charge-coupled device (CCD) detector. The resulting digitized interference fringe pattern is then analyzed by dedicated software to determine the angular misalignment between the two laser beams (and, hence, the misalignment between the cubes) at the sub-arcsecond level. If a null fringe pattern were achieved, it could be concluded that the laser beam points anti-parallel to the surface normal of the test cube. Knowledge of the distance from null (via the angular misalignment seen in the interference pattern) coupled with readings from azimuth and elevation encoders calibrated to the laser-pointing direction then gives the orientation of the cube surface normal vector in two (angular) dimensions. This is the same information as would be given by a theodolite aligned to the test cube, albeit with greater accuracy.

This system offers several advantages. The parts used in the prototype unit were off-the-shelf and relatively inexpensive. Whereas the uncertainty of a typical theodolite measurement is 1 to 2 arcseconds, the current theoferometer prototype has a demonstrated uncertainty of about 0.3 arcsecond. Moreover, the theoferometer makes it possible to completely automate the data-taking process, reducing the time required to take measurements. The net result is better metrology at lower cost, relative to metrology by use of an autocollimating theodolite.

This work was done by Ronald W. Toland and Douglas B. Leviton of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1). GSC-14753-1*

Rayleigh Scattering for Measuring Flow in a Nozzle Testing Facility

The facility can test nozzles up to 8.75-in. (22.2-cm) in diameter.

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A molecular Rayleigh-scattering-based air-density measurement system was built in a large nozzle-and-engine-component test facility for surveying supersonic plumes from jet-engine exhaust. The facility (see Figure 1) can test nozzles up to 8.75 in. (22.2-cm) in diameter. It is enclosed in a 7.5-ft (2.3-m) diameter tank where ambient pressure is adjusted to simulate engine operation up to an altitude of 48,000 ft (14,630 m). The measurement technique depends on the light scattering by gas molecules present in the air; no artificial seeding is required. Commercially available particle-based techniques, such as laser Doppler velocimetry and particle image velocimetry, were avoided for such reasons as requirement of extremely large volume of seed particles; undesirable coating of every flow passages, model, and test windows with seed particles; and measurement errors from seed particles not following the flow. The molecular Rayleigh-scattering-based technique avoids all of these problems; however, a different set of obstacles associated with cleaning of dust particles, avoidance of stray light, and protection of the optical components from the facility vibration need to be addressed.

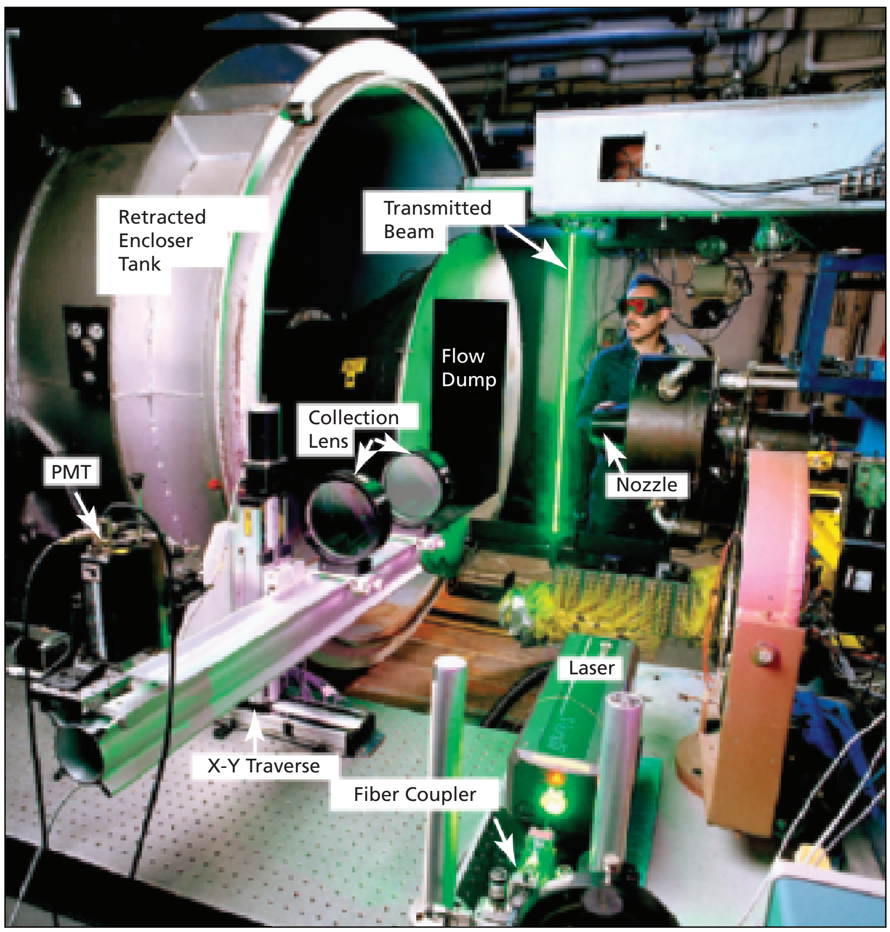

Fig. 1. The **Optical Arrangement** is shown with the enclosing tank retracted downstream.

To avoid a problem with facility vibration, light from a single-mode continuous-wave laser was transmitted into the vacuum tank by the use of an optical fiber. It was then collimated and passed through the plume. Rayleigh-scattered light from various points along the collimated beam was collected by a set of collection lenses placed outside the vacuum tank and measured by a photomultiplier tube (PMT). Large glass windows on the tank provided optical access. The collimator for the transmitted beam and the light-collection optics were placed on two synchronized traversing units to enable a survey over a cross-section of the nozzle plume. Although the technique is suitable to measure velocity, temperature, and density, in this

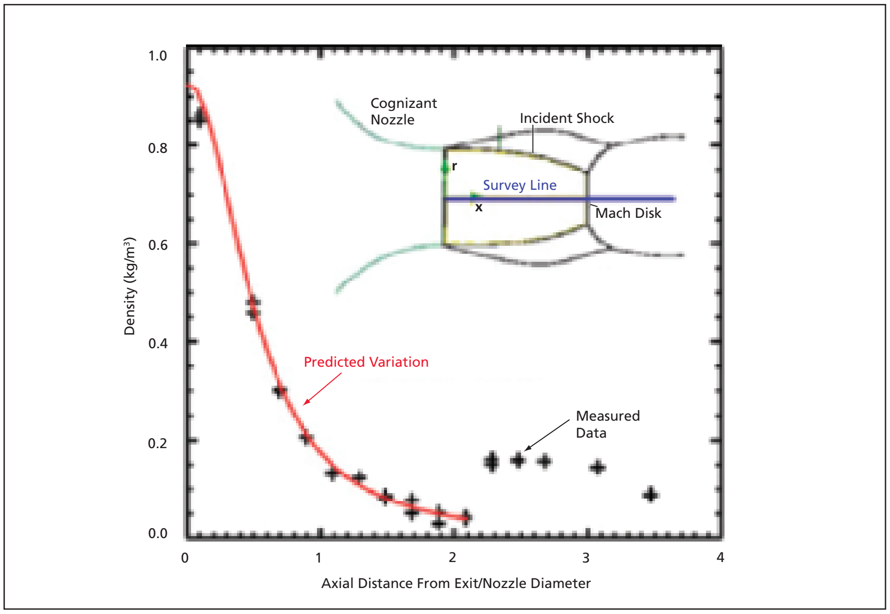

Fig. 2. **Density Variation** is shown along the centerline of a 5.06-in. (12.9-cm) diameter, nozzle-pressure-ratio 10, supersonic jet from a convergent nozzle.

first entry only air density was measured by monitoring intensity of the scattered light. Excellent comparison between theoretically predicted variation and the measured data along the centerline of a highly underexpanded supersonic jet provided validation to the measurement technique (see Figure 2).

This work was done by Carlos R. Gomez of **Glenn Research Center** *and Jayanta Panda of the Ohio Aerospace Institute. Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to:

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Refer to LEW-17627-1.