Spatially Resolved Species Measurements in a GO_2/GH_2 Propellant Rocket

M.J. Foust, T. Ni and R.J. Santoro

Propulsion Engineering Research Center
and
Department of Mechanical Engineering
The Pennsylvania State University
University Park, PA 16802

Statement of Problem

Local species concentration and temperature are among the most important parameters to characterize in a combustion system. However, the harsh environment in rocket chambers under hot-fire conditions limits the applicability of conventional probing methods for the acquisition of this information. Laser-based diagnostic methods show great promise for achieving this goal by providing instantaneous images of species concentrations and temperature.

Objective of Work

The objective of the current work is to develop a non-intrusive technique to experimentally determine the major species and temperature field in the combustion chamber of an uni-element rocket for a GO_2/GH_2 propellant combination.

Approach

The experiments were conducted at the Cryogenic Combustion Laboratory at Penn State University. The uni-element rocket chamber used is modular in design and is easily configured to provide optical access along the chamber length. A shear coaxial injector was used to introduce GO_2 and GH_2 into the combustion chamber. The nominal flow rates of GO_2 and GH_2 are 0.1 lb/s and 0.025 lb/s, respectively, resulting in an O/F ratio of four. The experiments were for a chamber pressure of 190 psia.

One-dimensional profiles of species concentrations and temperature were measured by using laser-induced spontaneous Raman spectroscopy. The Raman system consists of a flash pumped dye laser operating at 10 Hz and an intensified CCD camera. The dye laser has a typical pulse energy of 2 J at 511 nm and a pulse duration of 5 μs. The Raman emission was detected at a right angle to the laser beam. A narrow band interference filter was placed in front of the camera to selectively measure the number density of the species. For each rocket firing, 50 single-shot Raman images and 50 background images were captured. By using different optical filters, Raman images of oxygen, hydrogen, water and nitrogen (used for window cooling) were obtained. Measurements were conducted at 1, 2, and 5 inch downstream of the injector face. The ratio of the signal to background level for hydrogen and oxygen Raman images at 1 inch downstream is about 10. Further downstream, the background luminosity increases significantly. Thus, the species concentration can only be determined from averaged Raman images. The temperature profiles were calculated from averaged data of total species number density using the ideal gas law. Since the Raman signal is stronger in lower temperature regions, the averaged temperature generally underestimates the temperature in regions where temperature fluctuates highly.

Conclusions

Single-shot and averaged profiles of species concentration have been measured under combusting conditions. These results demonstrate that the laser-based technique can be effectively applied for in-situ measurements in a rocket chamber. Experiments with an improved detection system for obtaining images of instantaneous and simultaneous multi-species concentration and temperature are underway.

SPATIALLY RESOLVED SPECIES MEASUREMENTS IN A GO_2/GH_2 PROPELLANT ROCKET

M. J. Foust, T. Ni and R. J. Santoro

13th Workshop for CFD Applications in Rocket Propulsion
NASA/Marshall Space Flight Center

April 25-27, 1995

PENNSTATE

Propulsion Engineering Research Center

OVERVIEW

- **Demonstrate Application of Raman Spectroscopy**
- **Present Measurements Using 2 Techniques**
  - **Optical Bandpass Filters**
    - **Good Light Collection for Obtaining Single Species**
    - **Cannot Assess Flame Luminosity Contribution**
    - **Simultaneous Species Measurements Require Multiple Detectors**
  - **Spectrometer**
    - **Provides Simultaneous Species Measurements Using Single Detector**
    - **Assessment of Flame Background**
    - **Needs Wide Dynamic Range**
- **Summarize Raman Experiments**

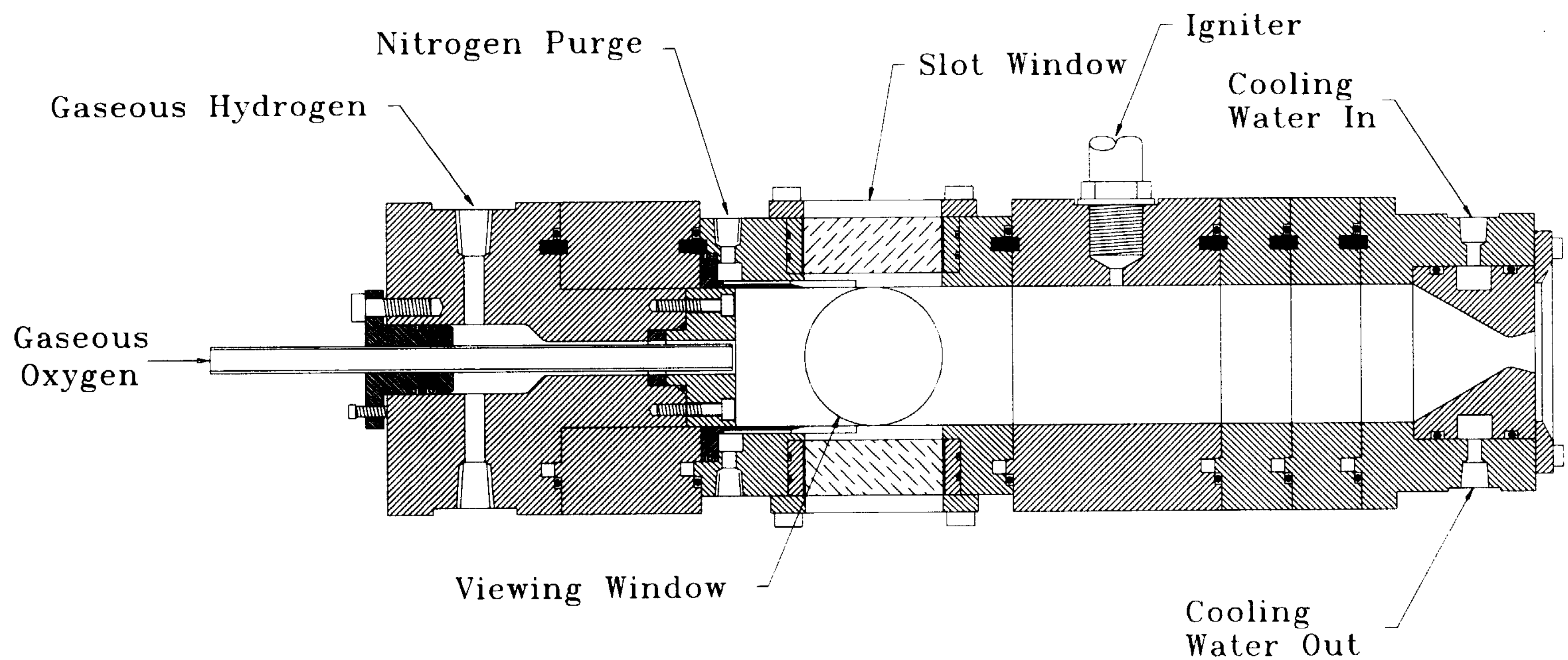
MOTIVATION

- **Improved Fundamental Understanding of Combustion-Driven Flows**
- **Combusting Flowfield Measurements used for CFD Code Validation**
- **Performance Assessment for Candidate Gas/Gas Injectors in Reusable Launch Vehicle Program**

APPROACH

- **Experiments in a Uni-Element Rocket**
- **Apply Laser-Based Diagnostic Techniques**
  - ☐ **Laser Doppler Velocimetry**
  - ☐ **Laser-Induced Fluorescence of OH**
  - ☐ **Laser Light Scattering from Tracer Particles**
  - ✓ **Laser-Induced Raman Spectroscopy**

OPTICALLY-ACCESSIBLE ROCKET CHAMBER



PENNSTATE

Propulsion Engineering Research Center

GO_2/GH_2 ROCKET TEST CONDITIONS
Shear Coaxial Injector

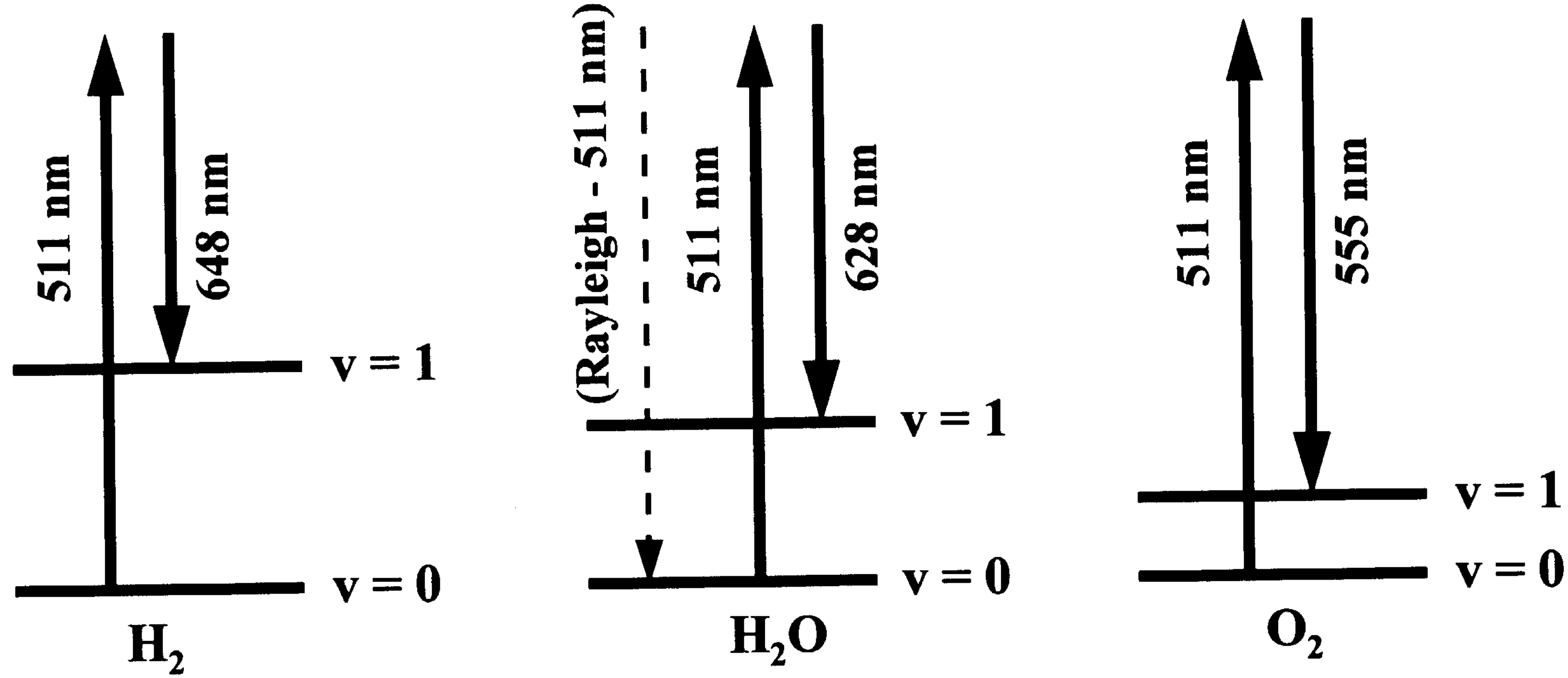
GH_2 Mass Flow Rate kg/s (lbm/s)	0.010 (0.023)
GO_2 Mass Flow Rate kg/s (lbm/s)	0.042 (0.092)
GN_2 Mass Flow Rate kg/s (lbm/s)	0.010 (0.022)
GO_2/GH_2 Mixture Ratio	4.0
Chamber Pressure MPa (psia)	1.29 (187)

PENNSTATE

Propulsion Engineering Research Center

RAMAN SPECTROSCOPY

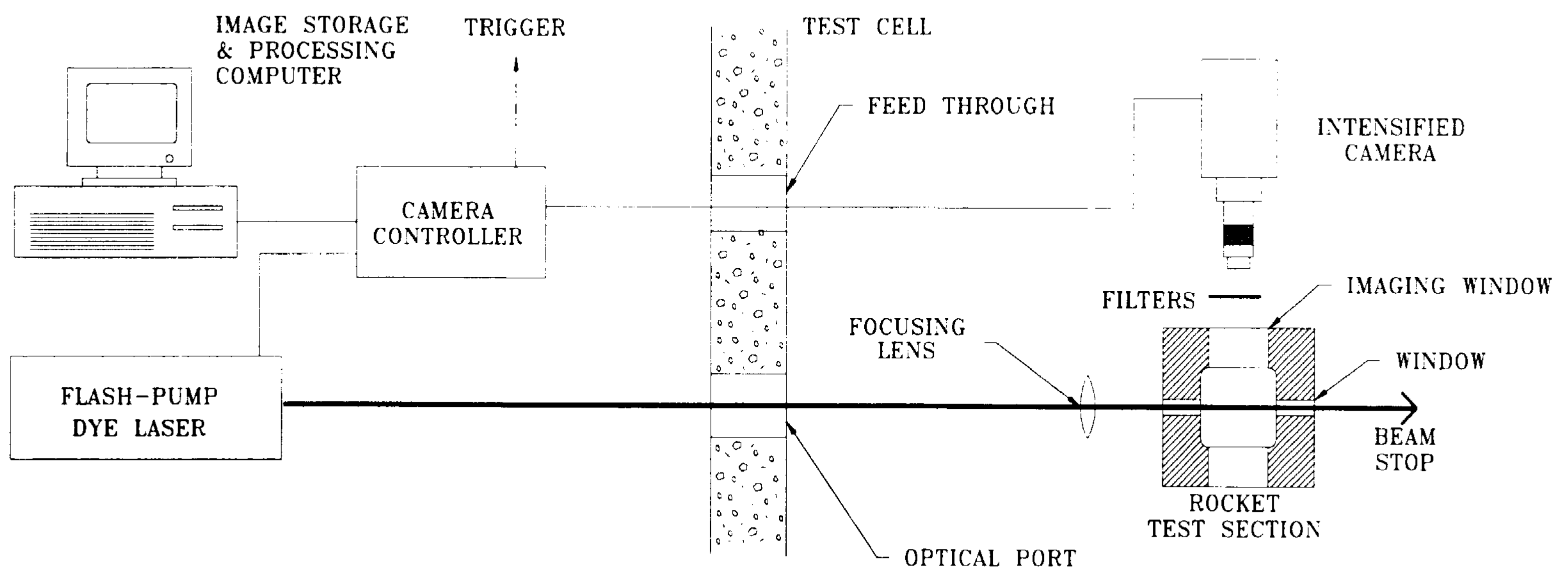
Stokes Vibrational Shift



- Raman Signal Specific to Each Species
- Linearly Proportional to Species Number Density
- $1 / \lambda^4$ Wavelength Dependence

EXPERIMENTAL SETUP

- **Optimized System for Collecting Weak Raman Signal**



PENNSTATE

Propulsion Engineering Research Center

SPECIES MEASUREMENTS IN GO_2/GH_2 Rocket

- **Obtained 35 Instantaneous Line Images Individually for Each Species (GO_2, GH_2, H_2O and GN_2 - Purge) During 4 sec. Rocket Firings**
- **Calibrated Measurements for Each Species Using Pure Gas Concentration**
- **Extracted Average Species Mole Fractions from 100 Images**

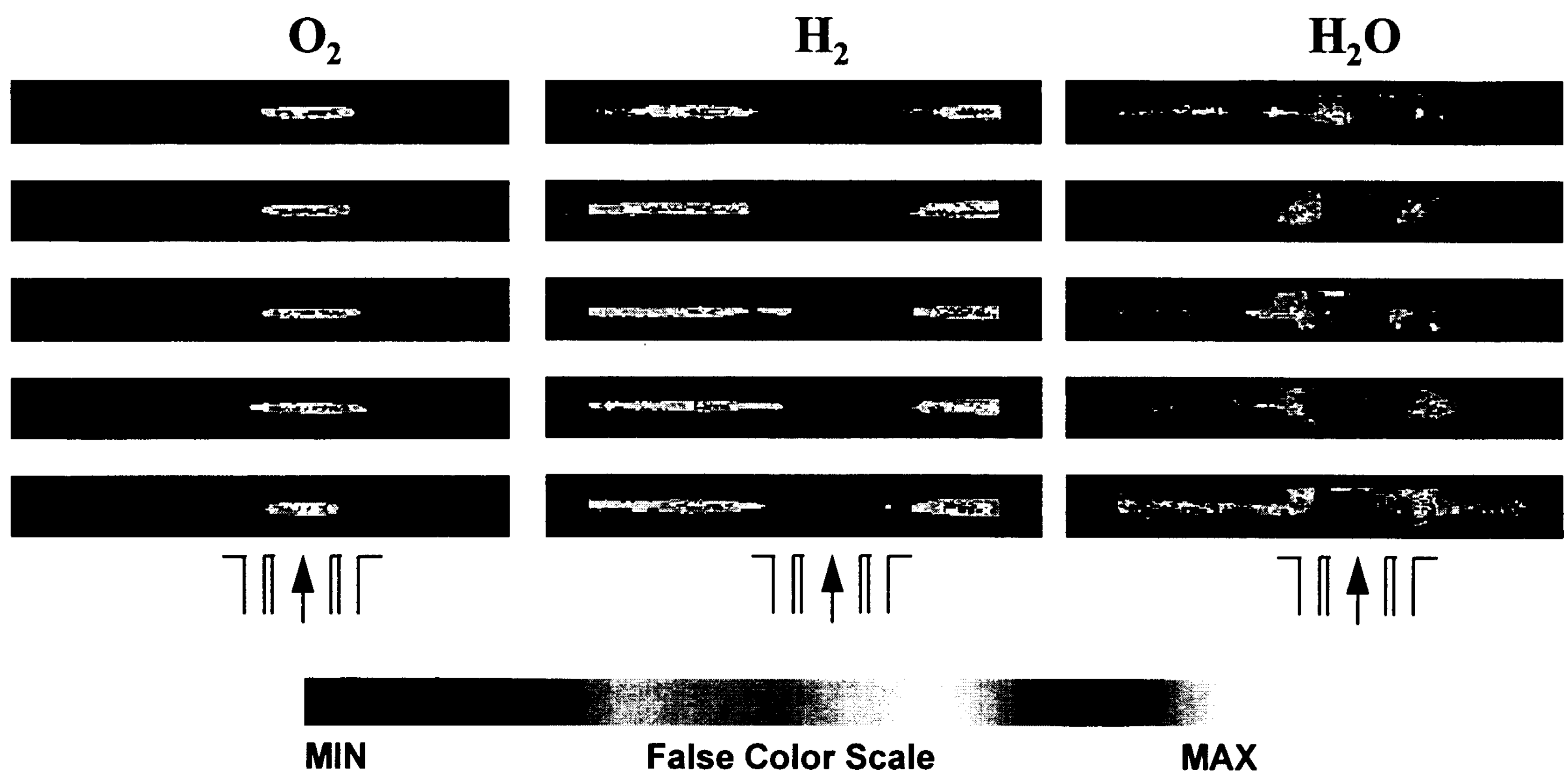
PENNSTATE

Propulsion Engineering Research Center

INSTANTANEOUS RAMAN IMAGES

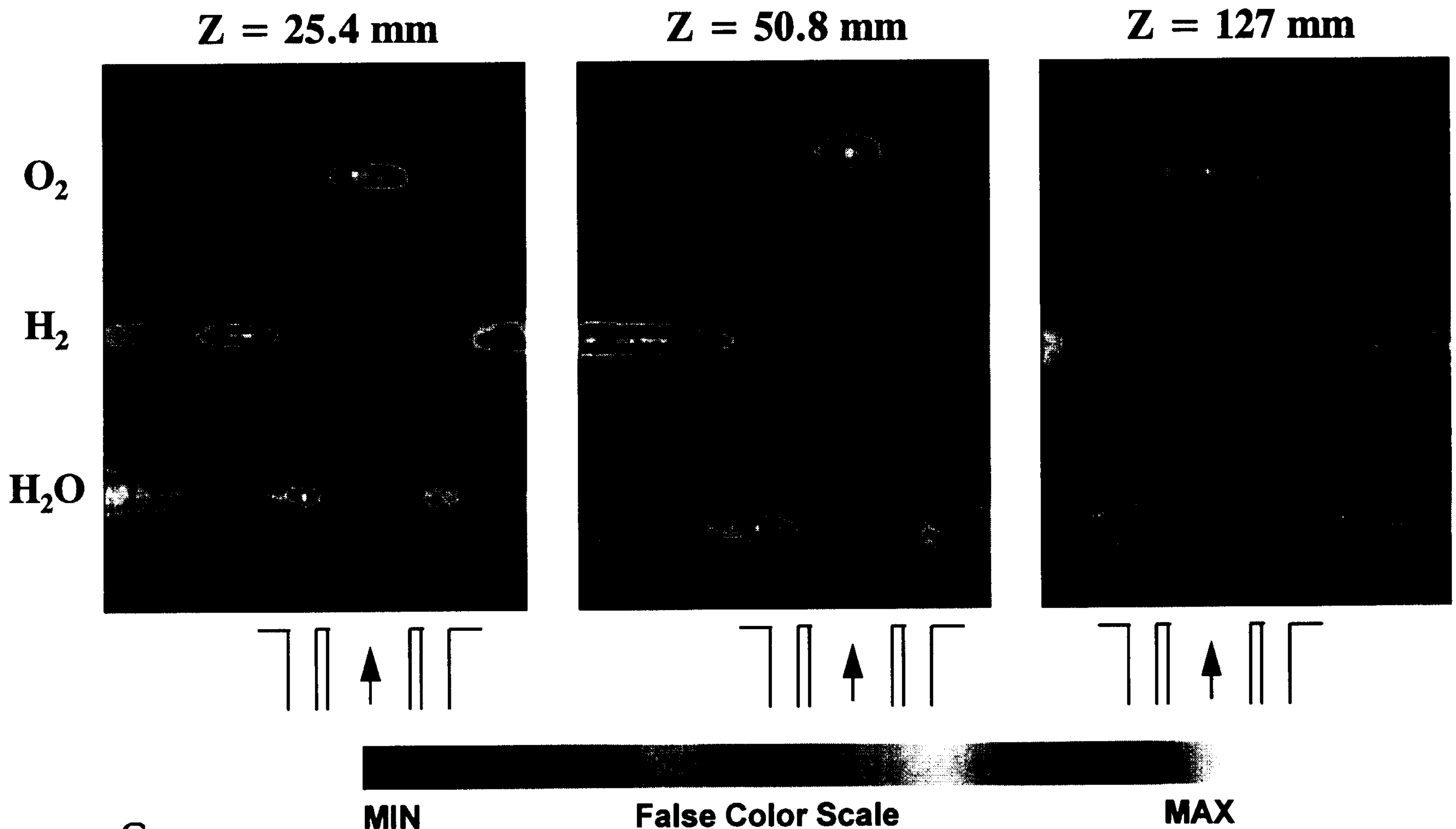
Shear Coaxial Injector

25.4 mm from Injector Face



MEAN RAMAN IMAGES

Shear Coaxial Injector

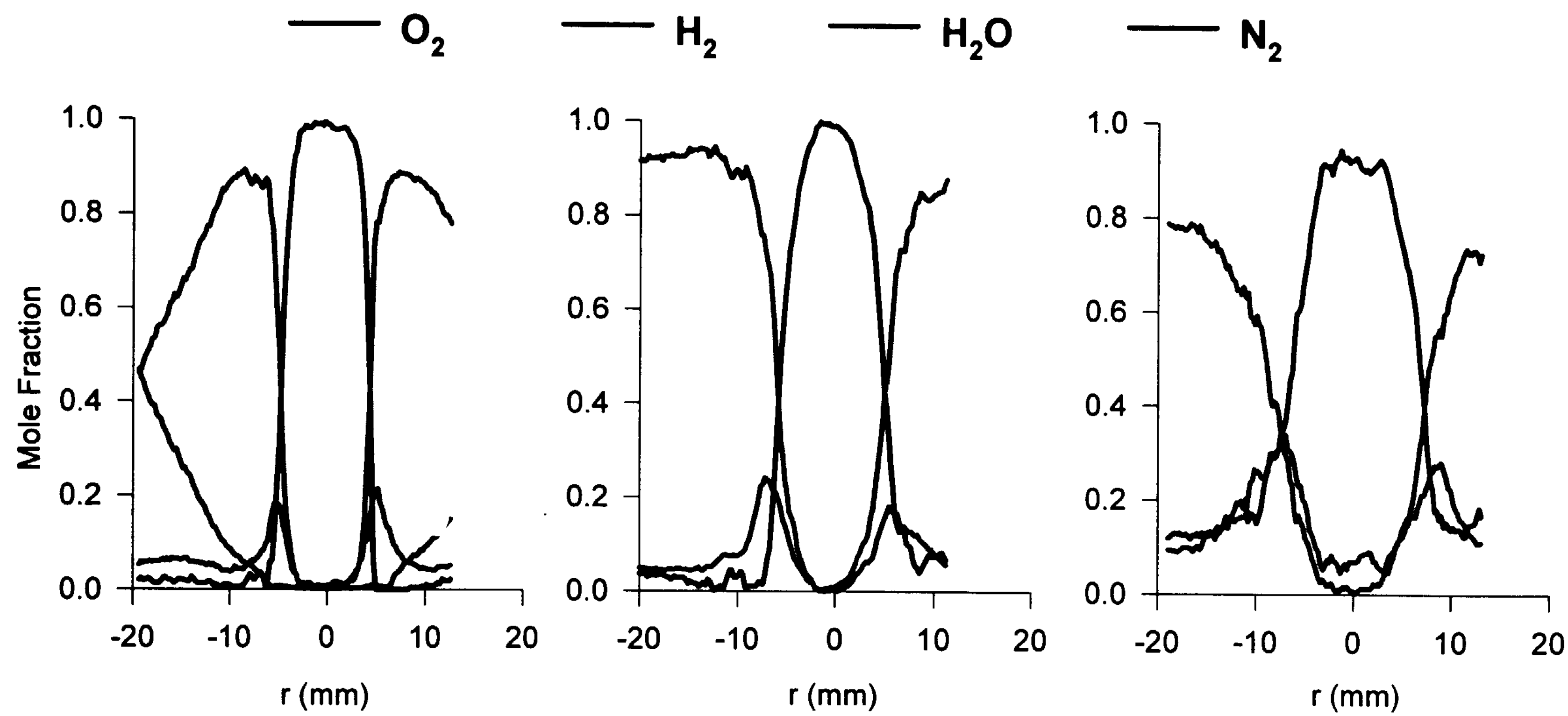


PENNSTATE

Propulsion Engineering Research Center

SPECIES MEASUREMENTS

Radial Profiles of Species Mole Fractions



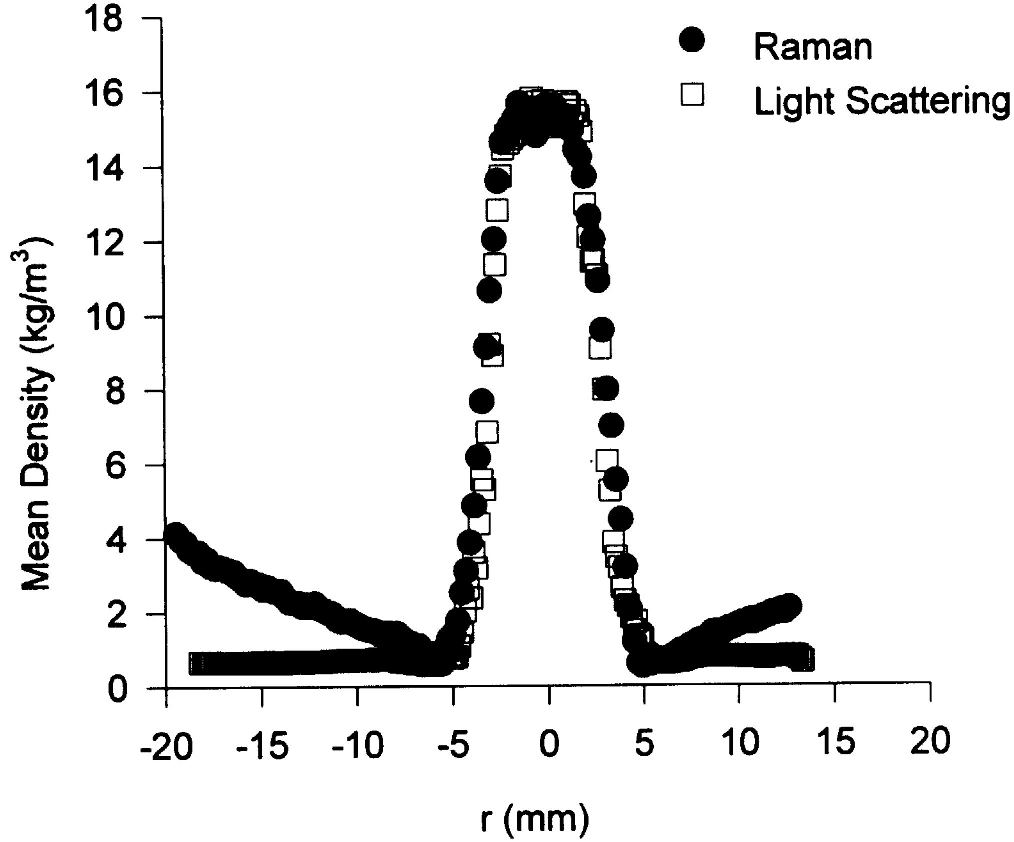
Z = 25.4 mm **Z = 50.8 mm** **Z = 127 mm**

PENNSTATE

Propulsion Engineering Research Center

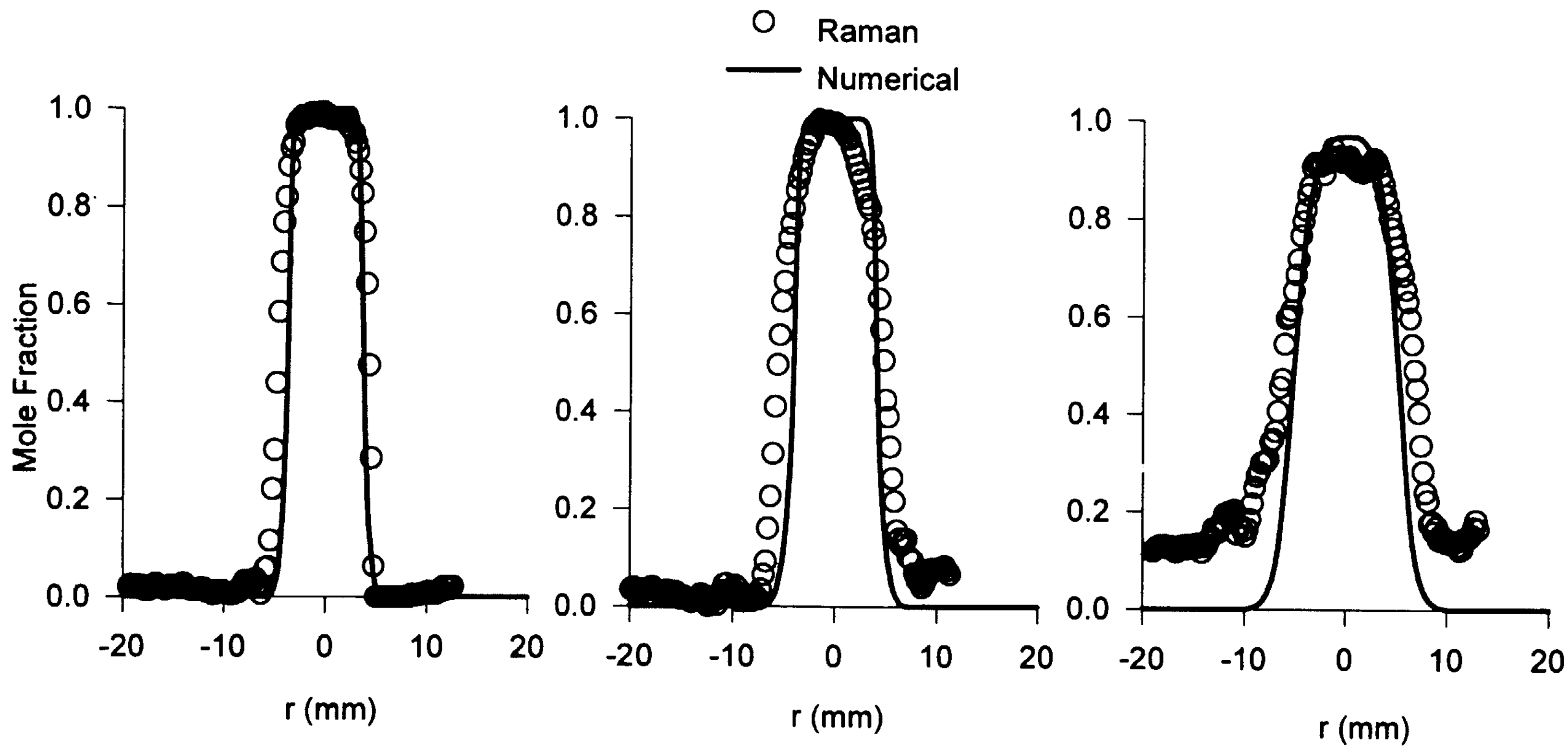
EXPERIMENTAL MEASUREMENTS

Mean Density Comparisons @ 25.4 mm from Injector Face



GO_2/GH_2 ROCKET

Oxygen Mole Fraction Comparisons



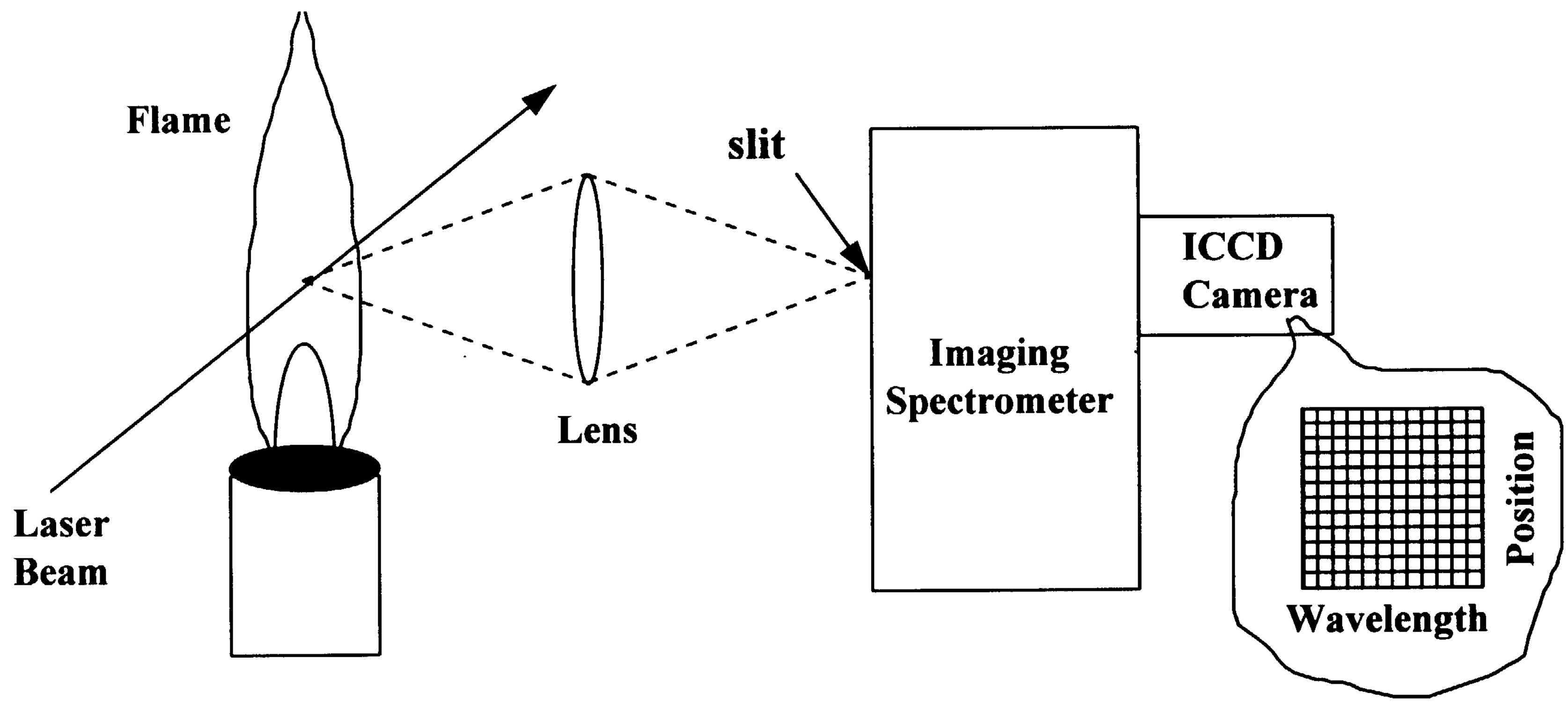
Z = 25.4 mm **Z = 50.8 mm** **Z = 127 mm**

- **Computation Predicts Faster Combustion Rates**

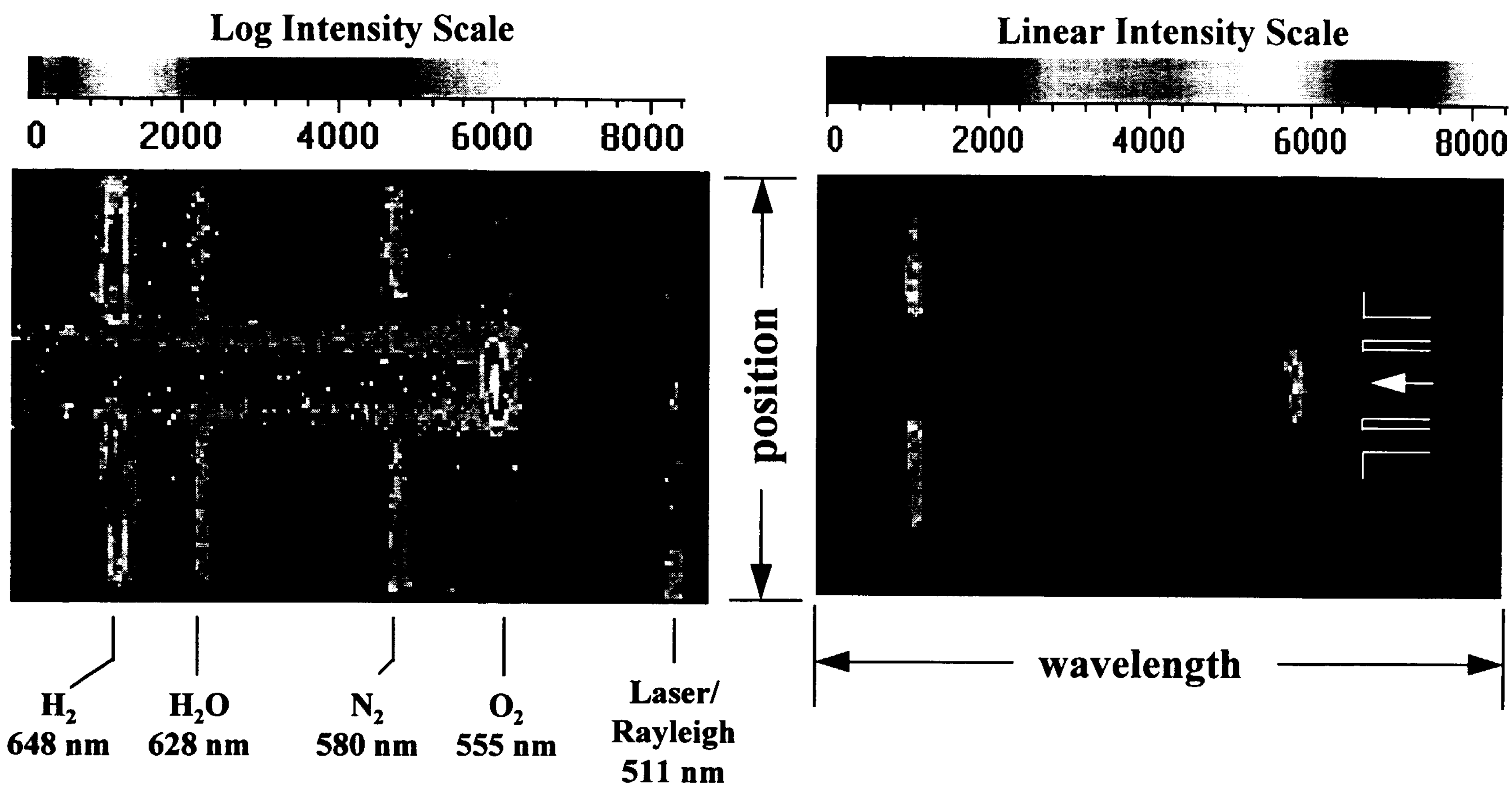
PENNSTATE

Propulsion Engineering Research Center

SINGLE-SHOT MULTI-SPECIES DETECTION
(Recent Development)



SIMULTANEOUS SPECIES MEASUREMENTS
25.4 mm from Injector Face



PENNSTATE

Propulsion Engineering Research Center

SUMMARY/CONCLUSIONS

- **2 Techniques for Raman Species Detection**
  - **Optical Bandpass Filters**
    - **Single-Shot Measurements for a Single Species**
    - **Spatially Resolved Average Species Mole Fractions**
    - **Feasible in Relatively Low Flame Background**
  - **Spectrometer**
    - **Single-Shot Multiple Species Measurements**
    - **Possible Method for Subtracting Flame Background Luminosity**
- **Shear Coaxial Injector Exhibits Poor Mixing**
  - **GO_2 Core Region Extends Beyond Mid-Chamber**
  - **H_2O Mole Fraction Levels Low**

ACKNOWLEDGEMENTS

- **Funding by NASA/Marshall Space Flight Center Under Contract NAS-8-38862 is Gratefully Acknowledged**

PENNSTATE

Propulsion Engineering Research Center