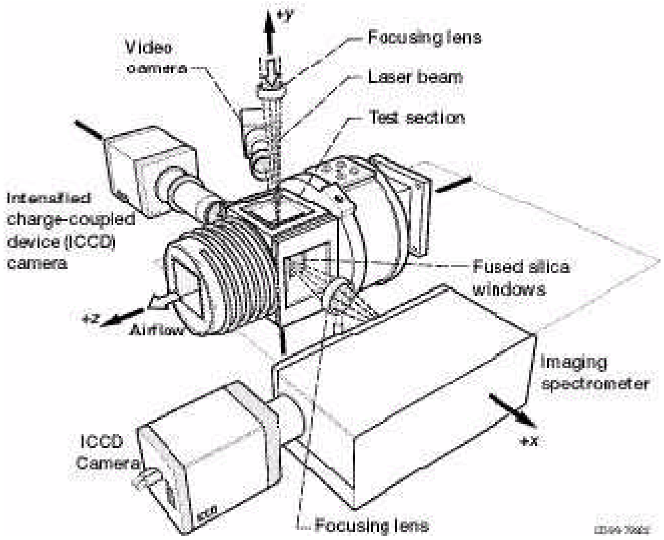
One-Dimensional Spontaneous Raman Measurements Made in a Gas Turbine Combustor

The NASA Glenn Research Center and the aerospace industry are designing and testing low-emission combustor concepts to build the next generation of cleaner, more fuel efficient aircraft powerplants. These combustors will operate at much higher inlet temperatures and at pressures that are up to 3 to 5 times greater than combustors in the current fleet. From a test and analysis viewpoint, there is an increasing need for measurements from these combustors that are nonintrusive, simultaneous, multipoint, and more quantitative. Glenn researchers have developed several unique test facilities (refs. 1 and 2) that allow, for the first time, optical interrogation of combustor flow fields, including subcomponent performance, at pressures ranging from 1 to 60 bar (1 to 60 atm).

Experiments conducted at Glenn are the first application of a visible laser-pumped, one-dimensional, spontaneous Raman-scattering technique to analyze the flow in a high-pressure, advanced-concept fuel injector at pressures thus far reaching 12 bar (12 atm). This technique offers a complementary method to the existing two- and three-dimensional imaging methods used, such as planar laser-induced fluorescence. Raman measurements benefit from the fact that the signal from each species is a linear function of its density, and the relative densities of all major species can be acquired simultaneously with good precision. The Raman method has the added potential to calibrate multidimensional measurements by providing an independent measurement of species number-densities at known points within the planar laser-induced fluorescence images. The visible Raman method is similar to an ultraviolet-Raman technique first tried in the same test facility (ref. 3). However, the visible method did not suffer from the ultraviolet technique's fuel-born polycyclic aromatic hydrocarbon fluorescence interferences.

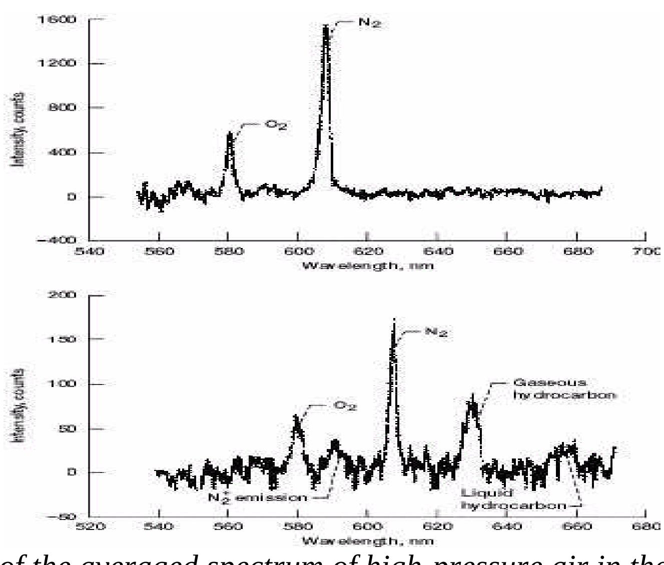


One-dimensional, visible Raman setup and the optically accessible combustor test *section.*

The preceding figure shows a schematic of the Raman diagnostic setup. The visible laser beam enters vertically through a window at the top of the combustor. Raman scattering is measured normal to both the incident laser beam and to the direction of its electric vector, the latter in order to maximize the Raman signal.

At the measurement location, Jet-A fuel is partially evaporated and generates a strong hydrocarbon signal in addition to nitrogen and oxygen signals. Single-shot and averaged spectra and images of the combustor speciation were obtained--with oxygen, nitrogen, gaseous, and liquid hydrocarbons clearly visible--with acceptable resolution over a wide range of engine cycle conditions.

The following figure shows a 200-shot average spectrum of air at a pressure of 12 bar and a temperature of 400 °F (top) and a 2600-shot average spectrum of air with injected fuel inside the combustor at 900 °F and 10 bar (bottom). The ratio of oxygen versus nitrogen peak height in the fuel-injected case is the same as for the pure air, which indicates that no reaction has taken place. A large number of peaks in addition to the oxygen and nitrogen lines seen in both cases are identified in the top figure as hydrocarbon fuel components and fragments. In addition, a broader peak appears in the top figure, slightly below the predicted location of water. This peak is substantially more pronounced at lower temperatures and is attributed to Raman scattering of liquid alcohol compounds (OH-vibration) in the fuel (ref. 4). Further applications and refinements of this technique to the harsh environment within advanced liquid-fueled, gas turbine combustors should lead to a better understanding of the physical and chemical processes of these combusting flow fields.



Top: Comparison of the averaged spectrum of high-pressure air in the combustor at 400 °F and 12 bar. Average over 200 single-shot spectra; spectrometer slit, 100 µm; laser energy, 47 mJ/pulse (output). Bottom: Comparison of the averaged spectrum of fuel injected in air at 900 °F and 10 bar. Spectrometer slit, 100 µm; average of 2606 laser pulses; laser energy, 50 mJ/pulse.

References

1. Locke, R.J., et al.: Optical Fuel Injector Patternation Measurements in Advanced Liquid Fueled, High Pressure, Gas Turbine Combustors. Combust. Sci. Technol., vol. 138, nos. 1-6, 1998, pp. 297-311.

2. Hicks, Yolanda R.; Locke, Randy J.; and Anderson, Robert C.: Optical Measurement and Visualization in High-Pressure, High-Temperature, Aviation Gas Turbine Combustors. NASA/TM--2000-210377, 2000. http://gltrs.grc.nasa.gov

3. Gu , Yongwei, et al.: 1-D, UV-Raman Imaging From a High-Pressure, Jet-A Fueled Gas Turbine Combustor. AIAA Paper 2000-0773, 2000.

4. Mewes, Bernd; Bauer, Gerd; and Brueggemann, Dieter: Fuel Vapor Measurements by Linear Raman Spectroscopy Using Spectral Discrimination From Droplet Interferences. Applied Optics, vol. 38, no. 6, Feb. 20, 1999.

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