2001064804

Rotational Relaxation Analysis of Nitrogen in Low-Density Freejet Expansions

Lawrence. A. Gochberg
National Research Council

Brian. L. Haas
Thermosciences Institute

NASA Ames Research Center, Moffett Field, California, USA 94035-1000

The phenomena of rotational relaxation of nitrogen has been examined by numerous investigators over many years. One of the experiments which has been performed examines nonequilibrium flow in low-density free jet expansions. Data have been taken in such flows using a variety of techniques, including time-of -flight methods and electron beam fluorescence spectroscopy. The direct flow properties measured in these different investigations, such as density and translational, rotational and vibrational temperatures generally show reasonable agreement. However, this kind of correlation from experiment to experiment tends to be lost when these data are analyzed to obtain rotational relaxation time or collision number[1,2]. The goal of such data analyses is to generate a succinct model for rotational relaxation in nitrogen which is essential for the computation of nonequilibrium rarefied flows. The objective of the present work is to process a large body of experimental data in a consistent manner to yield relaxation model parameters of the greatest utility for flow computations.

The Parker[3] formulation of the rotational relaxation collision number, Z_R as a function of translational temperature, T_T, is chosen for this investigation. The two adjustable parameters, Z_R^∞ and T^*, are defined as:

$$Z_R = \frac{Z_R^\infty}{\left[1+\frac{\pi^{3/2}}{2}\left(\frac{T^*}{T_T}\right)^{1/2}+\left(\frac{\pi^2}{4}+\pi\right)\left(\frac{T^*}{T_T}\right)\right]} . \tag{1}$$

The analysis method employed will computationally solve the equations of motion for the expansion including rotational relaxation. The basic equations of state, momentum and energy are set forth by Repetski and Mates[4] as:

$$p=\rho RT_T , \tag{2}$$

$$\frac{dp}{dx}+\rho u\frac{du}{dx}=0 , \tag{3}$$

$$\frac{5}{2}R\frac{dT_T}{dx}+R\frac{dT_R}{dx}+u\frac{du}{dx}=0 , \tag{4}$$

where p is pressure, ρ is density, R is the Universal gas constant, x is position along the jet centerline, u is centerline jet velocity, and T_R is rotational temperature. The rotational relaxation (Jeans') equation is:

$$\frac{dT_R}{dx}=\frac{T_T-T_R}{u\tau_R} , \tag{5}$$

where τ_R is the rotational relaxation time. The flow field is assumed to exhibit an isentropic translation temperature from a spherical source. A curve fit to the Mach number profile as a function of position in the freejet by Quah et al[5] will be used.

The results from a large number of different freejet experiments have been obtained, which give either the terminal rotational temperature in the flow, or a rotational temperature profile as a function of position in the expansion. The best fit for the Parker relation adjustable parameters will be found in a manner closely following Gallagher and Fenn[6] for each data set. In the latter work, a linear relation was used for Z_R rather than the Parker form. The latter will exhibit a more realistic behavior at high temperature.

The Gallagher and Fenn work with freejet expansions provides the only analysis of freejet data to date which uses a temperature dependent collision number. Their results exhibit good agreement with Z_R data from experiments other than freejets, in the range of temperatures quoted. The proposed analysis with the improvement in the data reduction technique will be applied to a large number of freejet expansion experiments, producing two new results. First, a large body of data on free jet expansions will have been analyzed in a uniform manner for the first time. Second, we will obtain new constants for the Parker expression for the rotational relaxation collision number as a function of temperature. This work will be of essential value to researchers performing computations of nonequilibrium flows using either continuum methods or direct simulation Monte Carlo techniques.

This work will be presented domestically at the 18th Ground Test Conference in Colorado Springs, Colorado, June 20-24, 1994 in a paper entitled, "The Electron Beam Fluorescence Technique in Hypersonic Aerothermodynamics", by L. A. Gochberg.

References

[1]Belikov, A. E., Sukhinin, G. I. and Sharafutdinov, R. G., "Nitrogen Rotational Relaxation Time Measured in Freejets", Rarefied Gas Dynamics, *Progress in Astronautics and Aeronautics*, Vol. 116, 1989, pg. 40

[2]Gochberg, L. A., "Rotational Nonequilibrium in Low Density Heated Free Jet Expansions of Nitrogen", Ph. D. Dissertation, University of California at Berkeley, April, 1993

[3]Parker, J. G., "Rotational and Vibrational Relaxation in Diatomic Gases", *Physics of Fluids*, Vol. 2, No. 4, 1959, p. 1622

[4]Repetski, J. J. and Mates, R. E., "Rotational Temperature in an Underexpanded Jet", Physics of Fluids, Vol. 14, No. 12, 1971, p. 2605

[5]Quah, C. G. M., Fenn, J. B., and Miller, D. R., "Internal Energy Relaxation Rates from Observations on Free Jets", Rarefied Gas Dynamics, Eleventh International Symposium on Rarefied Gas Dynamics, 1979, Vol. 2, p. 885

[6]Gallagher, R. J. and Fenn, J. B., "A Free Jet Study of the Rotational Relaxation of Molecular Nitrogen from 300-1000 K", Rarefied Gas Dynamics, Ninth International Symposium on Rarefied Gas Dynamics, Vol. 1, p. B.19-1