HOLOGRAPHIC FLOW VISUALIZATION AT NASA LANGLEY

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ABSTRACT

Holographic flow visualization systems at two NASA Langley facilities, a hypersonic blow-down tunnel using CF_4 gas and an expansion tube with very short test time, are described. A pulsed ruby laser is used at a CF_4 tunnel for single pulse holography, double pulse with several minutes between exposures, and dual plate holographic interferometry. Shadowgraph, schlieren, and interferograms are reconstructed from the holograms in a separate reconstruction lab. At the expansion tube the short run time of 200 microseconds requires precise triggering of its double pulsed ruby laser. With double pulse capability of 10 to 1200 microseconds pulse separation, one pulse can occur before and one after flow is established to obtain fringe free background interferograms (perfect infinite fringe) or both pulses can occur during flow in order to study flow instabilities. Holograms are reconstructed at the expansion tube with an in-place setup which makes use of a high power CW Argon laser and common optics for both recording and reconstructing the holograms. The holographic systems at the CF_4 tunnel and expansion tube are operated routinely for flow visualization by tunnel technicians. Typical flow visualization photographs from both facilities are presented.

INTRODUCTION

During the past decade holographic interferometry has largely superseded the classical Mach-Zehnder interferometer as the interferometric technique with best potential for measuring density in aerodynamic research facilities. Holographic interferometry is a nonintrusive optical technique which offers the additional capability over conventional interferometry of recording for later reconstruction the flow and no-flow optical fields. It is the interference between these two optical fields which yields fringe shift data necessary for density calculations.

Several variations of holographic interferometry exist. The first method and simplest to be applied to wind-tunnel testing was the double pulse method (1, 2). In the double pulse method both the flow and no-flow recordings are made on the same photographic plate. A disadvantage of the double pulse technique is the inability to conveniently adjust the fringe orientation or spacing after a tunnel run. This adjustment of fringe orientation and spacing is sometimes desirable to aid in analyzing the fringe shift data.

A second variation of holographic interferometry is to record only the no-flow optical field (3). The reconstructed no-flow field is then made to interfere with the real-time flow optical field. Although this technique has the advantage of continuous time resolved data as often required for shock or expansion tubes (4), there is still the inability to adjust fringe spacing and orientation after data is taken.

Still another variation is the recording of the flow and no-flow fields on separate photographic plates (5). A tilt or translation can be introduced between the reconstruction of the flow and no-flow fields to vary the fringe orientation and spacing after the fields are recorded. This technique, sometimes called dual plate holography, has been demonstrated to be a useful tool in aerodynamic research (6, 7).

CF_4 TUNNEL DESCRIPTION

The hypersonic CF_4 tunnel is a blow-down type facility with a maximum run time of 60 seconds. The purpose of using CF_4 as the test gas is to better simulate the real-gas effects on blunt bodies (8). The Mach number of the tunnel ranges from 6.1 to 6.4, depending on temperature and pressure. The test section is a 1.5m diameter tank 1.8m long with 3 cm. thick schlieren quality side windows.

HOLOGRAM RECORDING AT CF_4 TUNNEL

A single pulse ruby laser mounted on a large tripod clamped to the tunnel floor for stability is used to record the holograms. A Pockels cell Q-switches the laser to produce up to 50 millijoules of energy with a pulse half-width of 20 nanoseconds at 6943Å. An intracavity aperture and etalon ensure good spatial and temporal coherence of the emitted radiation.

Remote charging, capacitor dump, and firing controls for the laser are located in the tunnel control room so that the laser can be manually fired by the tunnel operator at the proper time during flow. A key interlock prevents accidental firing of the laser from the control room while personnel are working in the tunnel room. A 6 milliwatt He-Ne alinement laser is positioned on the tripod behind the ruby laser on precision rotation and translation stages to facilitate alinement of the interferometer system. A capping shutter between the He-Ne and ruby lasers protects the He-Ne laser during ruby laser firings. Collinearity of the ruby and He-Ne beams is ensured by passing the He-Ne beam through the intracavity aperture and then centering the beam on a spot burned by the ruby laser on a piece of film located about 4 meters from the ruby laser.

The basic optical layout (9) consists of a large diameter (40 cm) scene beam which passes through the test section and a reference beam which passes over the test section and is not expanded until just before intersection with the scene beam at the hologram plane (figure 1). The conventional off-axis Z-arrangement used previously for white light schlieren applications at the tunnel forms the scene beam. The distance from the beamsplitter to the holograms is 15 meters. The hologram plate holder which is mounted on a large tripod clamped to the floor can be translated vertically between exposures in order to introduce horizontal reference fringes when double pulse holographic interferometry is used. For dual plate holographic interferometry a separate no-flow hologram is made either before or after the run. All of the optics except the lasers and holograms are mounted from a large movable beam which traverses the tunnel.

HOLOGRAM RECONSTRUCTION LAB

A separate lab containing a 50 milliwatt He-Ne and a one watt argon laser is used for reconstructing the holograms to obtain shadowgraph, schlieren and interferograms of the flow field. The reference beam-to-hologram recording geometry is duplicated during reconstruction by enlarging the beam with a 50 mm beam expander and directing the enlarged reconstruction beam at the hologram at the same angle as for recording. Collimation is checked with a shearing plate interferometer (10) for both recording and reconstruction of the holograms. The relative positions of the no-flow and flow holograms can be varied with a dual plate positioner (6) in order to generate interferograms with the desired fringe spacing and orientation. Photographs of the reconstructions are made with a 20 x 25 cm view camera and a low power biconvex lens used to image the model onto the film plane. A 10 x 13 cm camera back is also available for instant photographs and ease of enlargement to sizes greater than 20 x 25 cm. Both lens and film back can be adjusted independently. A razor blade mounted on a positioner is used at either the horizontal or vertical beam focus for schlieren.

EXPANSION TUBE DESCRIPTION

The expansion tube consists of a driver or high pressure chamber, an intermediate chamber which is evacuated and filled with the desired test gas, and an expansion or acceleration chamber (11). A single or double high-pressure primary diaphragm apparatus separates the driver and intermediate chambers. A low pressure secondary diaphragm separates the intermediate and expansion chambers. The secondary diaphragm can be removed to operate the facility as a conventional shock tube. The pressures in the chambers are adjusted to give the desired simulated environment. The bursting of the primary diaphragm causes a shock wave to propagate downstream which, in turn, bursts the secondary diaphragm. A new shock wave followed by the test gas then propagates downstream. Test gases include air, He, H_2, N_2, O_2, A , Ne, CO_2, CF_4, and C_2F_6. Models placed in a downstream dump tank are observed through 8.2 cm thick schlieren quality windows. Expansion tube run times are typically about 200 microseconds.

HOLOGRAM RECORDING AT THE EXPANSION TUBE

The ruby laser used to record holograms at the expansion tube can be either singly or doubly pulsed with pulse separations of from 10 to 1200 microseconds. (Other characteristics of the laser are similar to those of the single pulse ruby laser already described.) If one pulse occurs before and one 150 microseconds later after flow is established the hologram will produce upon reconstruction an infinite fringe interferogram free from residual background fringes. These residual background fringes (or distortions in reference straight line fringes) can occur if the ambient refractive index fields differ between exposures as may occur for exposures several minutes apart. If the two pulses both occur after flow is established then flow instabilities between the time of the two pulses can be studied.

Remote charging and dump controls for the laser are located in the facility control room. The laser is triggered during a run from a thin-film gauge which detects shock arrival 4 meters upstream of the model to allow time for energy pumping by the laser flashlamp. The laser pulse or pulses are detected with a photodiode located at the edge of the scene beam. The photodiode time history is compared with a pressure transducer history located close to the model to determine the time of laser firings relative to shock arrival at the model.

The basic optical layout at the expansion tube is similar to that already described for the CF_4 tunnel except that 2.5 cm thick aluminum tables support the ruby laser and most of the optics. These tables provide additional setup flexibility as well as increased stability when compared to the setup at the CF_4 tunnel. The table on the hologram side of the setup also supports a one watt argon laser which is used for in-place reconstruction of the holograms.

HOLOGRAM RECONSTRUCTIONS AT THE EXPANSION TUBE

To reconstruct the holograms at the Expansion Tube a mirror is placed in the reference beam to direct the argon laser beam into the expanding and collimating optics used to record the hologram. Film backs (10 x 13 cm and 20 x 25 cm) are arranged in a folded configuration to permit varying magnifications. The reconstruction laser beam path is enclosed for safety so that reconstructions can be viewed and photographed with the overhead room lights on. The in-place film backs have also been used during a run to record laser schlieren on infrared film simultaneous to the holographic recording. Knife-edge cut-off and focus are set using the He-Ne alinement laser prior to the run. An interference filter is used in front of the infrared film to prevent test section after-glow from fogging the film.

FLOW VISUALIZATION EXAMPLES

The technique used most often at the two facilities has been dual plate holography (6). In dual plate holography separate flow and no-flow holograms are made. By varying the relative position of the two plates upon reconstruction the reference fringe spacing and orientation of the interferograms can be altered. Schlieren and shadowgraph can be reconstructed from the flow hologram alone.

The flow and no-flow holograms record the flow and no-flow scene beams as separate spherical waves which to first order converge to points behind the hologram. Hence the generation of interference fringes by two point sources (12) can be used to describe the formation of the reference fringes in dual plate holography. If the plates are adjusted such that the flow and no-flow point sources are separated normal to the viewing screen then circular fringes are seen. If the two point sources are separated in a plane parallel to the viewing screen then to first order straight line reference fringes are seen which are perpendicular to the line connecting the two sources. The fringe spacing is given by $(\lambda Z)/D$ where λ is the wavelength, Z is the distance from the plane containing the point sources to the viewing plane, and D is the spacing of the point sources. Curved fringes are observed for other point source geometries. For plane wave illumination the reconstructed point source will translate with the same magnitude and in the same direction as the hologram is translated. For example, to generate straight line horizontal reference fringes the two holograms must be separated vertically from their positions where the two reconstructed point sources coincide.

The interferograms can also be reconstructed and reference fringes varied without moving the two holograms. This type reconstruction is sometimes called Sandwich Holography (13). Since reconstructions are normally at a lower wavelength than that used for recording, the reconstruction beam must be slightly converging to ensure that the two reconstructed point sources are in the same image plane. Reference fringe orientation and spacing can then be altered by varying the angle of incidence of the reference beam.

Figure 2 is a horizontal knife-edge holographic schlieren made at the CF_4 tunnel of a 60° half-angle cone with a 1.27 cm nose radius at 0° angle-of-attack. Free stream density was 0.024 Kg/m^3.

A dual plate interferogram for the same run is shown in figure 3. A different orientation of the reference fringes is shown for the same run in figure 4. A plot of density increase behind the shock versus distance from the model axis for this run is shown in figure 5. The plane of evaluation was 3cm. behind the nose of the model. A standard technique for axisymmetric flows which uses an approximation to the Abel inversion of the fringe shift equation (14) was used to compute the density from the measured fringe shift. The overshoot at the shock is caused by this computational scheme.

Figure 6 illustrates a double pulse interferogram of another conical model in which the pulses are separated by several minutes. Either the hologram or another part of the setup is shifted slightly between exposures to generate straight line reference fringes. For finely spaced fringes the two reconstructed flow and no-flow point sources from the double pulse hologram are separated sufficiently such that a knife-edge can be used to block the no-flow point source and hence obtain schlieren. Figure 7 is a schlieren obtained from the double pulse hologram used to make figure 6.

Figure 8 was made from a low contrast double pulse hologram. Due to variations in laser parameters between exposures the no-flow reconstruction from the hologram was noticeably brighter than the flow reconstruction. By placing the proper neutral density filter in the no-flow point source reconstruction the contrast was enhanced (figure 9). Note also that there is a very slight shift of the reference fringes when comparing figures 8 and 9. Hence a similar technique of introducing various thicknesses of filters in either the flow or no-flow point source reconstructions can be used to shift the reference fringes slightly to generate more fringe-crossing data from a double pulse hologram than is normally available.

Figures 10, 11, and 12 are examples of schlieren, horizontal reference fringe and infinite fringe interferograms of a flat-face cylinder model in the expansion tube. The three photographs were made from the same flow hologram. For the two interferograms a no-flow hologram was used with the flow hologram to generate dual plate interferograms. Figure 13 is a double pulse interferogram of the same model under similar run conditions. The first laser pulse occurred just before shock arrival and the second pulse occurred 150 microseconds later after flow was established. Note the absence of residual fringes in the freestream (compare to figure 12).

For the shadowgraph of figure 14 the expansion tube was operated as a shock tube which resulted in higher density levels. The model is a 20° half-angle wedge. The primary shock had not left the field-of-view when the laser fired. In figure 15 a no-flow hologram is used with the flow hologram of figure 14 to form a dual plate interferogram.

Figure 16 shows a double pulse holographic interferogram of the flow about an 80° half-angle cone for a high density shock tube run.

FUTURE WORK

Presently at Langley various fringe shift readup techniques are being investigated to determine a suitable technique for routine interferogram data analysis. Future work at the expansion tube includes the installation of a continuous wave laser schlieren system to obtain time resolved flow visualization with a high speed framing camera which will be used in conjunction with the pulsed laser system. Plans have also been made to install a holographic interferometer at a third facility for 2-D airfoil testing. For 2-D flows the density can be computed directly from the fringe shift with no need to invert the integral fringe shift equation as required for 3-D flow fields. This inversion of the fringe shift equation causes the fringe shift data to be differentiated and hence the density computation for 3-D flows is affected more by scatter of the fringe shift data than for 2-D flows.

CONCLUSION

Holographic flow visualization systems presently in operation at two NASA Langley facilities have been described. The systems have the capability for interferometric measurements which in some cases yield the density flow field about a model. Examples of shadowgraph, schlieren, and interferograms have been presented. A simple first order model of dual plate holography based on the generation of interference fringes between two point sources has been discussed. The ability to increase contrast, shift reference fringes and obtain schlieren from double pulse holograms has been demonstrated.

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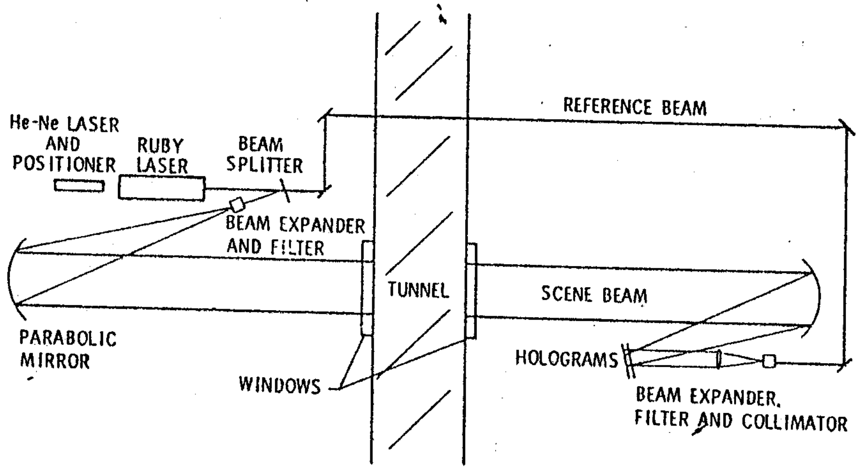

Figure 1 - Holographic setup at CF_4 tunnel.

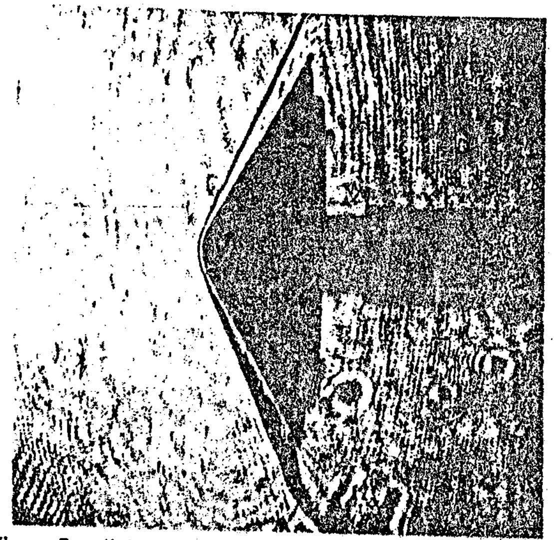

Figure 2 — Holographic schlieren using horizontal knife-edge.

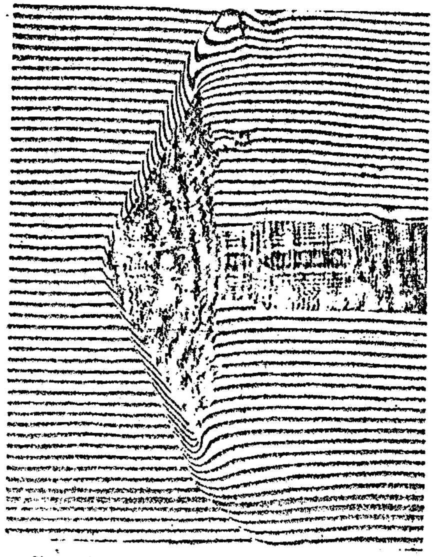

Figure 3 – Dual plate holographic interferogram adjusted for horizontal fringes.

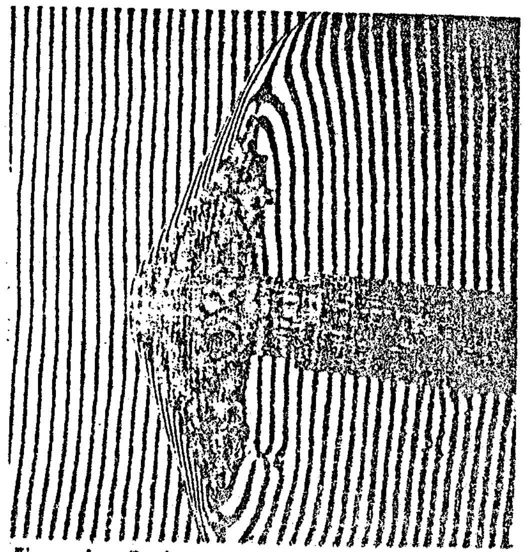

Figure 4 — Dual plate holographic interferogram adjusted for vertical fringes.

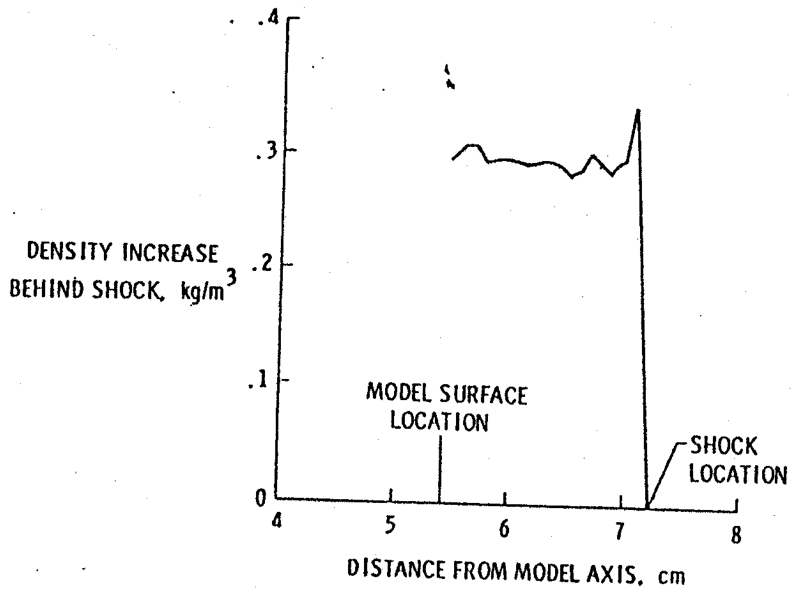

Figure 5 - Density plot.

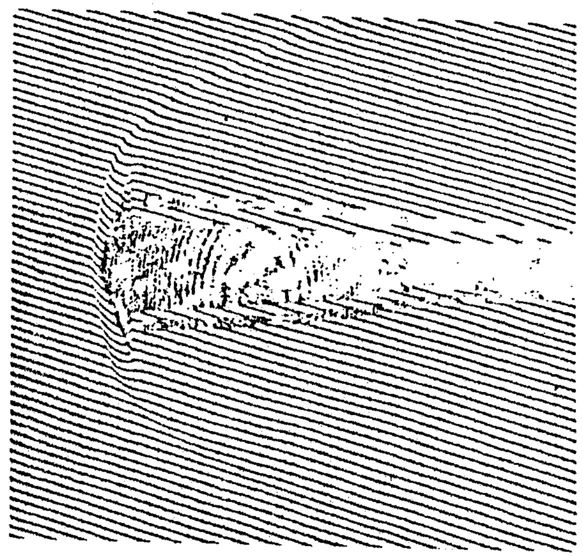

Figure 6 - Double pulse holographic interferogram.

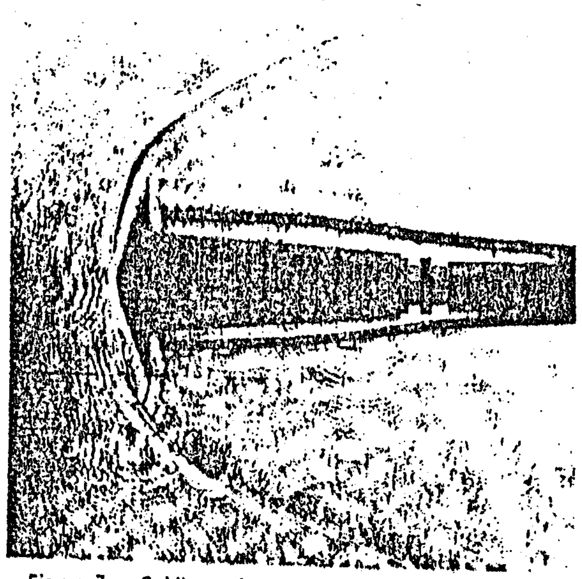

Figure 7 – Schlieren from double pulse interferogram.

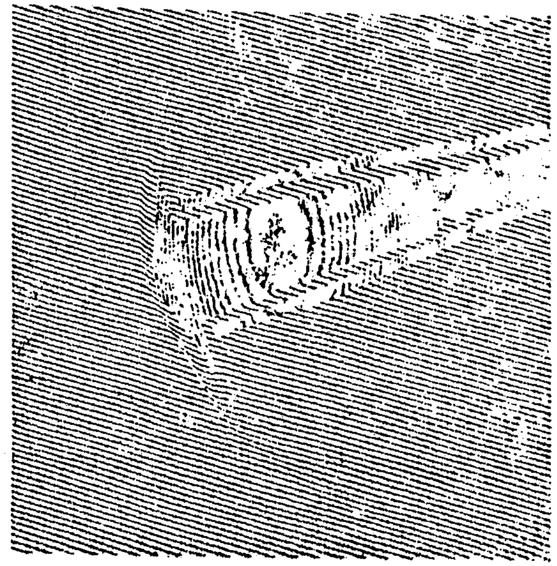

Figure 8 - Low contrast double pulse holographic interferogram.

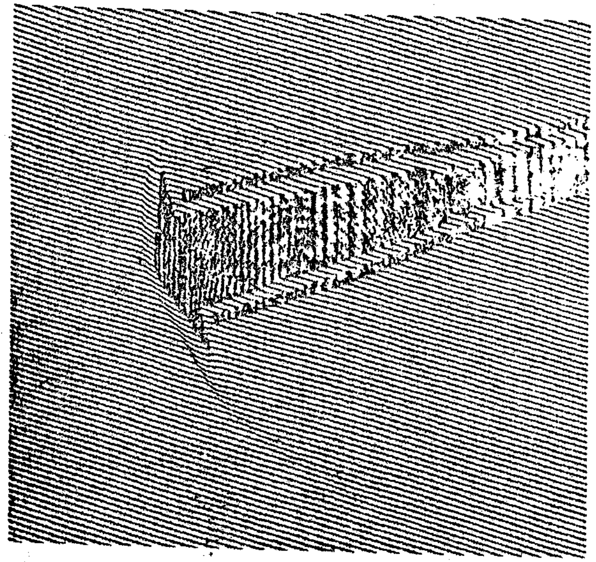

Figure 9 — Double pulse interferogram after contrast enhancement.

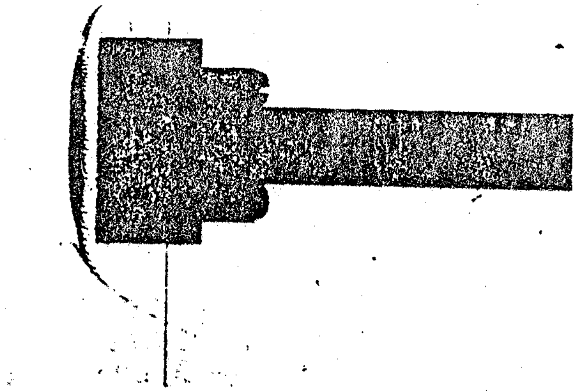

Figure 10 — Holographic schlieren using vertical knife-edge.

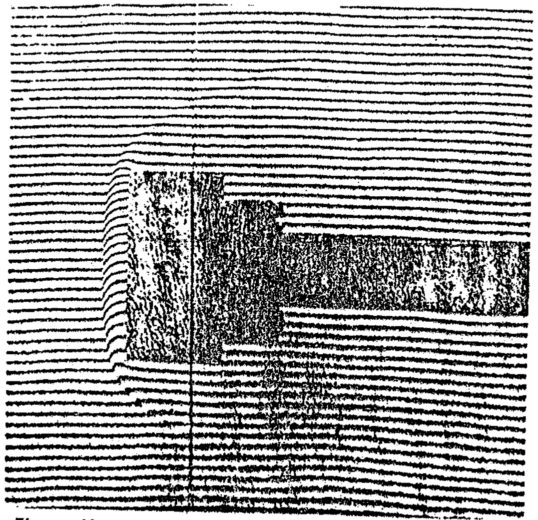

Figure 11 — Dual plate holographic interferogram adjusted for horizontal fringes.

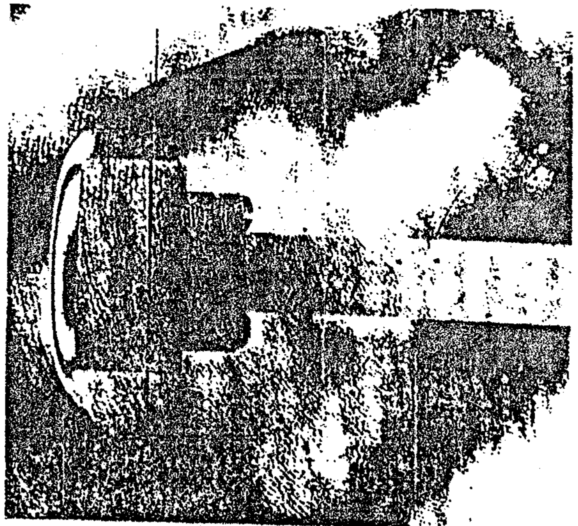

Figure 12 — Dual plate holographic interferogram adjusted for infinite fringe.

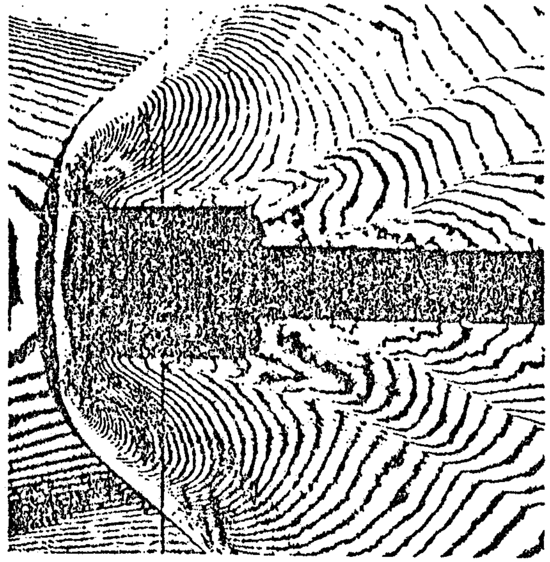

Figure 16 – Double pulse holographic interferogram.

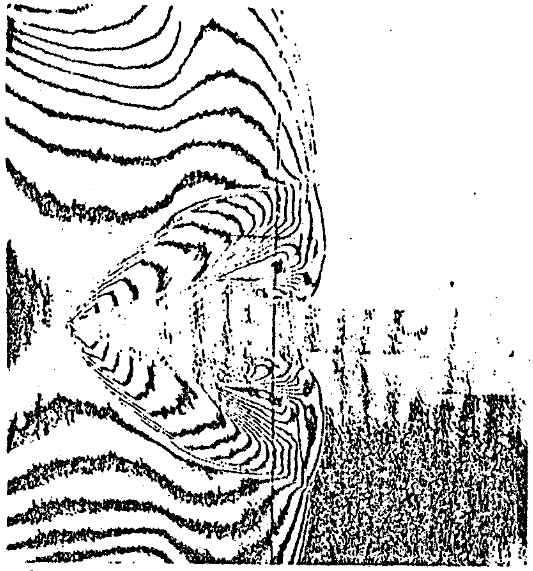

Figure 15 – Dual plate holographic interferogram.

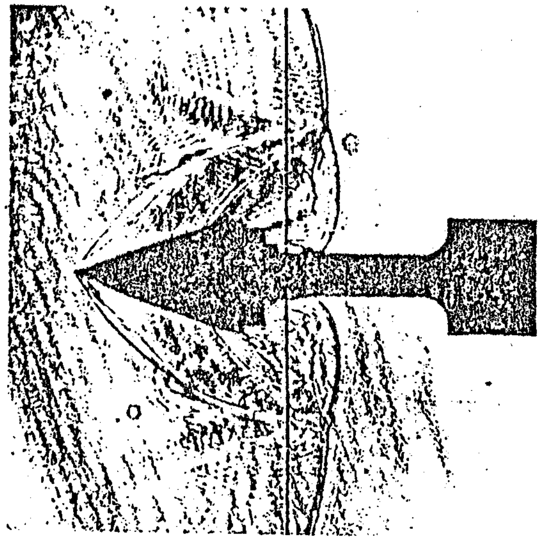

Figure 14 – Holographic shadowgraph.

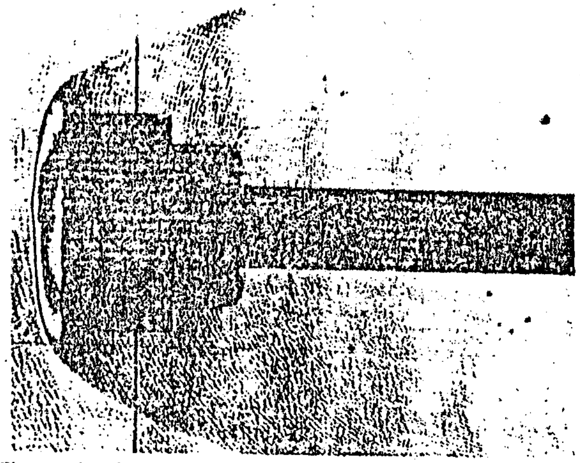

Figure 13 - Double pulse holographic interferogram with 150 microseconds pulse separation.