FLOW VISUALIZATION IN A CRYOGENIC WIND TUNNEL USING HOLOGRAPHY

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Results of holographic flow visualization are presented from tests made in the Langley 0.3-Meter Transonic Cryogenic Tunnel which was operated over a temperature range from 100 to 300 K and a pressure range from 1.1 to 4 atm. Interferometry at the facility may be of limited use at the low-temperature--high pressure conditions because of the jumbled nature of the reference fringes. The shadowgraph technique appears to be the best means of visualizing shocks at these high-density conditions. The spot size at the focus of the reconstructed beams was measured and used as an indicator of density fluctuations in the flow field. These density fluctuations appear to be caused by temperature fluctuations of the test gas which are relatively independent of tunnel conditions.

Introduction

The Langley 0.3-Meter Transonic Cryogenic Tunnel (0.3-m TCT) uses cryogenic gaseous nitrogen to simulate transonic flight conditions at a considerable power savings when compared with noncryogenic transonic facilities [1]. With temperature as a test variable, the effects of aeroelasticity, Mach number, and Reynolds number can be separated, thus permitting testing not previously possible in conventional wind tunnels. The purpose of this paper is to report the first attempts at flow visualization in the 0.3-m TCT by using holography. The results of this study may also be applicable in the selection of flow visualization for the National Transonic Facility at the Langley Research Center, which also will use the cryogenic concept.

Results and Discussion

The experimental arrangement (fig. 1) is described in reference 2. Holograms were made with a pulsed ruby laser over a temperature range from 100 to 300 K and a pressure range from 1.1 to 4 atm. The Mach number was

0.77 for all tunnel tests except for those at 300 K and 4 atm at which the Mach number was limited to 0.65. The angle of attack was set at either 0^o, 4^o, or 8^o for the tests. A reconstructed schlieren photograph and interferogram of flow made at 250 K and 2 atm is shown in figure 2. The schlieren photograph was produced by placing a vertical knife-edge close to the focus of the reconstructed beam in order to emphasize the shocks. The interferogram was produced with the two-hologram method in which the reconstructed beam from a no-flow hologram is made to interfere with the reconstructed beam from a flow hologram. The relative orientation of the two holograms can be adjusted to shift the location and orientation of the reference fringes. The same flow hologram was used for both the schlieren photograph and the interferogram.

As the tunnel temperature was lowered, the shock became much more visible until a very broad dark band was noted at the shock location, even for a focused shadowgraph. At those conditions where the shock was optically strong, the best visualization was obtained with a focused shadowgraph and, thus, schlieren was not necessary for emphasizing the shock. Figure 3 shows a holographic reconstruction of a focused shadowgraph of flow at 100 K and 4 atm. Note the grainy appearance of the reconstruction and the very strong (optically) shock. Since the grainy structure of the reconstruction becomes smallest at a focus corresponding to the center of the test section, the disturbance causing this graininess most likely lies within the test section rather than in the plenum or outside the tunnel. (A similar graininess noted in reference 3 was attributed to turbulence in the flow field.) The lowest temperature at which usable interferograms have been produced by using two-hologram interferometry is 125 K, although the interpretation of the interferogram would be difficult because of the excessive waviness of the fringes.

Figure 4 shows interferograms made in the 0.3-m TCT over a range of conditions. These interferograms were produced during the holographic reconstruction by directing the reconstructed collimated wave front to a glass plate which had a few seconds of wedge angle. The first and second surface reflections from the glass plate produced two laterally sheared wave fronts which interfered to produce, in the absence of a disturbance, straight-line fringes indicative of the amount of wedge (for collimated illumination). Although interpretation of laterally sheared interferograms can be difficult since a single shock now appears as two shocks, the relative insensitivity of the reference fringes to the setup geometry makes the technique useful when comparisons are desired. The location of the center of the photographs on the graph represents the tunnel flow parameters, total temperature, and pressure for that photograph. Equal-density lines are also drawn on the graph for comparisons. The interferogram labeled "test shot" at the lower left corner of the figure was made with the tunnel at 100 K and 1.5 atm with a Mach number of about 0.1. The interferogram labeled "test shot" at the lower right corner was made with the fan off at 300 K and 1 atm.

Changes in density can occur because of small fluctuations in temperature or pressure. For an ideal gas this relation is

$$\Delta\rho = \frac{m}{R}\left(\frac{\Delta p}{T} - \frac{p}{T^2}\,\Delta T\right)$$

Thus, for constant Δp and ΔT, $\Delta\rho$ due to small pressure variations would be 3 times greater and $\Delta\rho$ due to small temperature variations would be 36 times greater at 100 K and 4 atm than at 300 K and 1 atm. If the response due to an optical flow-visualization technique is plotted against both $1/T$ and p/T^2, it may be possible to determine whether the response is due primarily to temperature or to pressure fluctuations in the flow. If, for example, the density variations are due primarily to pressure fluctuations, then the optical response at different pressures and temperatures correlates better when plotted against $1/T$ than when plotted against p/T^2.

For this series of runs, a convenient parameter (optical response) that can be plotted against $1/T$ and p/T^2 is the spot size at the focus of the reconstruction. This spot size is defined to be the beam width which contains 80 percent of the beam energy and is found by scanning the focus with a knife-edge at a known constant velocity. Measurement of the rise time of the signal from a photodetector located behind the knife-edge then determines the spot size. Plots of spot size against $1/T$ and p/T^2 (normalized to 1 atm and 300 K) are presented in figure 5. Note that the correlation of spot size is much better when plotted against p/T^2 than when plotted against $1/T$, which indicates that the density variations across the flow may be largely due to temperature fluctuations rather than to pressure fluctuations. The linearity of the plot of p/T^2 also suggests that the temperature fluctuation (which is proportional to the slope) is relatively independent of tunnel conditions.

Concluding Remarks

Holographic flow-visualization tests have been made in the Langley 0.3-Meter Transonic Cryogenic Tunnel over a temperature range from 100 to 300 K and a pressure range from 1.1 to 4 atm. A graininess and jumbling of fringes and an increased spot size of the focused reconstruction were noted as the temperature was lowered and the pressure was increased. The density variations which produce these effects appear to be due to temperature fluctuations in the test-section flow rather than to pressure changes. At the high-density conditions, the shadowgraph technique appears to be the best means of visualizing shocks in the flow field.

References

1. Ray, Edward J.; Ladson, Charles L.; Adcock, Jerry B.; Lawing, Pierce L.; and Hall, Robert M.: Review of Design and Operational Characteristics of the 0.3-Meter Transonic Cryogenic Tunnel. NASA TM-80123, 1979.

2. Burner, A. W. and Goad, W. K.: Flow Visualization in a Cryogenic Wind Tunnel Using Holography. NASA TM-84556, 1982.

3. Belz, R. A. and Menzel, R. W.: Particle Field Holography at Arnold Engineering Development Center. Opt. Eng., vol. 18, no. 3, May-June 1979, pp. 256-265.

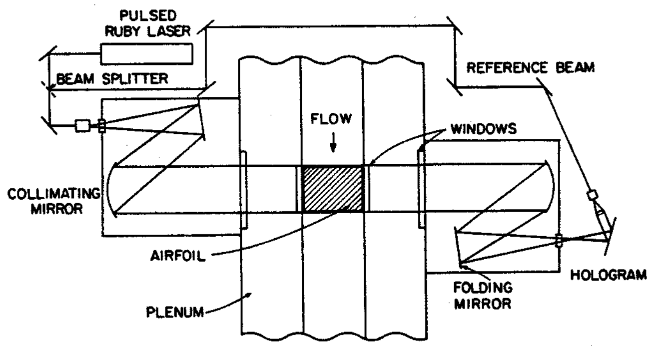

Figure 1.- Schematic drawing of holographic system in the 0.3-m TCT.

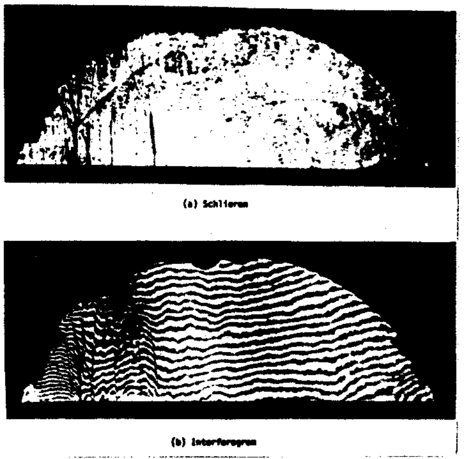

Figure 2.- Holographic schlieren photograph and interferogram of flow at 250 K and 2 atm at a Mach number of 0.77.

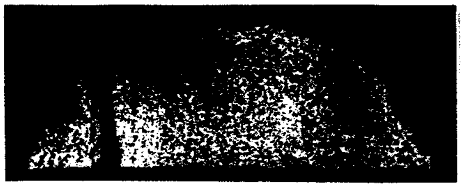

Figure 3.- Holographic shadowgraph at 100 K and 4 atm at a Mach number of 0.77..

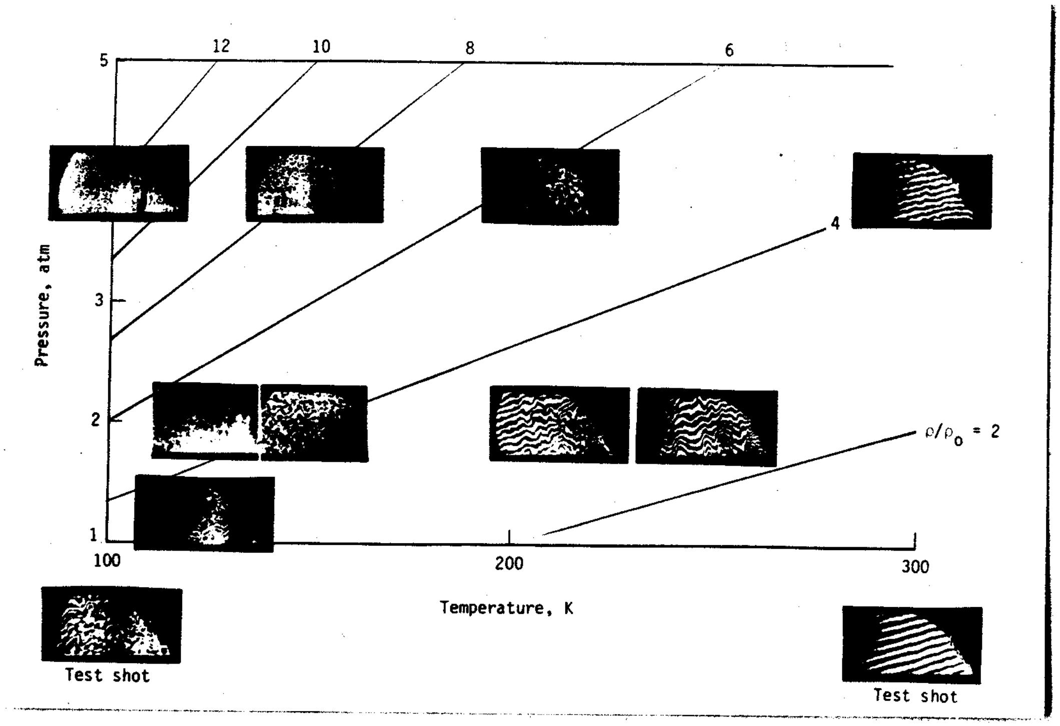

Figure 4.- Reconstructed shearing interferograms over a range of test conditions in the 0.3-m TCT.

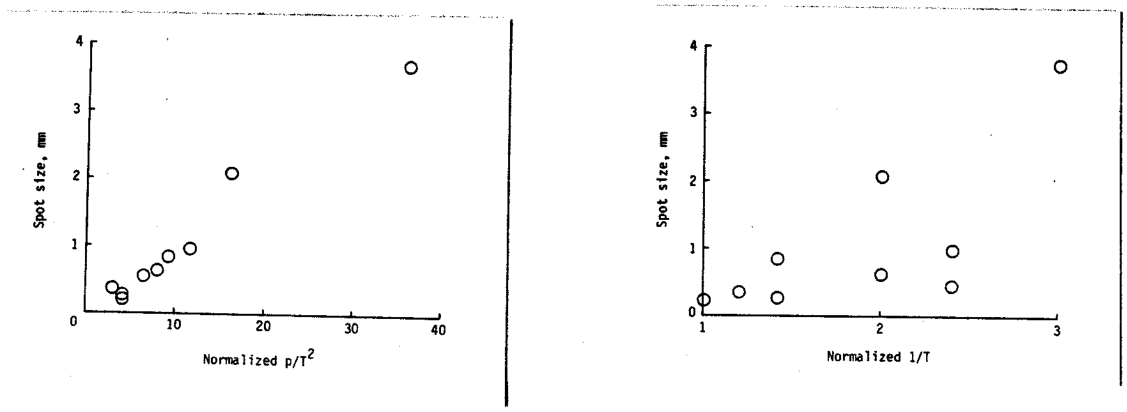

Figure 5.- Spot size of reconstructed images plotted against $1/T$ and p/T^2. Curves are normalized to 300 K and 1 atm.