NON-INTRUSIVE MEASUREMENTS IN A ROCKET ENGINE COMBUSTOR

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ABSTRACT

In recent years analytical tools to characterize combustor flow have been developed in order to support design. To facilitate anchoring of combustion related physical models and the CFD codes in which they are incorporated considerable development and application of non-intrusive combustion diagnostic capabilities has occurred. Raman spectroscopy can be used to simultaneously detect all polyatomic molecules present in significant concentrations and to determine gas temperature. This is because all molecules possess a distinct temperature dependent Raman spectrum.

A multi-point diagnostic system for non-intrusive temperature and species profiling in rocket engines has been developed at Rocketdyne. In the present effort, the system has been undergoing validation for application to rocket engine component testing. A 4 inch diameter windowed combustor with a coaxial gas-gas injector was chosen for this series of validation experiments. Initially an excimer-pumped tunable dye laser and later a solid state Nd-Yag laser served as excitation sources. The Raman signal was dispersed by a monochromator and detected by a gated, intensified Charged Coupled Device (CCD) array.

Experiments were carried out prior to each series of hot fire tests to ensure that the Raman signal detected was due to a spontaneous rather than a stimulated Raman emission process. Over sixty hot fire tests were conducted during the first series of tests with the excimer/dye laser. All hot fire testing was at a mixture ratio of 0.5 and chamber pressures of ~100 and ~300 psia. The Raman spectra of hydrogen, water vapor and oxygen recorded during single element hot fire tests were reduced and analyzed. A significant achievement was the attainment of single shot Raman spectra in cold flow tests. Unfortunately, the single shot signal-to-noise ratio detoriated to an unacceptable level during the hot fire testing. Attempts to obtain temperature data from the hydrogen Q1-branch profiles obtained in hot fire tests suggest that potentially complicating factors may render the approach of averaging data on the photodiode array invalid. A second series of hot fire tests was conducted with a 4 element coaxial injector using the Nd-Yag laser. A very compact and portable diagnostics set up was assembled for ease of alignment, relocation and flexibility. Measurements were made at several regions in the chamber in order to map concentration profiles. High spatial resolution and improved signal to noise characteristics were demonstrated.

Non-intrusive Measurements in a Rocket Engine Combustor

Rocketdyne Advanced Combustion Devices

S. Farhangi, T. Gylys, and R. Jensen

Workshop for CFD Application in Rocket Propulsion

NASA MSFC

April 1993

Rockwell International
Rocketdyne Division

CFD Workshop - 001
ACD 93 SF

C-8.

AGENDA

- Background / Need
- Progress (FY 92 & 93)

IMPROVEMENTS IN ROCKET INJECTOR/COMBUSTOR MODELING ARE REQUIRED

- Modeling of perfomance, durability, and stability of liquid rocket combustor systems relies heaviliy on correlations

- Advanced combustion physics modleling for CFD requires detailed experimental data for validation and anchoring.

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COMBUSTOR PERFORMANCE, COMPATIBILITY KEY DESIGN ISSUES

- **Vehicle weight / cost / size & payload driven by performance**
  - ELV benchmark: $30K / incremental kilogram of payload
  - Upper stage & SSTO thrust / weight critical
- **Chamber compatibility influences life / cooling / mission**
  - Blanching related to hot wall temperature/chemistry
  - Lower heat loads may reduce pump requirements
  - Split channels affect performance of aging fleet
- **Combustion stability related to performance**
  - Spray / mixing characteristics set stability margin
  - Performance / stability margin trades

CFD CODES BEST FOR PERFORMANCE / COMPATIBILITY DESIGN ANALYSIS

- **Complete combustion physics**
  - Spray / chemistry / flowfield models
  - Models general - not specific to hardware / operating conditions
- **Detailed representation of hardware geometry / combustion**
- **Performance "data" at all locations within combustor**
  - Pressures / temperatures / species / heat loads
  - All performance parameters measurable in hot fire

Confidence in CFD limited due to lack of required detailed validation data

RAMAN WELL SUITED TO OBTAIN KEY CODE VALIDATION DATA

- **Raman spectroscopy well understood / straightforward to apply**
  - Small fraction of laser light scattered from molecules yields Raman spectrum
  - Raman light shifted in wavelength from laser / unique to each specie
- **Non Intrusive measurements with existing technology**
  - Can obtain spacial data during hot fire testing
    - Temperature
    - Species concentration

ROCKETDYNE RAMAN DIAGNOSTIC CAPABILITIES

- **Local temperature / combustion gas species concentrations**
  - Simultaneous measurements at multiple locations
  - Simultaneous species / temperature data
- **Applicable to research / development combustors**
  - CFD code validation data in research combustors
  - Performance (mixing efficiency) assessment
  - Injector / chamber compatibility evaluation

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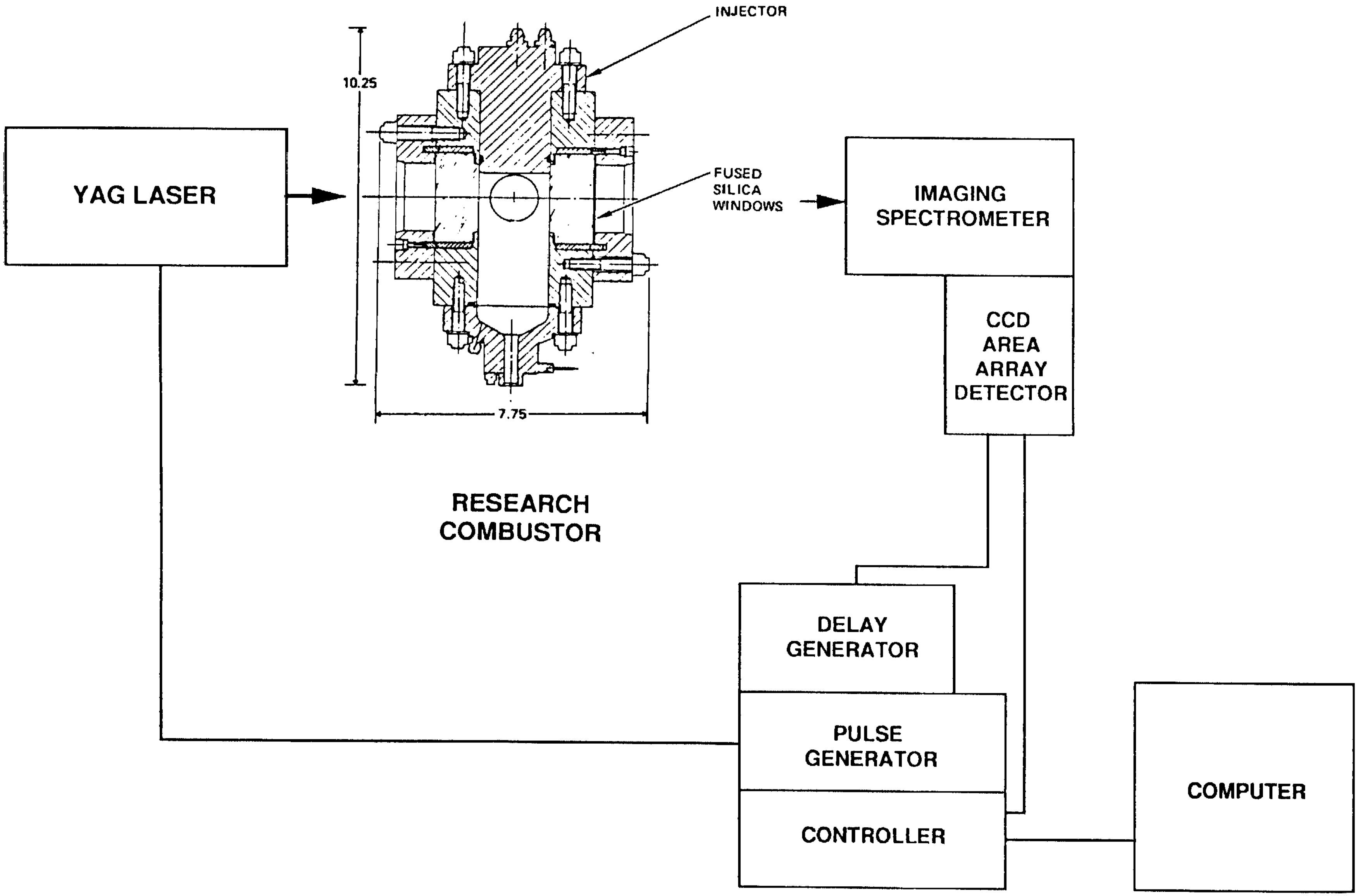
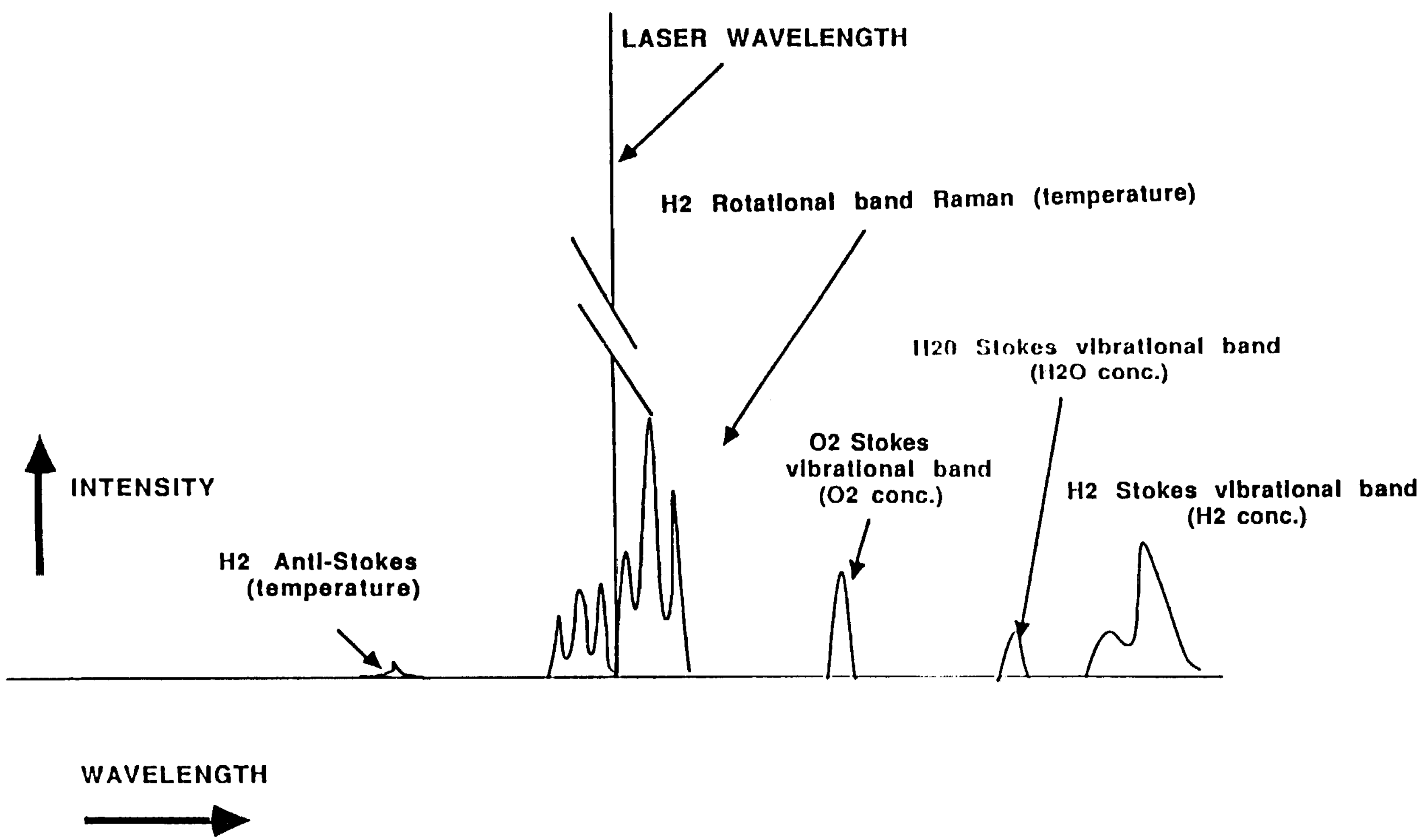
FY 92-93 RAMAN PROGRESS

- **Activated multi-point Raman system**
- **Raman species data obtained in single element combustor testing**
  - Concentration profiles reveal flame structure
  - Over 100 hot fire tests at 100 and 300 psia, MR = 0.5/various injectors
  - Ten simultaneous measurements each test
    - Data along lines at various locations downstream of the face
    - Concentrations averaged over multiple laser pulses
    - Efforts to get instantaneous data partly successful
- **Initiated assembly of multi-point "portable" Raman system**

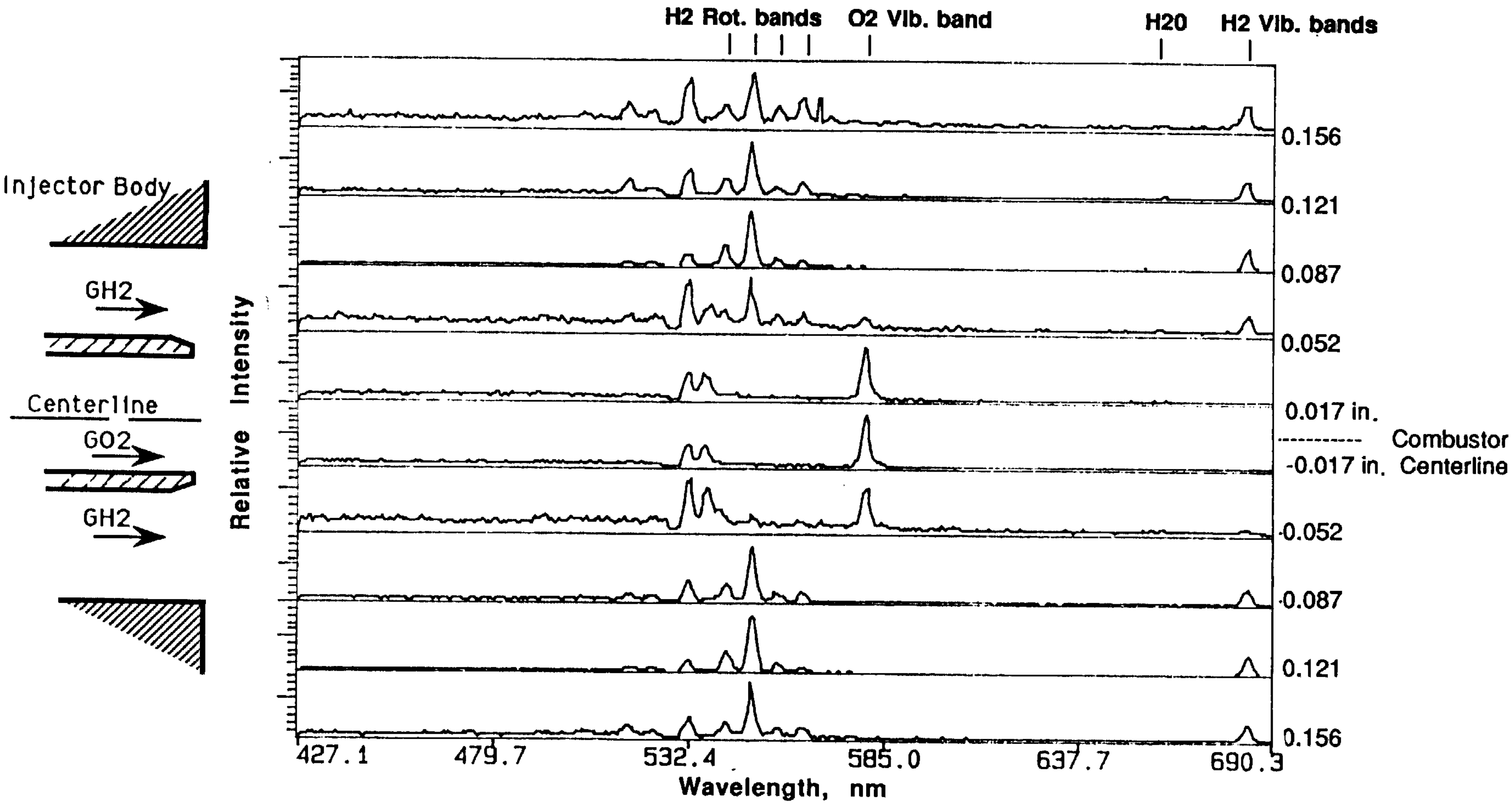
RAMAN SYSTEM FOR RESEARCH COMBUSTOR TESTING



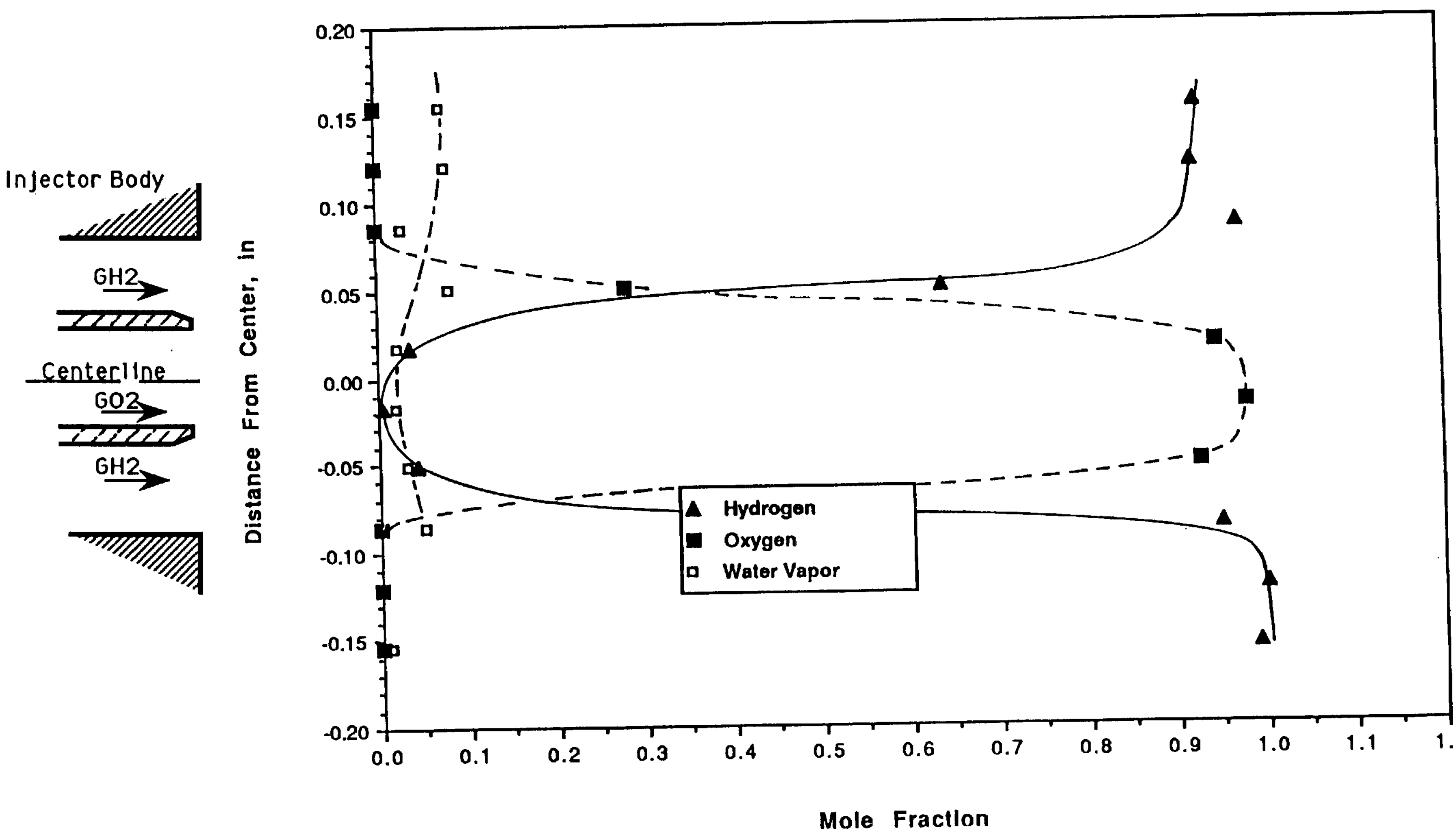
COMPLETE RAMAN SPECTRUM



MULTI-POINT HOT FIRE RAMAN SPECTRA, 150 g/mm
(Injector Face, Pc = 100 psia, MR = 0.5)

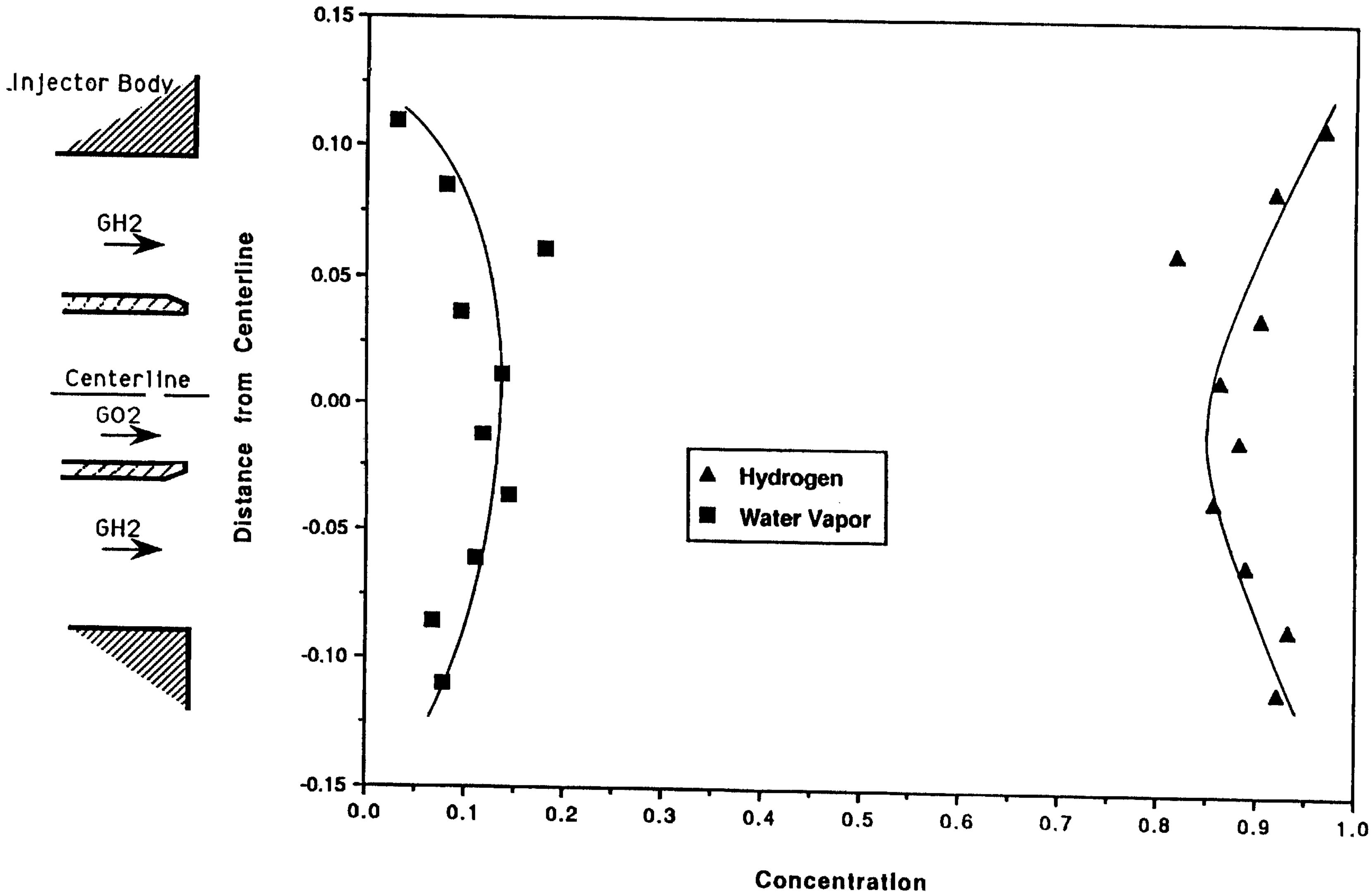


VARIATION OF SPECIES MOLE FRACTION WITH RADIAL DISRANCE
(TEST 16FR12, Injector Face, Pc = 100 psia, MR = 0.5)



molefrac.16fr12.g2
SF 3-93

VARIATION OF SPECIES MOLE FRACTION WITH RADIAL DISRANCE
(TEST A19R70, 1.5 in. from Injector Face, Pc = 120 psia, MR = 0.5)



con.dist.a19r70.g3
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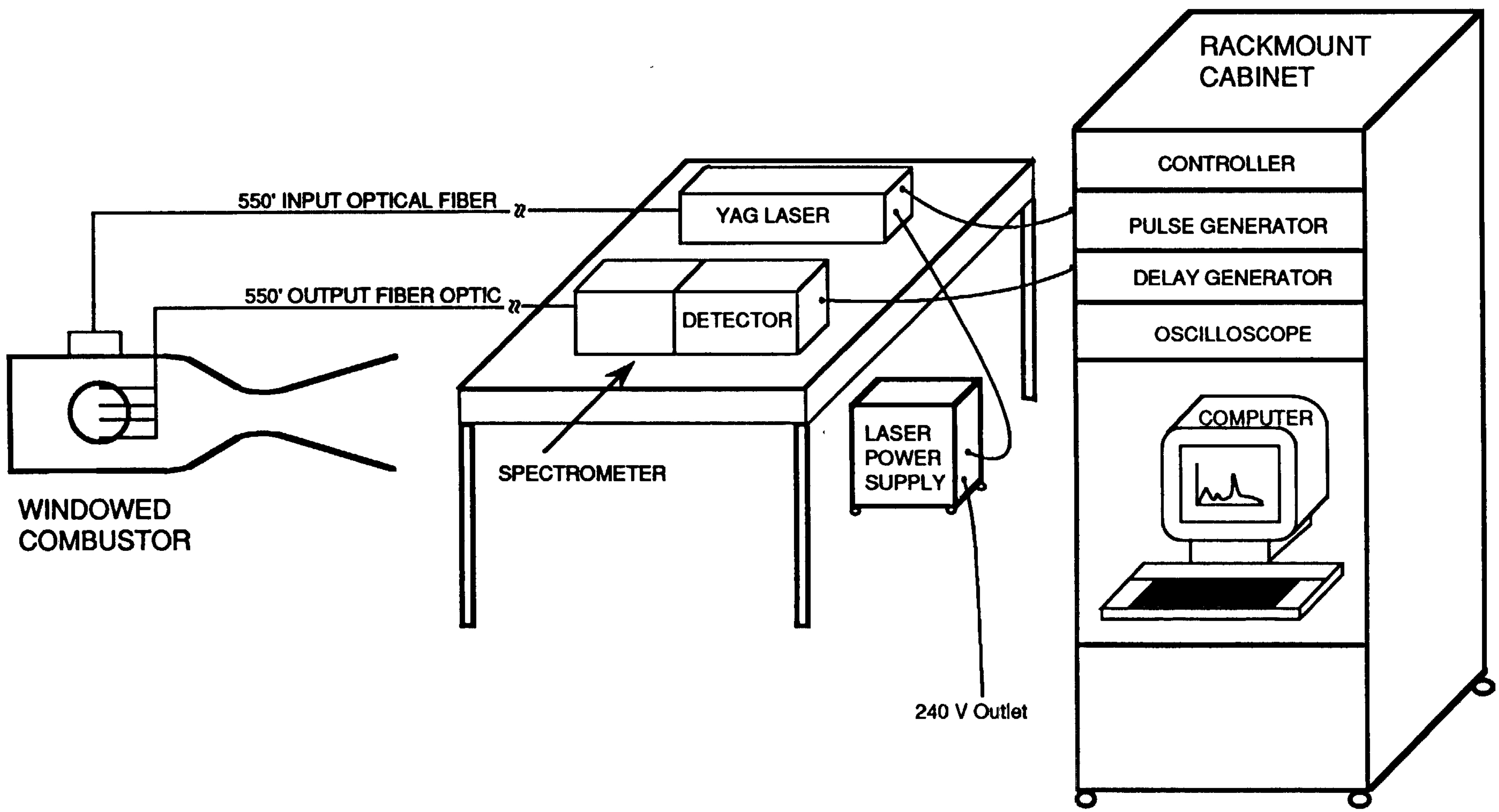
PORTABLE LASER RAMAN SYSTEM SCHEMATIC



Schematic
sf 11-92

SUMMARY

- Hot fire validation of multipoint Raman diagnostic progressing
  - 10 points simultaneously
    - Species concentration (0_2, H_2 & H_20 demonstrated)
    - Temperature
  - Data collection rate of 5-10 Hz , pulse duration of ~6 ns
- Portable Raman system with fiber optics in work
- Application to code anchoring effort now feasible