Technical Notes

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Boundary-Layer Transition on the Same Model in Two Supersonic Wind Tunnels

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Nomenclature

p_p = pitot pressure, Nm^{-2}
U = freestream velocity, m sec^{-1}
U/ν = unit Reynolds number, m^{-1}
Re_{tr} = Reynolds number based on the distance from the model leading edge to the end of transition
x = distance from leading edge, m
ν = kinematic viscosity, m^{2}sec^{-1}

Introduction

PREDICTION methods for boundary-layer transition based on stability theory are useful for subsonic flow conditions.[1,2] Such methods predict for supersonic flow transition Reynolds numbers of about 10^8, using Mack's theory.[3] This value is an order of magnitude higher than the values normally found in free flight and wind tunnels.

For supersonic wind tunnels, several empirical correlations have been developed. The method of Deem and Murphy (described by Hopkins et al.[4]) for adiabatic flat plates with zero leading edge thickness takes two parameters into account: unit Reynolds number and Mach number. The acoustical environment in the tunnels is used as the main parameter in the methods of Nagel[5] and of Pate and Schueler.[6] A simplification of Ref. 6 is given by Ross.[7] The rise in transition Reynolds number with increase of unit Reynolds number is explained by a reduction in effective sound disturbance level.

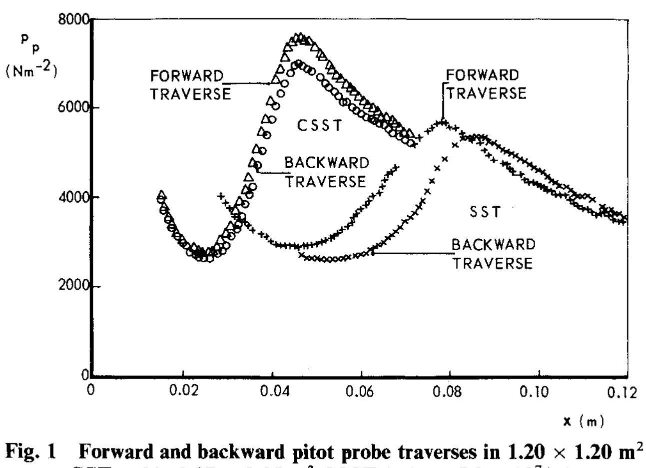

Fig. 1 Forward and backward pitot probe traverses in 1.20 × 1.20 m² SST and in 0.27 × 0.27 m² CSST (U/ν = 5.8 × 10⁷/m).

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At NLR, one model has been tested in two closely related tunnels of different size under identical flow conditions (Mach number and unit Reynolds number). Deem and Murphy[4] predict the same transition position, whereas different results are predicted by Refs. 5–7, because of the difference in acoustical environment.

Measurements

Two supersonic blow-down wind tunnels were used, the 1.20 × 1.20 m² SST and a scaled version, the 0.27 × 0.27 m² CSST with nozzle lengths of, respectively, 5.42 m and 1.22 m. The Mach number was 3.6 in both tunnels.

A standard hollow cylinder model from the University of Oxford[8] was used. Transition was measured with a sliding surface pitot probe. The location of maximum pitot pressure was taken as the transition "point" (Fig. 1).

Results

The results of the transition measurements are plotted for the CSST in Fig. 2 and for the SST in Fig. 3. The values of Re_{tr} as predicted by Refs. 4 and 6 are given too.

The measured transition length in the SST was about 1.7 times larger than in the CSST at a unit Reynolds number of 5.8 × 10^7 (Figs. 1–3).

The correlation of Deem and Murphy (described in Ref. 4) predicts the experimental results from the CSST well (Fig. 2), probably because it is based on data from tunnels of about the same size as the CSST. As it is based on Mach number and unit Reynolds number only, the same result is predicted for the SST. However the experimental value of transition Reynolds number is 70% higher (Fig. 3).

As the tunnel wall boundary layer is supposed to be an important parameter with respect to the acoustical disturbances, its value was measured in both tunnels. The experimental displacement thickness was used in the method of Pate and Schueler,[6] the predicted values are presented in Figs. 2 and 3.

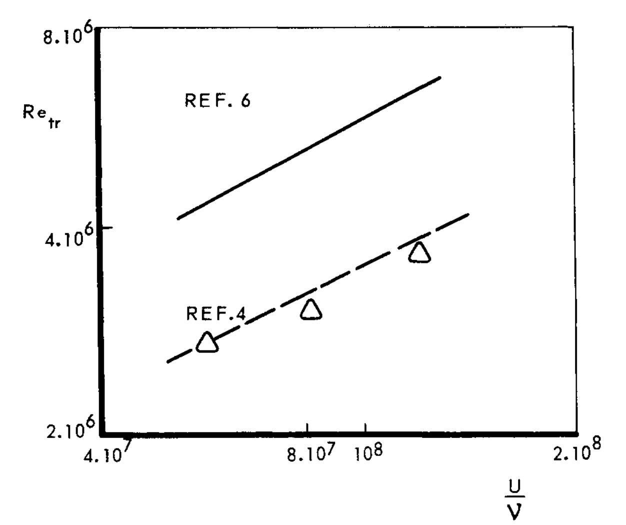

Fig. 2 Transition Reynolds numbers in 0.27 × 0.27 m² CSST compared with correlations.

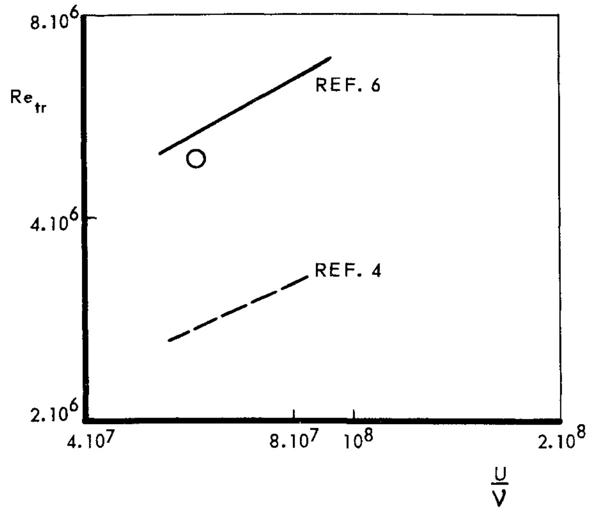

Fig. 3 Transition Reynolds number in 1.20 × 1.20 m² SST compared with correlations.

The prediction is good for the SST (Fig. 3), but about 70% too high for the CSST (Fig. 2).

Conclusions

The present experimental data underline the conclusions from the work of Pate and Schueler[6]: boundary-layer transition in wind tunnels at supersonic speed is not determined by Mach number, unit Reynolds number, and leading edge thickness only, but also by the tunnel environment.

The prediction methods which take the acoustic disturbances from the tunnel wall boundary layer into account (e.g., Ref. 6) predict a difference in the results from both tunnels, but a much smaller one than measured. It is not clear whether this is due to a wrong modelling of the acoustic disturbances or whether any other effect is present.

No decrease in the unit Reynolds number effect was found at very high unit Reynolds numbers, as might be expected on the basis of qualitative arguments.

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Density Survey in the Hypersonic Viscous Shock Layer on a Sharp Flat Plate

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THE hypersonic viscous sharp leading edge flow is a problem of fundamental importance in gasdynamics. The interest in this problem stems from the need to establish the low-density range of validity for the Navier-Stokes equations. Solutions based on the Navier-Stokes formulation are available for the transitional regime[1,2] and a number of investigators have reported surface and flowfield measurements[3,4] which show good agreement with these numerical solutions. Recently, Lewis[5] reported detailed surface and flowfield measurements in the kinetic flow region. Using the relative mean free path, λ_f, originally suggested by Kogan[6] as the scaling parameter for surface transport within the kinetic region, the different flow regimes in the disturbed flow region about the plate were defined. Lewis concluded in this study that the kinetic region extends to about $10\lambda_f$ downstream from the leading edge, followed by the merged region which covers the next $10\lambda_f$. Eventually, at $X \approx 20\lambda_f$, near continuum conditions prevail, and the strong interaction limit is approached. This Note presents experimental results of a density survey in the kinetic through strong interaction regions of a hypersonic sharp flat plate under cold wall ($T_w/T_o = 0.07$) conditions, as well as the correlation of the present and existing data using λ_f rather than the rarefaction parameter, $\bar{V}_{\infty_x} = M(c^*)^{1/2}/(Re_{\infty_x})^{1/2}$, as the scaling parameter. The results show that λ_f correlates the shock strength data remarkably well for over $30\lambda_f$ downstream from the leading edge of the plate.

This investigation was carried out using the electron beam fluorescence technique. This technique originally developed by Muntz[7] has since been used by a number of investigators in the study of rarefied gas flows. The experiments were performed in the PINY 8-ft hypersonic shock tunnel, and a detailed description of the tunnel and electron beam density probe are given in an earlier paper.[8] The measurements were made in nitrogen with a nominal Mach number of 18, with an equilibrium reservoir temperature of about 4000°K, and at one ambient density. This provides a freestream mean free path of 0.012 in. ($Re_\infty = 1500$/in.). Flow conditions were determined from measured values of the incident shock speed, reservoir pressure in the driven tube, and the measured value of the pitot pressure in the test section.

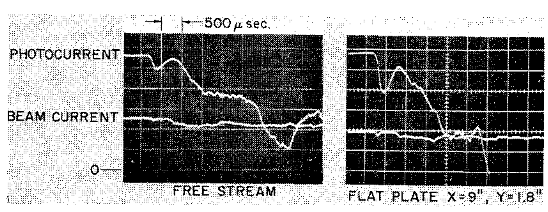

Fig. 1 Photocurrent and beam current during a test.

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