SYNOPTIC: Influence of Measured Freestream Disturbances on Hypersonic Boundary-Layer Transition,

R. D. Wagner Jr., D. V. Maddalon, and L. M. Weinstein, NASA Langley Research Center, Hampton, Va.; *AIAA Journal*, Vol. 8, No. 9, pp. 1664–1670.

Boundary-Layer Stability and Transition; Supersonic Flow

Theme

The objective was to provide a confirming experiment that sound radiation from the turbulent nozzle wall boundary layer plays a dominant role in model boundary-layer transition in hypersonic wind tunnels and is a major contributor to the commonly referred to unit Reynolds number effect on transition Reynolds number.

Content

This paper presents the results of a study of boundary-layer transition in hypersonic flow over a wide range of test conditions in the Langley $M = 20$ helium tunnel. The experiment includes: surveys of the nozzle wall boundary layer to establish if laminar, transitional, or turbulent flow exists on the nozzle wall, direct measurements of the freestream disturbances with a constant current hot-wire anemometer, and model boundary-layer transition detection using surface heat-transfer rates.

Boundary-layer surveys and surface Pitot pressures show that the nozzle wall boundary layer changes from laminar to turbulent over the operating stagnation pressure range of the facility. To study the attendant effects on the level of the freestream disturbances, hot-wire measurements were made in the test section near the tunnel center line; the disturbance level was nearly constant across the test core outside of the tunnel wall boundary layer. Signal spectra were recorded, and Kovasznay (and Morkovin) mode diagrams were generated over the operating pressure range. These mode diagrams, supported by the other experimental observations, identify the freestream disturbances as sound waves radiated from the turbulent boundary layer on the nozzle wall. The disturbances are lowest with a laminar boundary layer on the nozzle wall and highest when the boundary layer is transitional. When the boundary layer is turbulent the sound level decreases with increasing stagnation pressure (or, equivalently, increasing unit Reynolds number). The disturbance levels may be quite high, reaching a maximum of 3.5% rms mass flow fluctuation (this corresponds to a 6% rms static pressure fluctuation). However, only a 0.2% rms total temperature fluctuation, at most, was measured. These results are summarized in Fig. 1 where the measured rms mass flow fluctuation $\tilde{m}$ and total temperature fluctuation $\tilde{T}_t$ (1) in percent of the freestream mass flow m_∞ and total temperature T_∞ (1) are shown as a function of stagnation pressure $P_{t\infty}$.

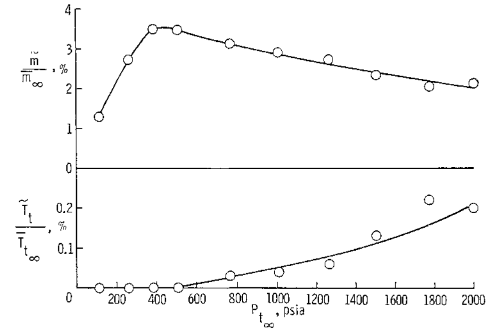

Fig. 1 Freestream rms mass flow and total temperature levels.

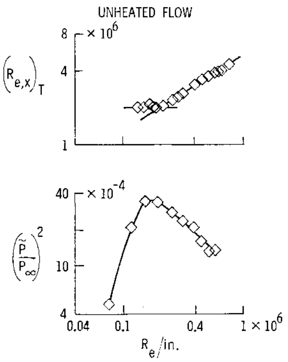

Fig. 2 Effect of freestream disturbances on transition.

Over the helium tunnel operating pressure range, boundary-layer transition was also measured on a 10° half-angle wedge; the local Mach number of the wedge flow was approximately 6.8 over the test range. These measurements and the sound pressure level measurements are summarized in Fig. 2. Therein, the Reynolds number at the beginning of transition $(Re_{,x})_T$ and the ratio of the mean square pressure fluctuation $\tilde{P}^2$ (which is a measure of the sound intensity) to the square of the freestream static pressure P_∞ is given as a function of unit Reynolds number Re/in. The unit Reynolds number corresponds to stagnation pressure. Obviously a strong coupling exists between the sound field in the freestream and the transition process on the model. The inverse correspondence of the two is nearly complete; transition appears to be dominated by the intense sound radiation from the nozzle wall boundary layer. The results also show that the freestream disturbances must be a major contributor to the commonly referred to unit Reynolds number effect on transition. Unfortunately, $(Re_{,x})_T$ could not be determined at unit Reynolds numbers below 0.13×10^6 because the presence of the model caused the tunnel wall boundary layer to separate and impinge on the model. It was expected that $(Re_{,x})_T$ would increase for unit Reynolds number below a value of 0.13×10^6 since then the sound intensity is greatly diminished when the tunnel wall boundary layer approaches laminar.