Engineering Notes

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Vibrational Nonequilibrium in a High Temperature Turbojet Engine

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Introduction

THE results of numerical calculations presented in Ref. 1 indicated that significant losses could be observed in high temperature turbine expansions due to vibrational nonequilibrium flow effects. The flow model assumed was a pure nitrogen gas with the vibrational energy distribution in the nitrogen molecule assumed frozen at the turbine inlet condition corresponding to a stoichiometric kerosine/air mixture. Downstream of the turbine expansion, the nitrogen gas was assumed to be equilibrated in a Rayleigh process. Performance losses of fully frozen flow with respect to equilibrium flow through the turbine expansion were predicted to be as high as 7% (see Fig. 1). Intuitively, these losses appeared excessive and the trend of the curves in Fig. 1 seemed odd because the losses did not appear to go to zero ($\eta_L = 0$) at zero turbine work ($\Delta T_w = 0$). Rough calculations produced numbers significantly different from those shown in Fig. 1; thus, it was decided that the calculations should be re-evaluated in detail. Both nitrogen and kerosine/air mixtures were evaluated with frozen and equilibrium chemistry assumed, using the program described in Ref. 2.

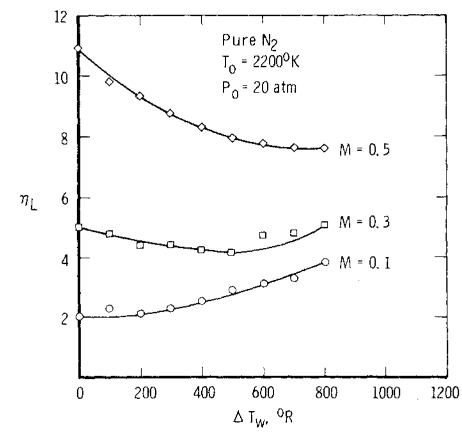

Fig. 1 Percentage performance lost due to vibrational freezing.[1]

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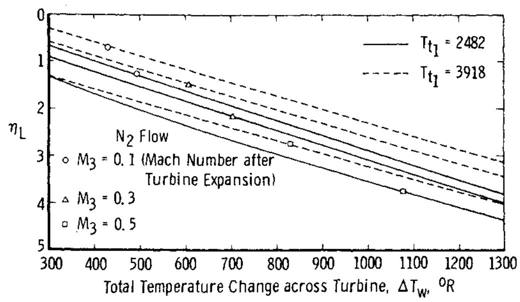

Fig. 2 Percent performance loss due to vibrational freezing (pure nitrogen flow).

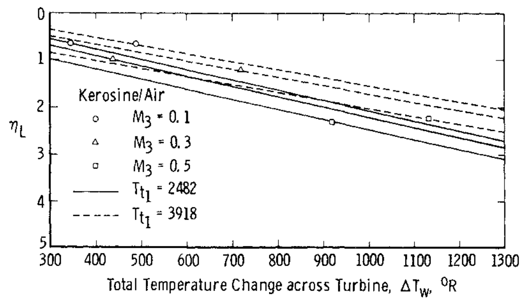

Fig. 3 Percent performance loss due to vibrational freezing (kerosine/air combustion products).

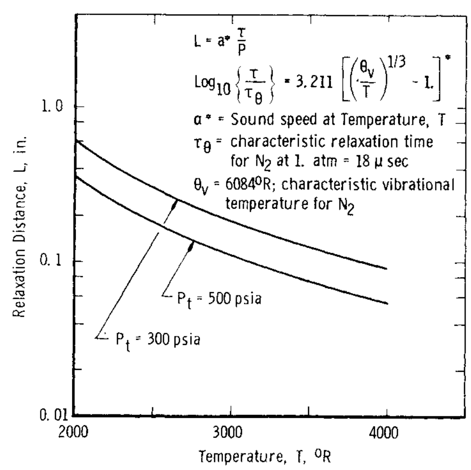

Fig. 4 Effect of temperature on the vibrational relaxation distance for nitrogen.

Results and Discussion

It was assumed that the vibrational energy distribution in the nitrogen molecule was frozen at the turbine inlet state throughout the turbine expansion that was followed by equilibration in a Rayleigh process. The loss of performance of frozen vibration flow with respect to equilibrium vibration flow was determined. Calculations were made for a pure nitrogen gas flow and kerosine/air combustion products for fuel/air ratios of 0.03 and 0.06. Both frozen and equilibrium chemistry models were investigated. The results for pure nitrogen are shown in Fig. 2 and for kerosine/air mixtures in Fig. 3. The isentropic expansions and Rayleigh process were evaluated using the gas tables of Ref. 3 for several cases. Excellent agreement was obtained. In accord with Ref. 1, the effect of assuming the flow to be frozen or in chemical equilibrium was negligible. The calculated losses would not be realized in practice since finite relaxation processes would significantly reduce them. The results of Phinney,[4] indicate that the nitrogen flow would be relaxed within a fraction of an inch, as shown in Fig. 4. An average temperature for the expansion process is assumed to be representative (bearing in mind that as the total temperature is decreased, the velocity of the flow is decreased), thus tending to compensate for the increase in relaxation time. The presence of carbon dioxide and water vapor would reduce this relaxation time significantly because of the near resonant collisional energy transfer processes[5,6]

Conclusion

The performance losses attributable to freezing vibrational energy in nitrogen should not be significant.

References

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[2]Osgerby, I. T. and Rhodes, R. P., "An Efficient Numerical Method for the Calculation of Chemical Equilibrium in the H/C/O/N/A System," AEDC-TR-71-256 (AD741825), April 1972, Arnold Engineering Development Center, Tullahoma, Tenn.

[3]Keenan, J. H. and Kaye, J., *Gas Tables*, Wiley, New York, 1957.

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Technical Comments

Comment on "Correlation of Wing-Body Combination Lift Data"

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NICOLAI and Sanchez[1] have presented some new experimental wing-body data in support of the well-known formula for wing-body lift

$$(C_{L\alpha})_{WB} = F(C_{L\alpha})_W \tag{1}$$

Here $(C_{L\alpha})_{WB}$ includes the lift of the wing in the presence of the body and the lift induced on the body by the presence of the wing, but not lift which is attributed to the body alone. $(C_{L\alpha})_W$ refers to the exposed portions of the wing (not a hypothetical wing extending through the body). Both coefficients are based on the area of the exposed wing. Since traditional wind-tunnel practice in testing wing-body combinations is to test, as the "wing alone," the hypothetical planform extended through the body, it is usually necessary to use theoretical values of $(C_{L\alpha})_W$ in Eq. (1).

Although formulas and methods closely related to Eq. (1) may be found in many early studies of wing-body interference, Ward[2] was apparently the first to make the explicit suggestion that, in such a formula, F could be closely approximated by a function of body diameter to the over-all span only, and that effects of Mach number and wing planform (aspect ratio, taper ratio, sweepback, etc.) would be small. Ward based his concept on the form which the wing-body lift takes in low aspect-ratio wing theory for wings centrally mounted on a circular cylindrical body, which is

$$(C_{L\alpha})_{WB} = (C_{L\alpha})_W(1 + d/b)^2 \tag{2}$$

or

$$F = (1 + d/b)^2$$

where d is the body diameter and b is total span of the wing-body combination.

The experimental data on delta wing-body combinations presented by Nicolai and Sanchez is of considerable interest since it covers a wide range of Mach numbers for the same configurations. However, the values of F they obtained appear to be considerably larger than those determined by other investigators at both subsonic and supersonic speeds. In addition, the variation of F with Mach number is larger than previous experimental data have shown.

Correlation in Ref. 3 (Fig. 8) of subsonic experimental data for six wings varying in d/b from 0.1 to 0.5, in aspect ratio from 0.5 to 6.1, and including rectangular, tapered and swept planforms, indicated that predictions according to Eq. (2) were generally good but tended to be between 5 and 10% low. Additional low speed experimental data (force tests) from Ref. 4 for a family of eight 45° sweptback untapered wing-body combinations, correlated herein, show similar small deviations from Eq. (2). These tests were run at Mach 0.14 and 0.29. Lift of the exposed sweptback wings was computed for these configurations from a formula due to Polhamus, quoted in Ref. 4.

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