The length of the compression region is evidently a strong function of cylinder diameter, at least for relatively small diameters. Thus Halprin's warning of the possibility of model size effects is certainly valid for cylinders, which tends to confirm his suggestion of making tests of size effects for two-dimensional steps.

References

[1] Halprin, R. W., "Step induced boundary-layer separation phenomena," AIAA J. **3**, 357–359 (1965).

[2] Sykes, D. M., "The supersonic and low-speed flows past circular cylinders of finite length supported at one end," J. Fluid Mech. **12**, 367–387 (1962).

Comment on "Nonequilibrium Effects on High-Enthalpy Expansion of Air"

Clarence J. Harris*

General Electric Company, Valley Forge, Pa.

The chemical composition and thermodynamic properties of coupled chemically reacting nonequilibrium expanding air flows have been obtained from complex numerical analyses.[1, 2, 3] Sets of values for given sets of initial conditions (reservoir pressure and temperature) have been obtained from these analyses and these results are presented herein in graphic form, based upon reservoir entropy. This type of presentation, i.e., a correlation in terms of reservoir entropy, permits a very convenient quantitative determination of the chemical composition of nonequilibrium expanding air.

This reservoir entropy correlation of the chemical species concentrations is shown in Fig. 1. The species concentrations (N_2, O_2, NO, O, and N) are plotted in terms of mass concentration (moles per gram of mixture). Tabulated at the top of Fig. 1 are the reservoir enthalpy values (H/RT_0 = 72 to 700), reservoir pressure values (10 to 8957 atm), and reservoir temperature (4000°K to 15,000°K) for each of the numerical solutions considered. The analytical data points shown with a flag were obtained from Ref. 1 where the l value is 4.74 cm. The l parameter defined in the relationship

$$A/A^* = 1.0 + (x/l)^2 \qquad (1)$$

is the ratio of the expanding nozzle throat radius to the tangent of the half-angle of the nozzle's asympote cone.[3] The quantity x is the axial distance along the nozzle measured from the nozzle throat. The analytical data used from Refs. 2 and 3 were based upon an l value of 1.0 cm and are the unflagged points in Fig. 1. Noting the oxygen (O) concentrations in Fig. 1, it may be observed that the larger l value gives lower concentrations in the entropy regime below values of S/R = 39.

Smooth lines have been drawn through the plotted numerical solutions for each species concentration (Fig. 1). This pictorial presentation allows one to observe readily phenomena discussed in Refs. 2 and 4. A noticeable deflection in the NO line occurs in the reservoir entropy range of S/R = 36 to 40. This rather abrupt and well-defined change in concentration is similar to the abrupt variation in frozen enthalpy pointed out in Refs. 2 and 4 with regard to departure from equilibrium. For reservoir entropy values in excess of S/R = 37.8, the N atom may be observed to become a large sink of the flow enthalpy. The NO production also is observed to be severely reduced in the vicinity of and above this reservoir entropy value.

Received November 1, 1965; revision received February 9, 1966.

* Physicist, Experimental Fluid Physics, Space Sciences Laboratory. Member AIAA.

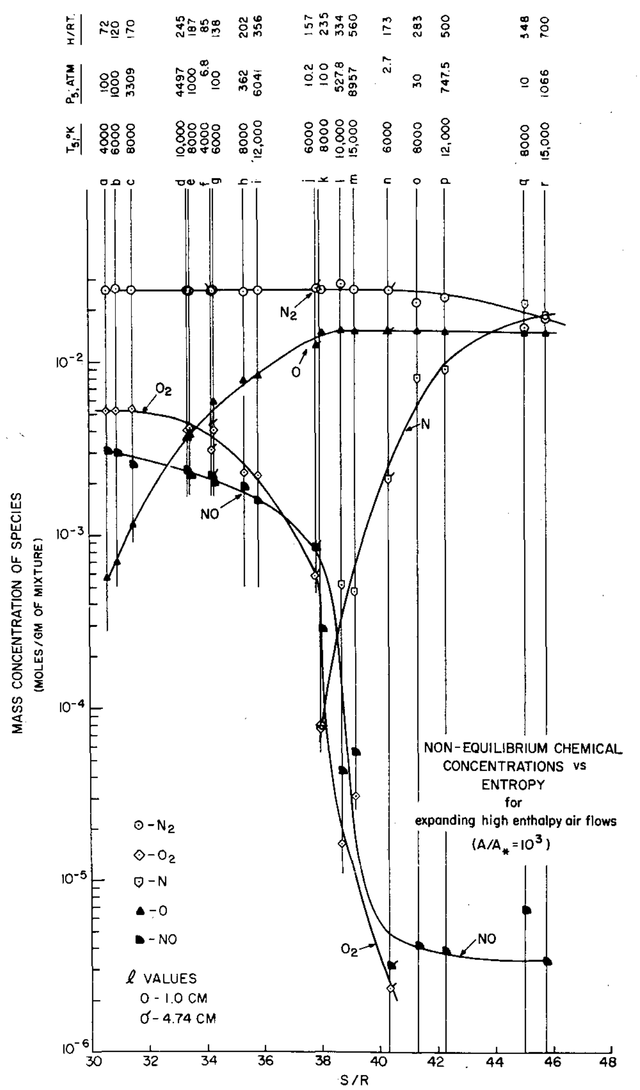

Fig. 1 Nonequilibrium chemical concentrations of air vs entropy at a nozzle area ratio, A/A_* = 10³.

The area ratio (A/A^*) of 10³ has been chosen so that freezing has occurred some distance upstream for each of the reservoir conditions represented; that is, for each reservoir condition it is found that the concentrations shown in Fig. 1 do not change appreciably with increasing area ratio. The interesting conclusion[4] to be drawn for the nozzle geometry and size (l = 1 cm) explored here is that the chemical state of the gas in the test section (provided that the test section is downstream of the nozzle area ratio at which freezing has occurred is a function only of the entropy level of the initial equilibrium expansion process. It has been found that this correlation readily allows other important processes associated with flight simulation in high performance shock tunnels[5] to be readily represented and displayed on the Mollier diagram.

References

[1] Boyer, D. W., private communication (July 1962).

[2] Lordi, J. A. and Mates, R. E., "Nonequilibrium expansions of high enthalpy air flows," Cornell Aeronautical Laboratory Rept. AD1716-A-3 (March 1964).

[3] Eschenroeder, A. Q., Boyer, D. W., and Hall, J. G., "Exact solutions for nonequilibrium expansions of air with coupled chemical reactions," Cornell Aeronautical Laboratory Rept. AF-1413-A-1 (May 1961).

[4] Lordi, J. A. and Mates, R. E., "Nonequilibrium effects on high-enthalpy expansion of air," AIAA J. **3**, 1972 (1965).

[5] Harris, C. J. and Warren, W. R., "Correlation of nonequilibrium chemical properties of expanding air flows," General Electric Document R64SD92 (December 1964).