FLOW VISUALIZATION IN THE LANGLEY 0.3-METER TRANSONIC CRYOGENIC TUNNEL AND PRELIMINARY PLANS FOR THE NATIONAL TRANSONIC FACILITY

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INTRODUCTION

The feasibility of flow visualization in cryogenic facilities is of interest at Langley with the anticipated start-up of the National Transonic Facility (NTF). The possible effects from the cryogenic environment (i.e., window distortion due to thermal contraction both in the mounts and in the window material itself and turbulence in the flow due to injected LN_2) need to be examined. The flow visualization techniques to be studied are schlieren, shadowgraph, moiré deflectometry and holographic interferometry. The test beds for this work are an in-house cryogenic test chamber and the 0.3-Meter Transonic Cryogenic Tunnel (TCT).

CRYOGENIC TEST CHAMBER DESIGN

The window material selected for the 0.3-Meter Transonic Cryogenic Tunnel and the National Transonic Facility was fused silica. This selection was based on the thermal shock properties, mechanical strength and good optical transmission. A chamber was constructed so that a schlieren system could be used to examine windows as they were subjected to the expected pressures and cryogenic temperatures. The chamber was fabricated from aluminum with double windows in each end. The inner windows were fused silica 12 inches in diameter and 2 inches thick while the outer windows were crown glass 10.5 inches in diameter and 1.56 inches thick (2.54 cm per inch). The chamber is shown in figure 1. The windows were mounted in AISI no. 304 stainless steel frames. The schlieren system had a sensitivity of 1 arc second under ambient conditions. The pressure load on the window would be controlled by venting LN_2 into the inner cavity while maintaining a reducing pressure in the cavity between the fused silica and the crown glass windows.

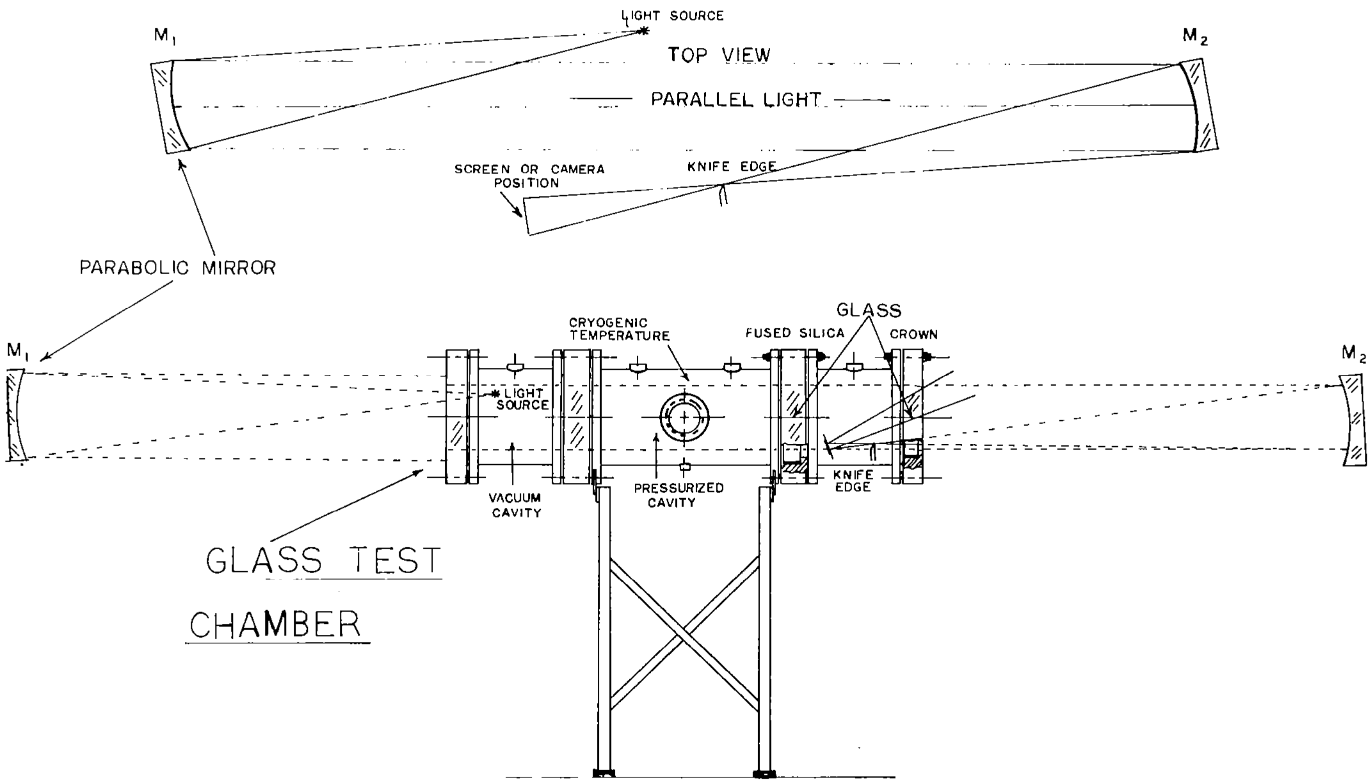


Figure 1

CRYOGENIC TEST CHAMBER

The cryogenic test chamber and schlieren system used to evaluate the window distortion at pressure differentials up to 50 psi and temperatures of 100° Kelvin are shown in figure 2. Changes in the detectable sensitivity of the system due to turbulence in the flow could be noted. The turbulence, however, was so severe it masked any possible "lens effects" due to window distortion.

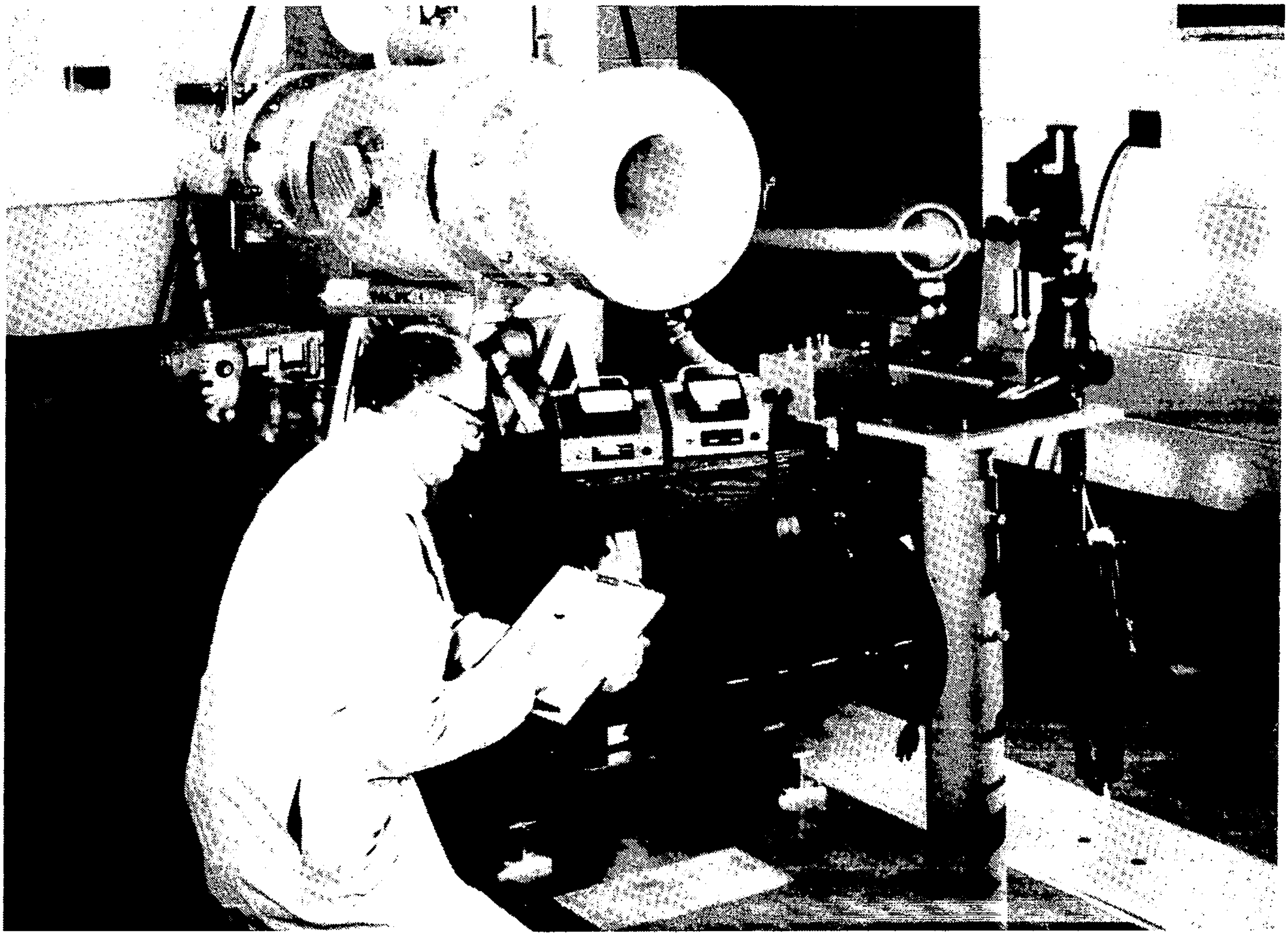


Figure 2

STRESS PATTERNS IN CRYO CHAMBER WINDOWS

The windows can be examined with polarizers and analyzers for stress concentrations during the cryogenic tests. This technique was not sensitive to the chamber turbulence and a heavy "cross" stress pattern was noted during the cooling of the chamber (fig. 3). The pattern and stress were determined to be in the outer crown glass window when the windows were individually checked. Since the window material to be used in the cryogenic tunnels is fused silica, which has a lower coefficient of expansion than crown glass, the distortion in the tunnel windows should be minimal.

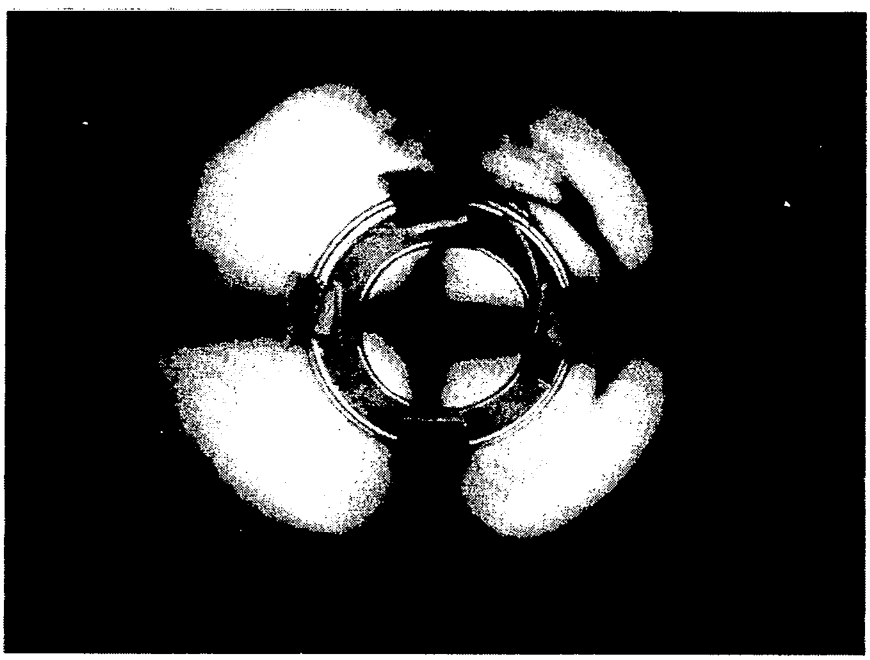
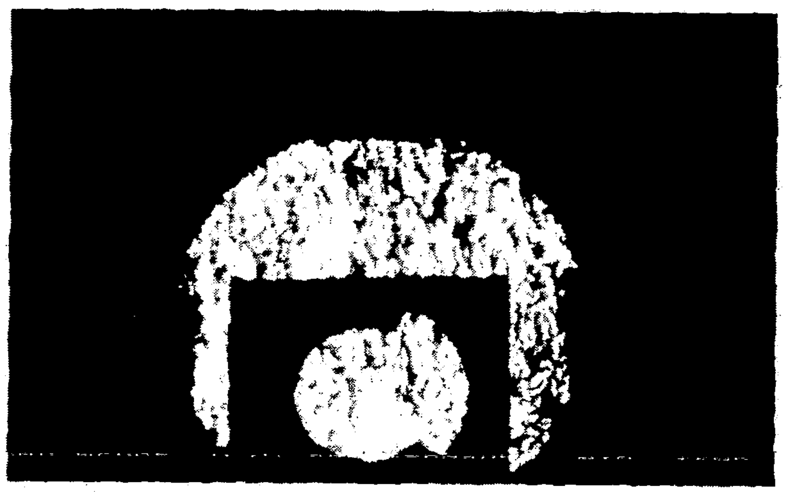


Figure 3

SCHLIEREN PHOTOGRAPHS IN THE CRYO CHAMBER

Schlieren test revealed the turbulence inherent in the chamber tests was a problem and masked the maximum angle of the sensitivity wedge (5 arc seconds). Although longer exposures integrate the turbulence the wedge angle is still obscured and no measurement of the system's sensitivity is possible. Frost and condensation on the chamber windows was a problem and indicated that flow visualization enclosures would be needed for the 0.3-Meter Transonic Cryogenic Tunnel (fig. 4).



3 ARC SECOND WEDGE, 0.01 SEC EXPOSURE, MIN. TEMP. -114°C

5 ARC SECOND WEDGE, 1 SEC EXPOSURE, MIN. TEMP. -123°C

Figure 4

DESIGN OF THE 2-D CRYO-TUNNEL

The schlieren housings were designed for the 0.3-m TCT to enclose the schlieren system. The enclosures or pods could be placed under a partial vacuum or flushed with dry nitrogen to eliminate the frost and condensation that would otherwise form on the plenum chamber windows (fig. 5).

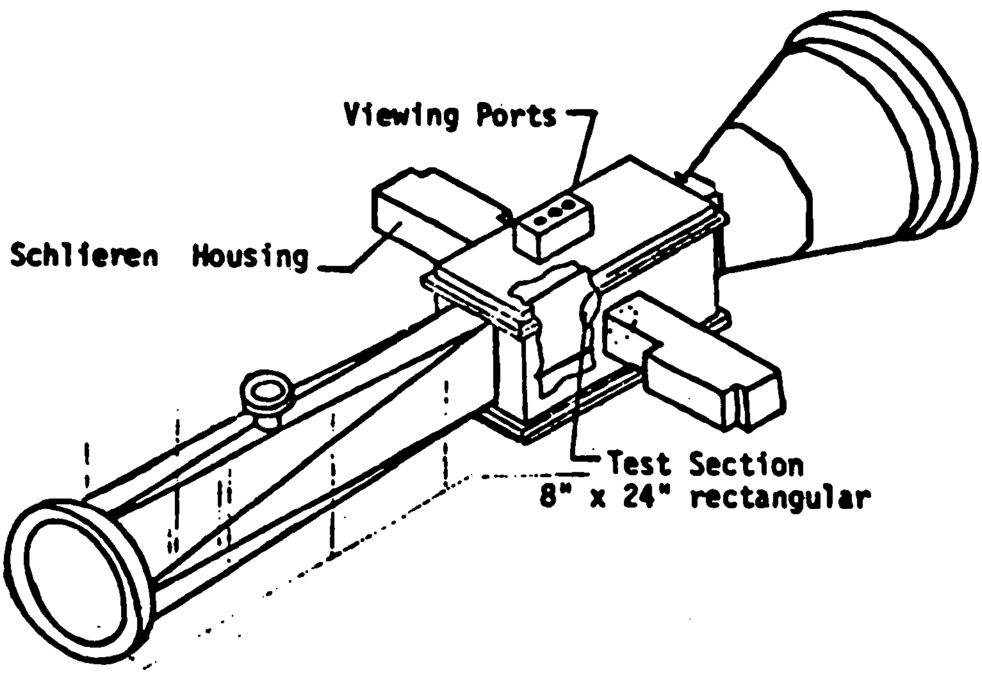


Figure 5

SCHLIEREN SYSTEM AT 0.3-METER TRANSONIC CRYOGENIC TUNNEL

The schematic in figure 6 shows a folded F/8 six inch diameter schlieren system enclosed in the schlieren pods. The light source and camera locations are external to the pods. The system's optical access to the test section is through two fused silica windows in each side of the tunnel. One window is a "D" shaped window mounted in the turntable holding the airfoil and the other window is in the outer plenum wall.

The schlieren system at the 0.3-m TCT has been configured to be similar to those envisioned for NTF and therefore restricted to using video cameras to record the flow visualization data. Alignment of the two pods for schlieren is more easily done at the 0.3-m TCT since the pods are not required to be mobile. The alignment problem will be significant for the NTF if schlieren is used; however, a shadowgraph system would be somewhat easier.

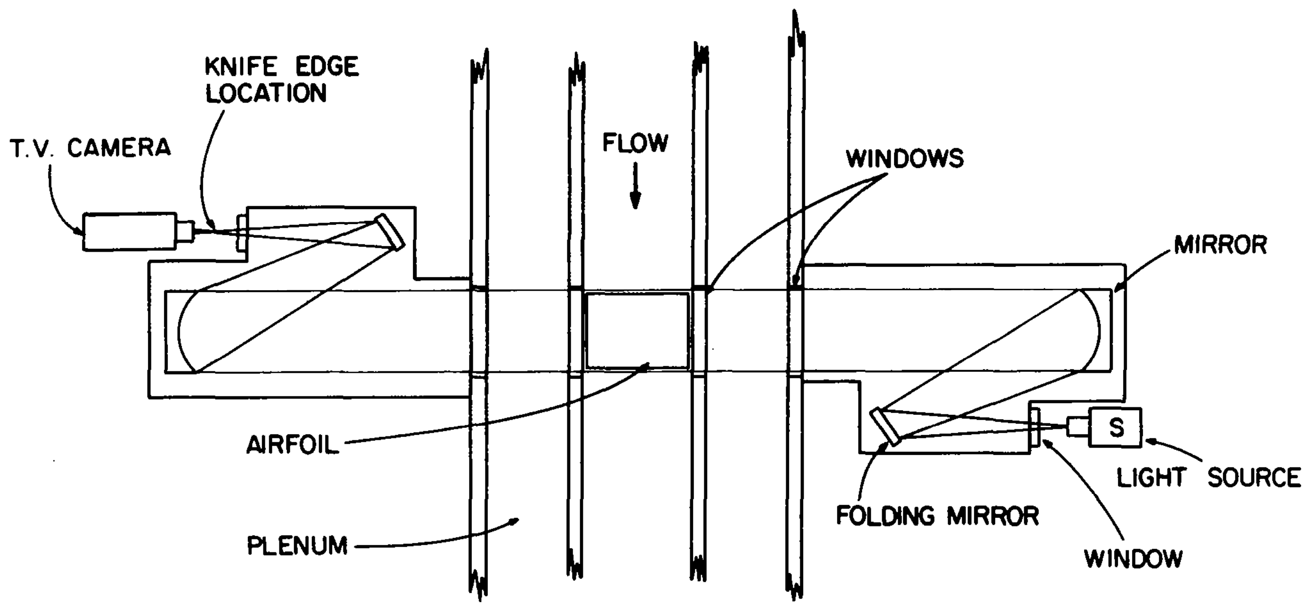


Figure 6

FLOW VISUALIZATION SYSTEM IN CRYOGENIC ENVIRONMENT

The schematic of the flow visualization system is shown at the top of figure 7. The photo on the left shows one of the pods mounted on the 0.3-m TCT. The right photograph shows two pods mounted on the tunnel which has the top of the test section removed to reveal the plenum area and the airfoil. The bottom photo shows the "D" shaped window mounted in the airfoil turntable which has been lifted out of the test section.

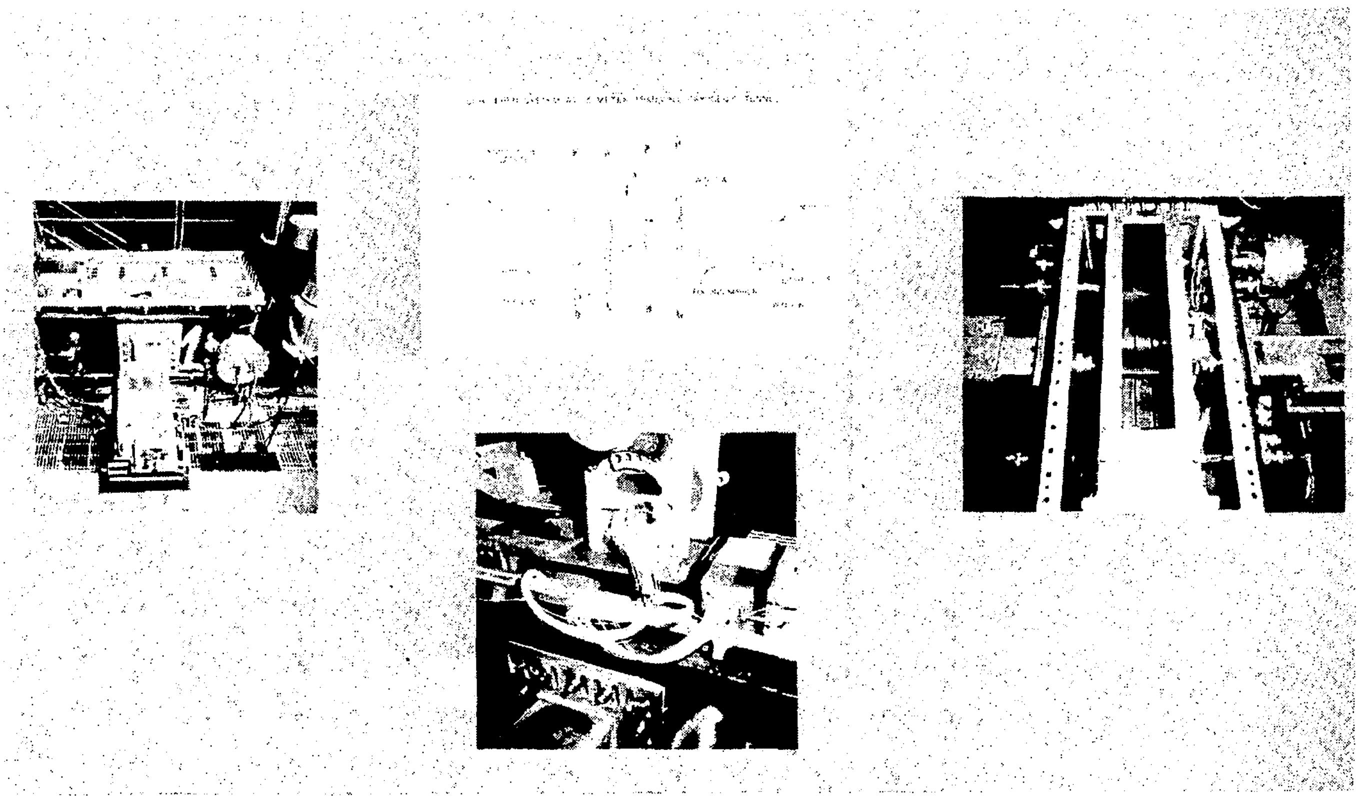


Figure 7

CRYO-TUNNEL WINDOW DESIGN

Prior to the tunnel runs in the 0.3-m TCT we experienced several window failures. One problem was the "D" window in the turntable was designed with an inside corner (fig. 8). Although the corner had a 0.063 inch radius it proved to be an area for crack growth. The window was changed to a double-beveled design having all outside edges. The window is mounted in a split frame which is bolted to the tunnel. Although none of the double beveled windows has failed the larger outer fused silica windows have experienced edge fractures and have been replaced. These fractures appeared to be due to compression so the AISI no. 304 stainless steel frames were enlarged and a foam teflon gasket was inserted to avoid any metal/glass contacts. As a result of this experience the windows for the NTF will have Invar frames and shall be doubled-beveled.

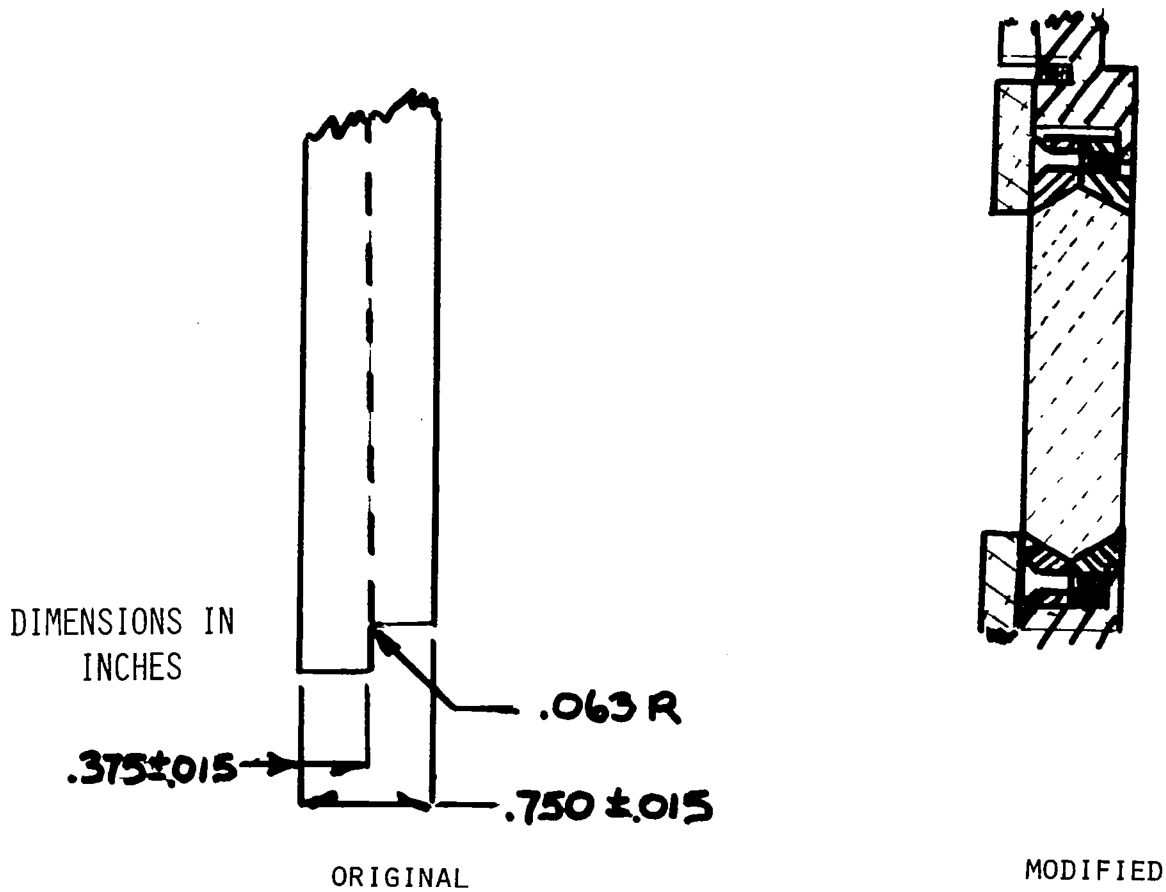


Figure 8

NTF TEST SECTION - TOP VIEW

There is a difference in the pod concept for the 0.3-m TCT and what will be necessary for NTF. Any NTF visualization system will have to be totally in the plenum area. The space constraints are shown in the NTF test section top view (fig. 9). The area that would be available for the protective pods is approximately 12.5 feet by 3 feet. The system can not be placed so as to block access to the test section so it will have to be mobile. The model may be as large as the six foot model shown. Optical access to the test section will be through windows mounted in the test section door, three windows on each side.

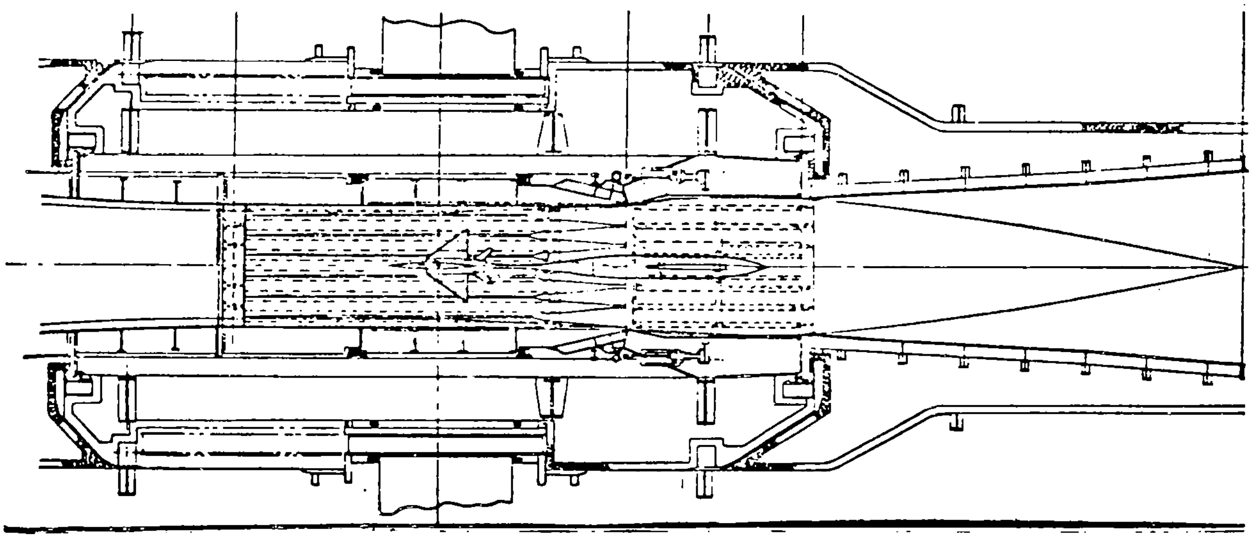


Figure 9

NTF TEST SECTION DOOR - END VIEW

The NTF test section door can have windows mounted in the central area. The door is hinged to move vertically. The area that is located in figure 10 to the left of the door in the plenum is the area available for the flow visualization system. There are about 3.5 feet from the center line through the door to the bottom of the upper "I" beam.

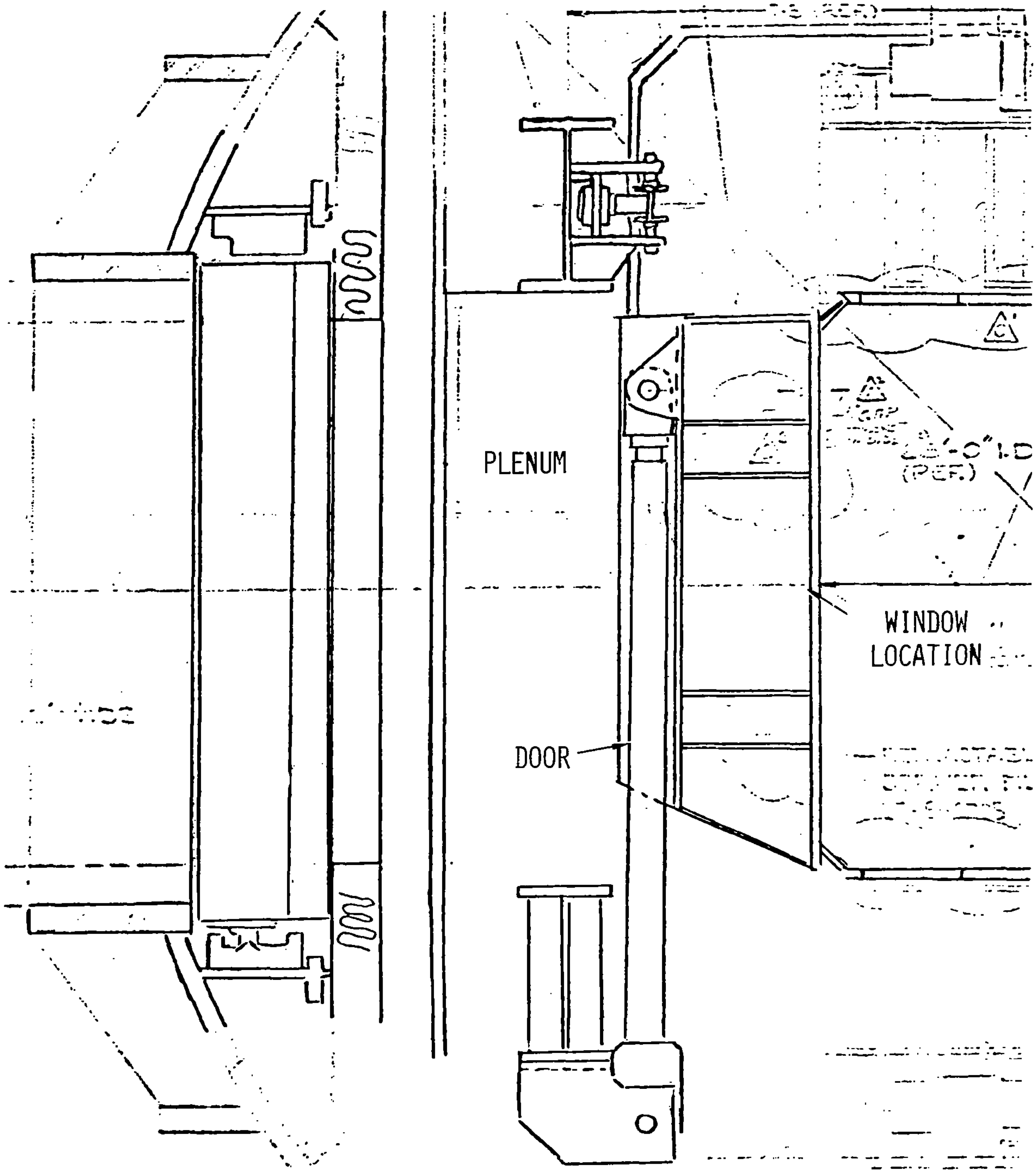


Figure 10

PRELIMINARY NTF SCHLIEREN SYSTEM CONCEPT

A conceptual design for the protective pods for the NTF system is shown in figure 11. The three quartz or fused silica windows are shown in the sides of the test section. The pods contain a 24-inch F/5 system which would allow about 2 feet of the model to be examined at any time. The data would be recorded on video cameras to permit rapid access to the data and avoid problems with the photographic films at cryogenic temperatures.

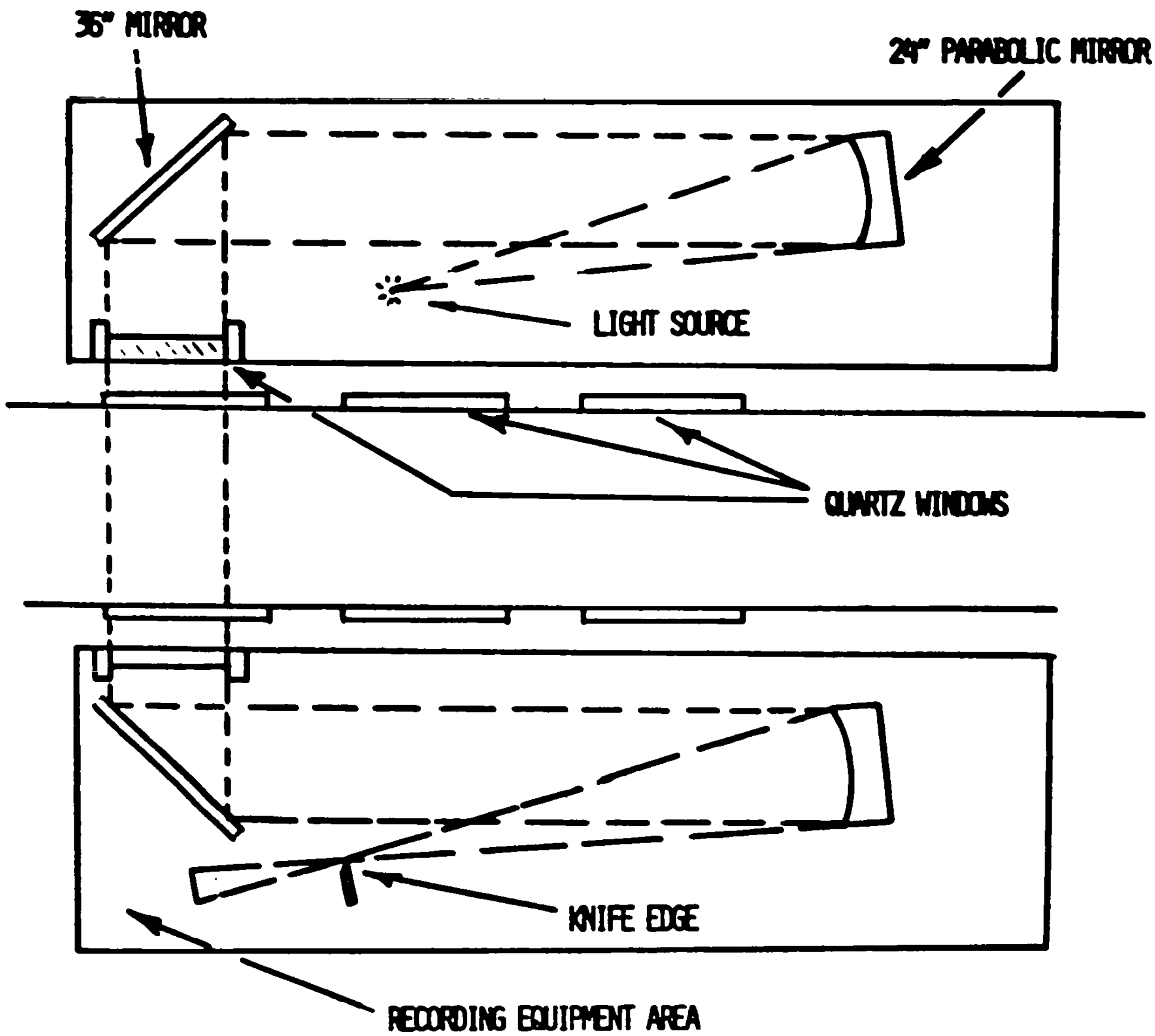


Figure 11

MOIRÉ DEFLECTOMETRY SYSTEM AT 0.3-m TCT

The pods could also be used for another technique that appeared to have promise: the moiré deflectometer (fig. 12). This technique uses the first pod with no changes from the schlieren system as a direct shadowgraph method. Refraction information can be encoded by two grids on the shadowgraph taken in the second pod by the video camera. The relative rotation between the two grids determines the direction and spacing of the resulting moiré pattern. The grid to grid spacing in the collimated light beam determines the sensitivity of the system for a particular grid frequency. In this test the grid frequency was about 2 lines per millimeter (50 lines per inch) and their separation was 131 millimeters. The sensitivity is calculated to be approximately 8×10^{-4} grams-cm^{-4} for a shift of one moiré fringe.

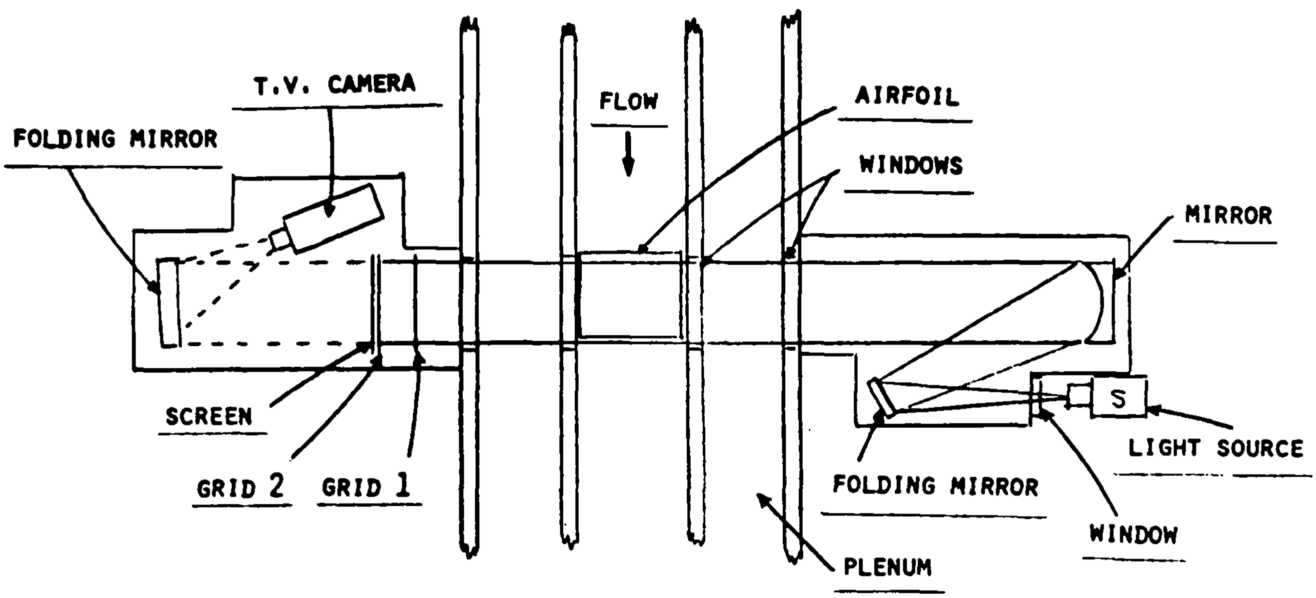


Figure 12

FLOW VISUALIZATION TECHNIQUES

A generalization on the flow visualization techniques we studied is shown in figure 13. The column "simplicity" refers the ease of alignment and setup. The four techniques are shadowgraph, schlieren, interferometry and moiré. The interferometry (holographic) work was done by Al Burner and is covered in his presentation (paper 20 of this compilation). The shadowgraph system is the easiest to set up, least expensive and least sensitive, detecting mainly shocks. The schlieren technique is intermediate in all categories and can detect density gradients. The moiré technique is similar to the shadowgraph in simplicity and cost but has a sensitivity more like a schlieren system.

TECHNIQUE	SIMPLICITY	RELATIVE COST	SENSITIVITY
SHADOWGRAPH	SIMPLE	LOW	LEAST SENSITIVE
SCHLIEREN	INTERMEDIATE	INTERMEDIATE	INTERMEDIATE
INTERFEROMETRY	COMPLEX	EXPENSIVE	MOST SENSITIVE
MOIRÉ	SIMPLE	LOW	INTERMEDIATE

Figure 13

EXAMPLES OF FLOW VISUALIZATION AT 0.3-m TCT

The results of the three flow visualization techniques are shown in figure 14. The model was a NACA 0012 airfoil mounted about half an inch below the window. The angle of attack was 0 degrees, Mach number was 0.85, temperature was 190° Kelvin and the pressure was 30 psi. Flow is from left to right and the midpoint on the 6 inch chord is indicated by the taller line on the moiré photograph. For scale the shorter lines in the photograph are located one inch on either side of the midchord line. The schlieren photo is of lower quality than expected. The video camera maintains a constant current and as the knife edge is introduced the gain is increased and a good gray scale cannot be attained. The shadowgraph shows the heavy shock. The moiré deflectometry pattern remained stable and a shift of almost one fringe was detected through the shock which corresponds to a density gradient of nearly $8 \times 10^{-4} (g/cm^3)/cm$. The preliminary recommendation is for the selection of moiré deflectometry as the best technique for flow visualization at NTF.

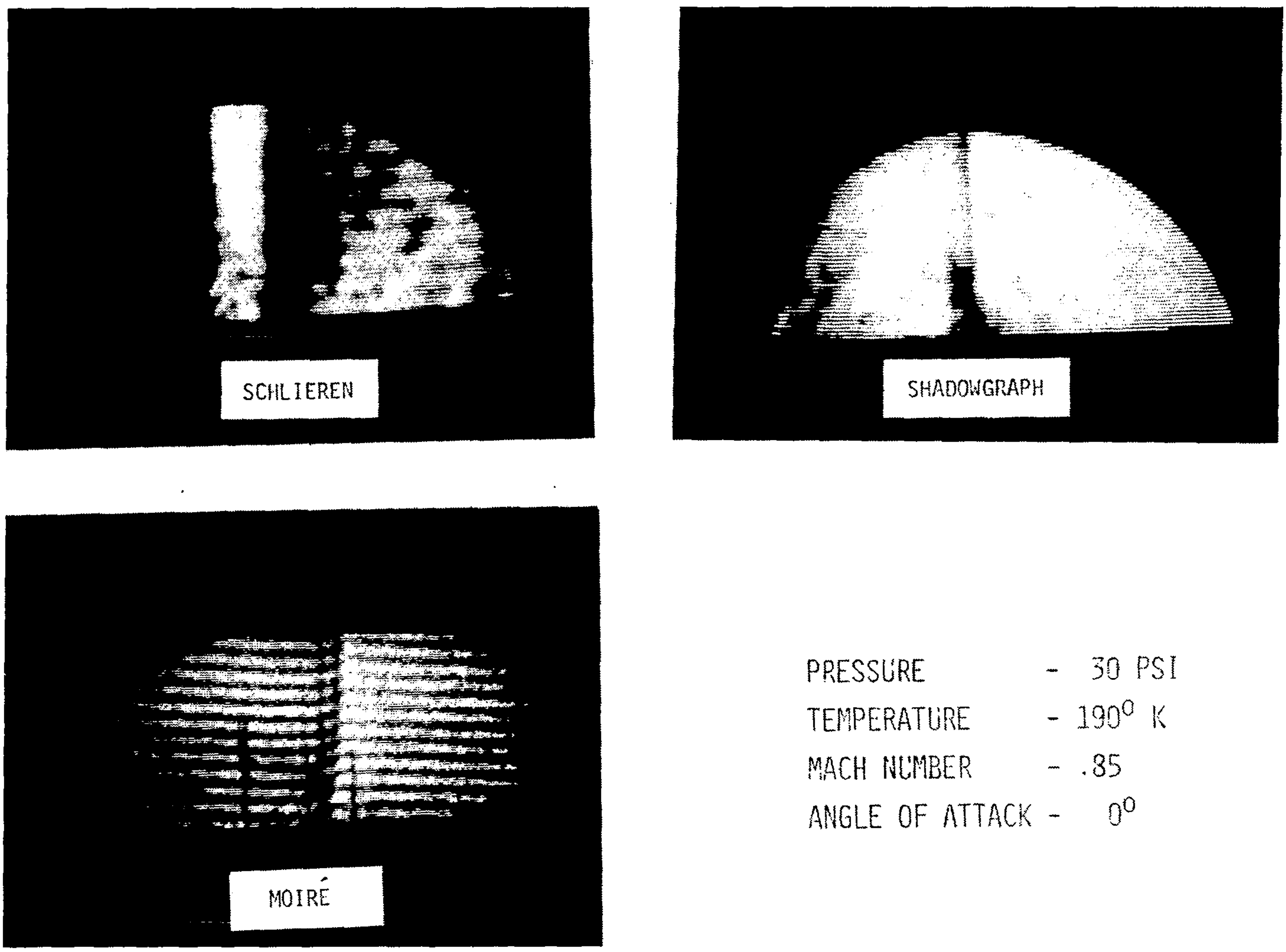


Figure 14