Heat Transfer to a Hemispherical Body in a Supersonic Argon Plasma

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Theme

MEASUREMENTS of heat transfer to a hemispherical model in a Mach 4.6, low density, argon plasma are reported. Of particular interest is the effect of local wall currents on the heat flux distribution for an electrically conducting wall. The results of applied magnetic field on heat transfer for the case when Hall effect is important are also reported.

Contents

Argon gas was ionized by a d.c. arc heater and expanded through a 3.81 cm exit diameter, conical nozzle into a large cylindrical test chamber. Freestream, centerline flow conditions at the test station were: static pressure = 28 N/m^2, density × velocity, ρV, = 0.405 kg/m^{2}sec, electron temperature = 3900°K, and electron number density = 9×10^{19}/m^3. The centerline stagnation pressure and enthalpy were 893 N/m^3 and 10.25×10^6 joule/kg, respectively. Also, Reynolds number = 46 (based on model radius and stagnation conditions), and the interaction parameter (electrical conductivity × magnetic field squared × radius/ρV) = 200/tesla squared.

The basic heat-transfer model was a 3.81-cm-diam copper hemispherical shell (wall thickness = 0.119 cm) attached to a brass afterbody. Thermocouples were located at 6° intervals through $\theta = \pm 72°$, (θ = polar coordinate). Two different configurations were: first, the conducting model—only the hemispherical portion was electrically conducting with respect to the plasma (past $\theta = 90°$ the model was electrically insulated from the plasma by a thin, sprayed layer of teflon); and the nonconducting model—the hemispherical portion was also sprayed with teflon, thus electrically isolating the entire model from the plasma. Steady, external magnetic fields were obtained by a battery powered, internal magnet. The field dropoff from the stagnation point along the centerline was close to that of a dipole. The transient thin-skin technique was used to deduce the heat-transfer rate. Exposure times were kept short to prevent teflon ablation. Care was taken to insure that the model was electrically floating.

Figure 1 gives the local heat flux distribution for both the conducting and nonconducting models. For the nonconducting model, the stagnation point heat flux is 29% lower than for the conducting model. This is not due to the thermal insulation of the teflon since an analysis showed that the teflon caused only about a 1% error in the calculated heat flux. Figure 1 also gives two theoretical laminar heat flux distributions[1-3]; the heat flux to the nonconducting model is in good agreement with the theories.

For the conducting model, both the magnitude and distribution of heat flux do not agree with the theories. In order to explain these discrepancies, the local current distribution to the model was obtained. A model with flush mounted probes, electrically isolated from the conducting surface, at $\theta = 0°$, 24°, 48°, and 72° was used. The model was electrically conducting to the plasma only up to $\theta = 90°$. Currents between probes and the model were measured. The results, given in Fig. 2, show that there was an electron flux to the surface at least up to $\theta = 72°$. However, since the model was floating the net current to the body must have been zero.

The above experiment demonstrates that despite the fact that a body is floating and the net current is zero, local currents to the body can exist—when the plasma potential in the shock layer is nonuniform. The variation of the plasma potential in

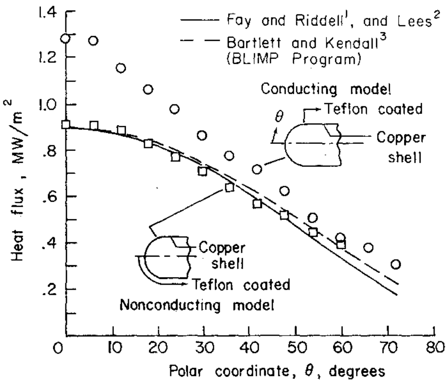

Fig. 1 Local heat flux distribution without magnetic field.

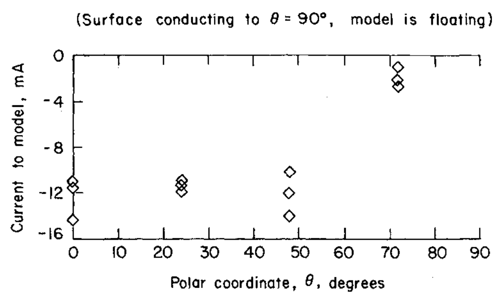

Fig. 2 Local current distribution.

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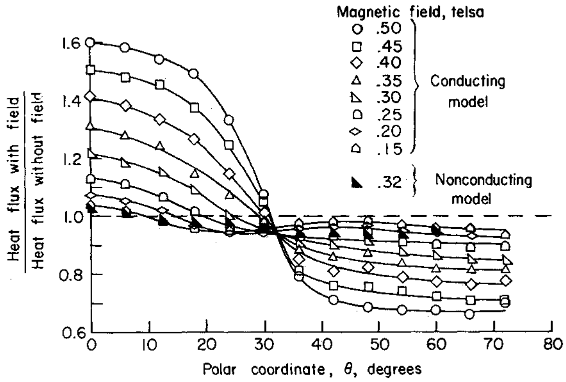

Fig. 3 Local heat flux distribution with magnetic field.

the shock layer was probably due to the nonuniform, measured, freestream potential; and the fact that the plasma potential changes across a shock, i.e., the curved shock induced an additional nonuniformity. From the above observations, it appears plausible that the increased heat flux near the stagnation region of the conducting model was due primarily to the local electron flux entering the model. Since the convective heat-transfer theories do not account for currents to the surface, it is not surprising that they do not agree with the experimental data obtained with the conducting model.

The changes in heat flux due to magnetic field are shown in Fig. 3. First, consider the nonconducting model results (solid symbols). At a magnetic field of 0.32 tesla, there is a slight increase in heat transfer at the stagnation region; this increase is unexpected and has not been predicted by available magnetogasdynamic (MGD) heat-transfer theories. Theoretical studies of MGD heat transfer have without exception predicted reduced stagnation point convective heat transfer. However, the predicted MGD reductions in heat transfer were all based on the decrease in velocity gradient dominating the increase in wall enthalpy gradient. But, for low Reynolds number flow with a cold wall, as is the present case, the increase in wall enthalpy may dominate. This may explain the small increase in the stagnation region heat flux with magnetic field. The most recent applicable MGD theory is that of Chen[4] who shows that for the present experimental condition, where $k^2 = 8.5$, and a magnetic field of 0.32 tesla, the stagnation point heat transfer should be substantially reduced. (See Ref. 4 for Chen's usage of the parameter k^2.) The disagreement between Chen's theory and the present experiment is perhaps due to an over estimation of Reynolds number for the experiment and/or the neglect of Hall effects in the theory.

For the conducting model, Fig. 3 shows that as compared to the heat flux distribution with zero field, the magnetic field increased the heat flux to the stagnation region, and reduced it beyond a field dependent θ. Additional experiments have shown that at the higher magnetic fields, when Hall effects become important, a Hall current flows away from the stagnation region of the model. This net flux of electrons to the surface apparently caused the large increase in heat flux to the stagnation region of the conducting model. Existing MGD heat-transfer theories do not consider Hall currents at the surface, so comparison with theory is not applicable.

In conclusion, the present experimental results call attention to the importance of local currents on heat transfer in low density ionized flow both with and without magnetic field. In the case of the conducting model, both with and without magnetic field, an electron flux entering the surface increased the stagnation region heat flux compared to the nonconducting model. For the nonconducting model, present theories predict well the heat transfer for zero magnetic field, but fail to predict the slight increase in heat transfer at the stagnation region with high magnetic field.

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