Effect of Transverse Enthalpy Gradient on Blunt Body Pressure Distributions in Hypersonic Flow

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IT has been found that the flow produced in an arc-heated facility is likely to have transverse gradients in total enthalpy. Greenshields[1] measured average core gradients of the order of 81 Btu/lbm/in. in the Langley Field 2500-kw arc tunnel. An experimental investigation was conducted at The Ohio State University Aerodynamic Laboratory to determine whether a stream with transverse total enthalpy gradient was an acceptable medium for model pressure testing. The effect of total enthalpy gradient on the pressure distribution over a blunted 9° cone was investigated in a Mach 10 wind tunnel designed to produce enthalpy gradient flow. The results of this investigation are presented here. A more complete description of the experimental work may be found in Ref. 2.

Transverse total enthalpy gradients as high as 80 Btu/lbm/in. were induced in the test region of the 3-in. Mach 10 nozzle by the injection of unheated air along the nozzle wall upstream of the sonic throat. The strength of the induced gradient was dependent on the stagnation temperature of the air issuing from the heater and the mass fraction of unheated air injected into the nozzle. The enthalpy gradients were determined with a self-aspirating thermocouple temperature probe calibrated for local stagnation temperature in terms of measured temperature and impact pressure. Preliminary studies with the air injection nozzle are described in Ref. 3.

The model tested in the enthalpy gradient flow was a 9° blunted cone with nose to base radii in the ratio of one to four. The model, with five pressure orifices on the conical surface, was tested at zero angle of attack in flows having three different levels of enthalpy gradient as well as in flow with no gradient. Estimates of the possible measuring errors indicated that the probable error in the model pressure ratios should be less than ±4%. The model pressure ratios from all the model tests are compared in Fig. 1 using a representative zero gradient test as the reference. On the basis of this comparison, it must be concluded that the induced enthalpy gradients had no measurable effect on blunt body pressure ratios.

The nozzle surveys showed that there were negligible transverse Mach number gradients induced in the nozzle test region because of the enthalpy gradient. According to Newtonian impact theory, the pressure at a point on the body is

$$P = P_\infty + 2\, q_\infty \sin^2\theta$$

where P_∞ is the freestream static pressure, q_∞ is the freestream dynamic pressure, and θ is the angle of the surface relative to the flow direction. Since the Mach number across the core can be considered constant, it follows that P_∞ and q_∞ are also constant whether there is an enthalpy gradient or not. Thus, Newtonian theory predicts no effect of enthalpy gradient on the pressure distribution on the body. It should be noted that this simplified theory does not account for any rotational effects produced by the enthalpy gradients and that it is only applicable to "cold" flow and "frozen" flow where γ, the ratio of specific heats, can be considered constant across the core of the nozzle.

The results of the enthalpy gradient study indicate that the presence of large total enthalpy gradients across the test region will not significantly affect the pressure ratios obtained experimentally over a blunted body in cold or frozen flows. This result may not be applicable for sharp nosed bodies.

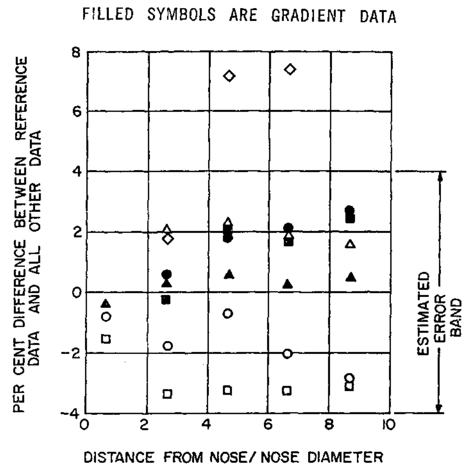

Fig. 1 Comparison of model pressure data.

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Air Ionization in the Hypersonic Laminar Wake of Sharp Cones

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Introduction

THE principal sources of plasma generation in the flow field of a sharp slender re-entry body are the boundary layer and laminar wake.[1–5] This note compares the relative influence of these two sources of electron production on the re-entry radar observables. The authors have previously presented scaling laws for nonequilibrium ionization in the laminar boundary layer of sharp cones.[6] These scaling laws were based on a simplified model of clean air ionization kinetics and gave reasonable agreement with the more exact numerical solutions.[3, 5]

In the same spirit, scaling laws are developed herein for clean air ionization in the laminar wake. In lieu of available test data, an examination of the numerical laminar wake solutions of Lien et al.,[2] Li,[4] and Pallone et al.[7] shows that species diffusion and fluid entrainment are much weaker than in the laminar boundary layer with a catalytic wall and that the most important single parameter is the peak static enthalpy. The results also show that a nearly constant static enthalpy level is maintained along the wake centerline. Although the pressure in the laminar wake is approximately ambient, about one order below that on the cone, the com-

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