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REMOTE DETECTION OF BOUNDARY-LAYER TRANSITION BY AN OPTICAL SYSTEM

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THE BOUNDARY-LAYER TRANSITION DETECTOR BASED ON DIFFERENTIAL INTERFEROMETRY

The boundary-layer transition detector, developed by Spectron Development Laboratories (see reference 11), uses a differential interferometer to nonintrusively detect transition in compressible boundary layers. The heart of the device is a highly sensitive differential interferometer capable of detecting optical path length differences of less than one-thousandth of the wavelength of the laser light. The high sensitivity of the interferometer is due, in part, to a compensator loop which is employed to adjust the phase relationship between the two beams of the interferometer to optimize the performance of the interferometer and to null out any low frequency (less than 1 khz) signals that might result from, for example, model vibration. Twin photodetectors generate the output voltage signal as well as information for controlling the compensator loop. Electronic signal processing is also essential for real-time assessments of the boundary-layer activity. (Fig. 1.)

- Nonintrusive - two beam method
- Capable of detecting variations in optical path lengths (i.e., density fluctuations) on the order $\lambda/1000$
- Transition detector consists of:
  - Optical system
  - Compensator loop
  - Detection system
  - Electronic signal processing
- The RMS voltage output is proportional to the difference in density fluctuations between the two beams (i.e., initial rise indicates onset of transition)

Figure 1

SCHEMATIC OF OPTICAL DETECTION SYSTEM

The differential interferometer uses a 5-mW helium-neon laser for its light source. The beam is then passed through a polarizing plate, which aligns the beam at a 45 degree angle from vertical and results in one beam having components of polarization in both the vertical and horizontal directions. The Pockell's cell, the key element for the compensator loop, provides a means of adding pathlength to one of the components so that the relative phase between the two components of the polarized beam is controllable. The beam expander and lens provide a collimated beam to the beam splitter and Wollaston (1). Wollaston (1) splits the original beam into two beams of orthogonal polarization which leave the Wollaston prism at predetermined, but different angles. These two beams pass through the boundary layer on the model at different locations. Differences in density fluctuations in the boundary layer at the two model locations manifest themselves as optical path length differences between the two beams. Light reflecting back from the model surface returns through the lens and Wollaston (1) and is directed by the beam splitter to Wollaston (2) and the two photodetectors. The photodetectors generate the signal voltage out and provide information for adjusting the Pockell cell for optimum interferometer performance. (Fig. 2.)

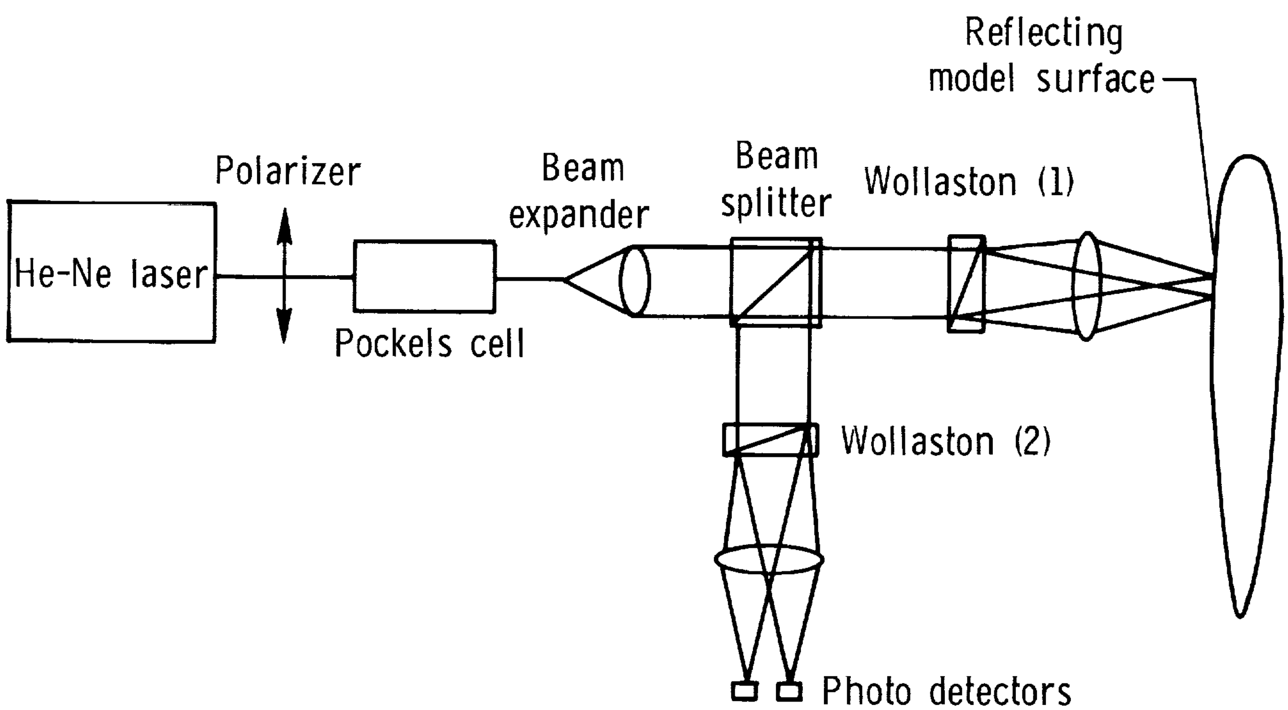

Figure 2

TRANSITION DETECTION SYSTEM AT THE BOEING MODEL TRANSONIC WIND TUNNEL

An important evaluation of the instrument occurred during June of 1986 when it was tested in the Boeing Model Transonic Wind Tunnel, which is a pilot tunnel with a 5- by 7-inch test section. The tunnel test section does not include a plenum and its sidewalls are of optical quality glass. As seen in figure 3, the instrument was set up on an optical bench next to the tunnel and the beam entered the tunnel normal to the test section side wall. An airfoil was mounted between the bottom and top walls. The beam struck the airfoil in a direction approximately normal to its surface. The electronic instruments that were used to store and assess the signal data in nearly real time are seen on the workbench behind the optical bench.

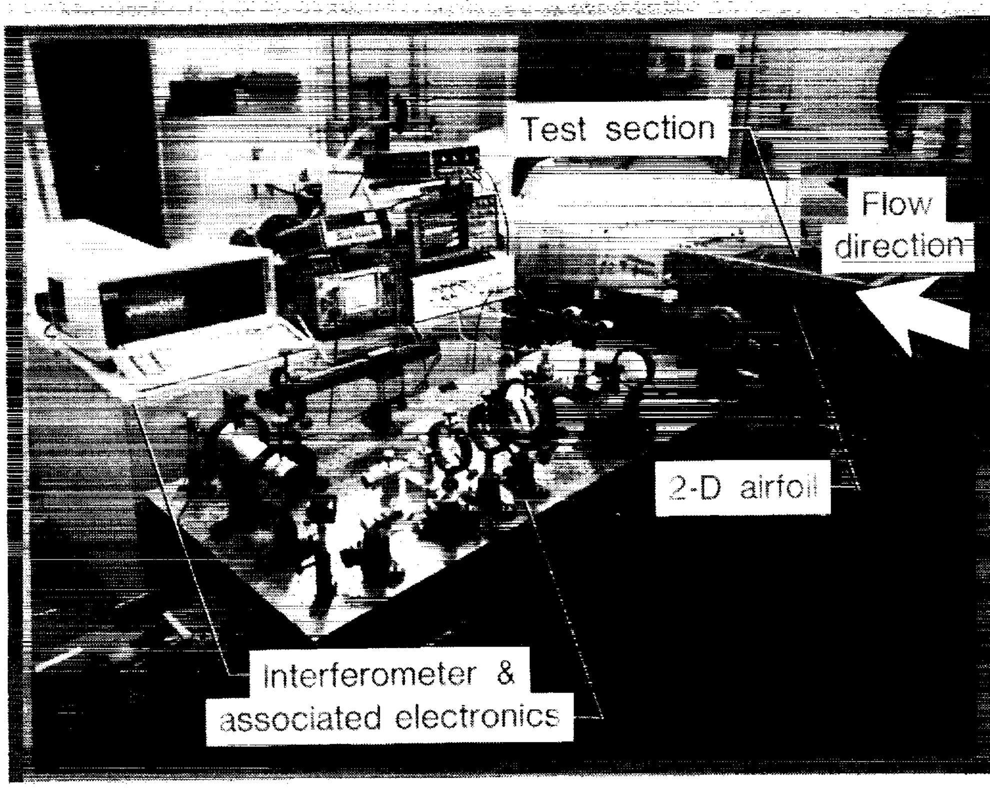

Figure 3

NATURAL AND TRIPPED BOUNDARY-LAYER TRANSITION PATTERN FROM FLOW VISUALIZATION

A 6-inch chord NACA 66-006 airfoil was used during the Boeing tests. Both laminar and turbulent flow are known to occur on this airfoil. Concurrently with the interferometry measurements, sublimating chemicals (napthalene) were used to independently determine where boundary-layer transition was occurring. The tunnel was operated at freestream Mach numbers of 0.7 and 0.8, which resulted in values of Reynolds number per foot approximately equal to 4 million. Figure 4 illustrates the type of pattern seen with the sublimating chemicals for a Mach number of 0.7 and with a roughness element attached to the leading edge of the airfoil.

Several interesting features of the flow are apparent. First, a distinct turbulent wedge emanates from the leading edge as a result of the roughness element, as marked by the absence of the sublimating chemical. (Absence of whitish chemical corresponds to a region of high heat transfer, or high surface shear stress, which is usually indicative of a turbulent boundary-layer state.) Second, at a location of about 5 inches from the leading edge (corresponding to the 1-inch location on the scale), it appears that natural transition is occurring independent of the turbulent wedges associated with either the tunnel side walls or the roughness element.

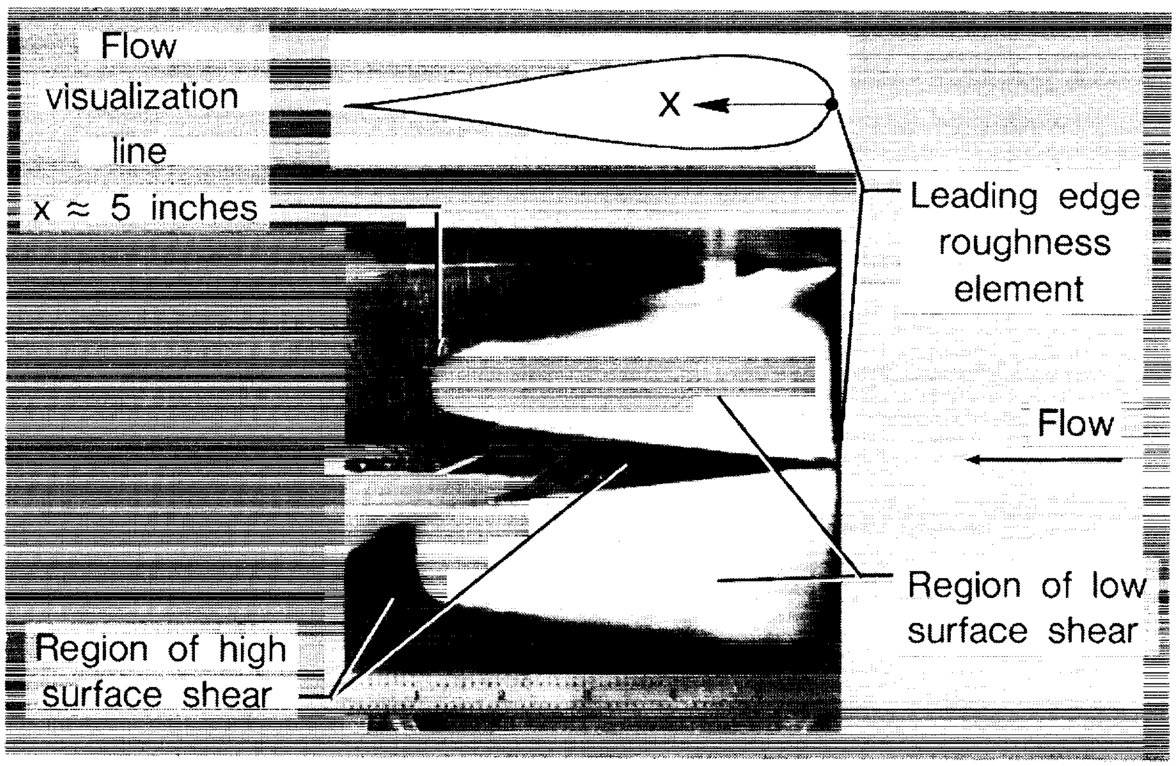

Figure 4

COMPARISON OF INTERFEROMETER SIGNAL AND FLOW VISUALIZATION FOR NATURAL TRANSITION

As an example of the type of data generated by the interferometer, figure 5 shows a plot of the RMS level of the signal for natural transition. The freestream Mach number was 0.70 and the chord Reynolds number was approximately 2 million. No roughness elements were on the model.

The instrument data, shown by the circles, demonstrate an increase in signal fluctuations (indicative of density fluctuations in the boundary layer) from a region 3.5 inches from the leading edge rearward. This area near 3.5 inches appears to coincide with the beginning of boundary-layer transition. The unsteadiness in the signal increases until 5.0 inches from the leading edge, where the unsteadiness reaches a maximum and where, in fact, the line of demarcation between absence and presence of chemicals was photographically determined at an earlier time. After this peak in activity, the signal RMS once again falls off as the fully turbulent region develops. However, the RMS level in the fully turbulent region appears to be approaching a value of about 6 millivolts as opposed to the laminar value of about 2 millivolts.

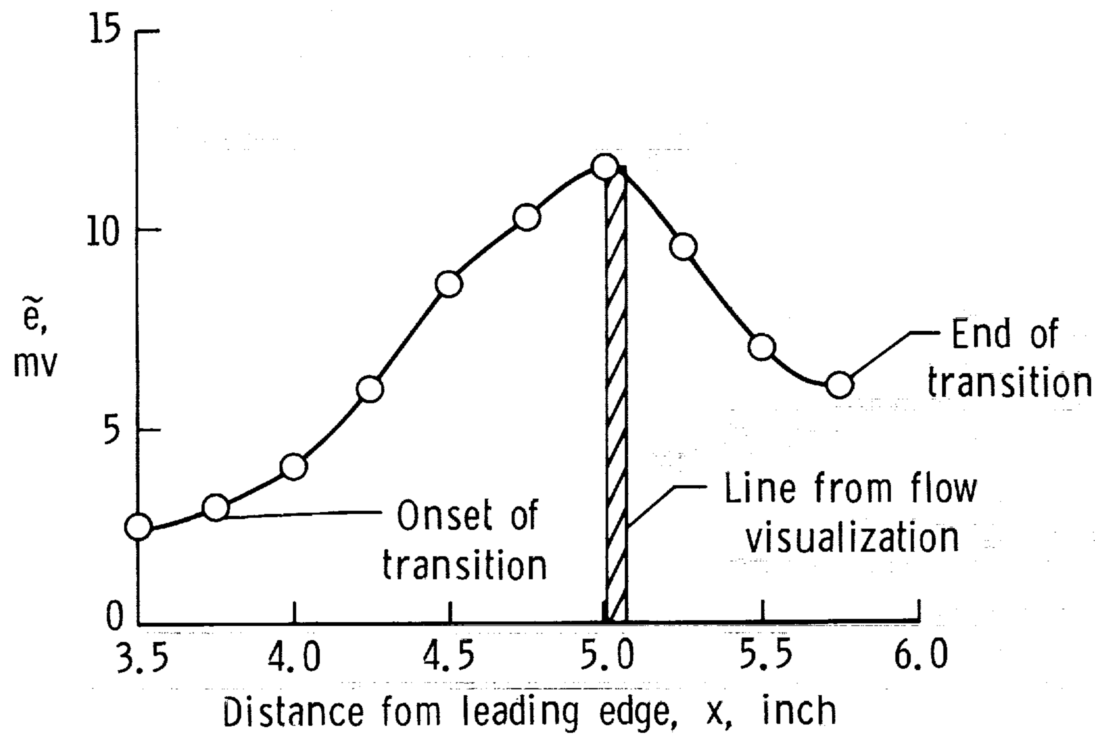

Figure 5

COMPARISON OF INTERFEROMETER SIGNAL AND FLOW VISUALIZATION FOR FORCED TRANSITION

A second example of transition detection is given for the case of transition triggered by the roughness element. The resulting turbulent wedge is traversed by the instrument in such a manner that the instrument moves from outside of the turbulent wedge to the centerline of the turbulent wedge. During the traverse, the chordwise distance is kept constant at 3.5 inches from the leading edge. The freestream Mach number was again equal to 0.70.

Once again, the RMS level of the signal is plotted on the vertical axis while the spanwise position of the beams is plotted along the horizontal axis. A spanwise distance of 0 inches is actually 1-inch from the centerline of the turbulent wedge while a spanwise distance of 1-inch corresponds to the centerline of the turbulent wedge. Again, the unsteadiness peak in the optical signal coincides with the boundary between the presence and absence of sublimating chemical. It is interesting that the interferometer would suggest that the actual turbulent wedge generated by the roughness element is not as well defined as the sublimating chemical test would suggest. (Fig. 6.)

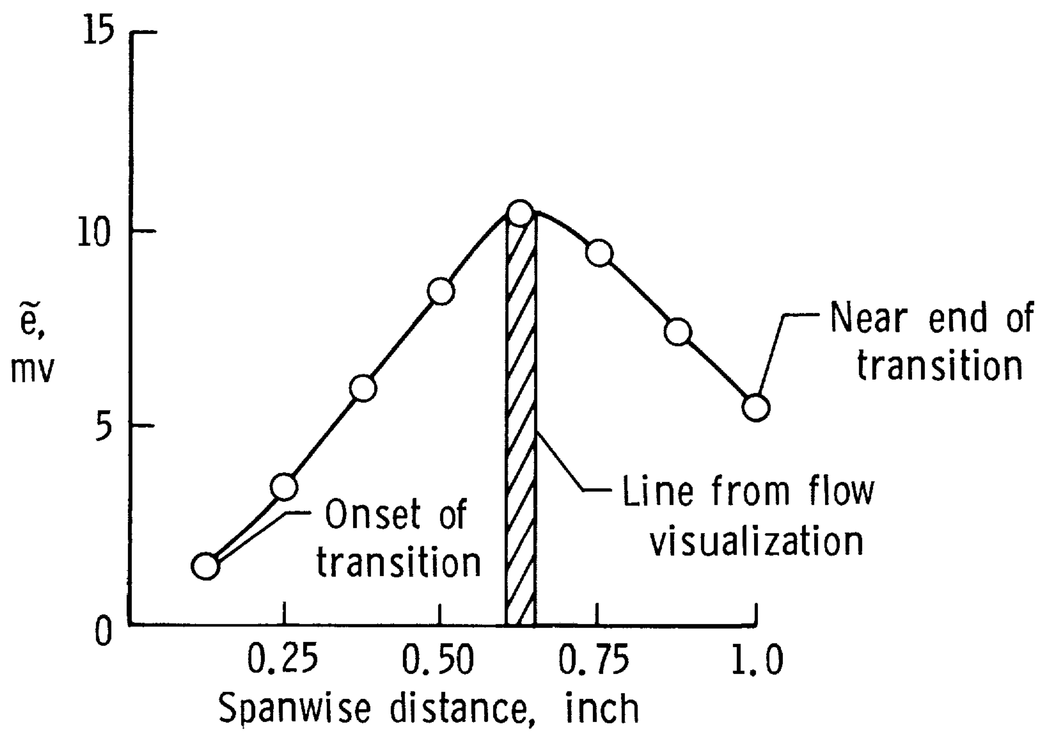

Figure 6

SUMMARY

This instrument development program has been funded because of the urgent need to measure boundary-layer transition in wind tunnels. In the course of this development program, a prototype instrument was designed, built, and tested. Recent transonic experiments in the Boeing Model Transonic Wind Tunnel show that the interferometer results correlate very well with sublimating chemical tests.