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Three-Dimensional Simulations of a Gas/Gas, Hydrogen/Oxygen Engine

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5f. WORK UNIT NUMBER**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**¹Air Force Research Laboratory (AFMC)

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MEMORANDUM FOR PRS (In-House/Contractor Publication)

FROM: PROI (STINFO)

16 Dec 2002

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2002-310**
Archambault, Mark R.; Perroomian, Oshin (Metacomp Technologies, Inc.), "Three-Dimensional
Simulations of a Gas/Gas Hydrogen/Oxygen Engine" (Viewgraphs)

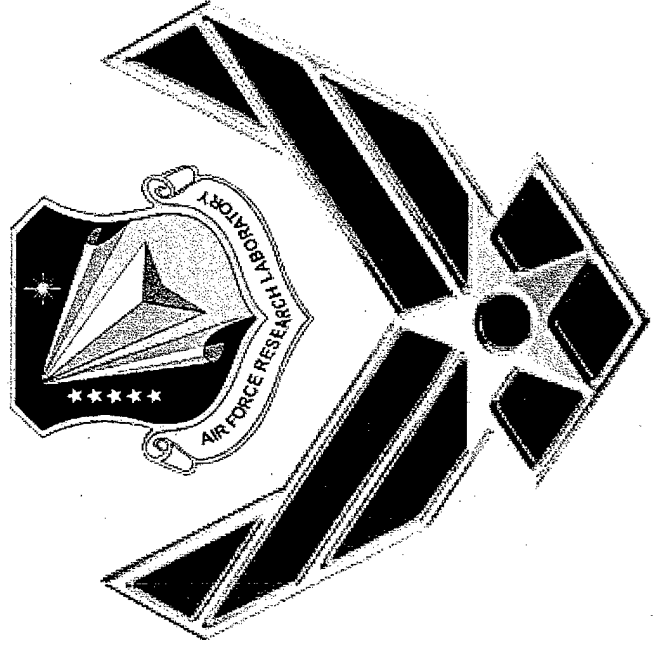
41st AIAA Aerospace Sciences Meeting & Exhibit
(Reno, NV, 6-9 Jan 2003) (Deadline: 5 Jan 2003)

(Statement A)

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127A

Three-Dimensional Simulations of a Gas/Gas, Hydrogen/Oxygen Engine

6 January 03



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Objective



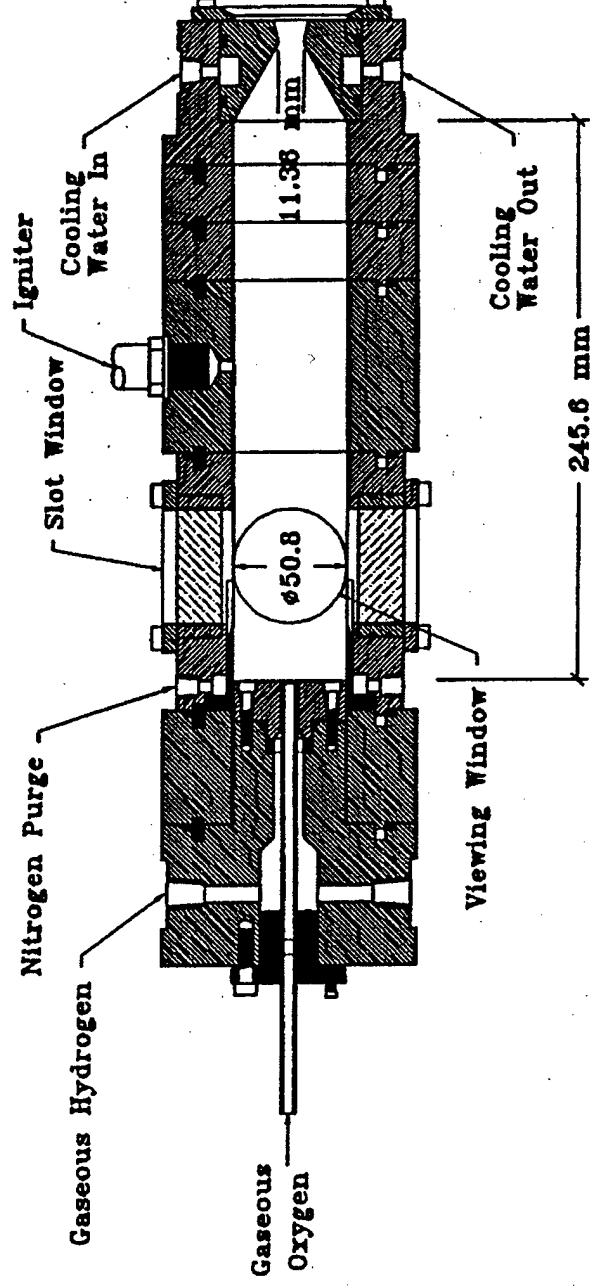
- **Develop design tools and methodologies for rocket injectors.**
- **Use experimental measurements to develop and anchor state-of-the-art flow codes.**
- **Determine level of fidelity required to reasonably reproduce the essential physical behavior of a coaxial gas/gas injector flow.**



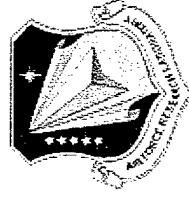
Previous Work



- Experiments — Penn State
 - OH-radical imaging
 - Velocity & species field measurements



from Foust, M.J., Deshpande, M., Pal, S., Ni, T., Merkel, C.L., & Santoro, R.J., "Experimental And Analytical Characterization of a Shear Coaxial Combusting GO_2/GH_2 Flowfield," AIAA 96-0646, AIAA 34th Aerospace Sciences Meeting & Exhibit, Reno, NV, Jan. 1996.



Previous Work

- Computational Modeling
 - DLR (AS3D)
 - 2nd-order explicit FV
 - MSFC (FDNS)
 - 3rd-order pressure-based predictor/multi-corrector
 - Penn State
 - 1st-order preconditioned, coupled, implicit, time-marching
 - AFRL
 - 2nd-order preconditioned, coupled, implicit, dual-time stepping. Steady and time-accurate.



Current AFRL Modeling Effort



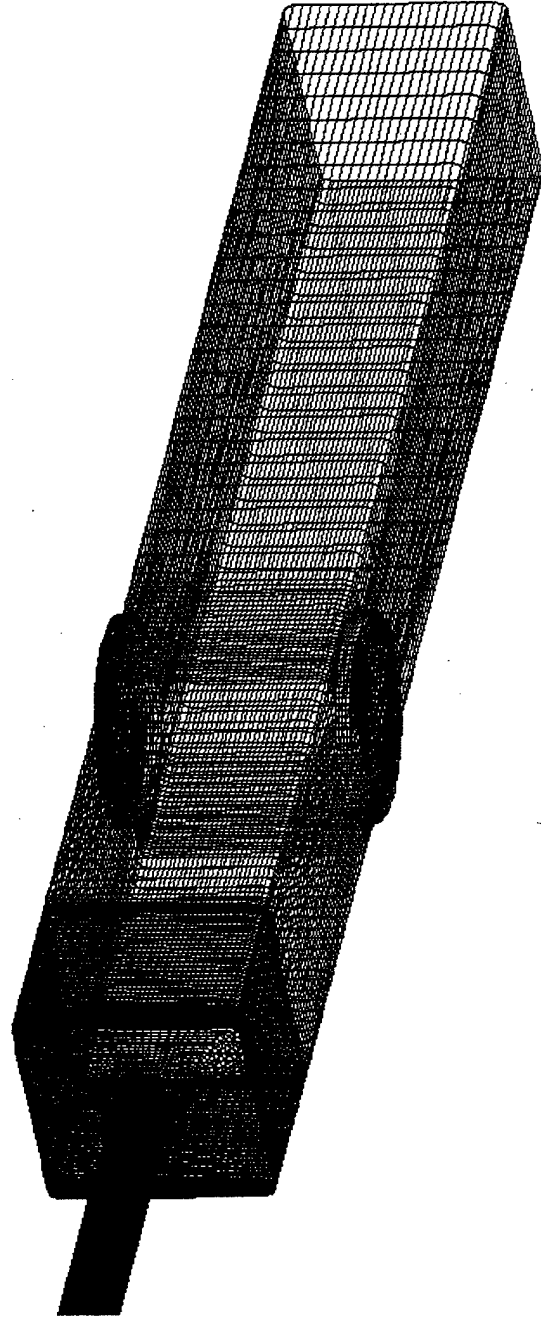
- CFD++ from Metacomp Technologies
 - RANS, LES, hybrid RANS/LES
 - Compressible with high- and low-speed capability
 - Finite rate & equilibrium chemistry
 - 3D structured & unstructured grids
 - Explicit (RK) and Implicit schemes
 - Steady & Unsteady
 - Preconditioning
 - Parallel



Current AFRL Modeling Effort



- Single-element, shear-coaxial, H_2/O_2 engine
- Refined grid resolution
- Steady & transient 3-D solutions
- Nitrogen curtain purge
- Prelude to multi-element analyses

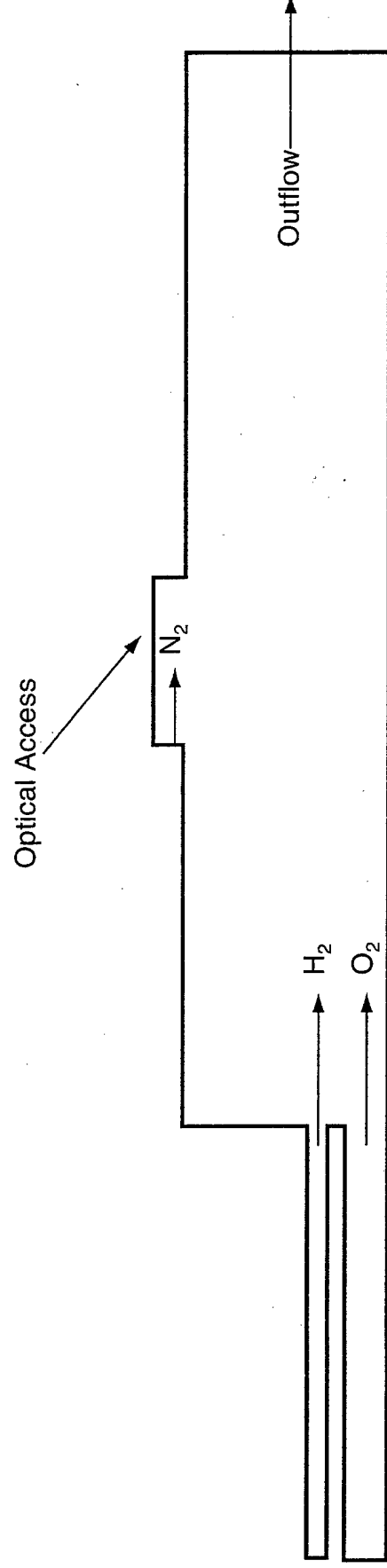




Current Computational Effort

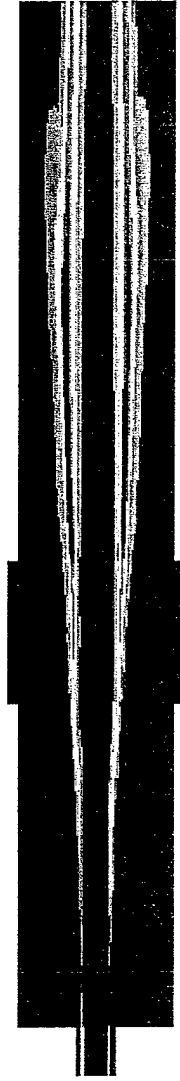


- Flow conditions
 - O_2 mass flow rate: 0.042 kg/s (0.1 lbm/s)
 - H_2 mass flow rate: 0.0103 kg/s (0.025 lbm/s)
 - N_2 mass flow rate: 0.01 kg/s (0.022 lbm/s)
 - Chamber pressure: 1.29 MPa
 - Inlet temperature: 297K
 - Laminar inlet flow, turbulence allowed to develop





Current AFRL Modeling Effort



3-D Steady



3-D Instantaneous



3-D Time-average



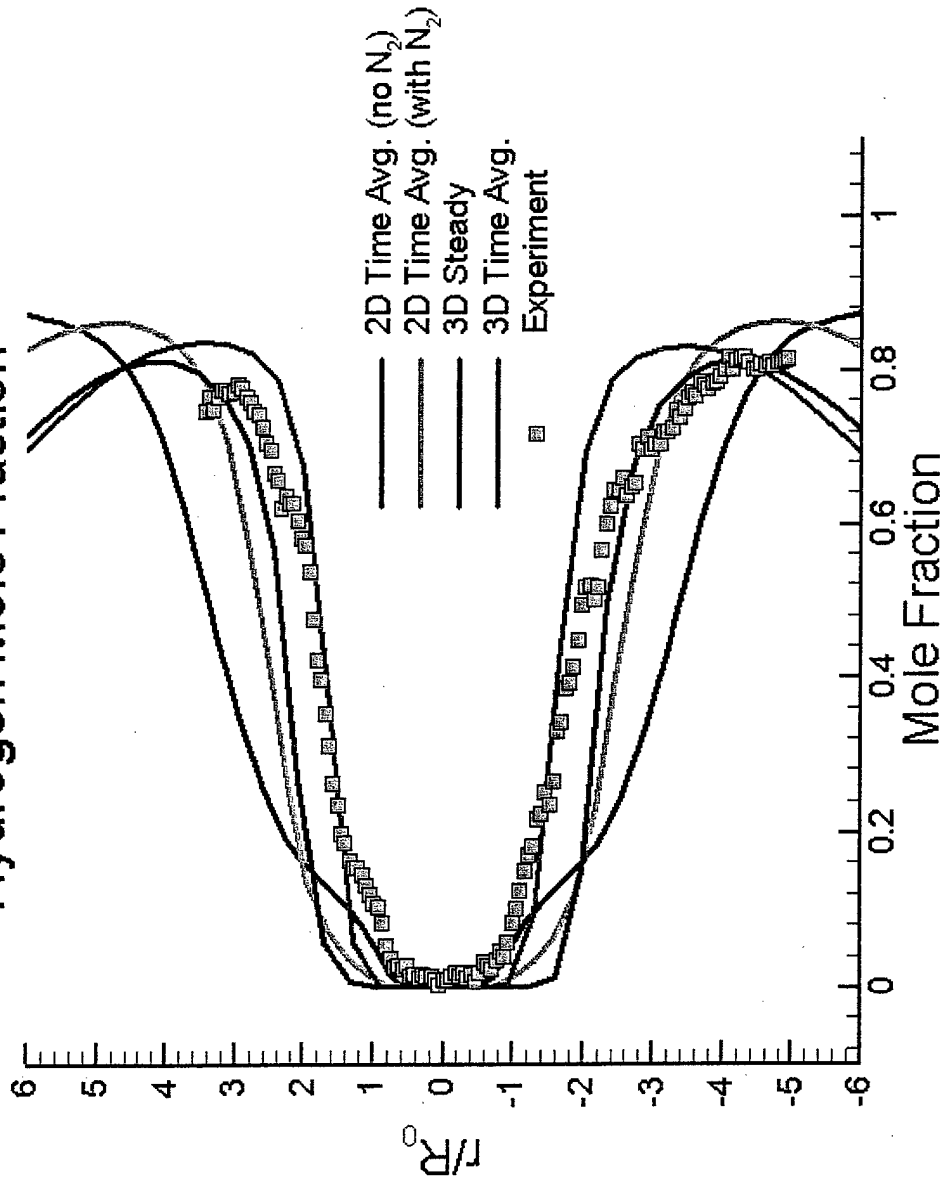
2-D Time-average



Current AFRL Modeling Effort



Hydrogen Mole Fraction



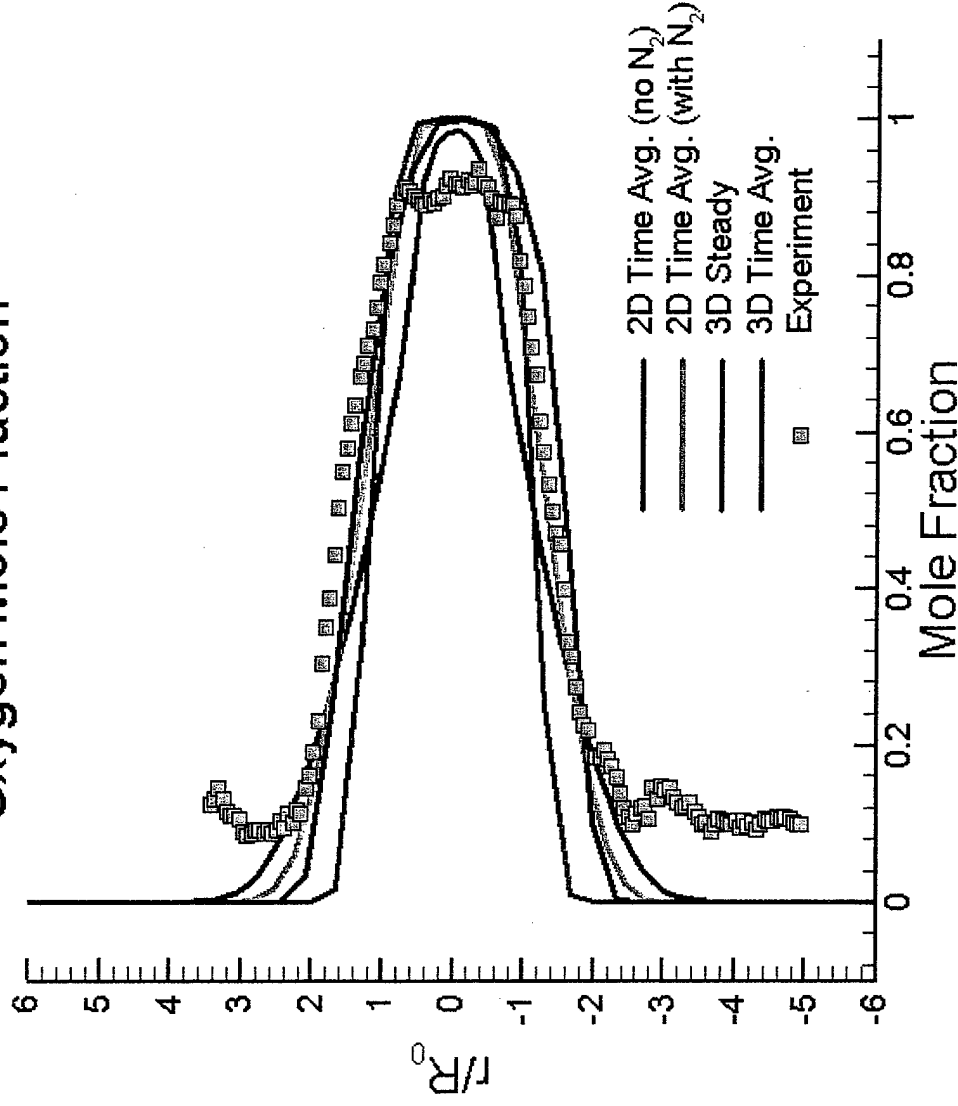
- Comparisons of level of modeling fidelity.
- 3D Time-avg. appears to provide best representation of data.
- No experimental uncertainties on data.



Current AFRL Modeling Effort



Oxygen Mole Fraction



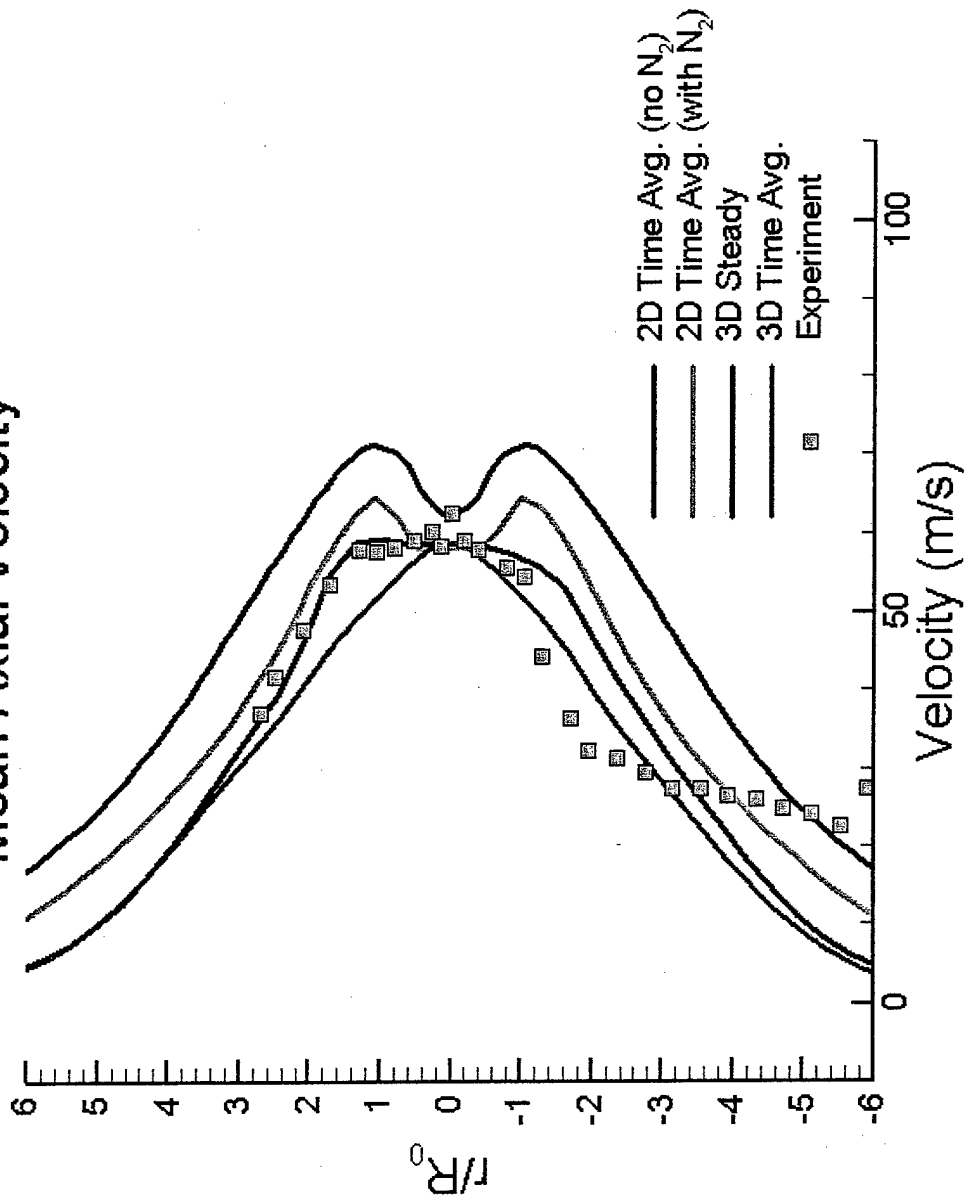
- Comparisons of level of modeling fidelity.
- Quantitatively similar profiles.
- 3D Time-avg. calculation deviates from data in outer part of shear layer possibly caused by flapping of actual flame.



Current AFRL Modeling Effort



Mean Axial Velocity



- 3D results do not predict peaks in the velocity profile from the greater injection velocity of the hydrogen

- Differences are likely due to the three-dimensional chamber geometry.

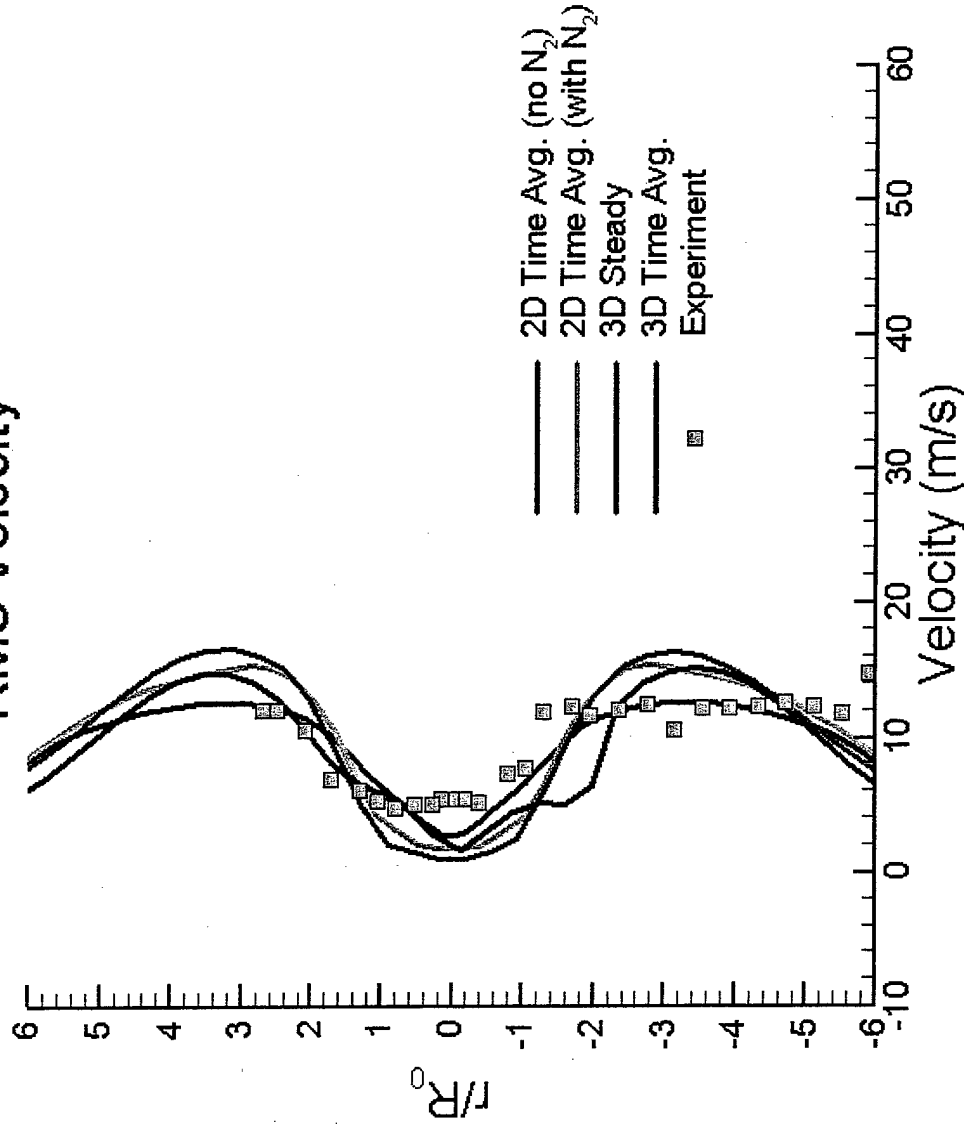
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Current AFRL Modeling Effort



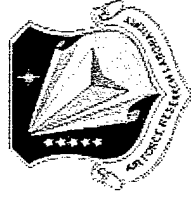
RMS Velocity



- Calculations are quantitatively similar.
- Appears that RMS velocities are a strong function of turbulence model, but not very sensitive to the degree of fidelity.



Nitrogen Curtain Purge



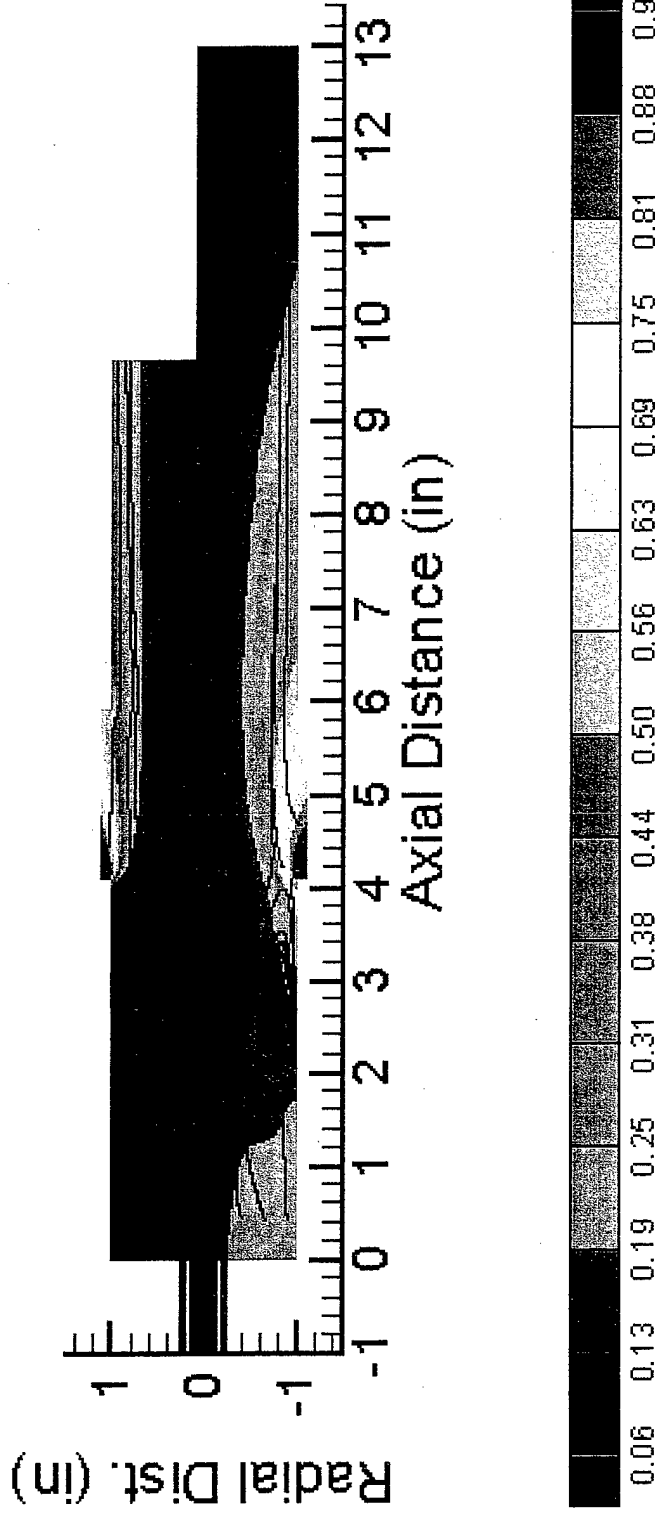
- Experimental feature used to cool optical access
 - Not likely to be in actual flight hardware
- Often neglected by modelers
 - Can result in deviation from experimental data in vicinity of wall
- In 2-D case, the windows are assumed to be axisymmetric. In 3-D case, the windows are located on top and bottom of chamber.



Nitrogen Curtain Purge



Contours of Nitrogen Concentration



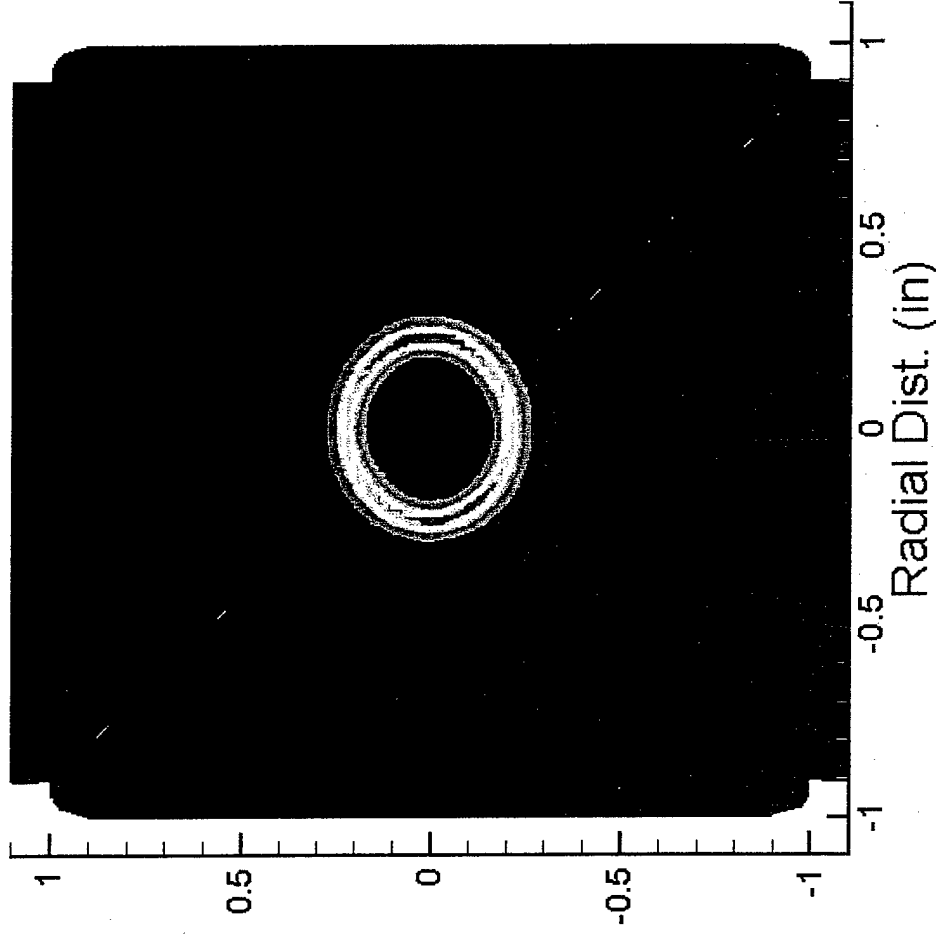
- 2-D (top half) compared with 3-D (bottom half).
- Slight shift forward of upstream recirculation zone in 3-D.
- Nitrogen being entrained upstream in 3-D case.



Current AFRL Modeling Effort

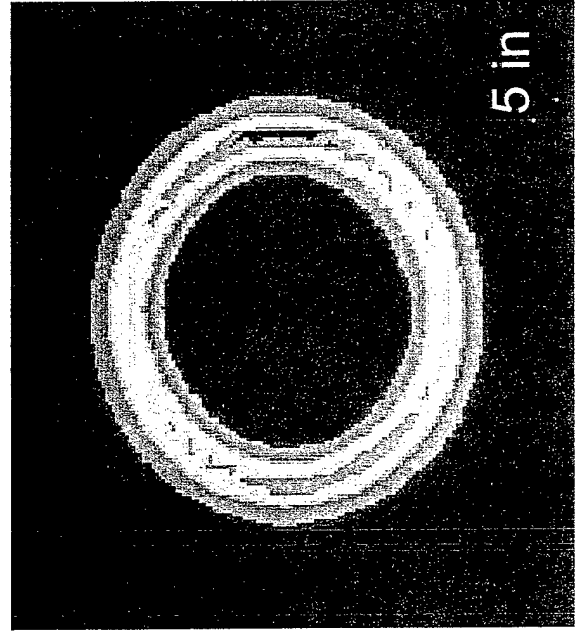
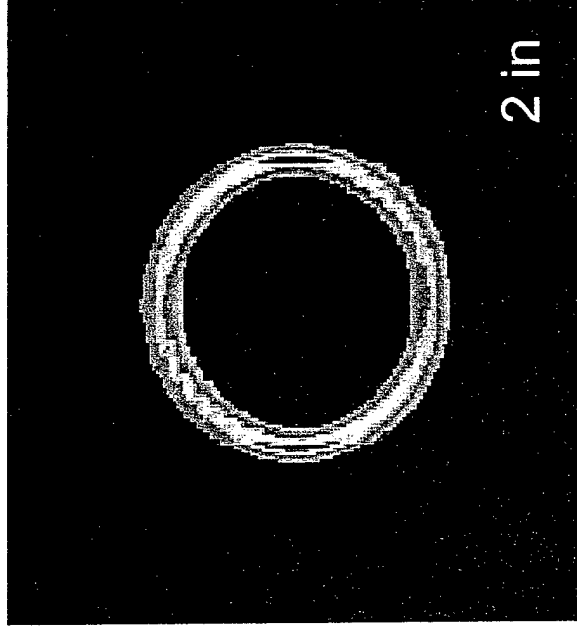
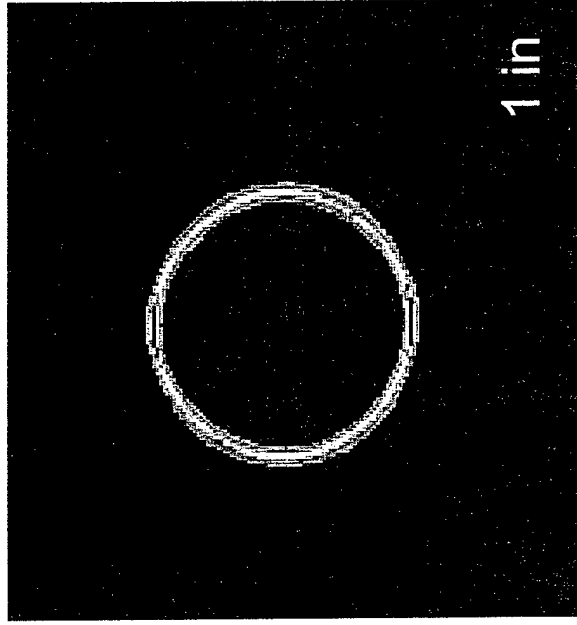
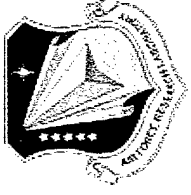


- No obvious three-dimensional patterns (such as helical structures) found.
- Slight variations in azimuthal direction can be attributed to the presence of the nitrogen purge.
- Suggests that planar or wedge symmetry could be used in future calculations.





Current AFRL Modeling Effort



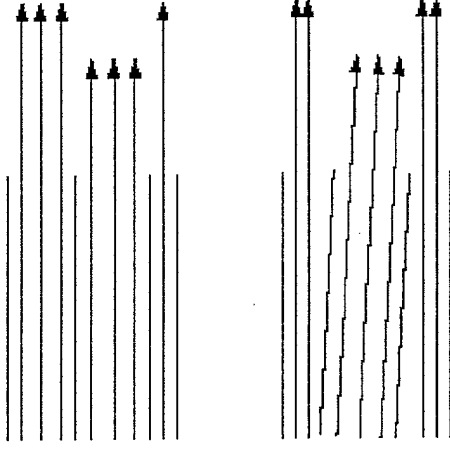
- Measurement indicates distance from injector.
- Streamtraces and contour plots do not indicate any temporal spatial changes in azimuthal direction.



Follow-On Plans



- Fully three-dimensional calculations
 - Oxygen Post Biasing
 - Off-axis parallel streams
 - Non-parallel streams
 - Multi-element injectors
 - Hydrocarbon
- Trend Analysis
 - Scalability





Summary and Conclusions



- Results indicate a marked difference between steady and time-accurate results. 3-D calculations seemed to predict the data as well as or better than 2-D calculations.
- A comparison between 2-D and 3-D models of the nitrogen purge showed differences that could be important when relying on CFD to design experiments.
- No evidence of 3-D patterns found in shear layer. Suggests that planar or wedge symmetry may be sufficient for future calculations.
- 3-D results are preliminary. Need to continue learning how to compute these types of flows to fully understand how to model this class of problems.