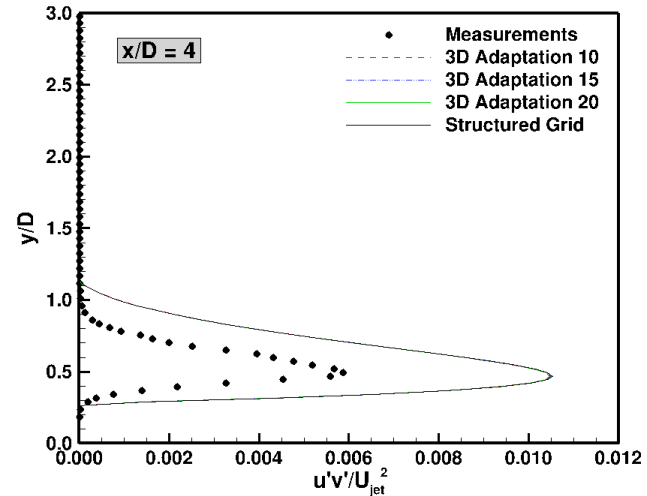
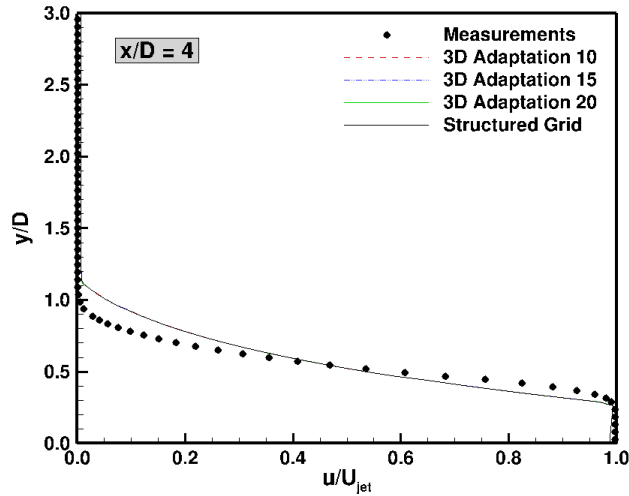
Comparison of Flow Properties Along the Centerline



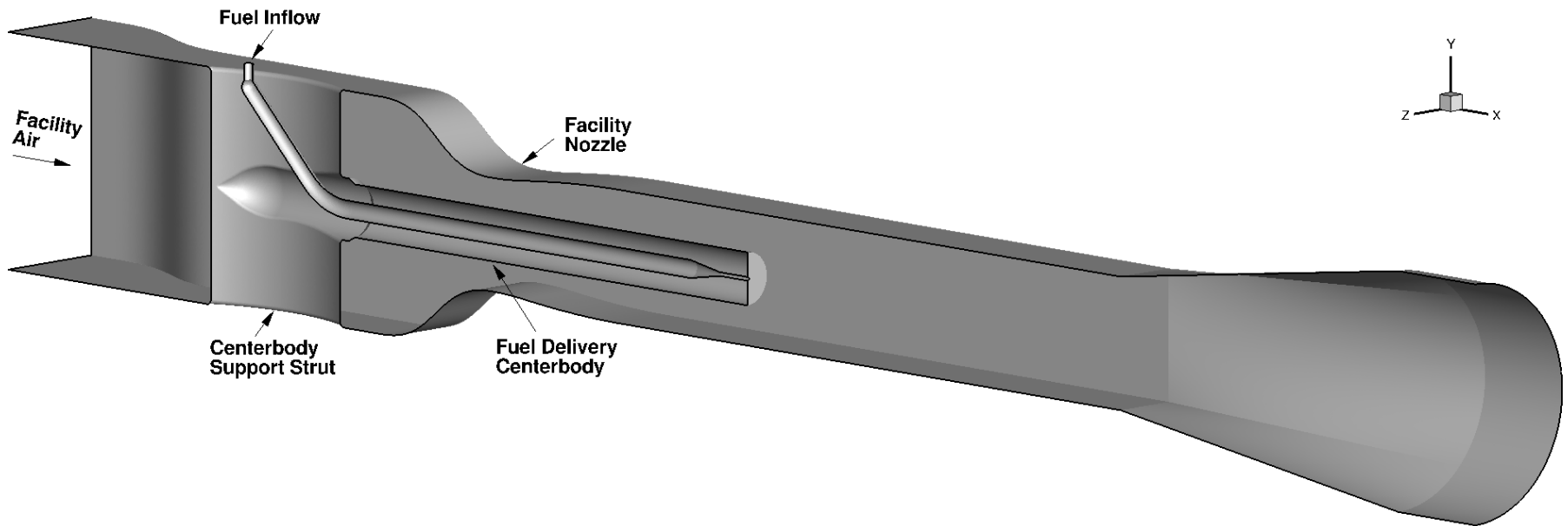
- True axisymmetric and 3-D sector computational domains were simulated.
- Axisymmetric domain cell counts (structured grid results used 604,800 cells):
 - 35,041 cells used for adaption step 10
 - 107,827 cells used for adaption step 15
 - 328,825 cells used for adaption step 20



Comparison of Profiles at Several Axial Stations

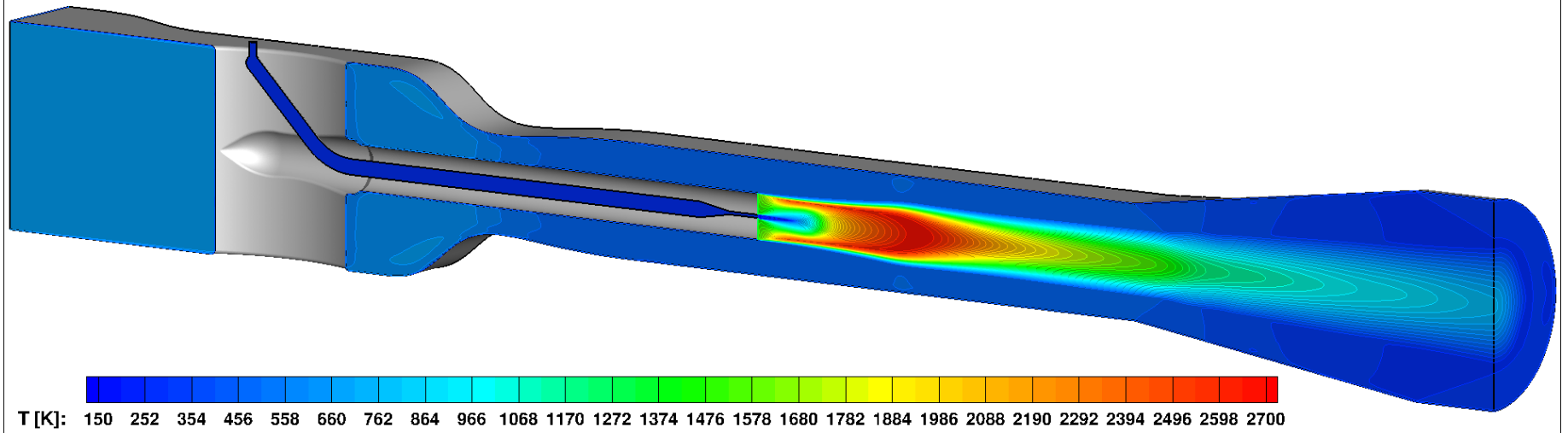
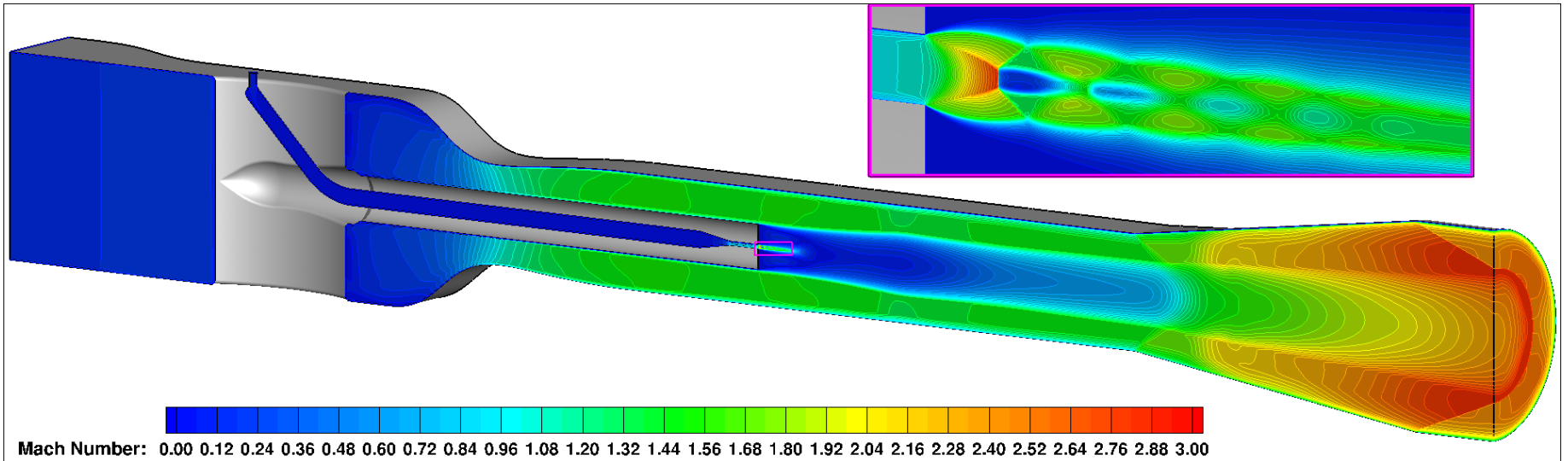
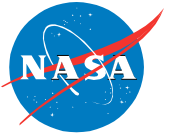


Coaxial Jet Experiment Geometry & Conditions

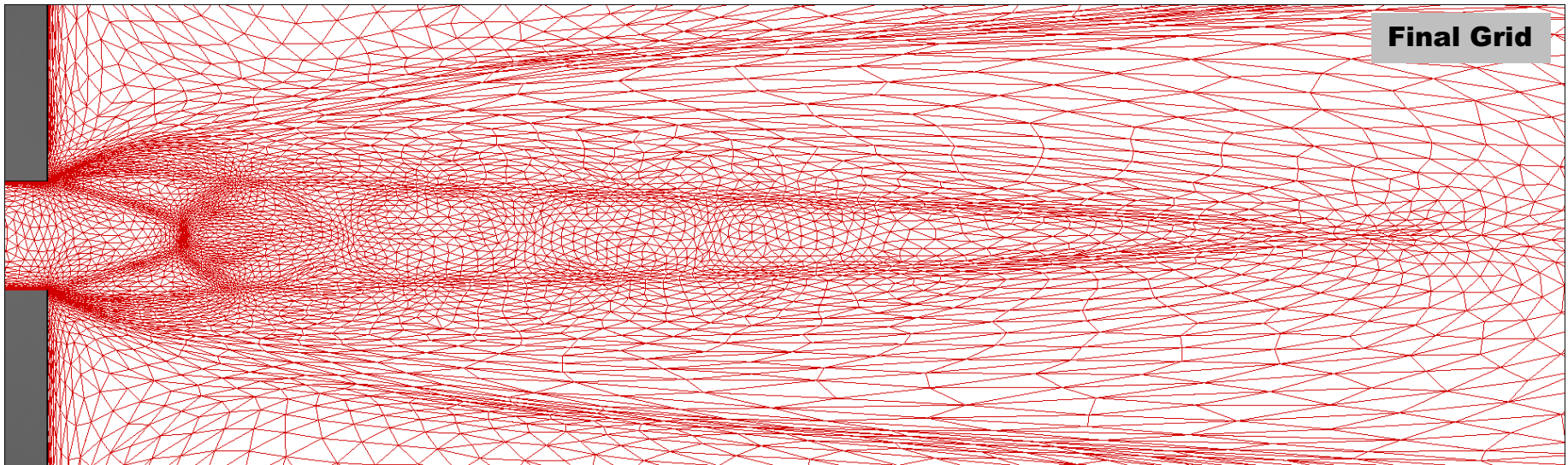
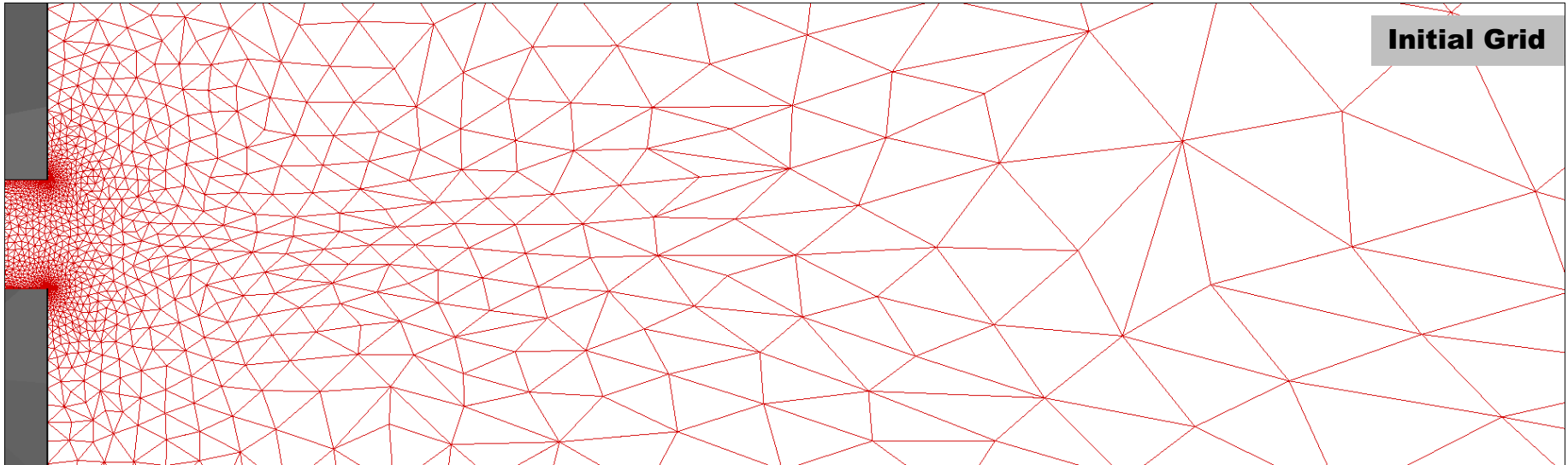


Facility Condition	Facility Inflow	Ethylene Inflow
Total Pressure [kPa]	827.37	N/A
Mass Flow Rate [kg/s]	N/A	0.01
Total Temperature [K]	699.8	300.0

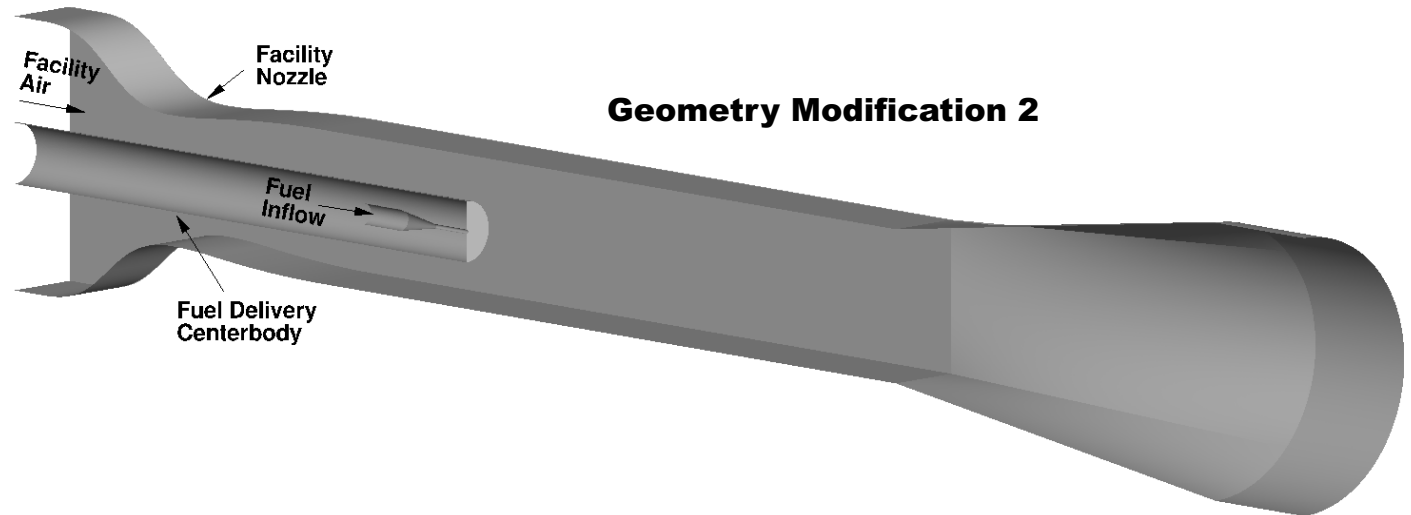
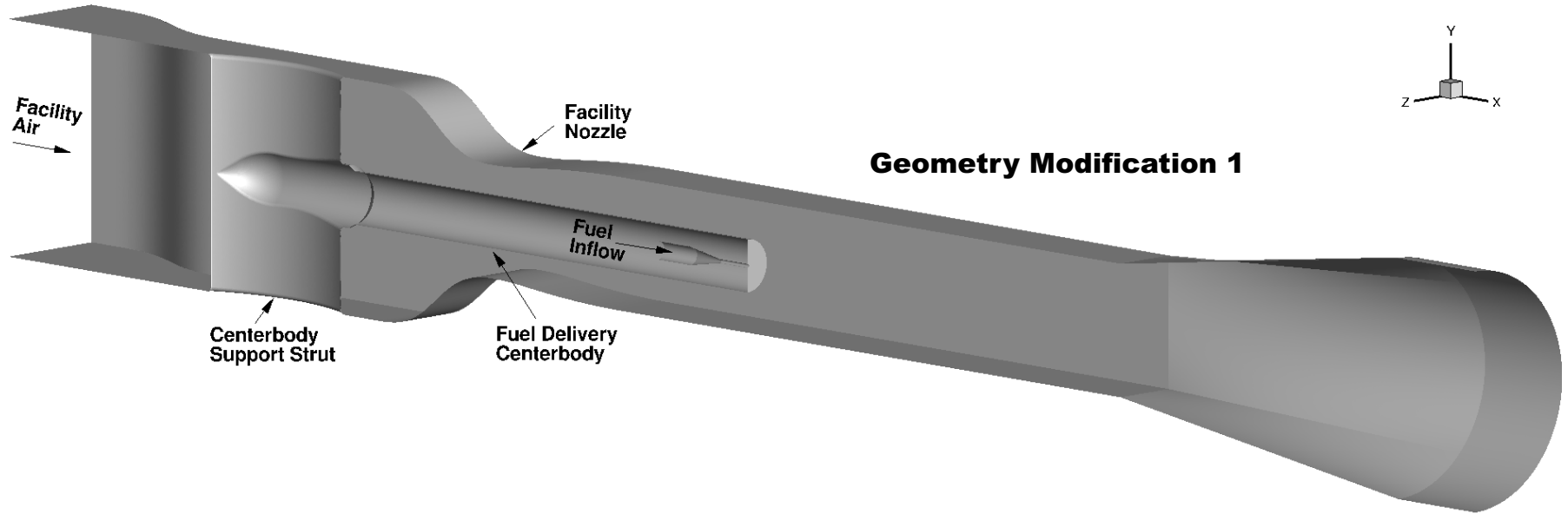
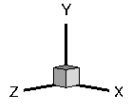
Coaxial Jet Flow Mach Number and Temperature



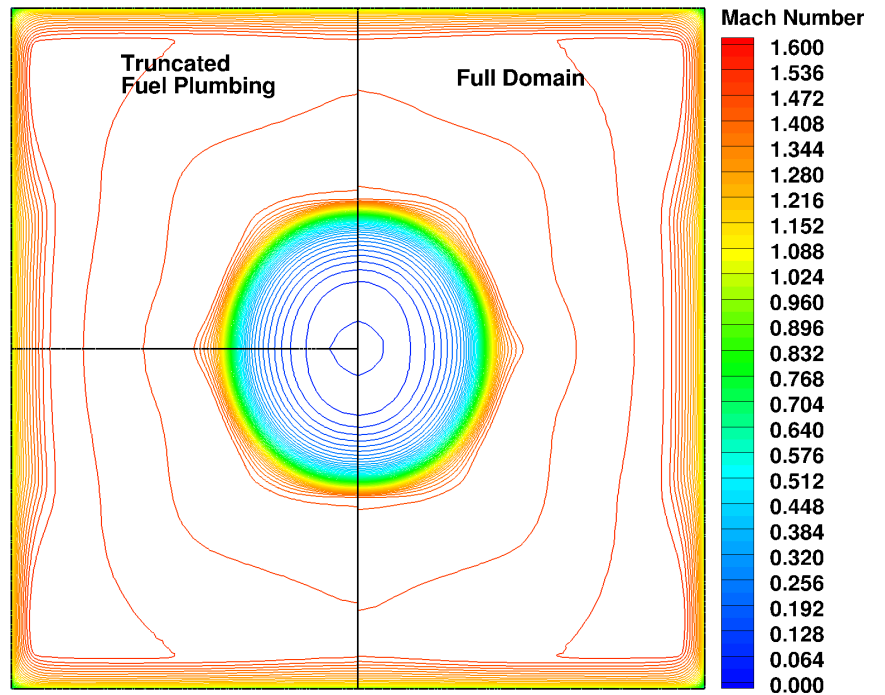
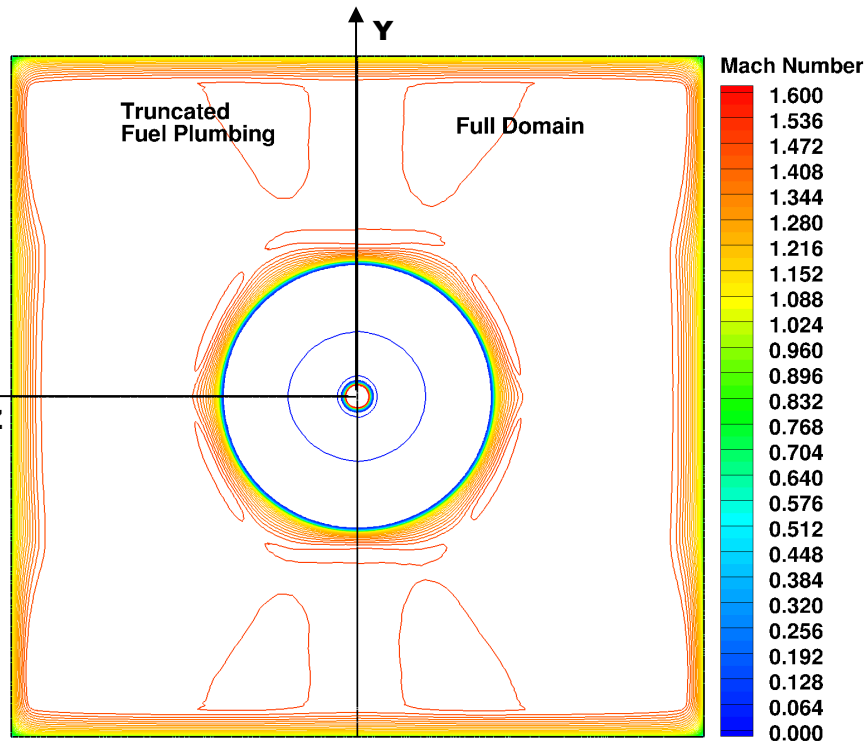
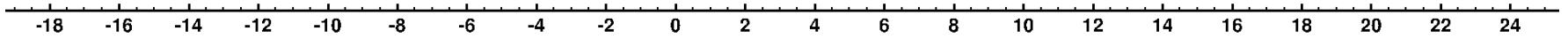
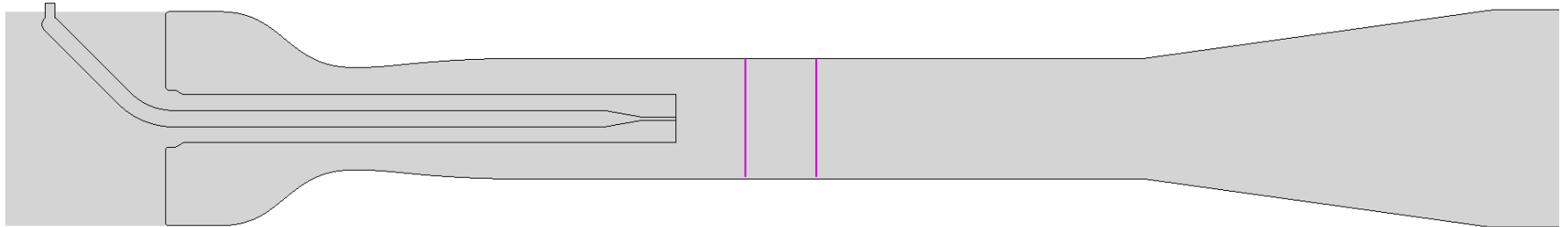
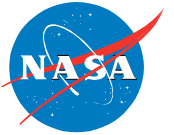
Coaxial Jet Flow Initial and Final Grids



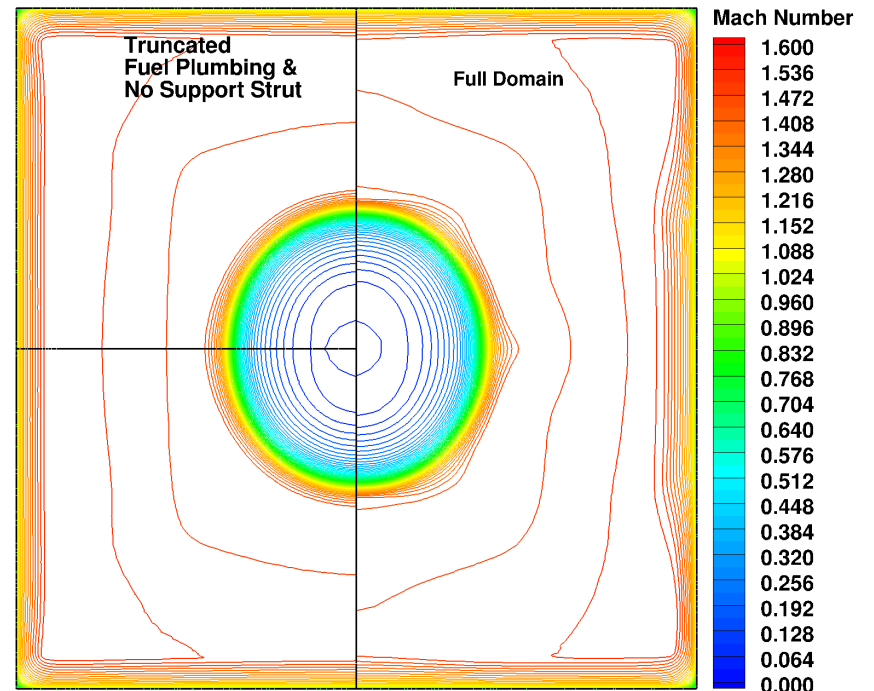
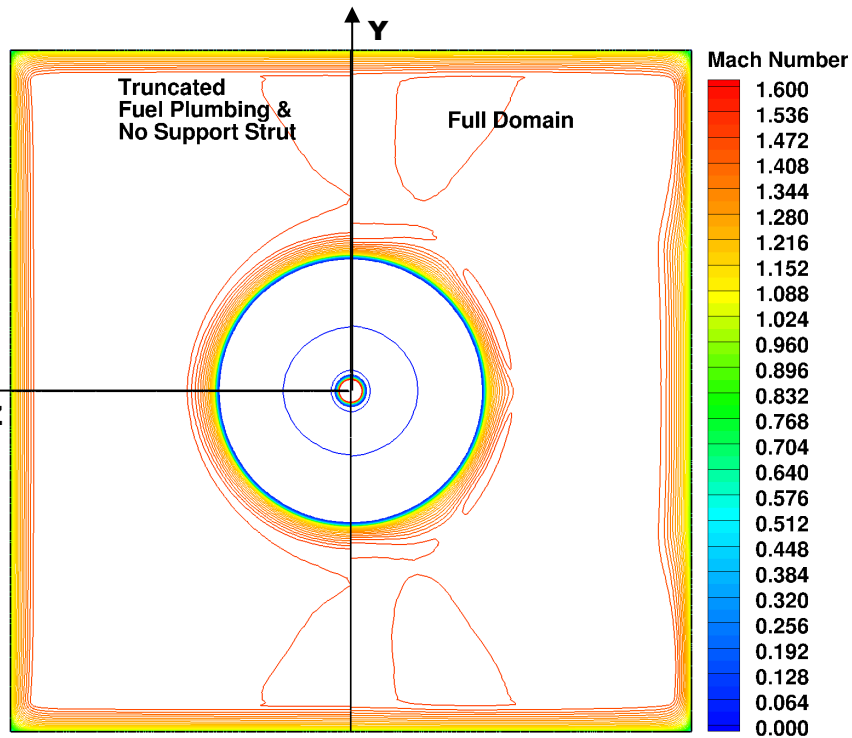
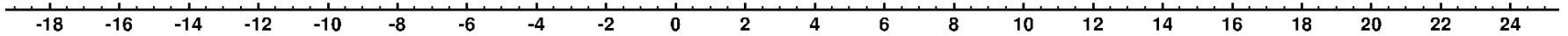
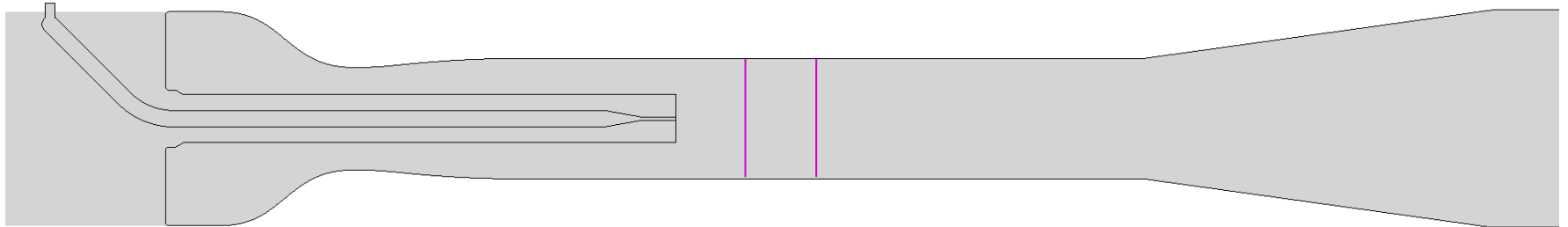
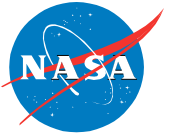
Coaxial Jet Geometry Simplifications



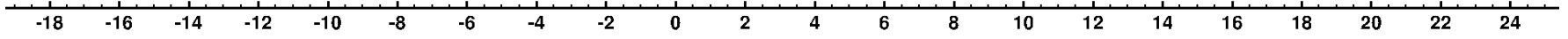
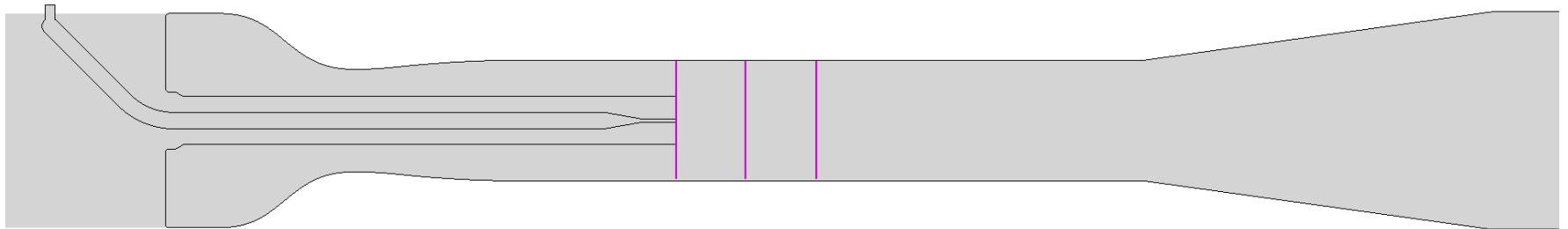
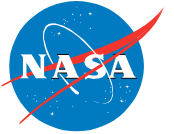
Mach Number at Selected Streamwise Stations



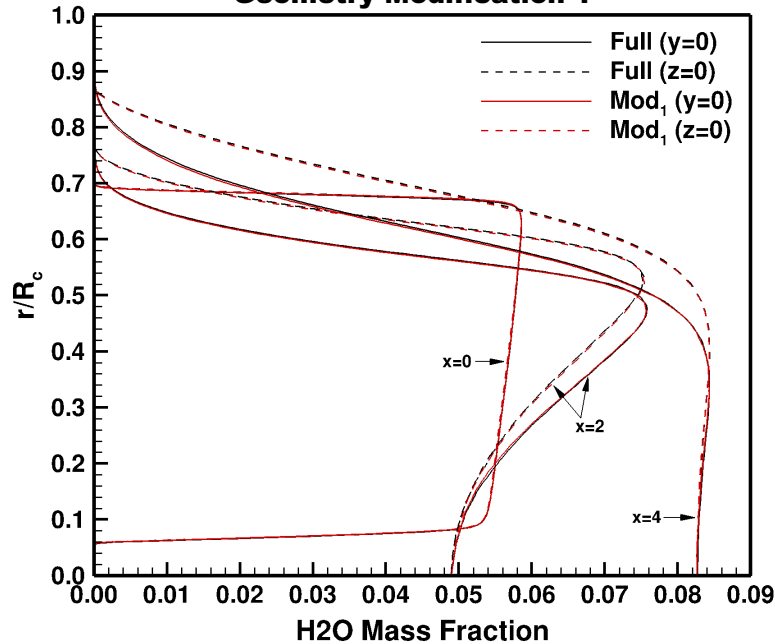
Mach Number at Selected Streamwise Stations



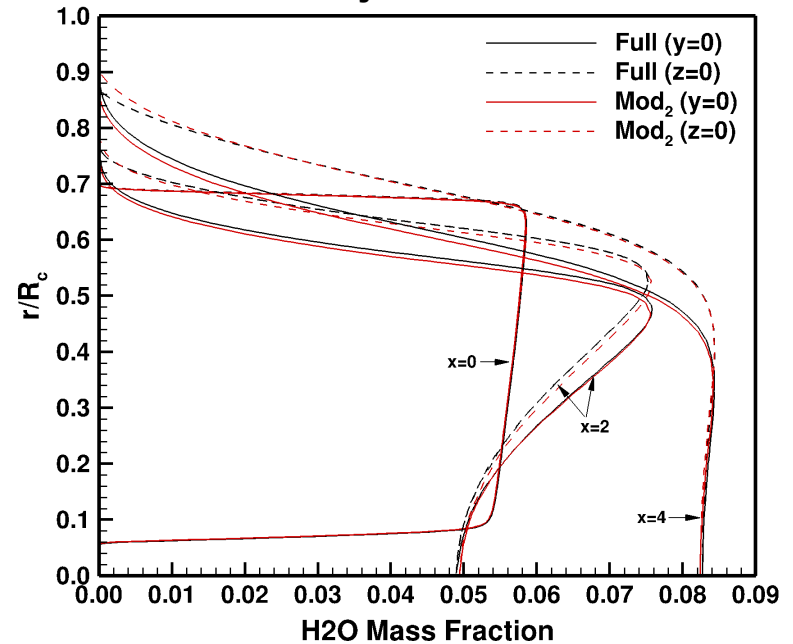
Radial Profiles of H₂O Mass Fraction



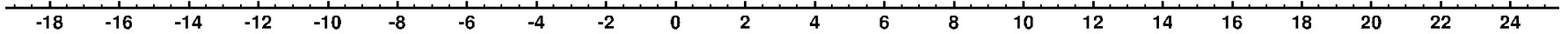
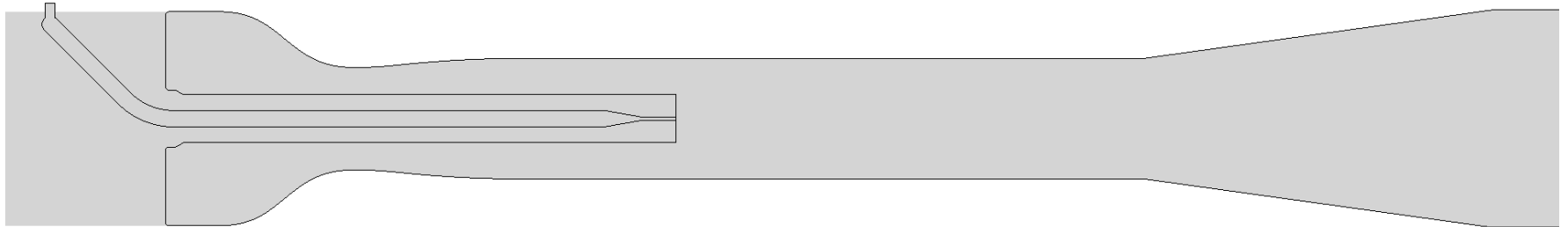
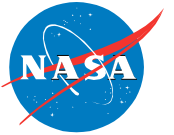
Geometry Modification 1



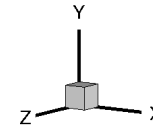
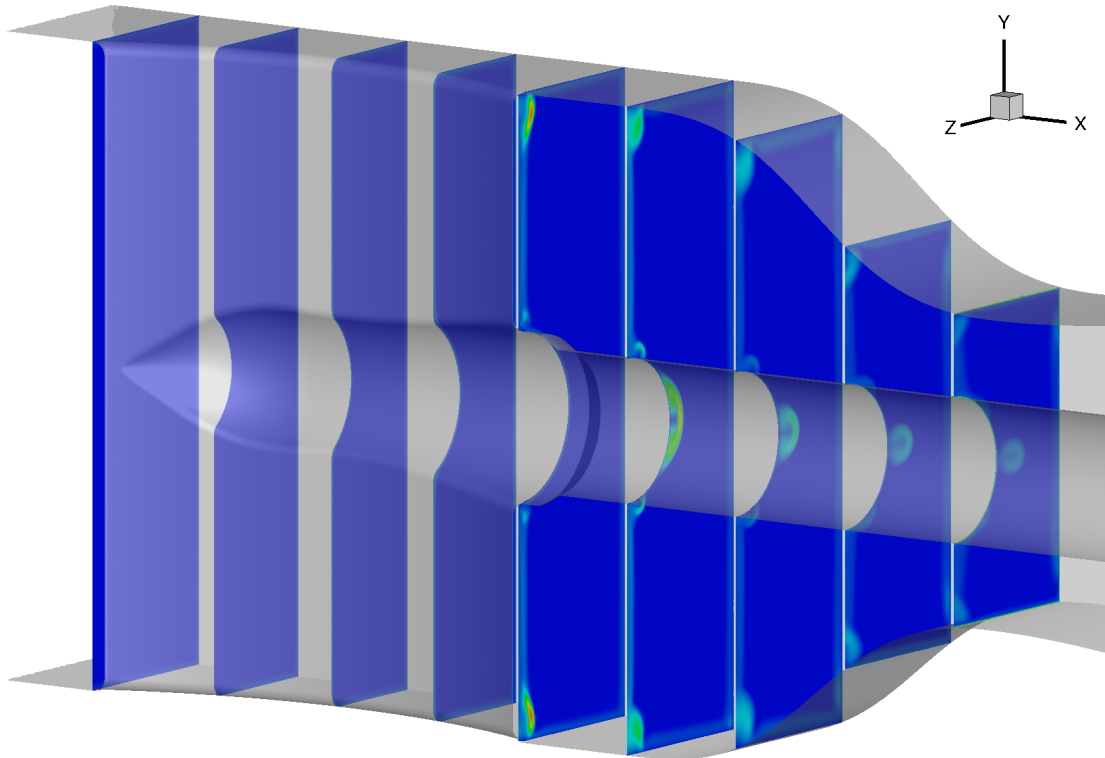
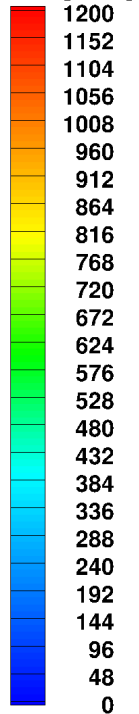
Geometry Modification 2

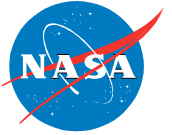


Flow Features from Strut/Centerbody Infrastructure



TKE [m^2/s^2]



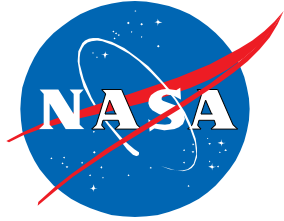


- **Pretest simulations have been performed to assess geometric sensitivities of a recently designed coaxial reacting jet experiment for CFD model validation.**
 - The concept for the experiment was derived from a validation data gap analysis performed in the High Speed Code Credibility Workshop series sponsored by AFRL.
- **CFD simulations took advantage of the *refine* automated workflow.**
 - Attractive option given the focus here on geometrical sensitivities.
 - Approach was applied to the PAW6 jet flow configuration to verify the efficacy of this workflow which relies on tetrahedral mesh elements.
 - Results were shown to be virtually indistinguishable from those obtained from expertly crafted structured grids with far fewer cells.
- **This effort was undertaken to determine of how much of the AFRL coaxial jet experiment facility hardware to include in simulations.**
 - 1st simplification ignored most of the upstream fuel piping.
 - 2nd simplification also ignored the upstream strut/centerbody infrastructure.

Summary



- **Results indicated that the upstream fuel piping could be ignored, but the upstream strut/centerbody support structure had a small but measurable impact on the test section flowfield.**
 - Vortical structures driven by transverse pressure gradients formed along the centerbody that persisted throughout the facility nozzle expansion process.
- **The azimuthal symmetry was lost in the wake region downstream of the centerbody regardless of whether the strut/centerbody support structure was retained.**
- **Potential for a workshop activity centered around this configuration in the future.**



Back-up Slides ...

