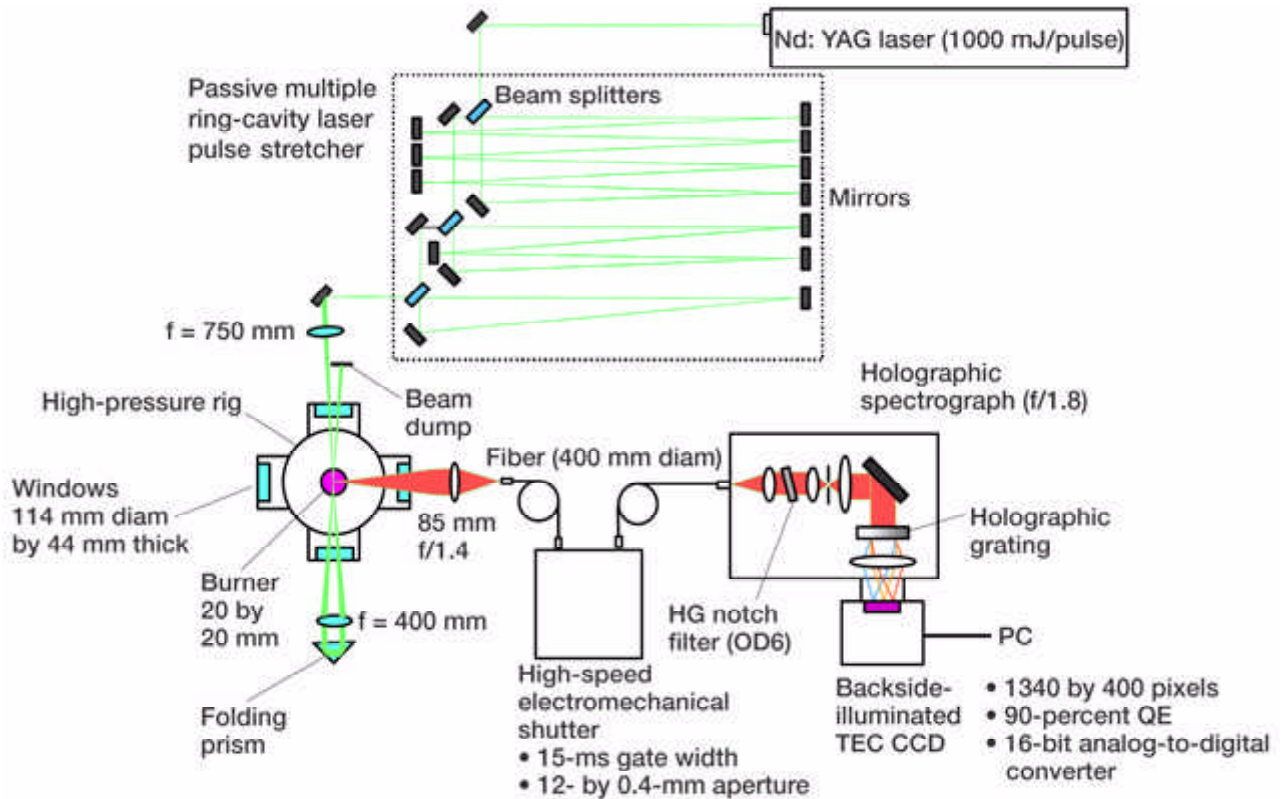
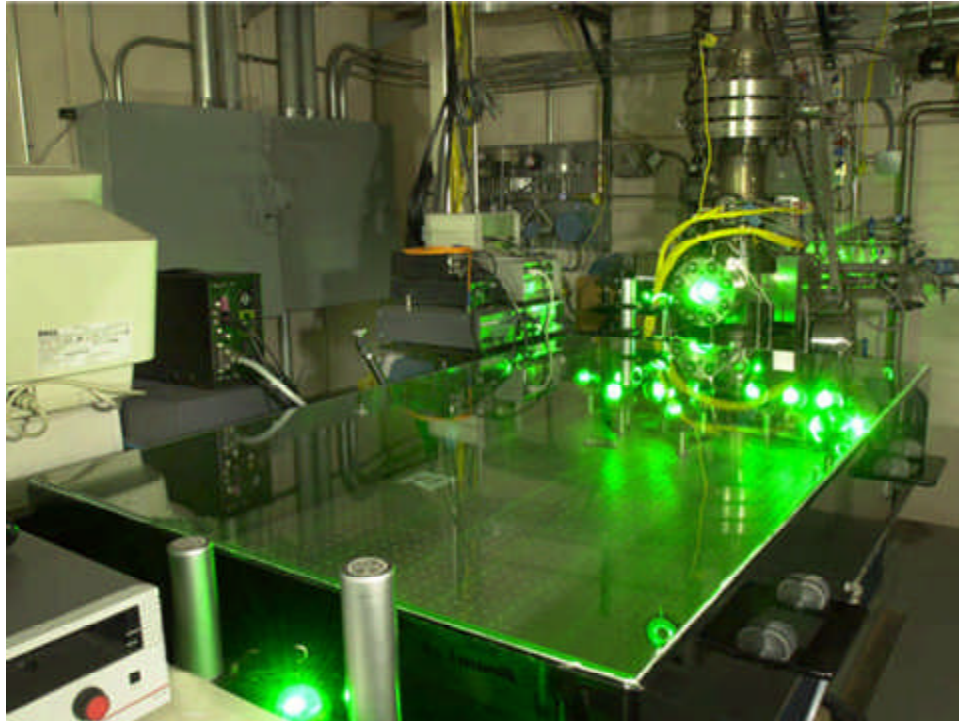


Spontaneous Raman Scattering (SRS) System for Calibrating High-Pressure Flames Became Operational

A high-performance spontaneous Raman scattering (SRS) system for measuring quantitative species concentration and temperature in high-pressure flames is now operational. The system is located in Glenn's Engine Research Building. Raman scattering is perhaps the only optical diagnostic technique that permits the simultaneous (single-shot) measurement of all major species (N_2 , O_2 , CO_2 , H_2O , CO , H_2 , and CH_4) as well as temperature in combustion systems. The preliminary data acquired with this new system in a 20-atm hydrogen-air (H_2 -air) flame show excellent spectral coverage, good resolution, and a signal-to-noise ratio high enough for the data to serve as a calibration standard. This new SRS diagnostic system is used in conjunction with the newly developed High-Pressure Gaseous Burner facility (ref. 1). The main purpose of this diagnostic system and the High-Pressure Gaseous Burner facility is to acquire and establish a comprehensive Raman-scattering spectral database calibration standard for the combustion diagnostic community. A secondary purpose of the system is to provide actual measurements in standardized flames to validate computational combustion models. The High-Pressure Gaseous Burner facility and its associated SRS system will provide researchers throughout the world with new insights into flame conditions that simulate the environment inside the ultra-high-pressure-ratio combustion chambers of tomorrow's advanced aircraft engines.



High-performance SRS system. The output of a frequency-doubled pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet) laser (532 nm) is temporally stretched using a passive three-cavity optical delay line. The stretched laser output (1000 mJ over 80 ns) is then focused into the measurement zone inside the high-pressure rig. The Raman-scattered light (signal) is collected perpendicular to the excitation laser beam and fiber-optically coupled into a high-speed electromechanical shutter system to reject background luminosity. The output of the shutter system is fiber-optically coupled to a high-speed holographic spectrograph fitted with a thermoelectrically cooled backside-illuminated charge-couple device (CCD) camera. The CCD camera images are processed by computer to yield the Raman-scattering spectrum. The spatial resolution of the probe volume is approximately 1.4 by 0.5 mm. (HG, holographic grating; OD6, optical density 6 (provides a 6-order magnitude attenuation in optical intensity); TEC, thermoelectrically cooled; QE, quantum efficiency (efficiency of detecting a single photon).)

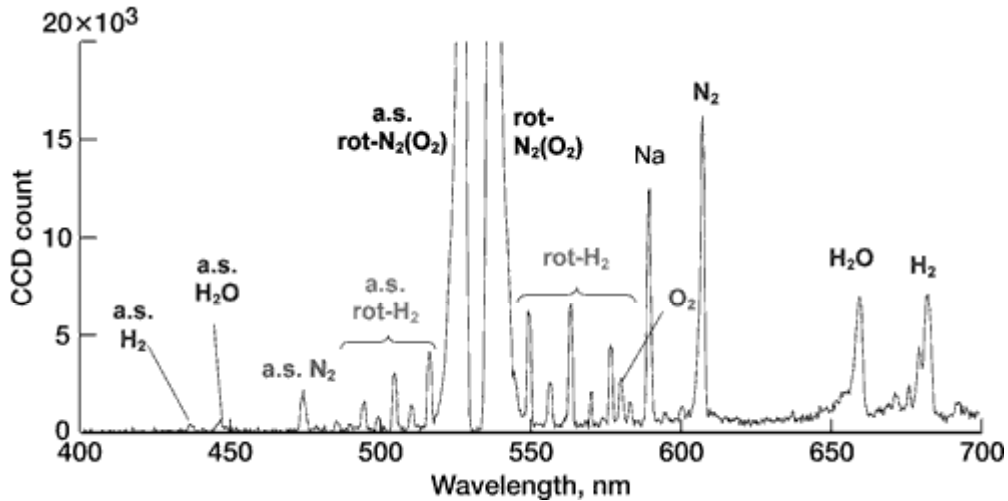


Photograph of the SRS diagnostic system in the High-Pressure Gaseous Burner facility. The bright green light scattered from the pulse stretcher mirrors is the 532-nm wavelength excitation laser light.

The schematic shows the SRS system, and the photograph shows the system in operation. The SRS system was designed in-house by Dr. Quang-Viet Nguyen of Glenn's Combustion Branch and built with the help of Dr. Jun Kojima (National Research Council Research Associate) and Raymond Lotenero (Akima Corp.). Many strategies and techniques are employed to maximize the weak Raman signal, including a high-pulse-energy (1000-mJ/pulse) laser, a pulse stretcher to avoid damaging the optical windows, a laser beam that is folded back through the probe volume to double the energy, high-speed optics and spectrograph to maximize collection efficiencies, and a custom-designed electromechanical shutter and backside-illuminated charge-coupled device (CCD) camera to achieve 90-percent quantum efficiency.

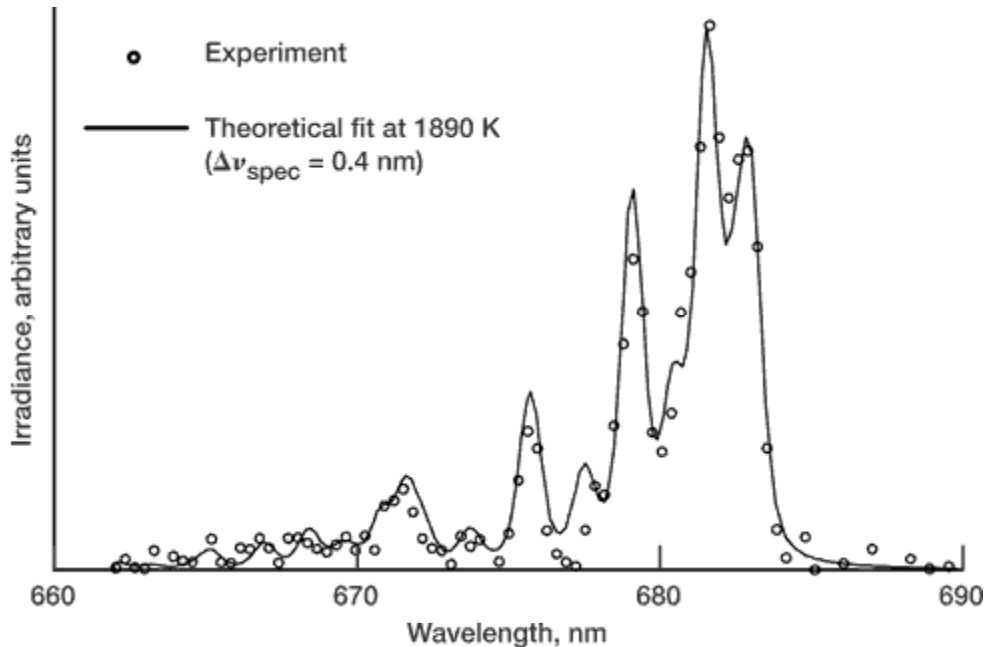
The following graph shows the SRS spectrum of a H_2 -air flame at a rig pressure of 20 atm and an equivalence ratio of 1.4. The two large features centered at 532 nm are the pure-rotational Raman features of nitrogen (N_2) and some oxygen (O_2). The spectral features to the left of the excitation wavelength (532 nm) are the anti-Stokes-shifted Raman-scattering signals, whereas the features to the right are the Stokes-shifted Raman-scattering signals. Both the shape of the spectral features and the ratio of Stokes to anti-Stokes signals permit temperature measurement with about 50-K accuracy. The amplitudes of the peaks enable major species concentration determination with about 2 mol% accuracy. Correlating the measured Raman signal response with chemical equilibrium predictions based on measured reactant flow rates allows one to map out a quantitative calibration of the SRS signals versus interferences. This process is repeated

for many different flame conditions, different flame reactants, and different pressures.



SRS spectrum of a H_2 -air flame at a rig pressure of 20 atm and an equivalence ratio of 1.4. The spectrum was averaged over 250 laser shots and collected at a low spectral resolution of 40 cm^{-1} . The entire visible spectrum from 400 to 700 nm can be captured in a single spectrum, enabling the simultaneous quantitative determination of species temperature and concentration (a.s., anti-Stokes; rot, rotational).

We have also developed a comprehensive theoretical Raman-scattering model for all the major species in hydrocarbon-air. As an example, the following figure shows a theoretically calculated vibration-rotation Raman spectrum of H_2 compared with experimental data. The data were obtained at a spectral resolution of 10 cm^{-1} in a 20-atm H_2 -air flame at an equivalence ratio of 1.4. The fitted temperature of 1890 K derived from the spectral shape is consistent with the temperature derived from both the pure-rotational spectrum of H_2 and the vibration-rotation spectrum of N_2 .



Comparison of a comprehensive theoretical model of Raman scattering that includes the effects of pressure broadening with the experimentally measured vibration-rotation Raman spectrum of H₂ at a pressure of 20 atm in a 20-atm H₂-air flame; Dn_{spec} , spectral resolution of the spectrograph.

Reference

1. Nguyen, Quang-Viet: High-Pressure Gaseous Burner (HPGB) Facility Became Operational. Research & Technology 2002, NASA/TM--2002-211990, 2003, pp. 116-117.

Find out more about the research of Glenn's Combustion Branch
<http://www.grc.nasa.gov/WWW/combustion/>.

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