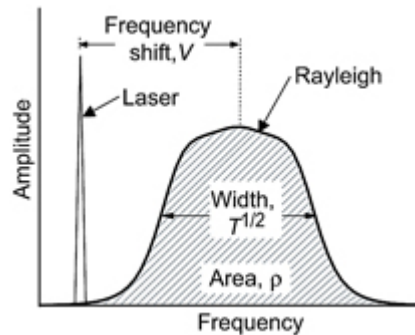


Molecular Rayleigh Scattering Techniques Developed for Measuring Gas Flow Velocity, Density, Temperature, and Turbulence

Nonintrusive optical point-wise measurement techniques utilizing the principles of molecular Rayleigh scattering have been developed at the NASA Glenn Research Center to obtain time-averaged information about gas velocity, density, temperature, and turbulence, or dynamic information about gas velocity and density in unseeded flows. These techniques enable measurements that are necessary for validating computational fluid dynamics (CFD) and computational aeroacoustic (CAA) codes. Dynamic measurements allow the calculation of power spectra for the various flow properties. This type of information is currently being used in jet noise studies, correlating sound pressure fluctuations with velocity and density fluctuations to determine noise sources in jets. These nonintrusive techniques are particularly useful in supersonic flows, where seeding the flow with particles is not an option, and where the environment is too harsh for hot-wire measurements.

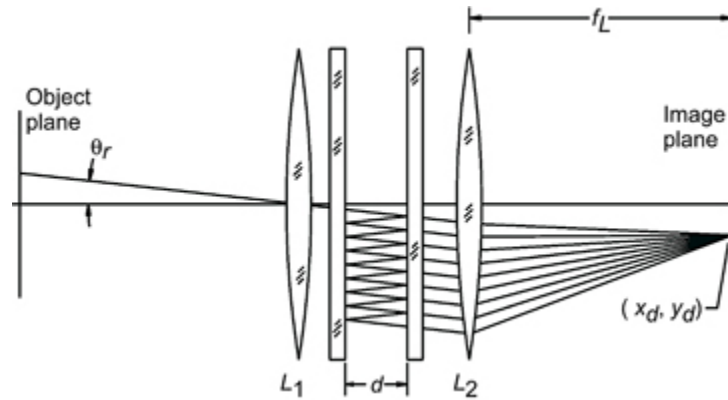


Rayleigh scattering spectrum.

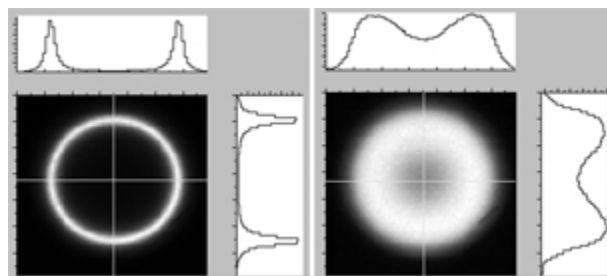
Molecular Rayleigh scattering is the result of elastic light scattering from gas molecules. When light from a single-frequency laser beam passes through a gas, the scattered light is shifted in frequency by the Doppler effect because of the bulk motion of the molecules. The optical frequency spectrum of Rayleigh scattered light contains information about the gas density, bulk velocity, and temperature. The preceding figure shows a Rayleigh scattering spectrum containing the narrow laser line and the broadened Rayleigh spectral peak. If the gas composition is known, the total intensity of the Rayleigh spectrum is directly proportional to the gas density. The frequency shift between the laser peak and the Rayleigh peak is proportional to the bulk flow velocity. The width of the Rayleigh spectrum is related to the gas temperature.

In both the time-averaged and dynamic measurement techniques, the spectra of the laser light and the Rayleigh scattered light are analyzed with a Fabry-Perot interferometer (see

the next figure) operated in the static imaging mode. The resulting circular fringe pattern contains spectral information about the light. The final figure shows sample fringe patterns for narrow-line-width laser light (left), and Rayleigh scattered light (right). The Rayleigh fringe is thermally broadened and shifted radially from the laser fringe by an amount proportional to the gas velocity.



Fabry-Perot interferometer.



Right: Sample fringe patterns. Left: Narrow-line-width laser light. Right: Rayleigh scattered light.

For time-averaged measurements, the resulting fringe pattern is recorded with a low-noise charge-coupled device (CCD) camera. Nonlinear least-squares analysis of the fringe pattern using a kinetic theory model of the Rayleigh scattered light provides estimates of the velocity, density, temperature, and turbulence of the gas flow averaged over the integration time of the camera.

For dynamic measurements, the camera system is replaced by a detection system consisting of three photomultiplier tubes (PMTs) operated in the photon-counting mode and sampled at rates up to 100 kHz. One PMT measures the total intensity of the collected scattered light to provide dynamic density information. A set of concentric mirrors is used to split the fringe pattern generated from the Rayleigh scattered light passing through the Fabry-Perot interferometer into inner and outer regions. The intensity of the light in the inner and outer regions of the fringe is monitored with the other two PMTs. The ratio of the intensities provides a measure of the flow velocity since the ratio changes as the fringe diameter increases or decreases. We are planning to extend the dynamic technique to allow for temperature measurement by increasing the spatial sampling resolution so that information about the width of the spectrum is available.

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Find out more about this research at <http://www.grc.nasa.gov/WWW/OptInstr/>

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