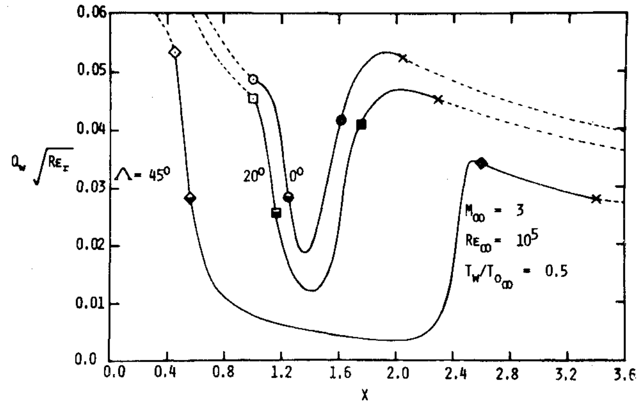

Fig. 5 Influence of sweep on heat-transfer distributions.

pressure region of the ramp. The surface heat-transfer distributions (note here $Q_w = q_w/\rho_\infty U_\infty{}^3$) accompanying these cases are shown in Fig. 5 to undergo excursions qualitatively similar to those of Fig. 4.

The over-all influence of sweep was quite surprising, it being expected that as the ramp was swept away from the mainstream direction (cross flow increased), the separation bubble would collapse to its ultimate configuration of zero pressure rise with zero separation bubble length. Contrary to this it seems that the flow appears to be approaching a state in which the separation bubble steadily increases in extent as the sweep increases, at least up to 45° of sweep. This is apparently directly connected with the decrease in the normal flow Mach number from 3 at zero sweep to approximately 2 at 45° of sweep. Free interaction studies (see Lewis et al.,[15] Stewartson and Williams,[16] and Werle, Polak and Bertke[4]) for the two-dimensional problem, indicate that lowering M_∞ should cause an increase in the interaction scale of a separated region for a fixed pressure rise. Here, this scale effect apparently is strong enough to counter the effect of decreasing pressure rise with increased sweep. One would expect that eventually this latter effect would dominate, possibly once the normal Mach number goes subsonic, but the present linearized supersonic flow model cannot be employed to investigate such a limit condition.

One final point of interest is the influence of cross flow on the reattachment heating levels. Of immediate interest is that the peak heating point is generally aft of the reattachment point and that the levels achieved do not seem to show much "overheating." This latter point though really depends strongly on the basis of comparison being used. Consider the peak heat-transfer level observed for $\Lambda = 0$, given by $Q_w = 0.054$ at $\chi = 1.95$. At the same point without the ramp present the heating level would have been 0.036 based on a square root decay from the value of 0.049 shown for $\chi = 1.0$. Thus, the ramp might be said to cause a local heating level 50% higher than its flat plate value. For sweep angle of 20° the overheating remains near 50% and this increases to 55% for 45° of sweep.

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Probe Interference in High-Speed Rarefied Flows

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Introduction

HIGH-SPEED flows which lie between the continuum and free molecular regimes have been extensively investigated with pitot probes and heat-transfer probes. It was assumed that as the flowfield is supersonic, probe disturbances are confined to a region downstream of the probe. The present investigation was prompted by anomalous results obtained when momentum flux (ρu^2) and mass flux (ρu) measurements were combined to give density and velocity profiles. These anomalies could only be explained by probe interference, which was confirmed by the independent density measurements described below. The purpose of this Note is to demonstrate that high-speed rarefied flows are disturbed by probes of the size normally used. This disturbance may only become apparent when an independent measurement of flow properties is performed.

Experimental Investigation

Measurements were conducted in a continuous running arc heated wind tunnel, using argon gas. The flow in the working

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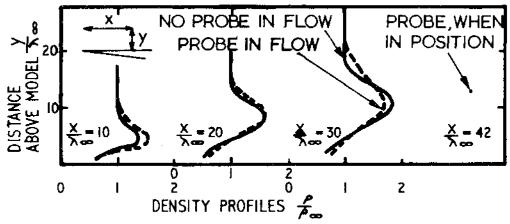

Fig. 1 Effect of transverse probe on density; $\lambda_\infty = 0.38$ mm.

section of the tunnel is highly luminous because of radiative decay of meta stable atoms previously excited in the high temperature arc. It has recently been shown[1] that this luminosity is directly proportional to local gas density. Measurements of luminosity with and without a probe in the flow can therefore be used to assess the extent of the effect of the probe on gas density. Conditions in the working section of the wind tunnel were as follows: Mach number 0(7), static temperature 0(100°C), mean free path λ_∞ 0(1mm). Two probes, typical of those normally used in low density measurements were used for these tests. One probe consisted of a 0.2-mm-diam tungsten wire transverse to the flow. The other probe consisted of a forward facing 1-mm-diam tube supported from beyond the downstream end of the model.

Photographs of the flow about the model were scanned with a photo-densitometer to determine the luminosity and hence the gas density in the flow. The profiles so obtained were reproducible. The process was also applied to photographs taken when one of the probes was present in the flow. Figure 1 shows the effect of the transverse probe. Density profiles were irregularly disturbed, even far upstream of the probe. In Fig. 1 the probe was immediately behind the shock wave which is the position at which maximum flow disturbance occurred. The forward facing probe had a more drastic and erratic effect on density. It was difficult to obtain useful information directly from these disordered profiles and therefore the profiles were used to find the shock position as shown in Fig. 2. It will be seen that the shock moves away from the model when the probe is introduced. This effect is more pronounced when the probe is placed in the faster flow away from the wall, which suggests that the probe is causing blockage. The presence of a small probe in a supersonic boundary layer would not be expected to seriously affect the external shock upstream of the probe. However, as the boundary layer and shock are merged, shock waves are highly sensitive to back pressure so that a substantial change in shock angle may result from the introduction of a probe into the boundary layer.

Conclusions

When probes are introduced into a high-speed rarefied flow, they cause disturbances to the flow structure which are likely to affect the results obtained, even when the probes are near free molecular and very small compared with the extent of the flow being investigated. The use of probes in rarefied flows should, therefore, be confined to the determination of gross features, such as the number and approximate position of shock waves in the flow about complex shapes.

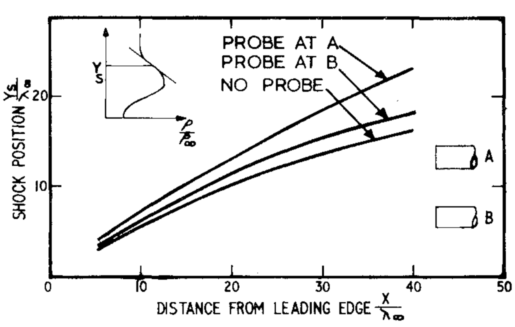

Fig. 2 Effect of forward facing probe on shock position; $\lambda_\infty = 0.38$ mm.

It is emphasized that the profiles obtained from probes may appear to be reasonable. It is only when data obtained from probes causing different amounts of disturbance are combined that anomalies appear. The fact that different probes cause different amounts of disturbance also accounts for the large scatter in the published data for shock position.

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Transonic Flow past Lifting Airfoils

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Nomenclature

$c(x)$ = camber distribution
$t(x)$ = thickness distribution
Γ = circulation

$$\sigma_E = \frac{1}{2\pi(\lambda_E)^{1/2}} \ln\left[(x-\xi)^2+\lambda_E(z-\zeta)^2\right]$$

$\Delta\,\partial\phi/\partial\zeta = (\partial\phi_u/\partial\zeta)-(\partial\phi_1/\partial\zeta)$
$\Delta\phi = \phi_u - \phi_1$

$$\frac{\partial\sigma_E}{\partial x} = \frac{1}{2\pi(\lambda_E)^{1/2}}\frac{(x-\xi)}{\left[(x-\xi)^2+\lambda_E(z-\zeta)^2\right]}$$

$f_E = \{\lambda_E-(K+\gamma+1)\phi_x\}\,\partial u/\partial\xi$
$\lambda_E = [K-(\gamma+1)\phi_x]$

Subscripts
E = elliptic type solution (subsonic case)
u = upper surface
1 = lower surface

During the last decade quite a few powerful methods both numerical and analytical have been developed[1] to solve the nonlinear transonic flow equation, in order to obtain the pressure distribution around airfoils. Among the approximate techniques may be cited the 1) hodograph method, 2) parabolic method, and 3) integral equation method. Nieuwland[2] in 1967 developed an indirect method for the potential flow around a family of quasi-elliptical airfoils based on hodograph techniques and the solutions of the hodograph equation are found for a given Mach number and a certain airfoil shape results. If a Mach number dependent parameter is changed, the airfoil shape gets altered. In this way shock free airfoils have been obtained whose uniqueness still appears to be doubtful. Numerical techniques have also been formulated by Steger and Lomax,[3] who have developed finite-difference schemes using a mixed finite-difference system both for lifting and nonlifting airfoils and have obtained interesting results. These sophisticated methods involve high-speed computers. In spite of these numerical methods there is still a need for simple engineering approximation useful for the aircraft designer. The method of local linearization developed by Spreiter et al.[4] continues to be sufficiently precise for quick evaluation. To the authors' knowledge, this technique does not

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