Technical Comments

Comment on "Rotational Relaxation in Hypersonic Low-Density Flows"

R. H. EDWARDS,* H. K. CHENG,† R. S. HICKMAN,‡ AND P. B. SCOTT§
University of Southern California, Los Angeles, Calif.

THE distribution of the rotational spectrum of the electron-beam-induced (0-0) vibrational transition in nitrogen can be used to infer the local rotational temperature. The first work to give a complete model for the excitation de-excitation process was that of Muntz.[1] This model was discussed by Robben and Talbot[2] and it was pointed out that the spectrally determined temperature appeared to be always greater than the predicted local translational temperature in both freejet expansions and in nozzles. Because of the importance of the measurement, considerable interest has centered on this discrepancy.

In a recent Note, Tirumalesa[3] has compared computed rotational temperatures in a freejet of nitrogen to the measured values obtained by Robben and Talbot[4] and Marrone.[5] It should be observed that apparent typographical errors and/or nomenclature inconsistencies exist in the Note in Eqs. (5 and 8–10).

The relaxation model used in the Note is

$$dT_r/dt = U(dT_r/dx) = (T_t - T_r)/Z_r\tau \qquad (1)$$

where τ is the time between bimolecular collisions and Z_r is the number of collisions required for rotational relaxation. T_t and T_r are assumed to be defined locally in the flow by equilibrium distributions for translational and rotational motion. Z_r can be expected to depend upon the local translational temperature, since the efficiency of rotational transfer should be a function of the relative collision velocity. Tirumalesa integrates Eq. (1) after supplying the required behavior of τ, U, and T_t in freejet for two constant values of Z_r, namely 5 and 10.

The integrated temperature profiles were compared to Marrone's data, and approximate agreement was effected by choosing a proper value of Z_r for each case considered. It was found that $Z_r = 5$ yielded reasonable fit to the data obtained for low values of the product of stagnation pressure and orifice diameter, while $Z_r = 10$ produced an approximate fit for large values of p_0d. On the basis of these comparisons, Tirumalesa concludes that the Muntz's model is valid and that the Robben and Talbot[2] correction is in error.

These conclusions can be questioned on several counts. First, the requirement that Z_r be dependent on p_0d is inconsistent with the assumptions underlying the Landau-Teller-type relaxation equation. Second, the values of Z_r used agree with Marrone's thesis, but are in direct contradiction with Miller's[6] work, which indicates that $Z_r < 5$. Third, other reduction schemes have yielded good agreement with different conclusions. Willis and Hamel[7] obtain agreement between theoretical predictions with Marrone's data modified by Robben and Talbot's correction. Willis and Hamel compute both translational and rotational relaxation, and make fewer assumptions than Tirumalesa's model. Fourth, recent data obtained by Ashkenas[8] can not be matched by Muntz's model.

In view of these considerations, it would seem that the adequacy of the Muntz model has not been substantiated and that the Robben and Talbot correction curve cannot be considered as incorrect.

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* Professor, Department of Aerospace Engineering.

† Professor, Department of Aerospace Engineering. Member AIAA.

‡ Associate Professor, Department of Aerospace Engineering. Member AIAA.

§ Assistant Professor, Department of Aerospace Engineering.

References

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Reply by Author to Edwards et al.

DUVVURI TIRUMALESA*
Cetec Corporation, Mountain View, Calif.

THERE is a printer's error in Eq. (8) of Ref. 1. Equation (8) should read $w = \ldots$ instead of $n = \ldots$. The interest of Edwards et al.[2] in bringing this error to the author's attention is genuinely appreciated. The preceding correction would remove any apparent inconsistencies in Eqs. (5 and 8–10) of Ref. 1 as pointed out by them.

Before answering the comments by Edwards et al.[2] it is necessary to bear in mind the following assumptions made in Ref. 1:

1) The perturbation of the translation temperature due to rotational relaxation is negligible permitting the use of the isentropic expression for the distribution of the translational temperature $T_t = T'_t/T'_0$ (primes denote dimensional quantities) along the freejet axis, namely,

$$T_t = a_1\bar{x}^{w_1} \qquad (1)$$

where a_1 is a constant, $\bar{x}$ is axial distance from some origin near the exit nondimensionalized by orifice exit diameter

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* Scientist. Member AIAA.