rectangular slot orifice, two other tube end conditions were used: an orifice plate perforated with a uniform pattern of $\frac{1}{2}$-in. diam. holes giving a total orifice area $A_* = 5$ in.^{2}, and the condition of the tube end fully open with sonic flow at the exit ($A_* = 1\frac{1}{2}$ in. × 5 in.). The diaphragm configuration was identical for the three tube end conditions. The presence of an orifice plate appears to have limited effect on the waveform; the waveform for the perforated plate is essentially the same as for no orifice plate (Fig. 5).

Figure 6 shows the effect of reduced p_o on $e(u_e)$ determined at the 7-ft station for the tube end fully open. At the lower pressure level two different diaphragm materials were used: 0.001 in. mylar, which tends to tear on rupture; and 0.0003 in. "red-zip" cellophane, which shatters into small fragments on rupture. No measurable difference in waveform was observed for the two materials.

In conclusion, the present study shows diaphragm generated expansion waves to have wavehead first derivatives that are essentially discontinuous. A wavehead first derivative measured at any x then determines a unique x,t coordinate system. In that system, noncentered plane waves are conveniently described by the function $e(u_e)$ determinable from a measured pressure or velocity history at any x. It might be added that through e a *local* conical similarity exists for the inviscid noncentered wave[1,2] in terms of the similarity variable $S = 1 + x/a_o t - e/a_o t$.

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Ion Current Collection by Cylindrical Electrostatic Probe in a Flowing Plasma

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Nomenclature

e = electronic charge
i = ion current
$i_{\parallel}$ = ion current when probe axis is parallel to flow direction
k = Boltzmann constant
m_i = ion mass
n = electron number density
r_p = probe radius
T_e = electron temperature
T_i = ion temperature
U = flow speed
V = probe potential with respect to plasma
θ = angle between probe axis and flow direction
λ_D = Debye length, $(\varepsilon_o kT_e/e^2n)^{1/2}$
λ_{ii} = ion-ion mean free path
λ_{in} = ion-neutral mean free path

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Introduction

THE behavior of cylindrical electrostatic probes in a flowing plasma are of substantial interest to those concerned with satellites, magneto-plasma-dynamic accelerators and high-temperature hypersonic wind tunnels. For such flow conditions, there are many aspects of electrostatic probe responses that remain unexplained. One of them is the effect of angle of incidence of the probe. In the intermediate values of probe radius to Debye length ratios ($0.1 < r_p/\lambda_D < 10$), Sonin[1] and Jakubowski[2] showed that an ion current peak occurred near zero angle of attack. In this Note, we present experimental results on ion current responses in a flowing plasma. Typical test conditions are as follows; $0.25 < T_i/T_e < 0.8$, $U/(kT_e/m_i)^{1/2} < 3.5$, $2 < r_p/\lambda_D < 200$. For the smallest radius probe, λ_{ii}/r_p ranged from 0.5 to 10 and λ_{in}/r_p was much larger than unity. In this range of parameters, if a sufficiently long cylindrical probe is directed along the stream, the response of the probe can be, in principle, interpreted within the framework of the theory of a stationary collisionless plasma.[3] However, the effect of the angle of incidence remains a substantial uncertainty,[1] because the potential distribution around the probe loses its symmetry and theoretical analyses are not made except for the special cases.[4,5]

Experimental Investigation

A d.c. arc jet was used as a plasma source. A supersonic plasma flow was obtained by being expanded from a Laval nozzle. Argon was used as the test gas. Details of this facility have been reported in Ref. 6.

The cylindrical probes used in this experiment were made of tungsten wire and their diameters ranged from 0.02 mm to 0.2 mm; the ratio of the probe length to the radius was larger than 100 except for the probe of 0.1 mm radius; the axial velocity of the flow was measured by the time-of-flight method to an accuracy of about 10%. The Mach number was obtained from the ratio of an impact and a static pressures, assuming the existence of a normal shock wave in front of the pitot-tube. The electron temperature and number density are evaluated from the current-voltage characteristic of the cylindrical probe which axis was parallel to the flow direction.

The influence of flow speed on an ion current was studied by turning the probe. Some examples of ion current variations are shown in Fig. 1 when the probe potential was held at a fixed value. In each case presented below, the dimensionless probe potential eV/kT_e was in the range of -20 to -30. It is found from Fig. 1 that typical probe responses of three kinds exist. In previous experiments,[1,2] the ion temperature was much smaller than the electron temperature and ion acoustic Mach number

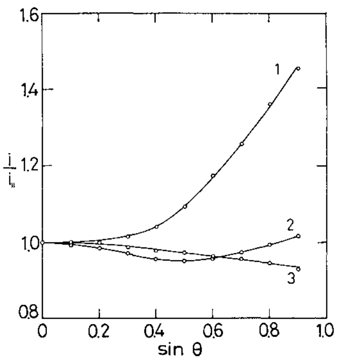

Fig. 1 Variation of ion current with probe orientation. 1) $r_p/\lambda_D = 69$, $r_p = 0.05$ mm, $U/(kT_e/m_i)^{1/2} = 3.5$, $T_i/T_e \approx 0.5$; 2) $r_p/\lambda_D = 150$, $r_p = 0.1$ mm, $U/(kT_e/m_i)^{1/2} = 2.2$, $T_i/T_e \approx 0.33$; 3) $r_p/\lambda_D = 4.4$, $r_p = 0.01$ mm, $U/(kT_e/m_i)^{1/2} = 1.3$, $T_i/T_e \approx 0.4$.

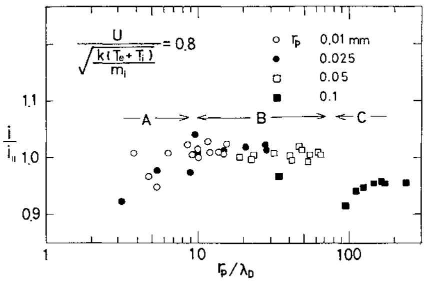

Fig. 2 Dependence of ion current on r_p/λ_D at $U/(k(T_e+T_i)/m_i)^{1/2}=0.8$.

$U/(kT_e/m_i)^{1/2}$ was used as the flow parameter. In this experiment, however, it is found that the probe response is influenced by the finite value of T_i/T_e as well as the flow speed. If the value of r_p/λ_D is same but T_i/T_e is not, the ion current variations cannot be interpreted by a single curve when $U/(kT_em_i)^{1/2}$ is used as the parameter. If $U/(k(T_e+T_i)/m_i)^{1/2}$ is used instead of $U/(kT_e/m_i)^{1/2}$, the incoincidence disappears. Thus we take $U/(k(T_e+T_i)/m_i)^{1/2}$ as the flow parameter, although this theoretical interpretation is somewhat clouded.

The dependence of $i/i_\parallel$ on r_p/λ_D is shown in Figs. 2 and 3. In these figures, $U/(k(T_e+T_i)/m_i)^{1/2}$ is fixed at 0.8 and 1.5. It is found that the variation of $i/i_\parallel$ can be divided into three different regions of r_p/λ_D. It was seen also in Fig. 1. In the range C, the ion current falls off at first, has a minimum value and increases as the flow speed increases. For the value of r_p/λ_D under 10, the ion current monotonically decreases in this experiment. In the middle range B, the ion current increases monotonically. In the limit of $r_p/\lambda_D \to \infty$, we consider the ion current variations in a flowing plasma do not depend on r_p/λ_D significantly. Thus the two different responses of $i/i_\parallel$ in the range of $r_p/\lambda_D > 10$ should be caused by another factor. In the range C, λ_{ii}/r_p are smaller than unity, while λ_{in}/r_p ranges from 20–40 for 0.1 mm radius probe and 40–80 for 0.05 mm radius probe, respectively. Consequently, we consider that the ion-neutral collisions bring about the decrease of the ion current in the range C. Since the ion-neutral collisions can be ignored except for the large radius probes, the ion current responses in the range A and B are due to the interaction between the sheath surrounding the probe and the ion drift. The sheath in a flowing plasma may be thinner than one in a stationary plasma in front of, or on both sides of, the cylindrical probe and be blown away backward. This effect makes the probe current decrease. On the other hand, the ion drift motion makes it increase. For the probe with thick sheath, the decrease of the ion current due to the sheath deformation is larger than the increment due to the ion drift motion. Thus the total ion current decreases as the flow speed increases. For the probe with thin sheath, the increment of the ion current due to the ion drift is the predominant part of the ion current variation. Thus the total ion current increases for the thin sheath. As shown in Figs. 2 and 3, these reasons lead to the decrease of the ion current in the range of $r_p/\lambda_D < 10$, and the increment for the values of $r_p/\lambda_D > 10$.

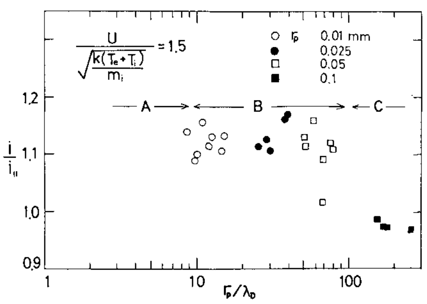

Fig. 3. Dependence of ion current on r_p/λ_D at $U/(k(T_e+T_i)/m_i)^{1/2}=1.5$.

In the range of A, λ_{in} is much larger than r_p and λ_{ii} is comparable with it. Thus the situation in which the ion current decreases in this experiment is quite different from that in the other experiments, in which it was described that the decreases of the ion current in the range of $r_p/\lambda_D \sim 1$ were due to the small values of λ_{ii}/r_p[7] or λ_{in}/r_p.[2] Stangeby and Allen[4] showed that the ion current decreased in the range of $r_p/\lambda_D \gg 1$ and $U/(kT_e/m_i)^{1/2} \ll 1$. This result disagrees with our experimental one. However, Swift-Hook and Andrews[5] showed that the ion current increased within the framework as Stangeby and Allen. This result showed the same trend as ours.

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Film Cooling by Oblique Slot Injection

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Introduction

WALL cooling by boundary-layer injection or transpiration is used in engineering applications.[1] The present investigation concerns the film cooling effectiveness of oblique injection from the wall into a compressible laminar boundary layer through single or multiple slots. Numerical solutions of the boundary-layer equations are obtained by a finite-difference method which has been extensively tested and found to be accurate, versatile, and very stable. Film cooling effectiveness is presented for a wide variety of injection configurations so that the effects of coolant mass flow, injection angle, boundary-layer thickness, slot width, and the presence of upstream cooling slots can be investigated. The results are interesting, and conclusions heretofore unreported are drawn regarding selection of film cooling parameters.

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