Title Chart

Turbulent Mixing of Primary and Secondary Flow Streams in a Rocket-Based Combined Cycle Engine

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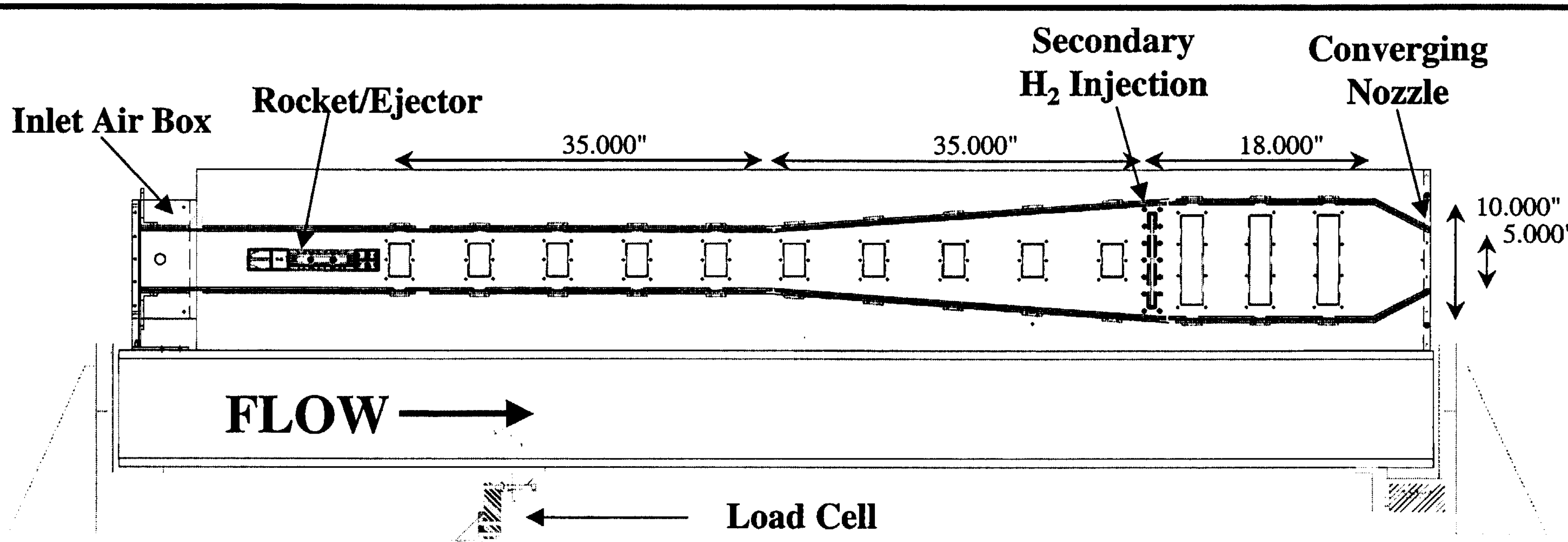
Program Background

- **Motivation**
  - Support NASA's 3rd Generation Launch Vehicle Technology Program
  - RBCC Is Promising Candidate for 3rd Gen. Propulsion System
- **Approach**
  - Focus on Ejector Mode Performance (Mach 0-3)
  - Perform Testing on Established Flowpath Geometry (Odegaard & Stroup, 1968)
  - Use Conventional Propulsion Measurement Techniques (Thrust, Flowrates, etc.)
  - Use Advanced Optical Diagnostic Techniques to Measure Local Combustion Gas Properties
- **Objectives**
  - Gain Physical Understanding of Detailed Mixing & Combustion Phenomena
    - Primary Flow Stream → Rocket Exhaust
    - Secondary Flow Stream → Entrained Air
  - Establish an Experimental Data Set for CFD Code Development & Validation

Rocket-Ejector Test Hardware- Direct Connect Mode



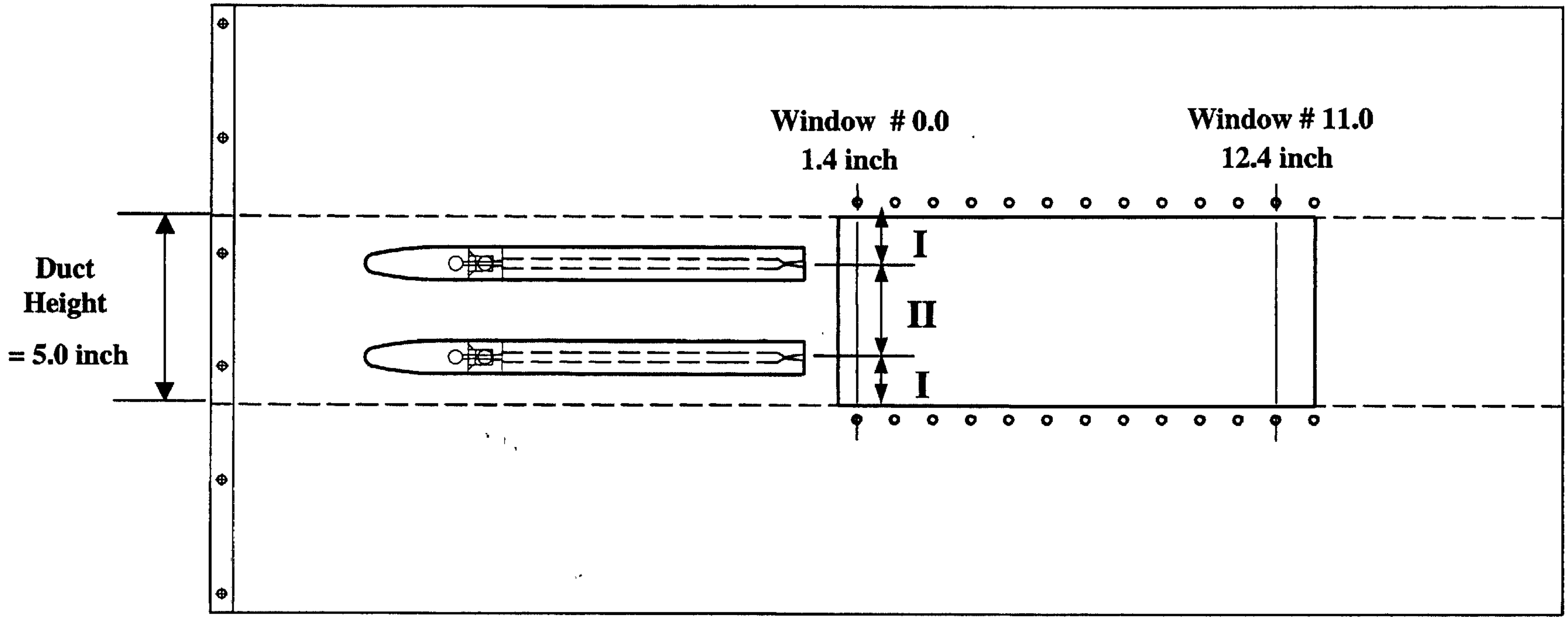
Basic Features

- 2-D Geometry (3" Wide)
- Modular Design
- Optical Access Windows
- Local Heat Flux & Static Pressure Measurement Ports

Thruster

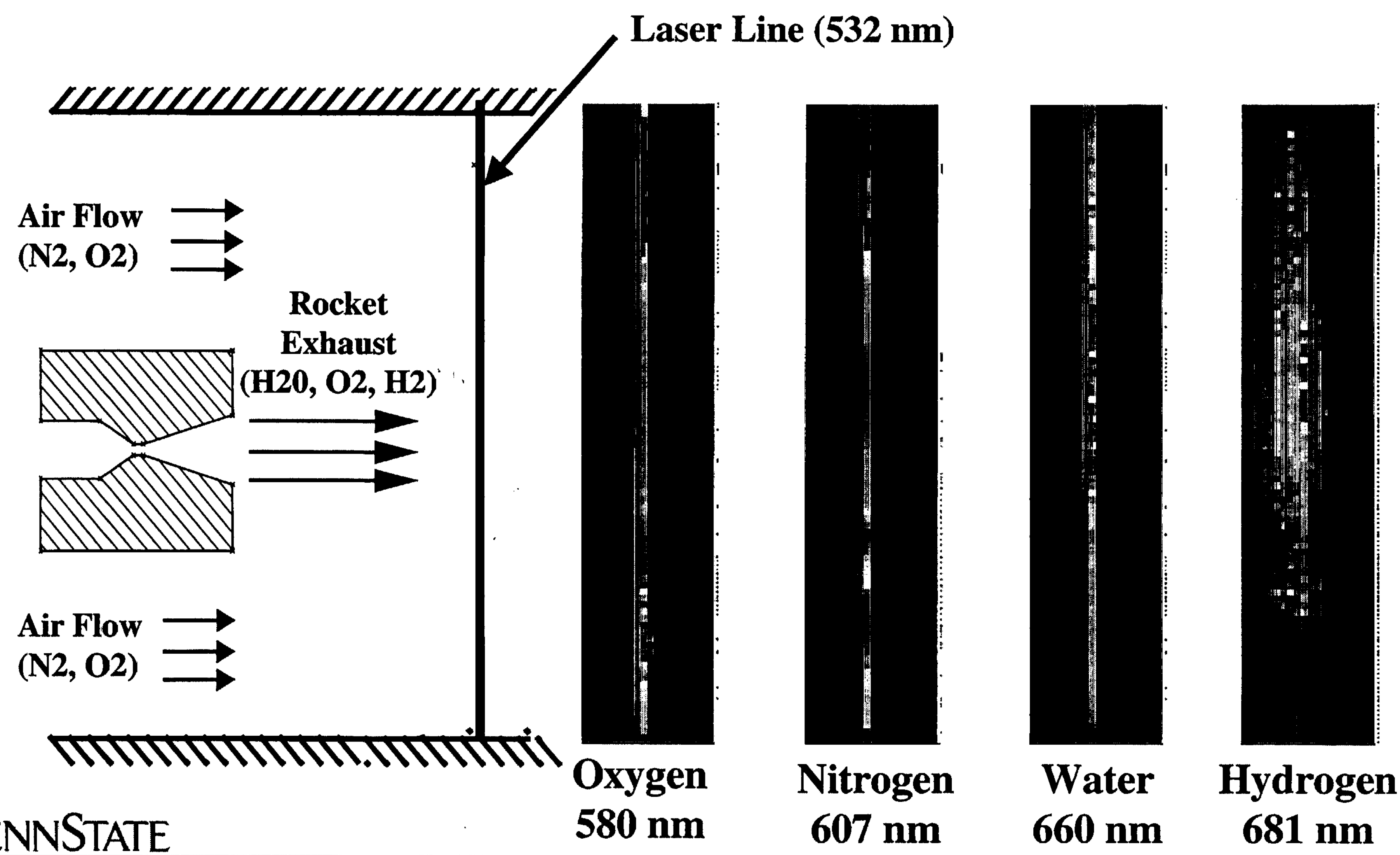
- GH2/GO2 Propellants
- Single or Twin Thruster Configuration
- 2-D Geometry
- Body Height= 1.75"
- AR= 3.3 Nozzle

Twin Thruster Configurations



Dimension	Case A	Case B	Case C
I	0.875	1.25	1.625
II	3.25	2.50	1.75

Raman Species Measurements



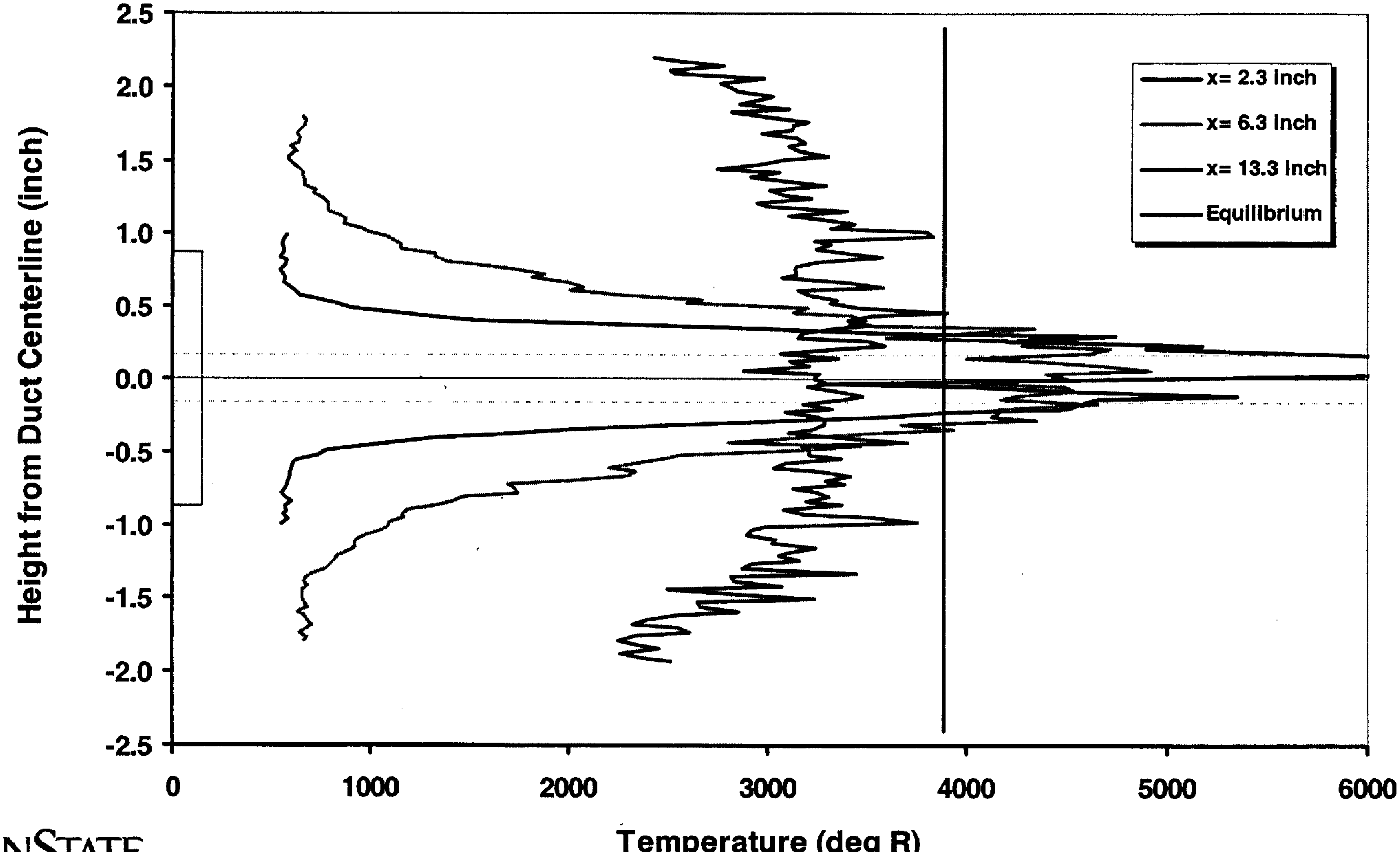
Test Conditions at Design Point

	Direct Connect				SLS	
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Rocket						
O/F	4	4	8	8	4	8
GO_2 Flowrate (lbm/s)	.188	.188	.243	.243	.188	0.243
GH_2 Flowrate (lbm/s)	.0470	.0470	.0304	.0304	.0470	.0304
Chamber Pressure (psia)	200	200	200	200	200	200
Duct						
Air Flowrate (lbm/s)	.630	.807	.630	.807	**TBD***	**TBD***
GH_2 Flowrate in Afterburner (lbm/s)	0	0	.0183	.0236	0	.0183
Excess GH_2 in Rocket Exhaust (lbm/s)	.0236	.0236	0	0	.0240	0
GO_2 in Airflow (lbm/s)	.147	.188	.147	.188	**TBD***	**TBD***
O/F Between GO_2 in Air and GH_2 in Duct	6.25	8	8	8	**TBD***	**TBD***

*For SLS conditions, Ejected Air Flowrate is Measured.

Raman Temperature Profiles

Case 6, Single Thruster



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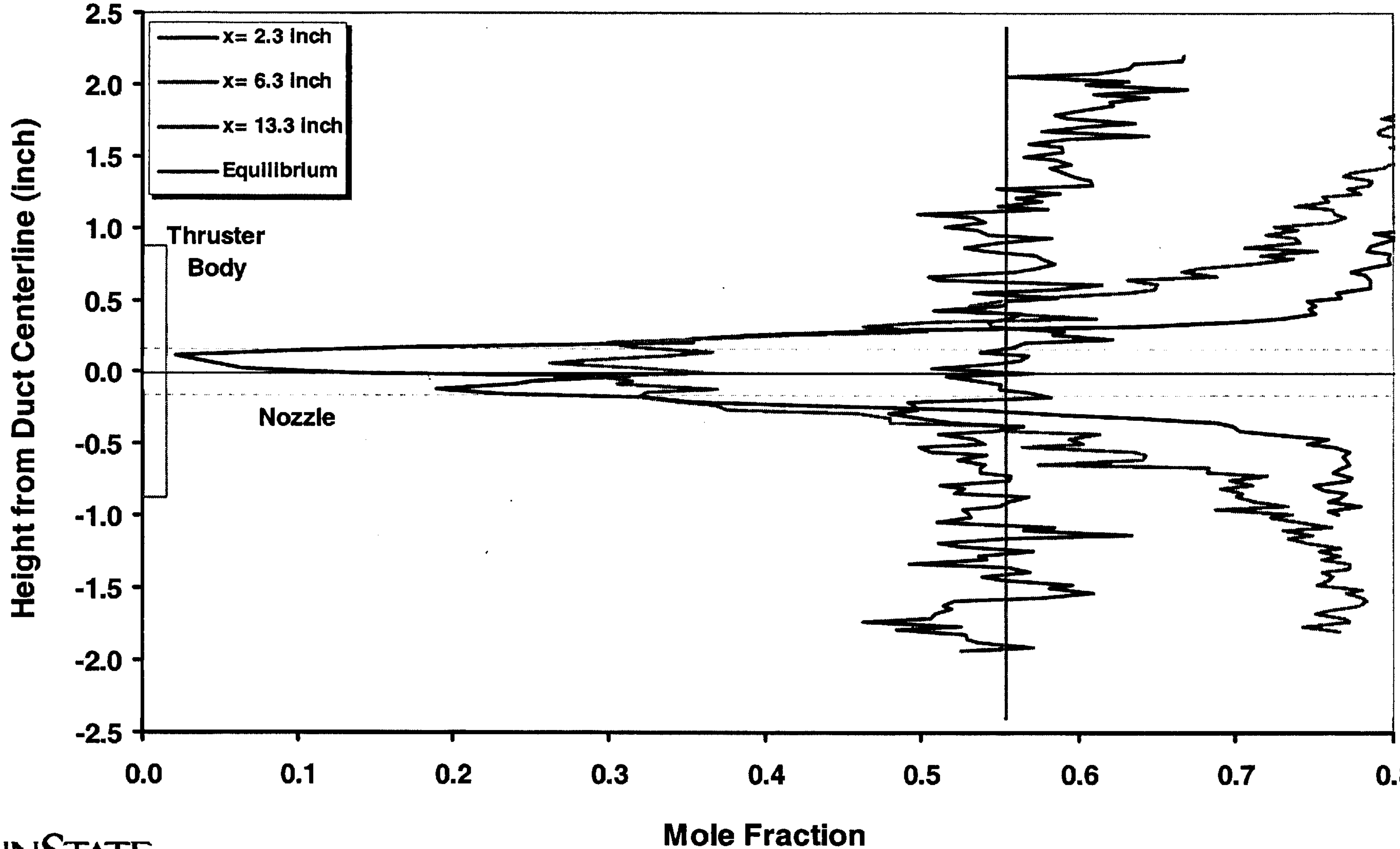
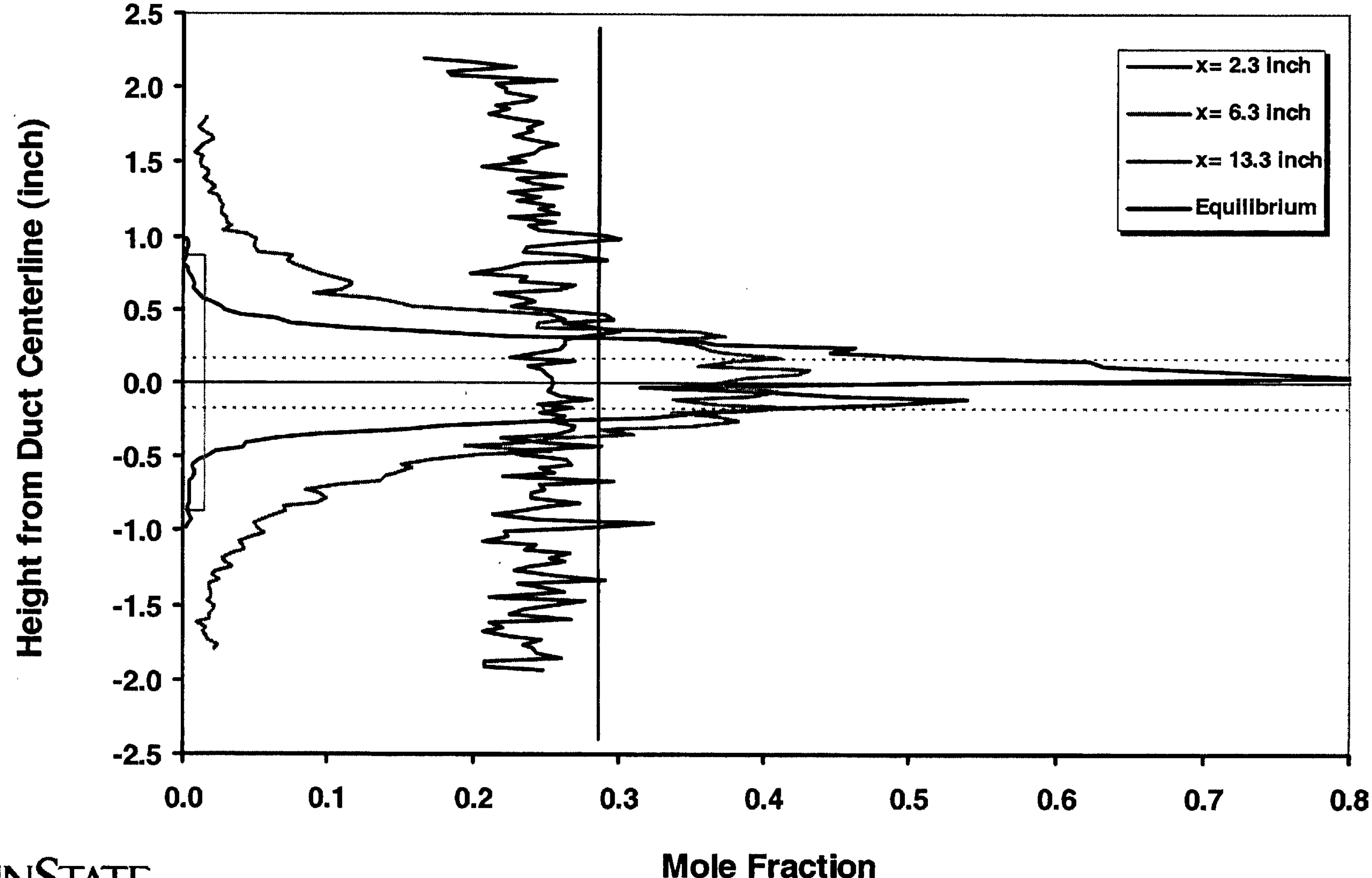
Nitrogen Mole Fraction Profiles

Case 6, Single Thruster



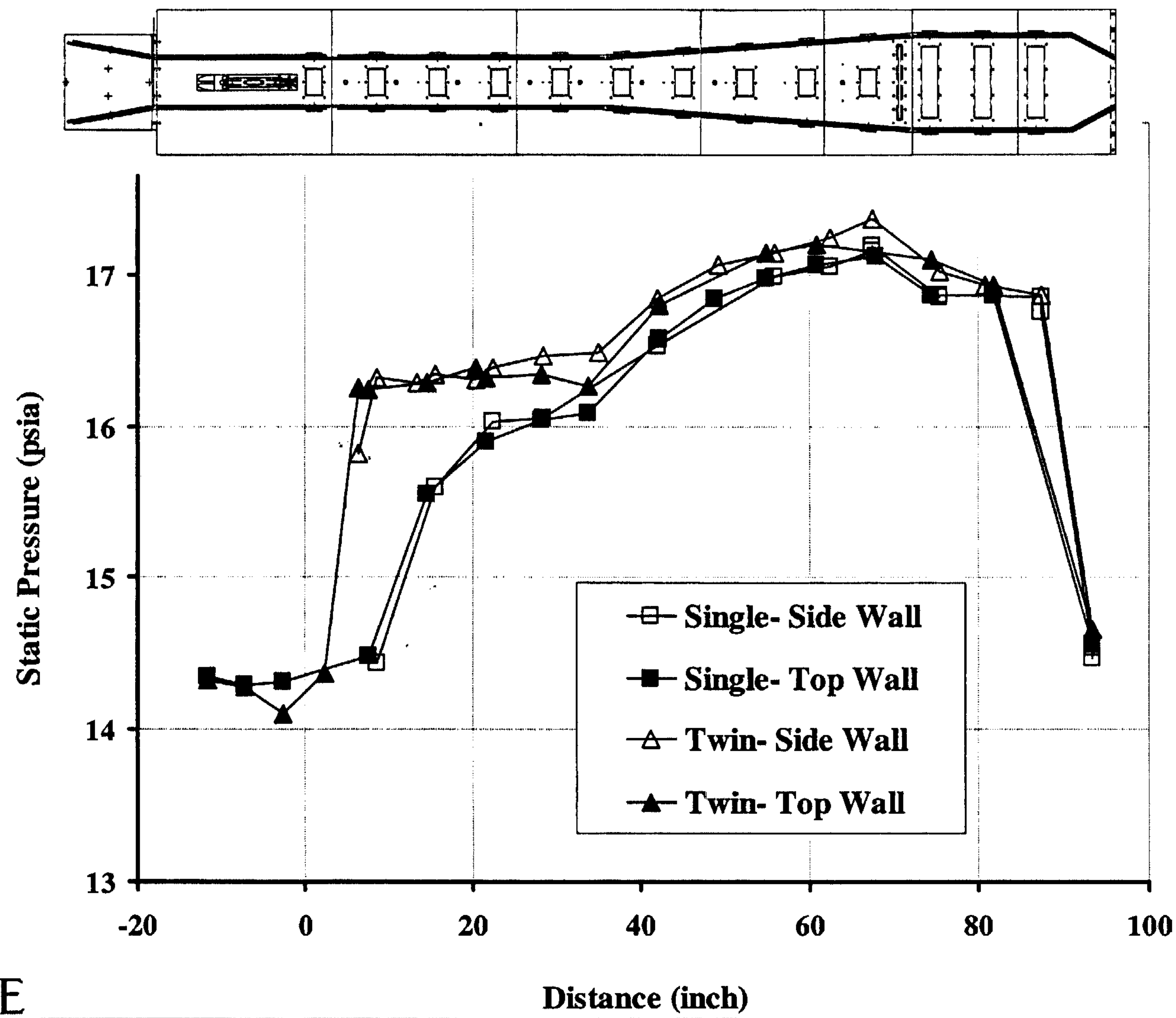
Water Mole Fraction Profiles

Case 6, Single Thruster



Static Pressure Comparison - Single vs. Twin

Case 6: Pc = 200 psia, MR = 8



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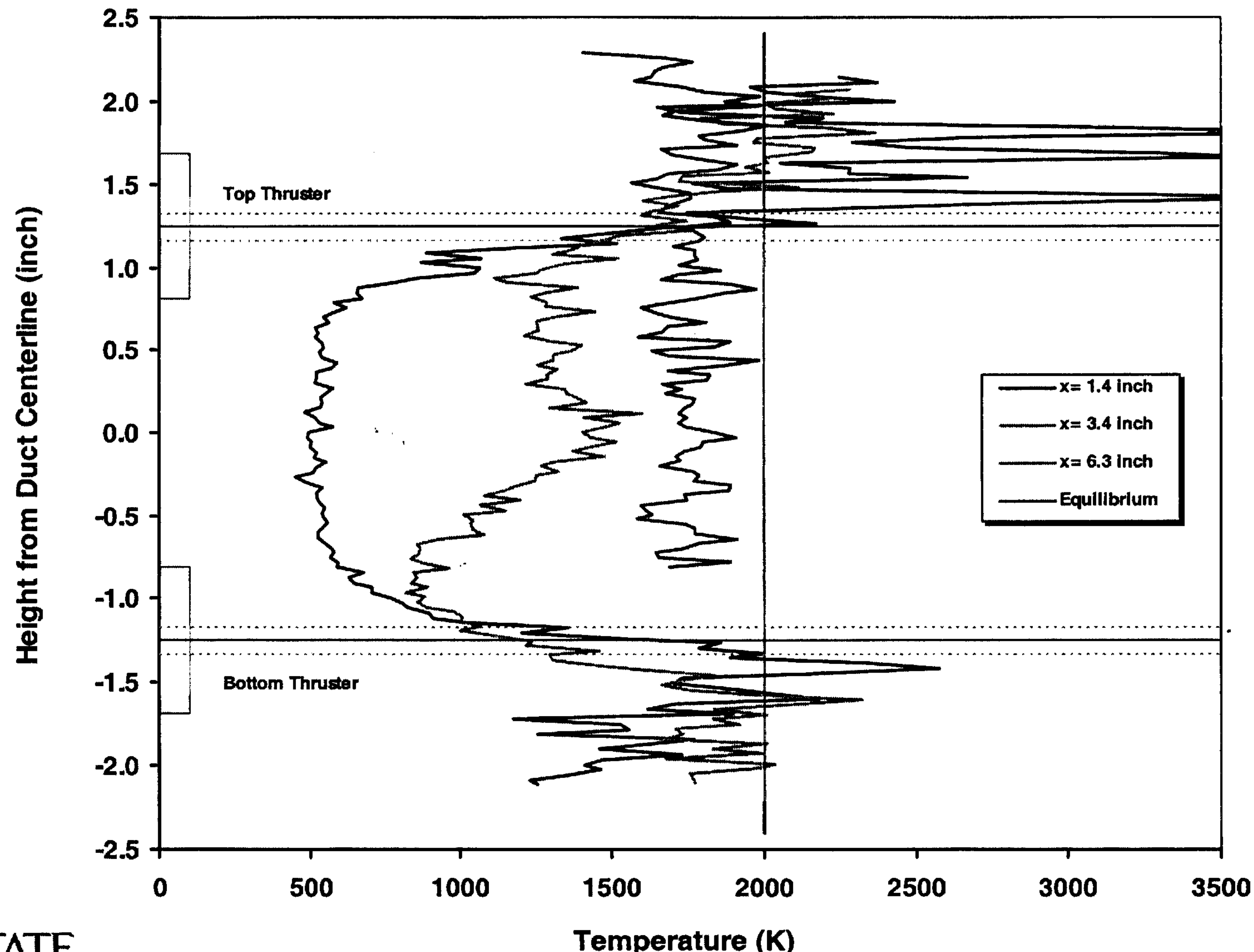
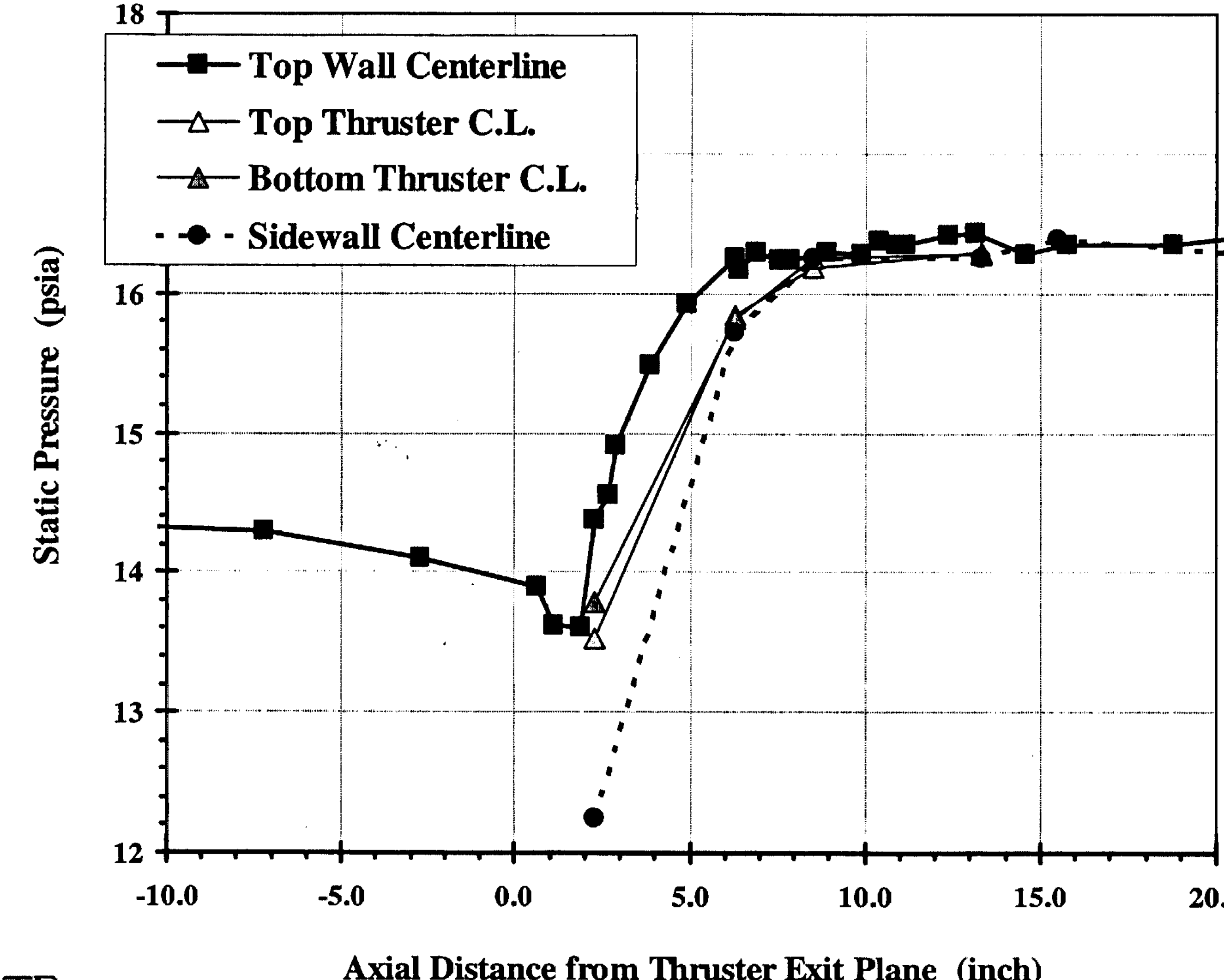
Raman Temperature Profiles

Case 6, Twin Thruster



Twin Thruster Static Pressure Profiles



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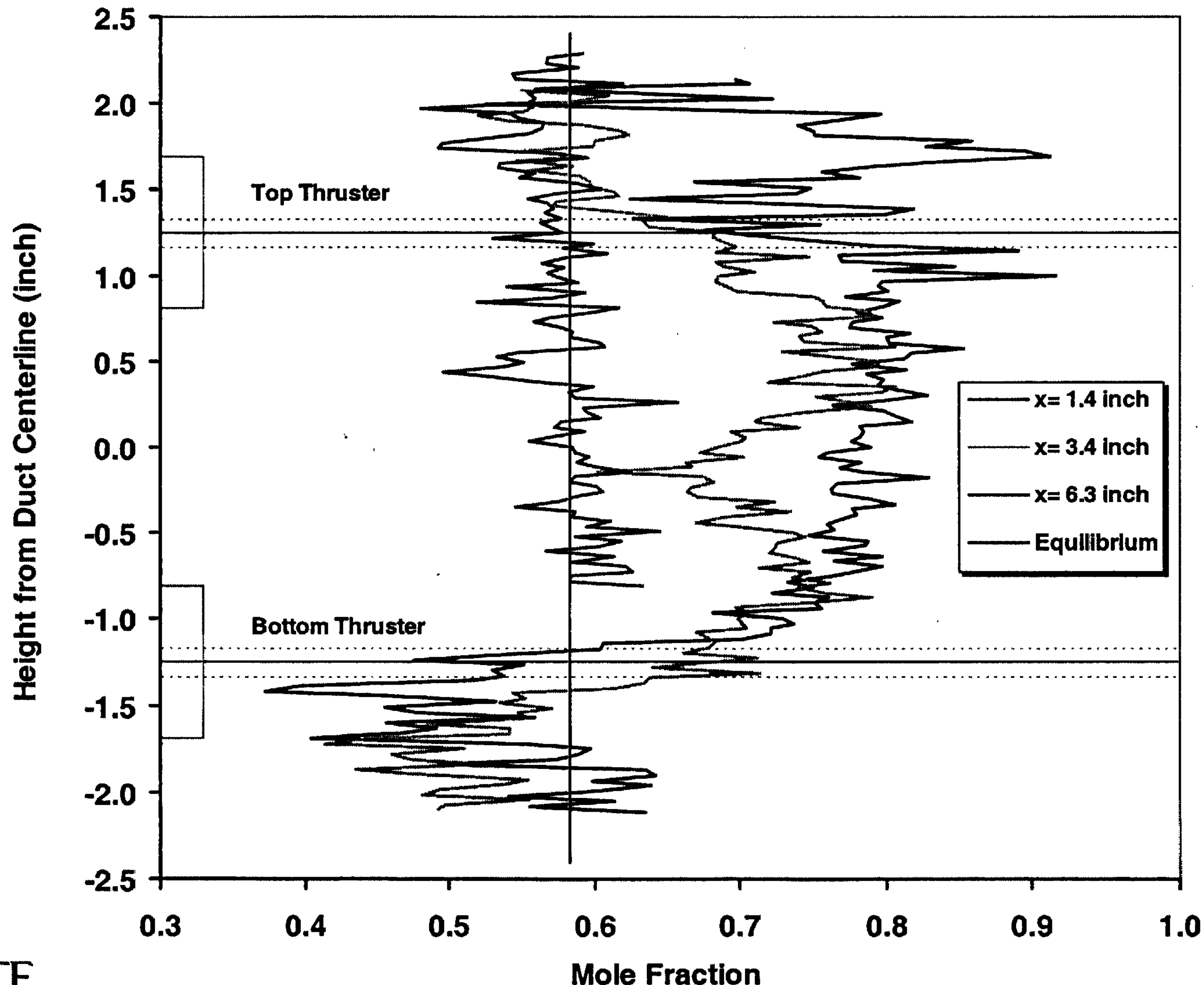
Nitrogen Mole Fraction Profiles

Case 6, Twin Thruster



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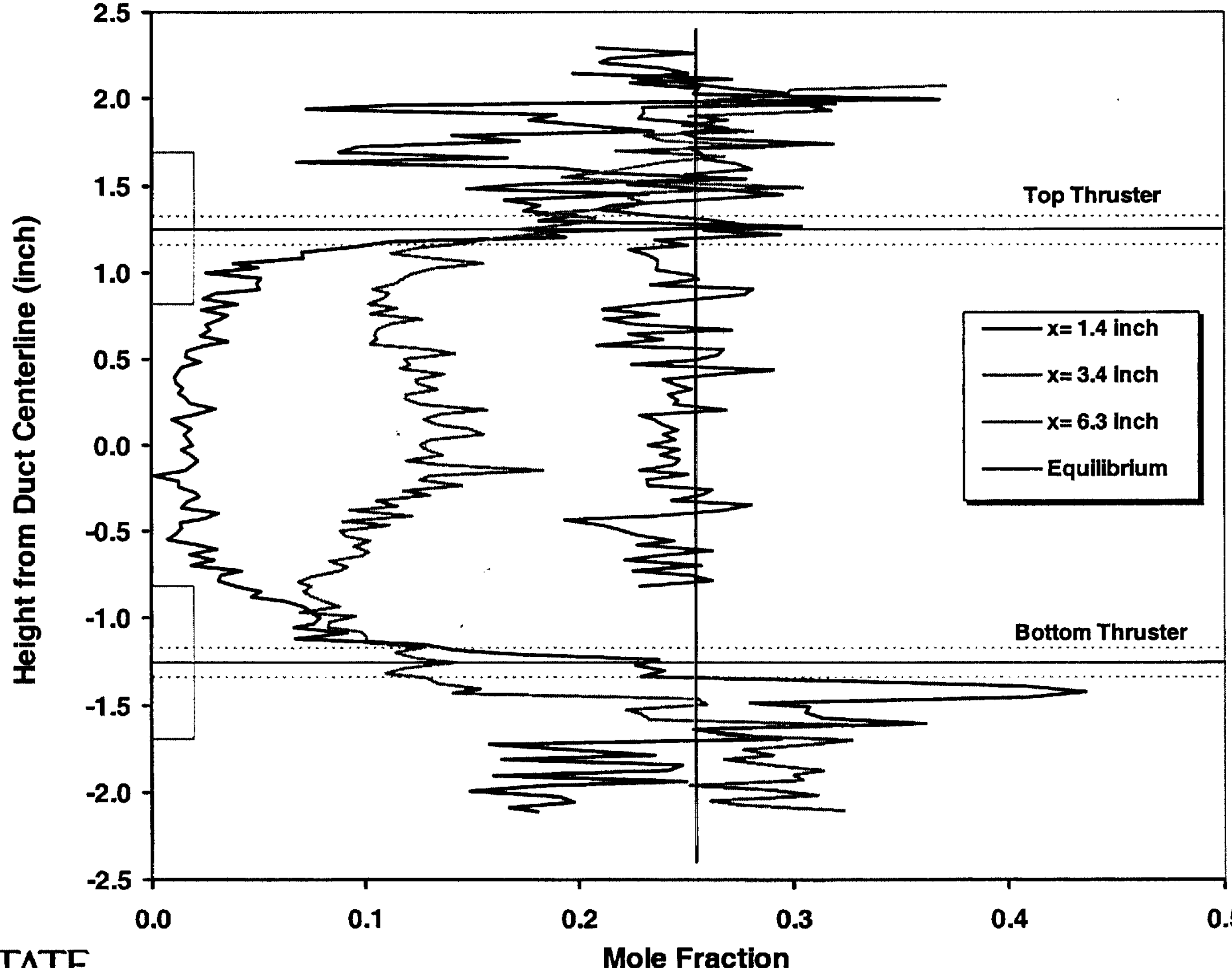
Water Mole Fraction Profiles

Case 6, Twin Thruster



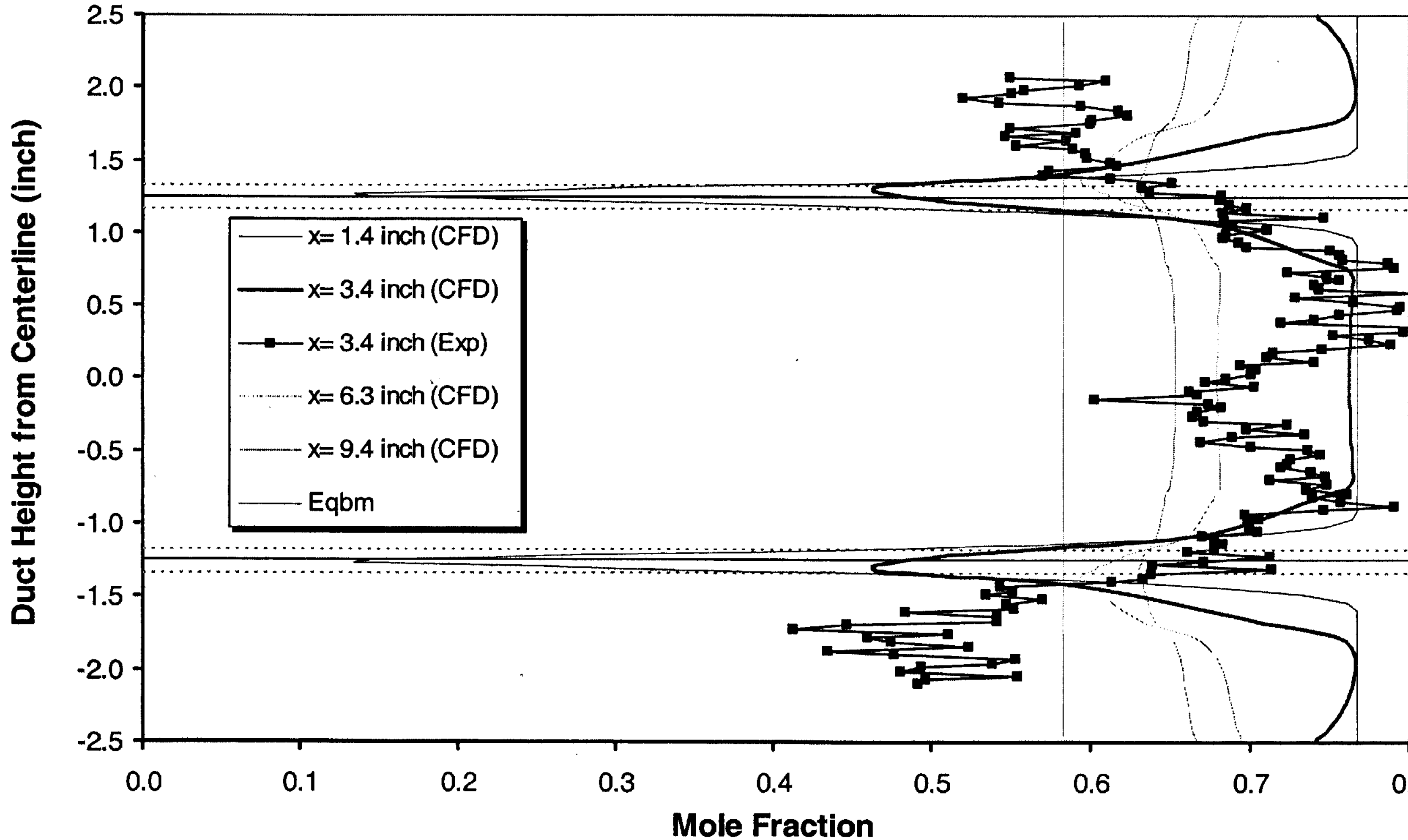
Mixing/Combustion Analysis

- CFD Modeling

- RBCC Performance Codes

CFD Results- Nitrogen Mole Fraction

Case 6, Twin Thruster



CFD ANALYSIS

- **Excellent Collaboration Between MSFC & PSU**
  - Example: Recirculation Bubble Problem
  - AFRL Also Performing CFD Analyses
- **Additional Challenges To Address**
  - Induced Air Flow Calculations [0.88 lb/s (CFD) vs. 1.22 lb/s (Exp)]
  - Primary/Secondary Mixing Length Predictions
  - Transverse Static Pressure & Velocity Profiles

Performance Analysis Tools

- **Objective:** Enhance Analysis Tools With Physically-Based Shear Layer Mixing Model

- **Current Codes Lack Detailed Physics of Mixing Process**
  - Example: GASL-Developed "THRSTER" Code

  - Many Physical-Based Features ➔ Combustion Modeled with Chemical Kinetics

  - Mixing Model
    - 1-D Code with 3 Fluid Streams: Primary, Secondary & Mixed Fluid
    - Mixing Model Based On NASA/Langley Supersonic Mixing Correlation (SCRAMJET)
      - *Linear Model Based on Empirical Supersonic/Supersonic Mixing*
      - *User-Specified Mixing Length*

  - THRSTER Code Can Match Experimental Static Pressure Profiles, BUT Only With User Specified Inputs

Performance Analysis Tools (cont.)

- **Approach:** Apply Current Knowledge on Turbulent Shear Layer Mixing

  Reference: Dimotakis, P.E., "Turbulent Free Shear Layer Mixing and Combustion," Chap. 5, High-Speed Flight Propulsion Systems, Vol. 137, Progress in Astronautics and Aeronautics, AIAA, 1991.

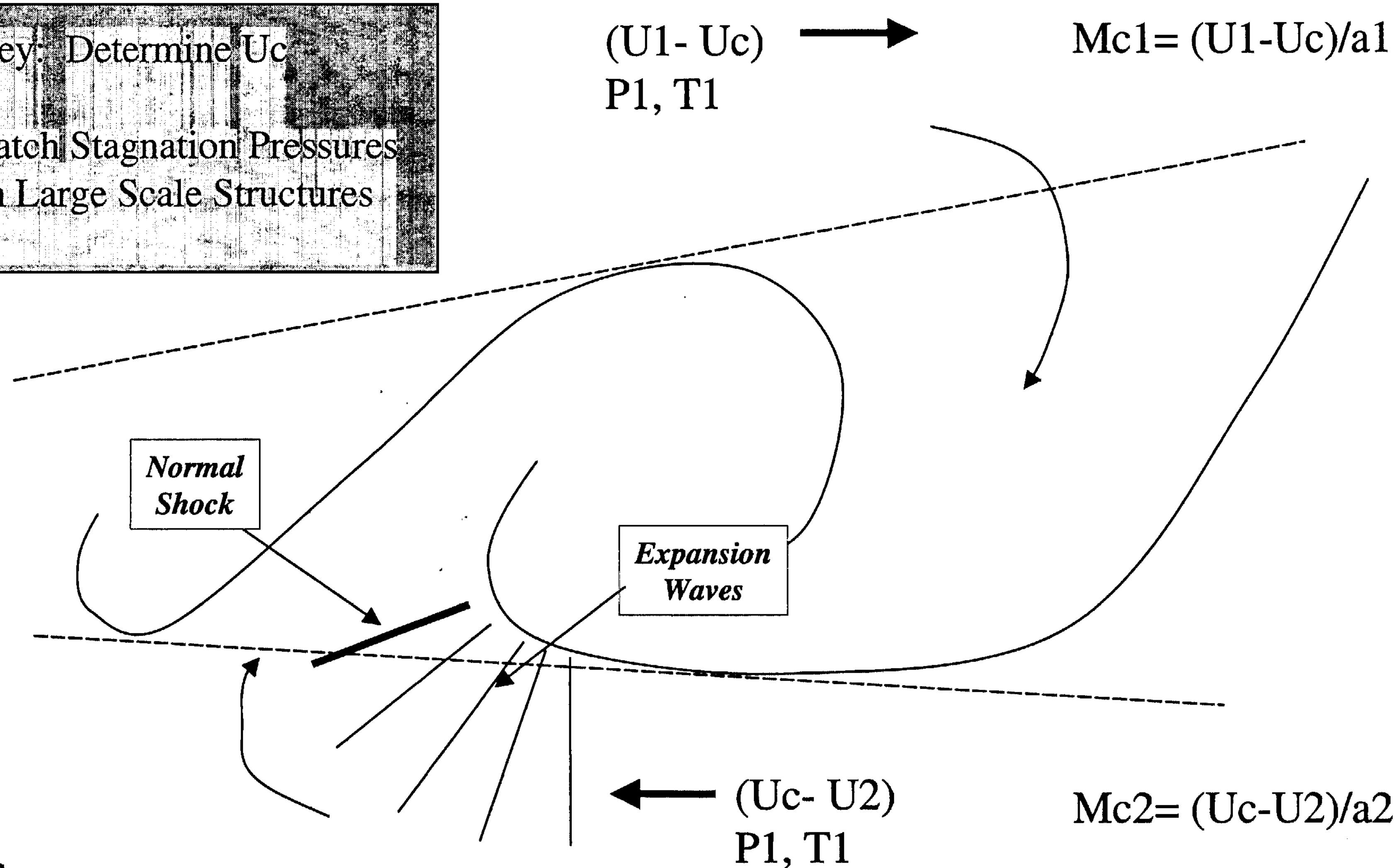
- **Mixing Model Based on Convective Reference Frame of the Large-Scale Structures in the Mixing Region**
  - Convective Mach Number Based on Relative Velocities
  - Physical Arguments Based on Simple Parameters

    $\mathbf{r} = \rho 2/\rho 1$ $\mathbf{s} = U2/U1$

  - Selection Rules for Shock Location
  - Predictions for-
    - Fluid Entrainment Ratio- Fluid Not Necessarily Entrained In Equal Portions
    - Mixing Layer Spreading Angles- Not Necessarily Symmetric

Shear Layer Mixing

- Key: Determine Uc
- Match Stagnation Pressures in Large Scale Structures



SUMMARY

- **Significant RBCC Ejector Mode Database Has Been Generated**
  - Single & Twin Thruster Configuration
  - Global & Local Measurements

- **Ongoing Analysis & Correlation Effort**
  - MSFC CFD Modeling
  - Turbulent Shear Layer Analysis

- **Potential Follow-On Activities**
  - Detailed Measurements of Air Flow Static Pressure and Velocity Profiles
  - Investigate Other Thruster Spacing Configurations
  - Perform Fundamental Shear Layer Mixing Study
  - Demonstrate Single-Shot Raman Measurements