View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

DEMONSTRATION AND ANALYSIS OF FILTERED RAYLEIGH SCATTERING FLOW FIELD DIAGNOSTIC SYSTEM

Joseph N. Forkey, Walter R. Lempert, and Richard B. Miles
Princeton University
Princeton, New Jersey

Filtered Rayleigh Scattering (FRS) is a diagnostic technique which measures velocity, temperature and pressure by determining Doppler shift, total intensity, and spectral lineshape of laser induced Rayleigh - Brillouin scattering. In the work reported here, this is accomplished by using a narrow linewidth, injection seeded, Nd:YAG laser sheet to induce Rayleigh - Brillouin scattering from gas in a flow. This light is passed through an optical notch filter, and transmitted light is imaged onto an intensified CCD camera. By monitoring the grayscale value at a particular pixel while the laser frequency is tuned, the convolution between the Rayleigh -Brillouin scattering profile and the filter transmission profile is attained. Since the filter profile can be independently measured, it can be deconvolved from the measured signal, yielding the Rayleigh - Brillouin scattering profile. From this profile, flow velocity, temperature, and pressure are determined.

In this presentation, we discuss the construction and characterization of two of the most critical components of the FRS system - the optical notch filter, and a newly developed frequency measurement apparatus - and demonstrate their utility by presenting FRS measurements of velocity, temperature and pressure.

The filter which we have used for these experiments consists of a glass cell 2 inches in diameter, and 4 inches long, with 2 inch diameter sleeves extending 2 inches beyond each of the two windows. A few iodine crystals were placed in the cell before it was evacuated and sealed. The temperature of the cell was monitored and controlled by a RTD element cemented to the cell wall, and heating tape, which covers the entire cell body and sleeves and a temperature feedback controller. The pressure of the cell was set by controlling the temperature of a side arm 'cold tip' which was kept at a lower temperature than the cell body. The side arm was enclosed in a water jacket, and water temperature was controlled by a water bath with a temperature stability of better than +/- 0.1 C. For all filter based measurement schemes, accurate characterization and optimization of the filter being used is crucial for obtaining accurate measurements. To this end, we have developed a computer based model which predicts the transmission profile of our molecular iodine based optical notch filter for various cell temperatures and pressures. This model utilizes spectroscopic constants taken from the literature to determine the frequency location of all absorption lines of molecular iodine from the ground X electronic state to the excited B state. All transitions with v"=0-19, J"=0-200, v'=0-69, and ΔJ=+/-1 are considered. Each of these lines is split into 14 or 21 hyperfine lines using published coupling constants for nuclear electric quadrupole and magnetic hyperfine interactions. A Boltzman distribution is assumed for the population of states; a Gaussian lineshape is assumed for each of the hyperfine absorption lines, and Franck-Condon factors from the literature are used to determine relative line strengths. Details of this model will be discussed. In addition, we have performed a number of experiments to characterize the filter for a number of different operating conditions. These characterizations have been attained with transmission uncertainties of +/- 0.5%, and frequency uncertainties of +/- 2 MHz, over a full tuning range greater than 35 GHz. These characterizations, which have been used to validate the model and to analyze FRS data, will also be presented.

Most filter based techniques for measuring velocity, including FRS, rely on the measurement of Doppler shift. Therefore, any systematic error in the measurement of laser frequency, either during an experiment, or during the calibration of the optical notch filter will result in a systematic error in the measured velocity. In this presentation, we will discuss the details of a frequency measuring technique which is capable of continuously measuring laser frequency with a precision of +/- 2 MHz. This corresponds to a typical velocity error of +/- 1 m/s. This accuracy is achieved by making use of a heterodyne technique which measures laser frequency relative to the iodine absorption line located at 18789 cm^{-1}. This is accomplished by locking the frequency of the doubled laser light (532 nm) from a reference cw, narrow linewidth Nd:YAG laser to the P142(37,0) absorption line of molecular iodine using a first derivative nulling technique. Residual fundamental laser light (1064 nm) from this laser is then overlapped spatially with the 1064 nm light from the laser whose frequency is being measured. This overlap results in a heterodyne beat signal with an oscillation frequency equal to the difference in optical frequencies between the reference laser, and the laser being measured. This heterodyne beat frequency is measured by a high speed photodetector and frequency counter. Details of this technique will be discussed, along with an analysis of the system indicating that measurements with a precision of +/- 2 MHz are possible over a range of 80 GHz.

Finally, we demonstrate the use of the equipment discussed above in Filtered Rayleigh Scattering planar measurements of velocity, temperature and density, by presenting measurements made in ambient air conditions and in a Mach 2 jet.

Outline

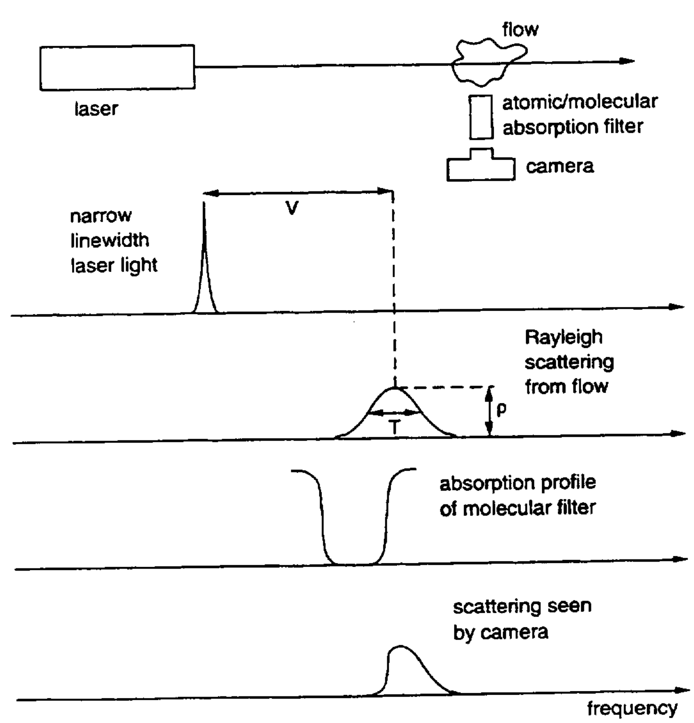
- Basic Concept

- Filter
  - Model
  - Experimental Characterization

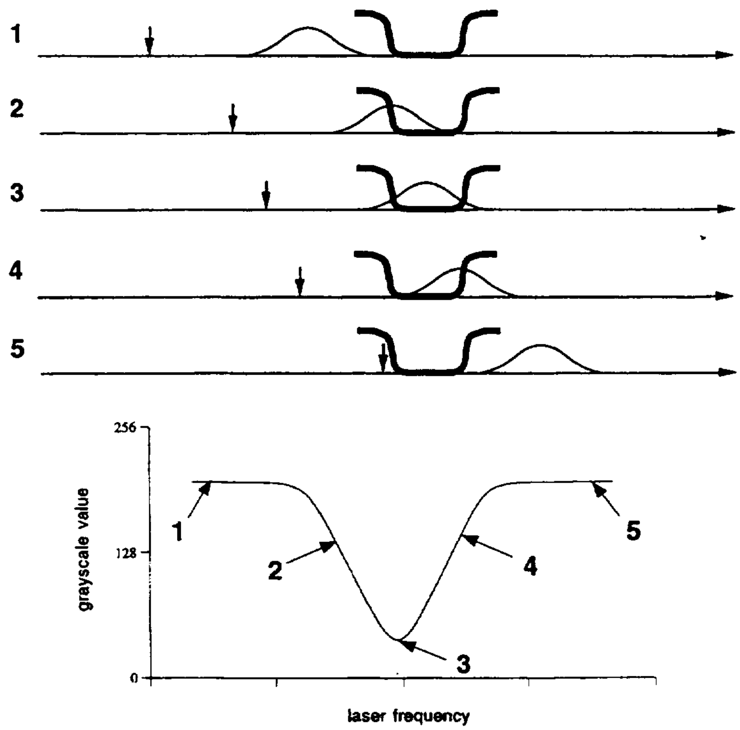
- Laser
  - Frequency Measurement
  - Frequency Tuning

- Experimental Results

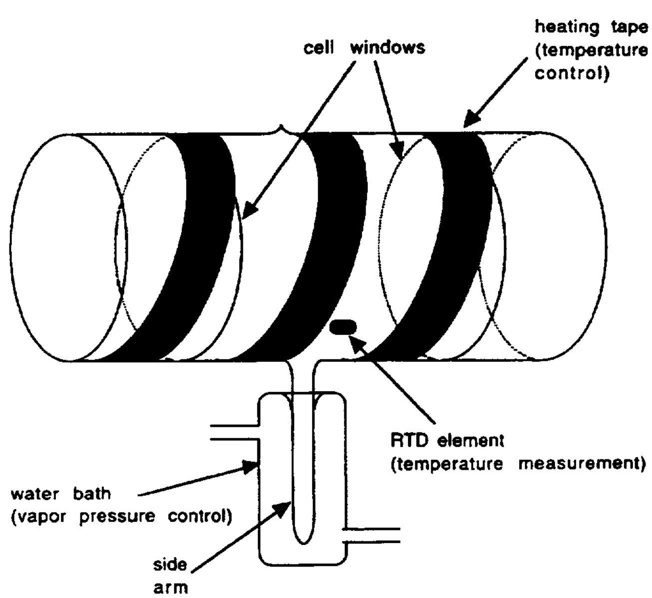
Basic Concept



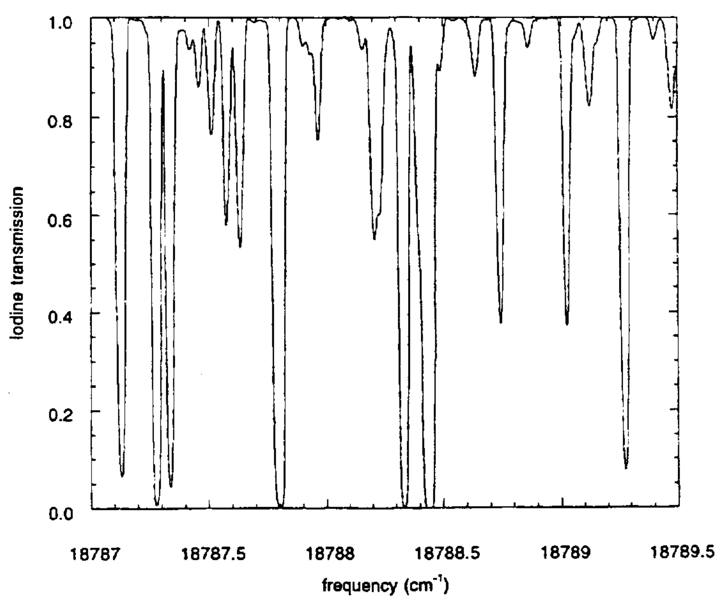
Determination of Flow Parameters via Laser Frequency Tuning



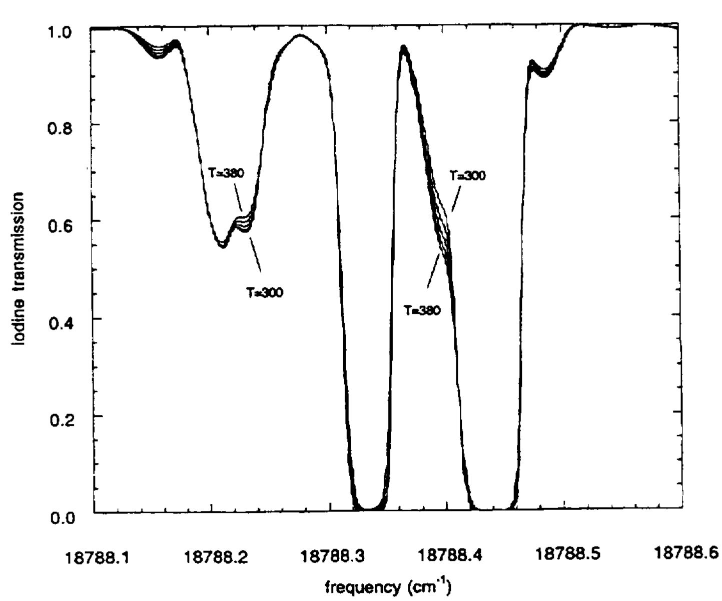
Filter



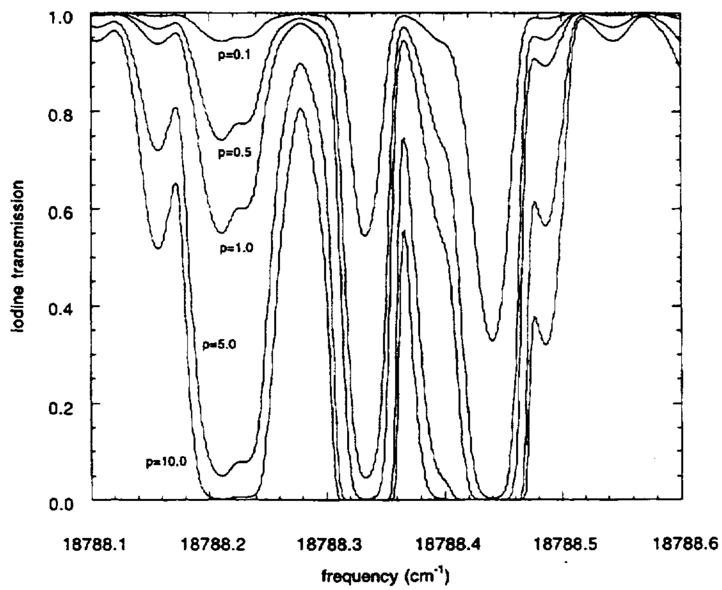
model prediction for 1 torr, 370 K, 10 cm



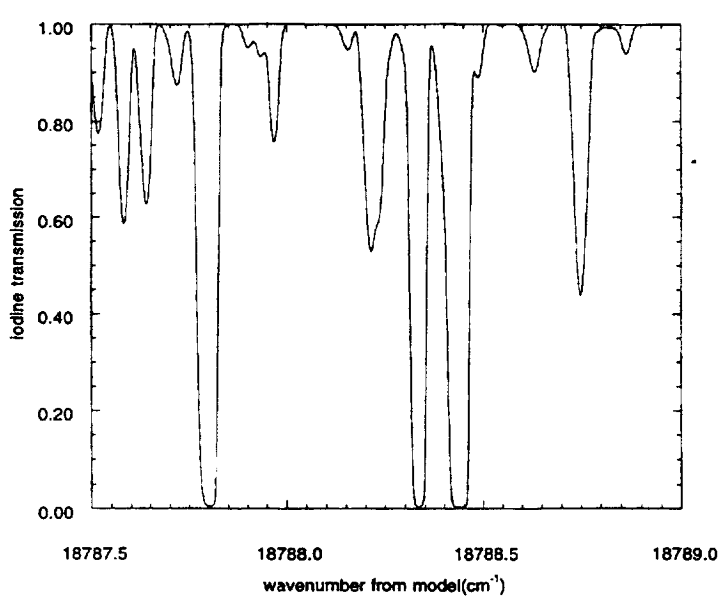
model predictions for various cell temperatures



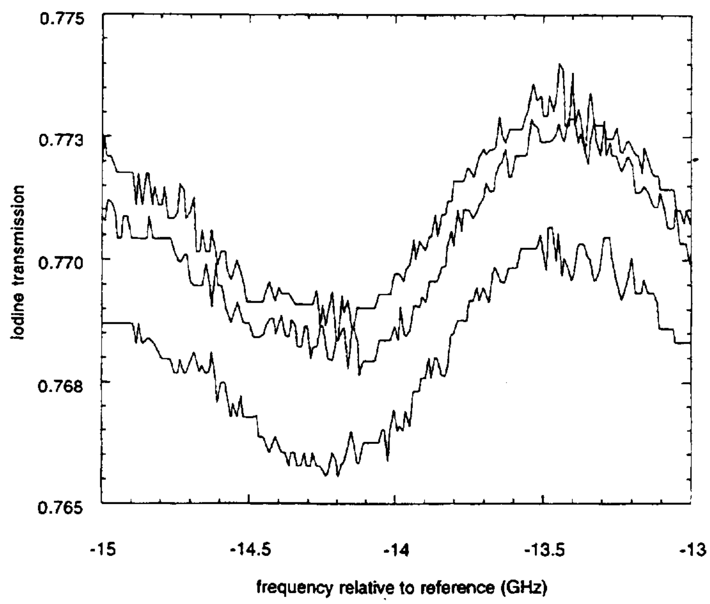
model predictions for various cell pressures



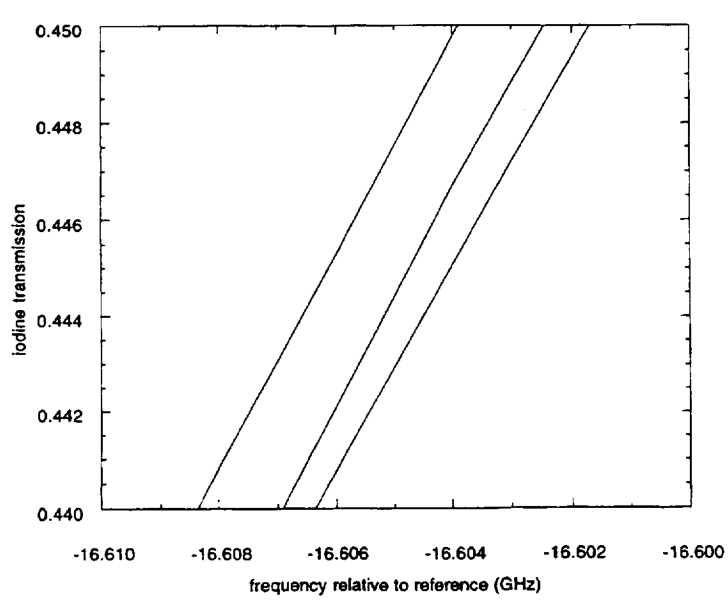
measured filter transmission profile: 353 K, 1.03 torr, 10 cm



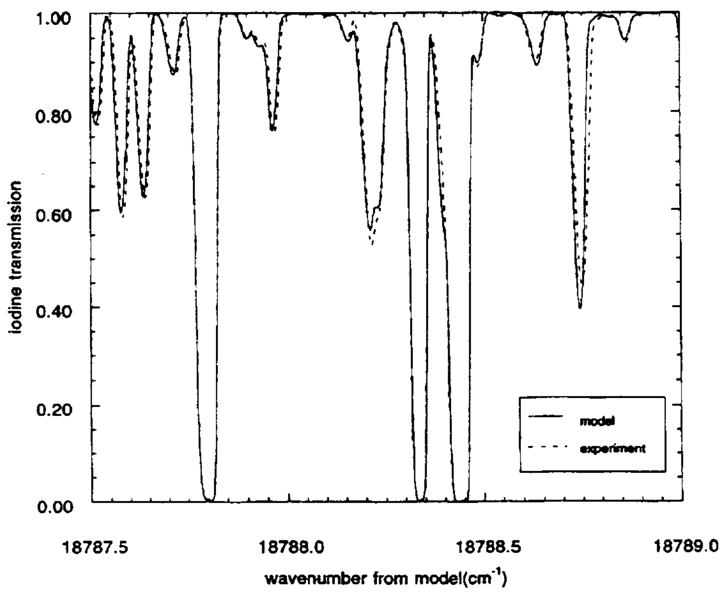
repeatability of transmission measurement



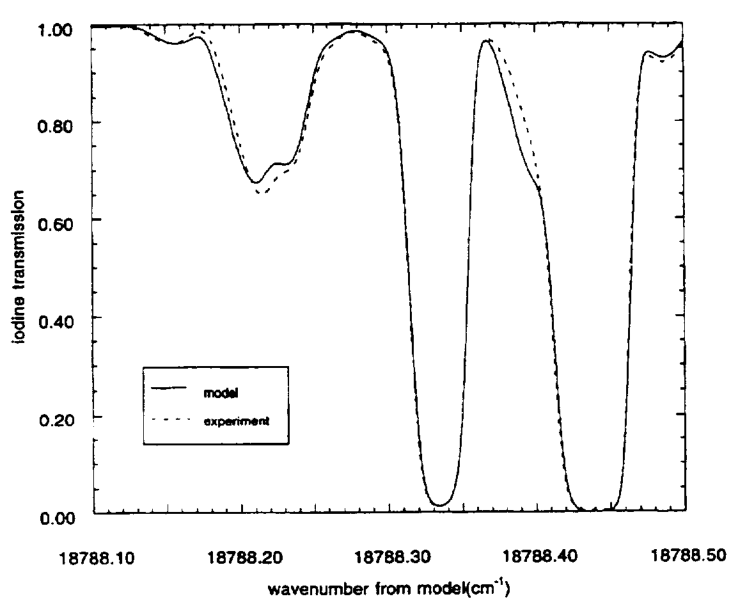
repeatability of frequency measurement



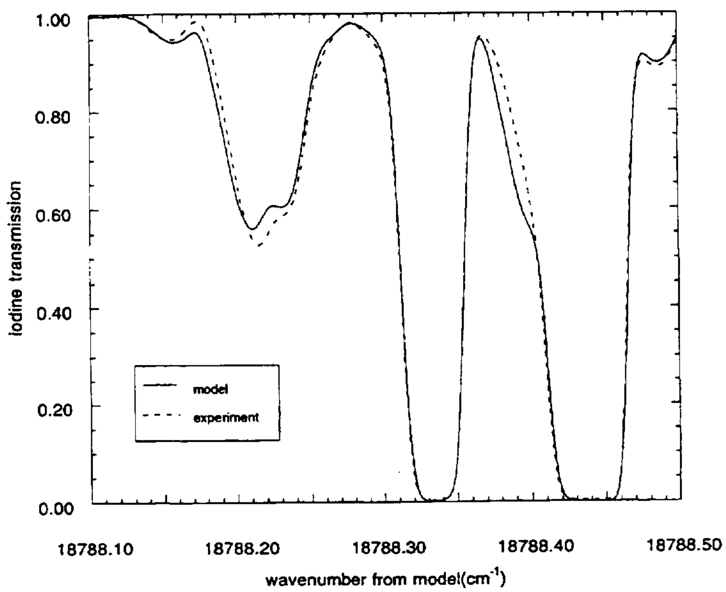
model versus data



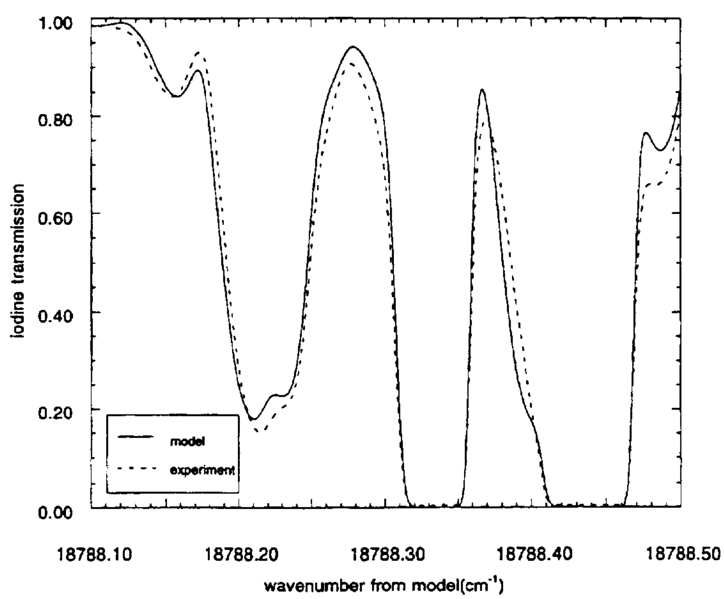
model versus data:
353 K, 0.7 torr, 10 cm



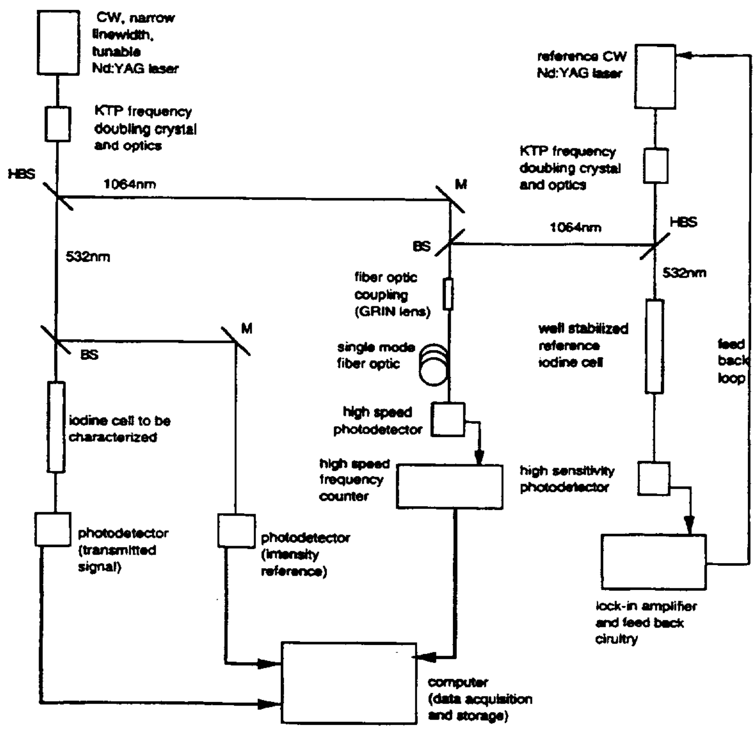
model versus data:
353 K, 1.0 torr, 10 cm



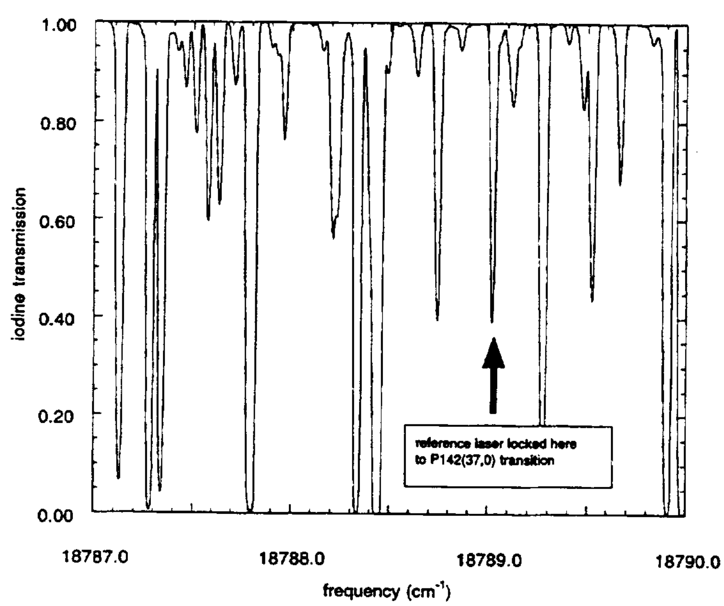
model versus data
353 K, 3.1 torr, 10 cm



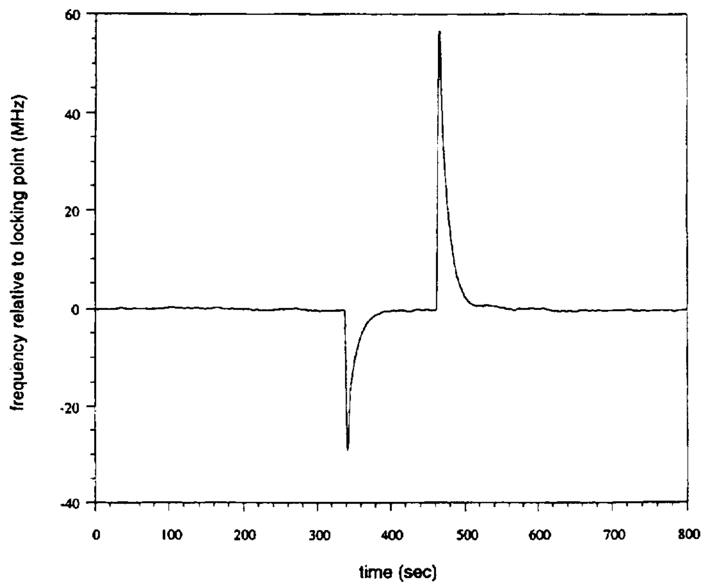
Accurate Characterization of Transmission Profile



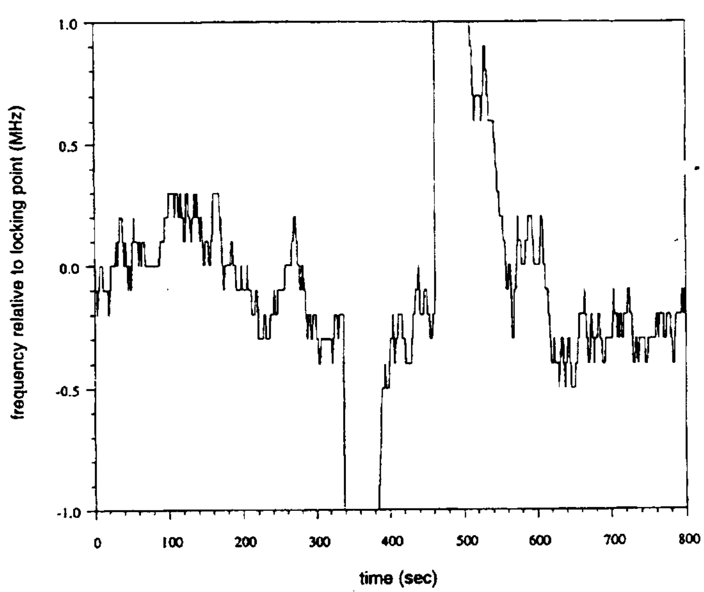
reference laser locking point



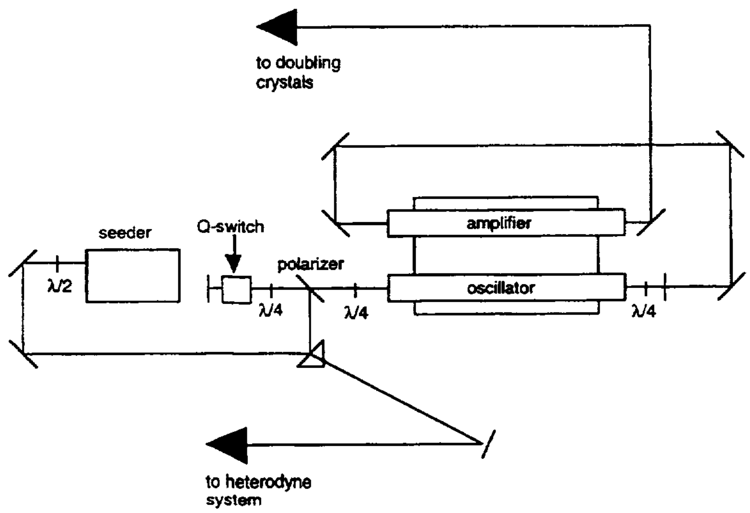
relocking of reference laser



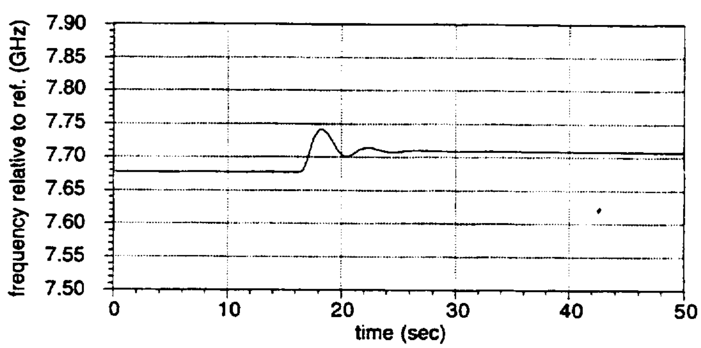
relocking of reference laser

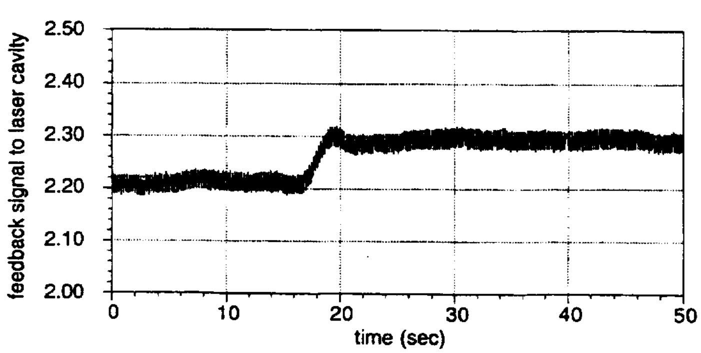


pulsed laser system

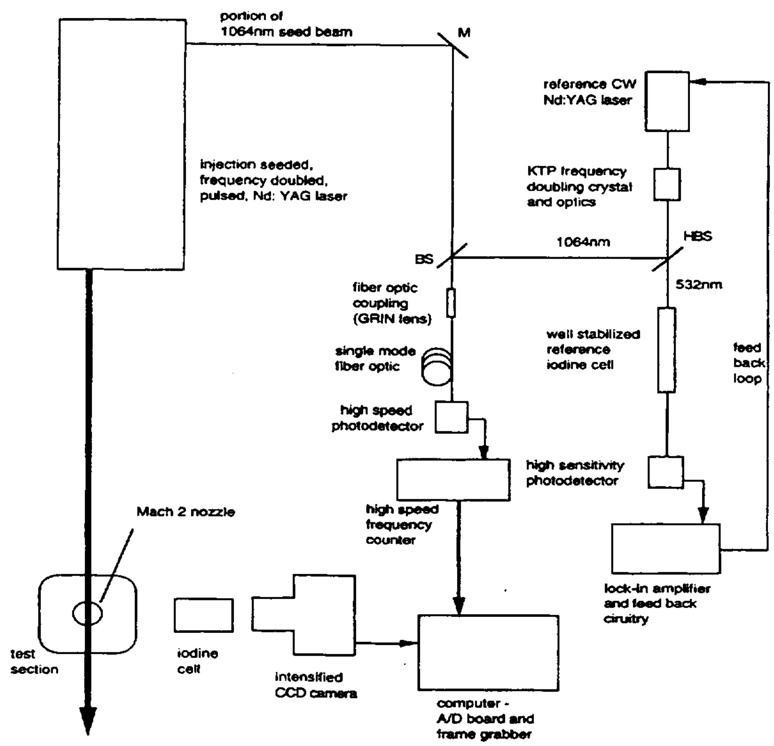


Characterization of Pulsed Laser Frequency

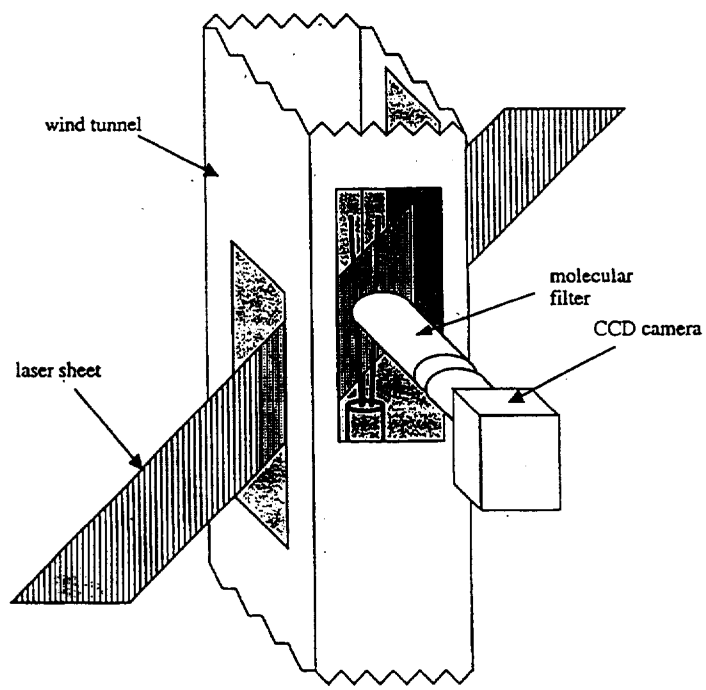




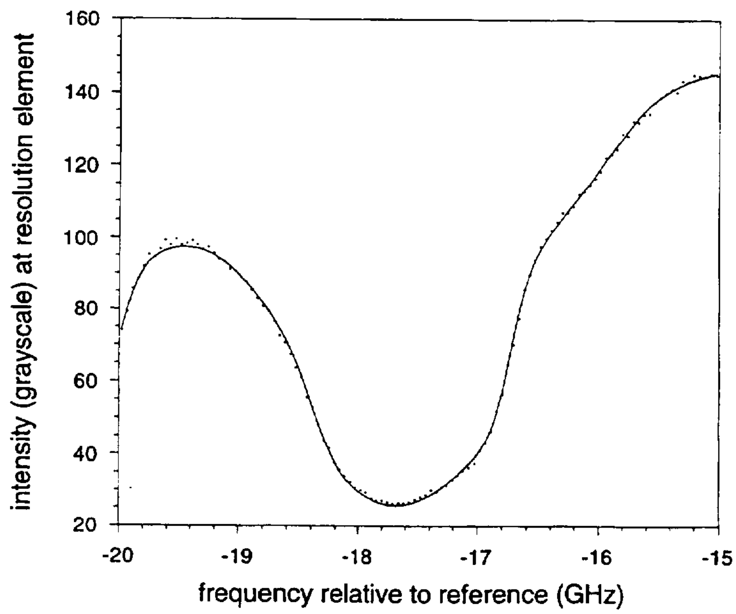
Experimental Setup



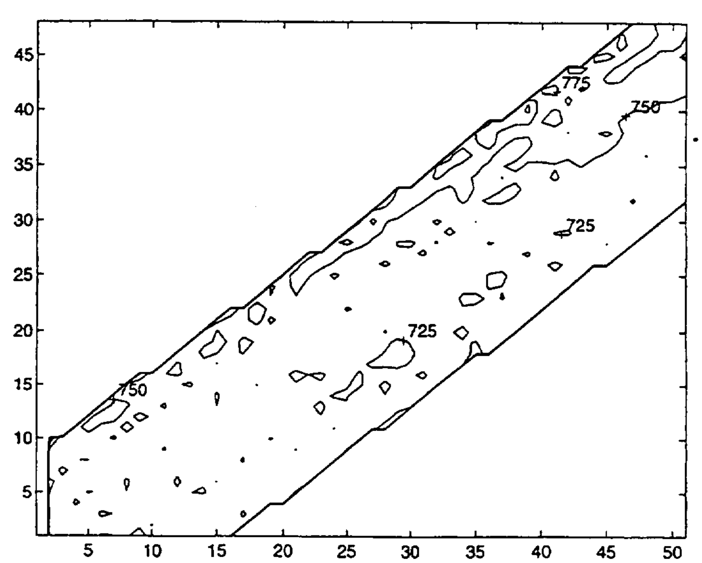
Experimental Geometry for Mach 2 Free Jet



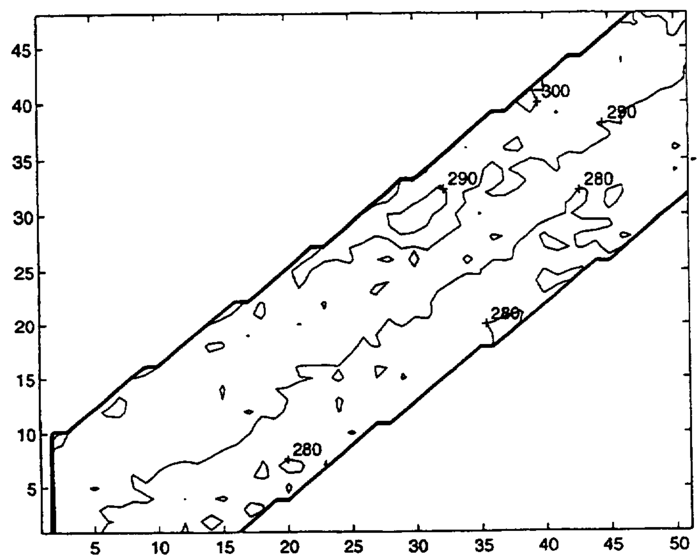
Fit to Data



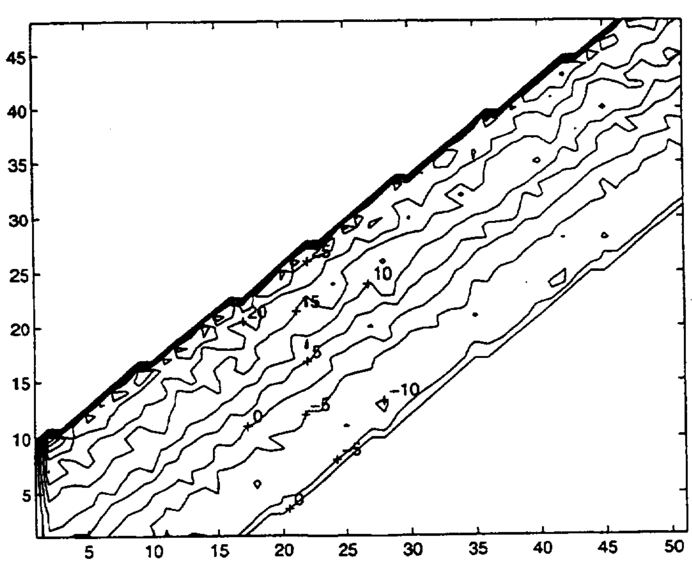
ambient air pressure (torr)



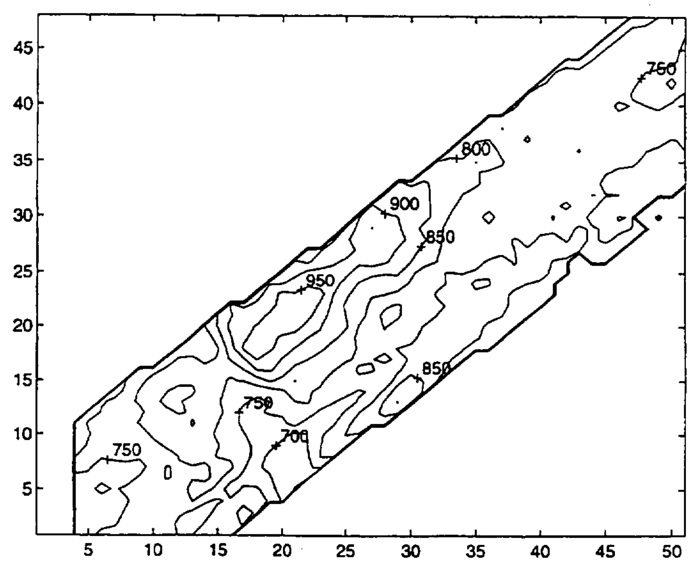
ambient air temperature (K)



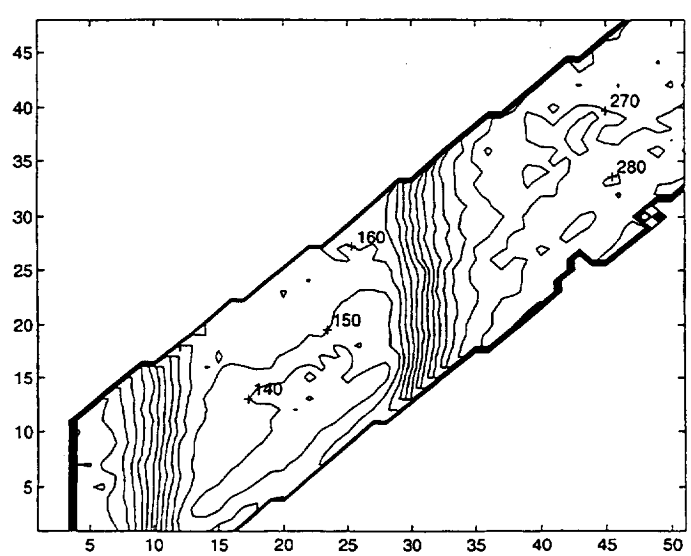
ambient air velocity (m/s)



mach 2 jet
static pressure (torr)



mach 2 jet
static temperature (K)



mach 2 jet velocity in direction of sensitivity (m/s)