Remote Sensing of CF_4 Number Density in a Hypersonic Flow Using Raman Scattering

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Theme

THE Raman scattering technique has been investigated for the remote measurement of local static gas number density and temperature in Langley's pilot model CF_4 tunnel. Laboratory results show that the intensity of the ν_1 normal vibrational mode of CF_4 is proportional to gas number density and can be used for the gas density measurements. Based on these experimental results a Raman system was designed and assembled for the CF_4 facility, and used to make measurements of local static gas number density. Measurements were made both through the shock region of a hemispherical model to determine normal-shock density ratio and across the freestream to provide a density profile of the test core. The tunnel was operated at a stagnation pressure of 1.55×10^7 N/m^2 and a stagnation temperature of 654°K at a Mach number of 6.4.

A temperature measurement technique using the ν_2 normal vibrational mode of CF_4 was verified in the laboratory from 300°K to 1000°K, but the Raman signal at freestream conditions was too small for a facility measurement of static temperature.

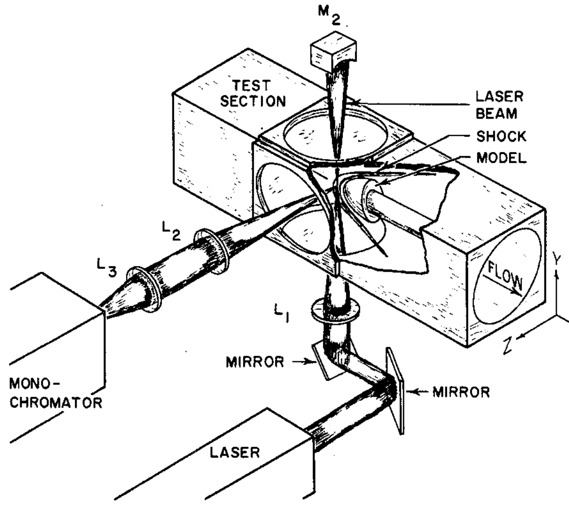

Fig. 1 Tunnel setup for measurements about a hemispherical model.

Content

The CF_4 facility[1] was designed to simulate forebody flowfields of very blunt configurations by matching the high normal-shock density ratios (without dissociation) which exist in hypersonic flight. In the past this density ratio, which is a critical simulation parameter, has been determined empirically by relating it to shock-standoff distance measurements taken from shadowgraphs. The Raman technique offers the potential for a direct, but remote, measurement of this ratio by providing the absolute values of gas number density in the freestream and behind the shock.

The Raman effect has been discussed by many authors.[2,3] Basically it is an inelastic scattering process in which the frequencies of the scattered radiation (the Raman bands) depend solely on the scattering species which are present and the frequency of the exciting radiation. In this experiment, the 20,492 cm^{-1} line of an argon laser was the exciting frequency, and the observed scattered frequencies were the characteristic modes of CF_4, ν_1 and ν_2. Figure 1 is a schematic of the Raman measurement system used at the CF_4 tunnel. The laser radiation is focused in the test section (7.6 cm in diameter) by lens L_1, and reflected back through the test section by the concave mirror, M_2. The Raman scattered radiation is collected by lens L_2, and imaged at the monochromator slit by lens L_3. The monochromator is set at the frequency of the ν_1 mode (19,584 cm^{-1}), and the intensity of this scattered radiation is detected by a photomultiplier and monitored with a digital photon counting system.

With the hemispherical model removed (Fig. 1), density measurements across the freestream (in the z direction) were made and Fig. 2 shows this freestream density profile. The profile

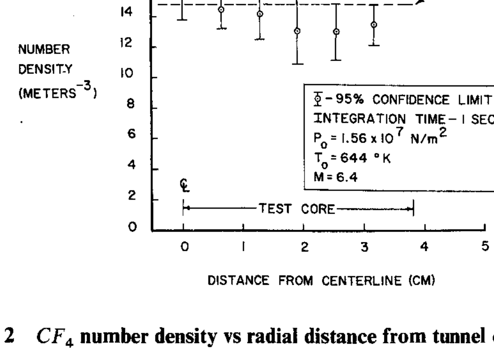

Fig. 2 CF_4 number density vs radial distance from tunnel centerline.

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Index categories: Research Facilities and Instrumentation; Supersonic and Hypersonic Flow.

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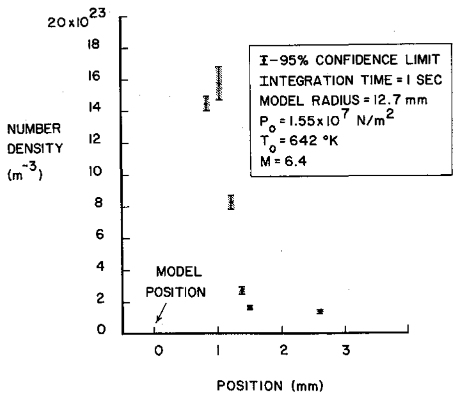

Fig. 3 CF_4 **number density vs upstream distance from a hemispherical model.**

indicates that a maximum value in gas density occurs at the tunnel centerline and a gradual decrease in gas density exists from the centerline through the test core. The calculated number density at the centerline is $1.48 \times 10^{23} m^{-3}$ which compares well with the average measured test-core value $1.40 \times 10^{23} \pm 0.23 \times 10^{23} m^{-3}$ (95% confidence level). For measurements of normal-shock density ratio, the hemispherical model (12.7 mm in radius) was used and gas density was measured in the x direction upstream of the model (Fig. 1). The region observed was centered on the centerline of the model and perpendicular to the flow direction and provided a resolution in shock position of 9.2×10^{-2} mm along the flow direction x. Figure 3 shows the measured number density variation from the nose of the model to 3-mm upstream of the model with the symbol width denoting the resolution in shock position. Based on the maximum and minimum number density values, the measured density ratio is 11.4 ± 1.6 (95% confidence level) which compares well with the calculated value, 12.

This study has shown that the Raman technique can be used to remotely measure the local static gas number density in the Langley pilot model CF_4 tunnel. One-second measurements of freestream gas density can be made repeatedly with less than a $\pm 15\%$ error and, by monitoring number density, shock-position and density ratio can be measured.

References

[1] Jones, R. A. and Hunt J. L., "Use of Tetrafluoromethane to Simulate Real-Gas Effects on the Hypersonic Aerodynamics of Blunt Vehicles," TR R-312, June 1969, NASA.

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[3] Salzman, J. A., Masica, W. J., and Coney, T. A., "Determination of Gas Temperatures From Laser-Raman Scattering," TN D-6336, May 1971, NASA.