SYNOPTIC: Effects of Flow Unsteadiness on Hypersonic Wind-Tunnel Spectroscopic Diagnostics,

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AIAA Journal, Vol. 8, No. 8, pp. 1478–1482.

Research Facilities and Instrumentation; Supersonic and Hypersonic Flow

Theme

A theoretical analysis is presented which permits proper accounting for time varying flow properties when interpreting conventional (i.e., time unresolved) spectroscopic measurements obtained in a wind tunnel. Nonlinear dependence of emission intensity on time varying flow temperature is shown to result in a nonlinear Boltzmann plot. A second-degree curve fitting procedure then yields, directly, the average and mean square temperature. Extension is made to show effects of rotational and vibrational temperature fluctuations on number density calculations.

Content

A generalized representation for the ratio of two measured spectral line intensities derived from a common spectrum takes the form

$$R = \exp \Delta E/kT \tag{1}$$

where ΔE is an incremental energy level separating the lines; k, Boltzmanns constant and T the appropriate temperature which may, in general, be time dependent. A Taylor's series expansion of Eq. (1) followed by truncation to second order and time averaged yields in log form

$$\ln\langle R\rangle = -\frac{\Delta E}{k\bar{T}}\left(1+\frac{\langle T'^2\rangle}{\bar{T}^2}\right)+\frac{1}{2}\left(\frac{\Delta E}{k\bar{T}}\right)^2\frac{\langle T'^2\rangle}{\bar{T}^2} \tag{2}$$

for

$$\frac{\langle T'^2\rangle}{\bar{T}^2}\left[\frac{\Delta E}{2k\bar{T}}\left(\frac{\Delta E}{k\bar{T}}-2\right)\right] \ll 1$$

In the steady flow case $T' = 0$ and one recognizes that Eq. (2) allows the usual determination of T from a plot of $\ln R$ vs $\Delta E/k$. When fluctuations in T are present, however, one sees that the Boltzmann plot is no longer linear but takes the form

$$\ln\langle R\rangle = a_1(\Delta E/k) + a_2(\Delta E/k)^2 \tag{3}$$

A second-degree curve fit to measured $\ln\langle R\rangle$ vs ΔE data then yields the average as well as mean square temperature in the form

$$\begin{aligned}\bar{T} &= 2/[(a_1{}^2 - 8a_2)^{1/2} - a_1] \\ \langle T'^2\rangle/T^2 &= |1 + a_1\bar{T}|\end{aligned} \tag{4}$$

The method requires at least three spectral lines providing different values of ΔE. Any two lines can then be referenced to the third. For electron beam analysis it is convenient to use the most intense line in the selected rotational spectrum as a reference.

It has been noted in the literature that the electron beam derived Boltzmann plot is often nonlinear. This could certainly arise when non-Boltzmann equilibrium effects are present. The present result suggests that additionally some of the reported curvature is a consequence of fluctuation effects.