RAYLEIGH SCATTERING MEASUREMENTS IN NASA LEWIS WIND TUNNELS

Richard Seasholtz
NASA Lewis Research Center
Cleveland, Ohio

ABSTRACT

Two applications of Rayleigh scattering for measurement of flow parameters in wind tunnels are described. The first is the measurement of one velocity component and static temperature in the vicinity of a 12 % scale ASTOVL aircraft model in the Lewis 9 ft by 15 ft low speed wind tunnel[1]. The model was equipped with high temperature and high pressure air supplies to simulate lift nozzles and suctions systems to simulate engine inlets. Light from a single frequency argon-ion laser was transmitted through a 140 m long multimode optical fiber to the test section and focused to a 1 mm x 4 mm probe volume coincident with a two-color LDV system probe volume. Data were obtained in two phases. In the first phase, measurements were made primarily to obtain gas temperature in the vicinity of the model. No seeding was used and LDV measurements were not taken. In the second phase, PSL seeding was used and Rayleigh data were obtained simultaneously with the LDV data. The Rayleigh measurements gave spanwise velocity and temperature. For these measurements, the nozzles were operated at less than their design temperature to avoid destroying the PSL seed. A significant observation was that the Rayleigh scattering measurements could be obtained even with the flow being seeded for the LDV measurements. This was possible because the spectral width of the Mie scattering was much narrower that the thermally broadened molecular Rayleigh scattered light. The estimated accuracy of the Rayleigh measurements was 10 m/s for velocity and 5 % for temperature.

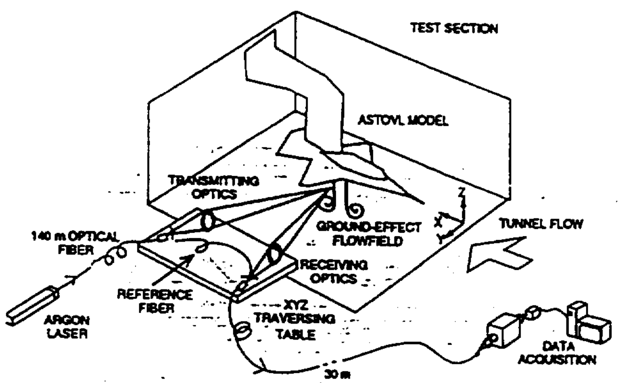
The second application is feasibility study to measure flow properties in a 4 inch by 10 inch supersonic wind tunnel[2]. This technique uses an injection seeded, frequency doubled Nd:YAG laser tuned to an absorption band of iodine. The laser beam was transmitted through a window in the tunnel roof and directed upstream by a mirror located near the second throat. Rayleigh scattered light was collected through a window in the side wall and filtered with an iodine cell to block light at the laser frequency. The Doppler-shifted Rayleigh scattered light that passed through the iodine cell was analyzed with a planar mirror Fabry-Perot interferometer used in a static imaging mode. An intensified CCD camera was used to record the images. The images were analyzed at several subregions, where the flow velocity was determined. Each image was obtained with a single laser pulse, giving instantaneous measurements. For proper modeling of the iodine filter transmission, it was necessary to measure the YAG laser frequency simultaneously with the measurement of the Rayleigh scattered light. This was done using a frequency stabilized helium neon laser as a reference. Problems in maintaining beam pointing direction and Fabry-Perot interferometer alignment were caused by the high acoustic noise levels in the test cell at higher mass flow rates. The velocity accuracy for single pulse measurements was estimated to be about 10 %, although some of this variation may have been due to flow fluctuations.

1. H.E. Kourous and R.G. Seasholtz, "Fabry-Perot interferometer measurement of static temperature and velocity for ASTOVL model tests", *Laser Anemometry 1994, Advances and Applications*, ASME FED-Vol. 191, pp. 65-70.

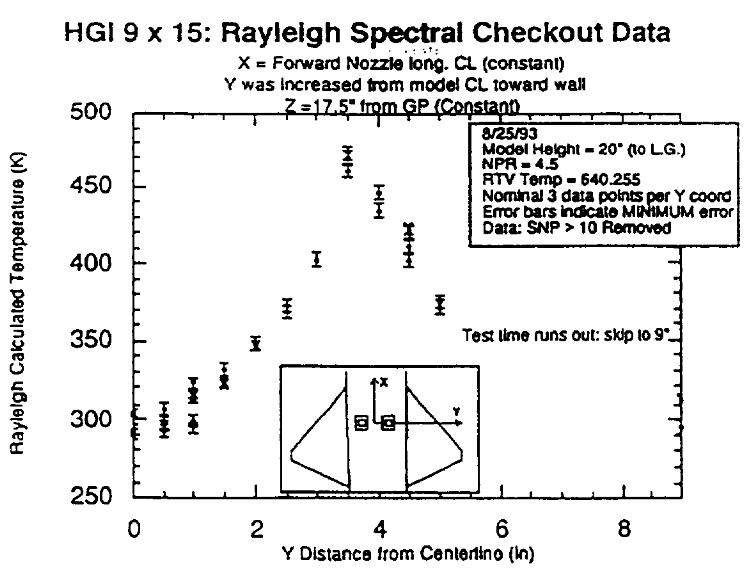
2. R.G. Seasholtz, A.E. Buggele, and M.F. Reeder, "Instantaneous flow measurements in a supersonic wind tunnel using spectrally resolved Rayleigh scattering", *SPIE Proceedings on Optical Techniques in Fluid, Thermal, and Combustion Flow*, vol. 2546, 1995.

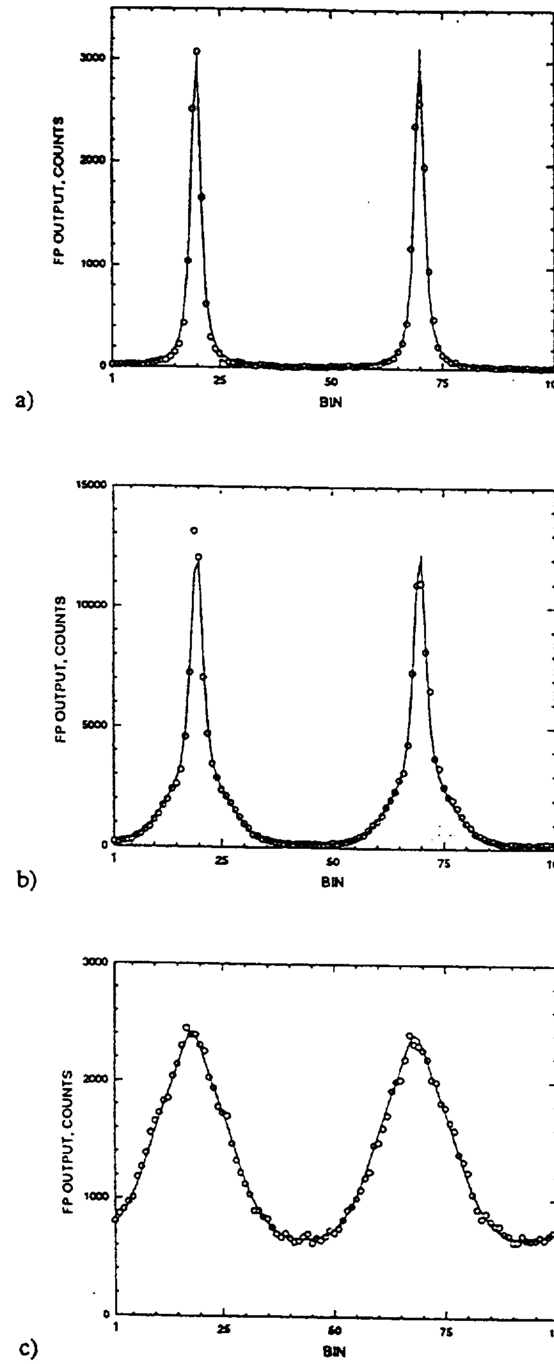
9 FT BY 15 FT LOW SPEED WIND TUNNEL

- Temperature and velocity measurements for ASTOVL HGI Study
- Scanning Fabry-Perot interferometer (time average measurements)
- Used with LDV to get 3 velocity components and temperature
- Long working distance (2.2 m)
- High particle loading in measurement volume (both ambient and seeded flow)
- Stray laser light not a problem
- Argon-ion laser (488/476 nm) coupled through long multimode fiber (140 m
- Scattered light transmitted by optical fiber to "quiet" room containing Fabry-Perot
- Estimated accuracy was 10 m/sec for measured velocity component and 5 % for temperature



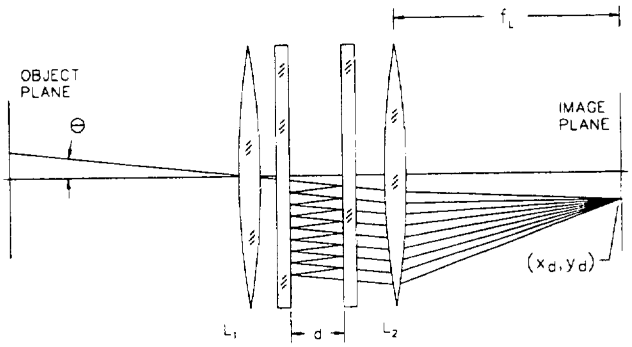
Optical configuration schematic showing wind tunnel test section, scale aircraft model, source laser, optical fibers, reference fiber, traversing table, Fabry-Perot interferometer, and data acquisition system.

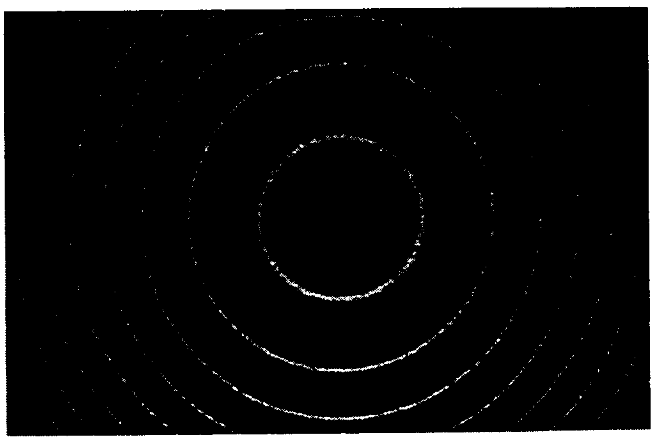




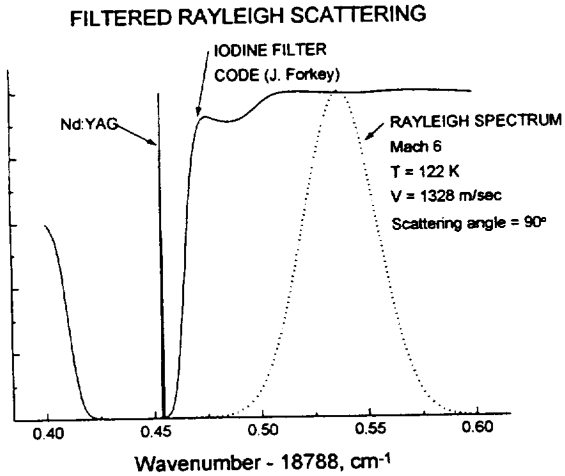
Spectra acquired by the Fabry-Perot interferometer: a) measured instrument function; (b) a Mie-dominated seeded-flow spectrum; and (c) a high temperature Rayleigh-dominated spectrum in unseeded flow.

Fabry-Perot interferometer





FILTERED RAYLEIGH SCATTERING

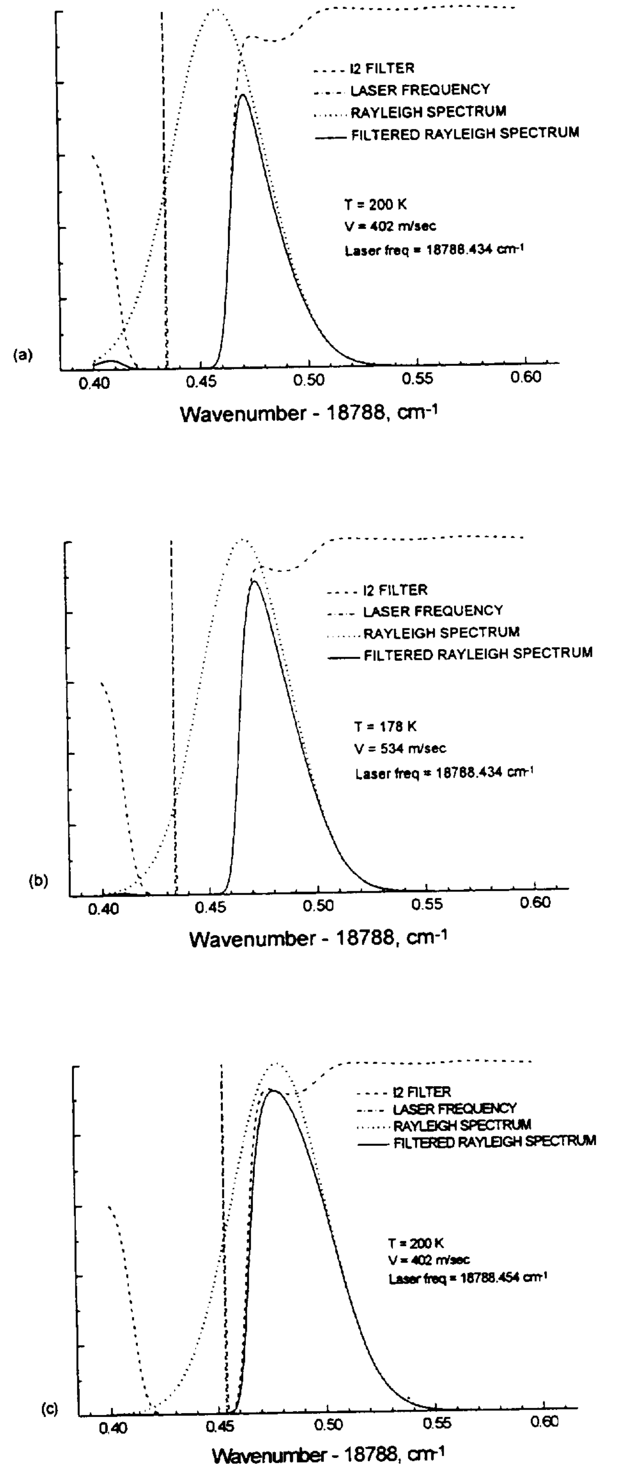


MODEL FUNCTION FOR FILTERED RAYLEIGH SCATTERING

$$< N_{D_q} > = \int_{\Omega}\int_{\Delta A}\int_{-\infty}^{\infty} [A_R S_R(f,\Omega) + A_W \delta(f-f_o)] I_{FP}(f,\theta_r)\, I_{I2}(f)\, df\, dA\, d\Omega + B_q$$

A_R - Rayleigh intensity
S_R - Rayleigh spectrum
I_{FP} - Fabry-Perot instrument function
I_{I2} - iodine filter transmission function
A_W - stray laser light intensity
B_q - broadband noise

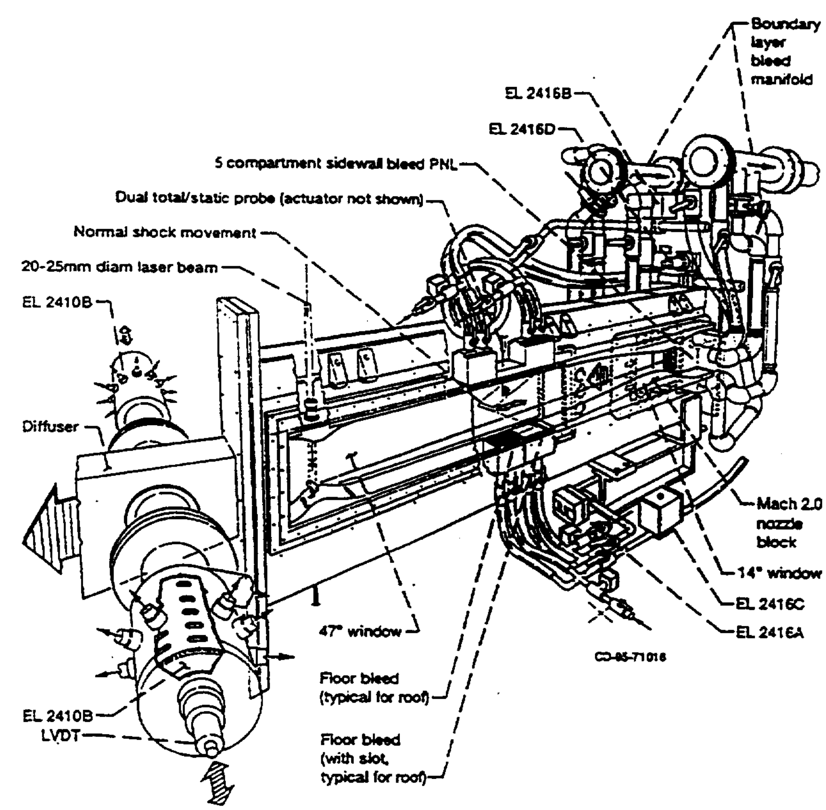
Integration is over frequency, pixel area, and collection angle



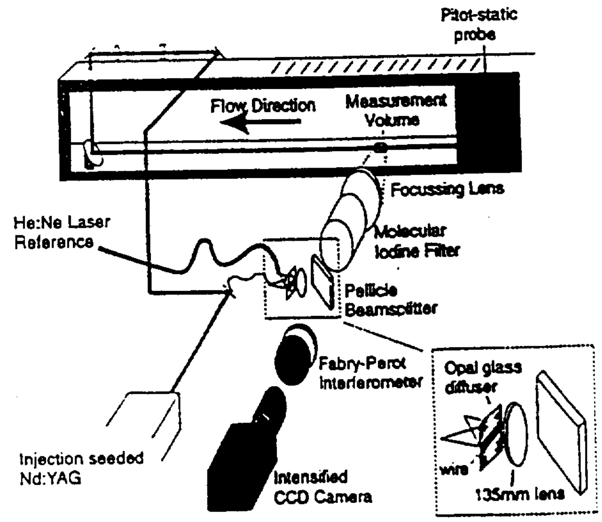
(a-b) Filtered Rayleigh scattering spectra for two flow conditions with the laser frequency equal 18788.434 cm^{-1} ; (c) spectrum for same flow condition as (a) with a laser frequency of 18788.454 cm^{-1}

4 INCH BY 10 INCH SUPERSONIC WIND TUNNEL (DUCT LAB)

- Instantaneous multipoint velocity measurements at about Mach 1.5
- Injected-seeded Nd:YAG laser (532 nm)
- Fabry-Perot used in static, imaging mode
- Few particles in flow (air filtered)
- Large amount of stray laser light
- Used iodine absorption cell
- Problems with vibration of Fabry-Perot at higher mass flow rates
- Assumption of adiabatic flow is used in data reduction, so independent temperature measurement was not obtained
- Estimated accuracy was 10 %

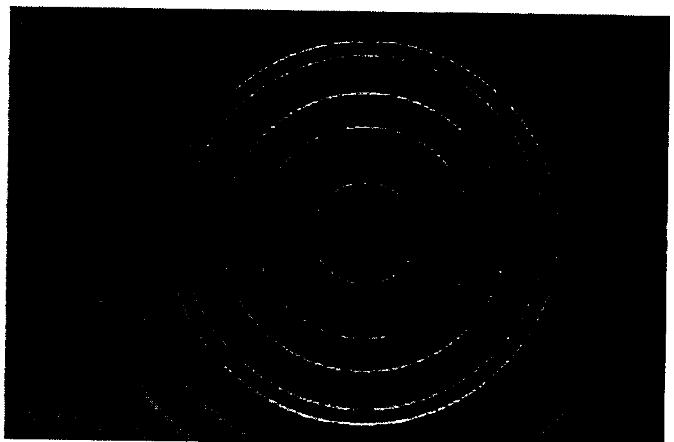


Supersonic Wind Tunnel (SWT) with shock shape position controls.

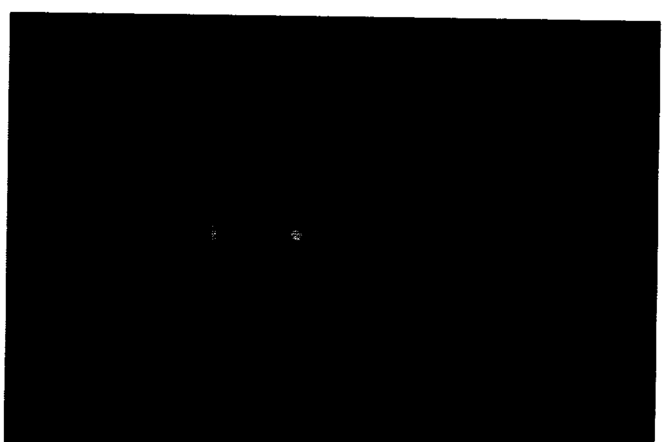


Optical arrangement for the Rayleigh scattering measurements.

(a)

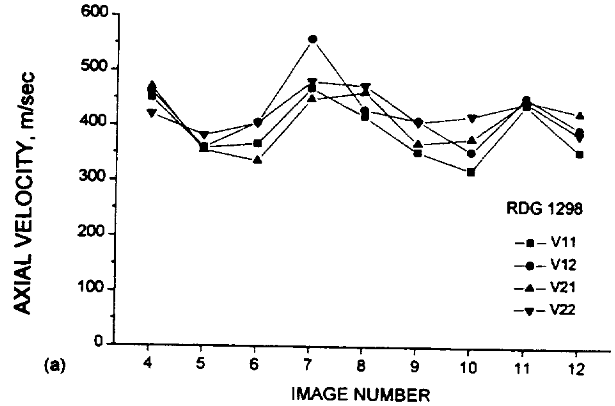


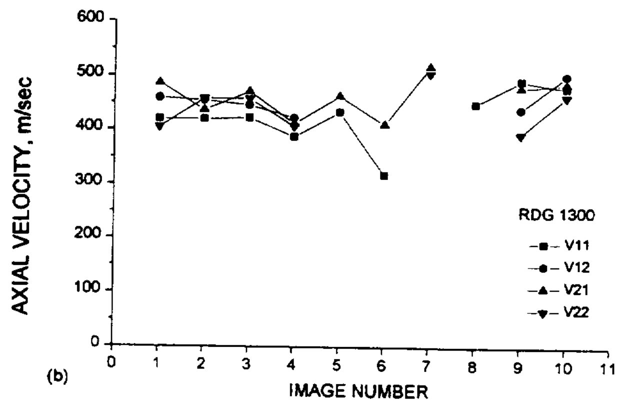
(b)



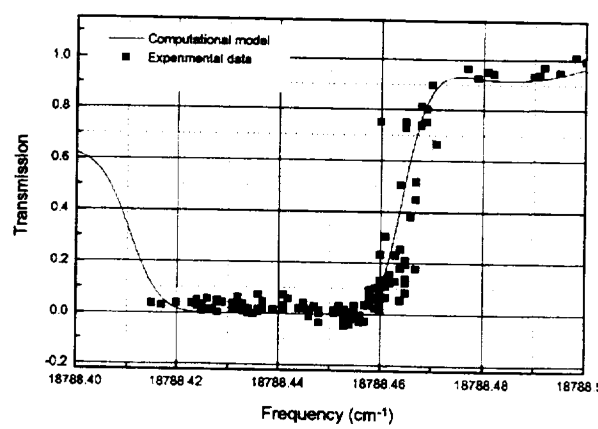
(c)

(a) Image showing Nd:YAG and HeNe reference fringes in upper and lower parts with Rayleigh scattered light in center; (b) image showing fit to Nd:YAG and HeNe reference fringes; (c) fit to model function for four subregions.





Axial velocity for number of images for two flow condition: (a) RDG 1298 (b) RDG 1300. Each image is from single laser pulse with velocity determimed for four subregions; gaps are result of lack of convergence for certain subregions.



Transmission of Nd:YAG light through iodine cell