FLOW VISUALIZATION TECHNIQUES

IN THE AIRBORNE LASER LABORATORY PROGRAM

by

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I INTRODUCTION

The design and testing of a three-dimensional structure, such as a turret/fairing assembly for laser applications, is a complex empirical problem. The attendant flow field is characterized by large scale turbulent structures, which are difficult to map without some form of flow visualization.

Toward this end, wind tunnel testing has been done in the Airborne Laser Laboratory (A.L.L.) program, using flow visualization techniques. The techniques used have included the methods of tufting, encapsulated liquid crystals, oil flow, sublimation and schlieren and shadowgraph photography.

The results have been directly applied to the design of fairing shapes for minimum drag and reduced turret buffet. In addition, the results are of primary importance to the study of light propagation paths in the near flow field of the turret cavity. Depending on the cavity azimuth and elevation angles this can involve a propagation path through shock patterns, separated flow regions, shear layers, or a combination of all three.

Therefore, the flow in the vicinity of the turret is an important factor for consideration in the design of suitable turret/fairing or aero-optic assemblies.

This presentation is in chronological order of wind tunnel tests. The different methods of flow visualization for each test are listed and discussed based on accompanying photographic figures.

SECTION II

RESULTS AND DISCUSSION

a. The first wind tunnel test covered in this presentation was termed the "Transonic Ten Pin Phase I Test" conducted in the Air Force Flight Dynamics Laboratory/Trisonic Gasdynamics Facility (hereafter referred to as AFFDL/TGF) from September to December, 1971.[1]

The flow visualization techniques used consisted of tufting and the use of encapsulated liquid crystal. Tuft results (Fig. 1) for Mach numbers (M_∞) of 0.55 and 0.60 indicate a large turbulent wake behind the on-gimbal turret, extending downstream beyond the right hand edge of the photographs. The tufts on the nose of the model are lying flat and unperturbed indicating a region of steady attached flow. Those farther downstream and not within the wake region are in unsteady motion indicative of a turbulent boundary layer.

The use of encapsulated liquid crystals (temperature sensitive material) to detect boundary layer transition and regions of high heat transfer (turbulent flows) is shown in figure 2. Warmer temperatures are revealed by blue-green color variations and cooler temperatures by red shades. A grit strip was applied to the nose of this particular model and existence of the resultant turbulent boundary layer is shown by the blue-green shades of the strips.

b. The next test covered was referred to as the "AMES I Test" conducted in the NASA Ames Research Center 14 ft wind tunnel during January and February, 1972.[2]

A shadowgraph is shown in Figure 3. The view is looking down on the turret with the turret cavity oriented 120 degrees downstream from the wind axis. A multiple shock system is apparent on the turret at an azimuth

angle of 80 degrees. The formation of this shock system is dependent on the cavity azimuth angle (Fig. 4).

c. Now we turn to a different test and a lesser practiced form of flow visualization. The test was called "Transonic Ten Pin Phase II" and was run in the AFFDL/TGF during May through August, 1972.[3] The flow visualization method used was sublimation of freon crystals. A timed sequence of photographs (Fig. 5) taken of an on-gimbal turret on a flat plate shows the areas where higher heat transfer rates occur. By definition these areas include the characteristic vortices on the turret and those shed from the turret/flat plate intersection.

Included in the flow visualization techniques for this test were oil flow and schlieren photography. Figure 6 is a schlieren photograph of an on-gimbal turret on simulated aircraft fuselage at $M_\infty = 0.90$. Due to the large model frontal area to test section area the flow is choked as evidenced by the strong shocks on the model nose and on the aft section of the model. Also evident in this schlieren are the turret turbulent wake and the buildup of the fuselage boundary layer.

The same configuration at the lower Mach number of 0.75 is shown in Figure 7 along with an oil flow at the same conditions. The flow features discussed in the last figure are still there only the shocks are weaker. The turret shock and resultant separation is confirmed by the oil flow which abruptly ends at mid turret. Several vortices on the turret appear as well as the large vortex behind the turret. This large vortex is just one of a pair of counter-rotating vortices that exist behind the turret. As will be seen later this vortex pair rapidly gives way to fully turbulent flow within three turret diameters downstream of the turret.

d. The technique of spraying oil on a model, as opposed to painting, was used at the Air Force Academy's Transonic Wind Tunnel during September, 1972.[4] The objective of this test was to develop minimum drag fairings. Oil flow visualization was used to map separated flow regions which contribute to the overall drag of the configuration. The fairing designated VK-6 (Fig. 8) shows some separation at the rear of the fairing as with all aft fairing designs. The aft portion of the turret is also in separated flow as is again the case with most turret/fairing assemblies.

e. Another entry into the Ames 14 ft wind tunnel with the same turret was termed the "Ames II Test" conducted from October to November, 1972. In this test the visualization technique of oil flow was applied. Figure 9 shows a turret/fairing combination designed by General Dynamics referred to as the full forward and partial aft fairing. The fence apparatus on the full forward portion of the fairing was designed to produce fully turbulent flow over the turret and eliminate adverse acoustic phenomena within the turret cavity. The oil was applied by a spray technique which resulted in a uniform "speckling" of the model surface. Hence, any separated flow regions would remain speckled and those of attached flow would streak. As can be seen the entire cutout region is in separated flow except for a small portion of the turret crown. Otherwise flow on the fairing is attached.

An AFFDL design (Fig. 10) named the FDL T-2 fairing consisting of a turret with rear fairing only was also tested. Again the cutout region (this time symmetrical) is in separated flow. Flow on the turret itself separates at mid turret. As seen in the previous shadowgraph a shock is located in this region. Therefore we can attribute flow separation to a shock-boundary layer interaction.

f. The Air Force Academy was used in January, 1976 for testing of a different fairing concept now being flown on the A.L.L. KC-135 aircraft (Fig. 11). This involved a fairing designed with simple geometric shapes that was both higher and wider than the turret irself. The objective behind this was to obtain a more definite flow reattachment after separation from the turret. The reattachment point now occurs within the cutout region between the turret and fairing. It is interesting to note the effect that turret cavity orientation has on the reattachment point. On the cavity side reattachment is delayed, while on the non-cavity side reattachment is early. Also evident from this figure are the characteristic separation at the fairing rear as well as the diverging wake of the turret/fairing assembly.

g. Returning to the NASA Ames 14 ft wind tunnel for further A.L.L. Cycle III/IV tests during October, 1976 we see the use of tufts on a 3/10ths scale model mounted to a flat plate (Fig. 12).[5] The unsteady flow in the cutout region is evident from the blurred images of the tufts, indicating several oscillations of the tufts within the camera exposure time setting. The flow is attached and smooth further back on the fairing. A composite sketch (Fig. 13) of two photographs reveals the attached flow on the rear of the fairing and on the forward portion of the turret.

h. In December of 1977 the full scale on-gimbal turret plus Cycle III/IV fairing was flight tested at Edwards Flight Test Center in California. Flow visualization consisted of tufting the turret, fairing and a large portion of the fuselage.[6] Photographs (Fig. 14) were then taken from a chase plane. These reveal a significant region of unsteady flow in the turret/fairing cutout. The tufts in this region have either been removed or frayed due to the violent unsteady flow.

In 1978 during a flight from Kirtland AFB, New Mexico to Wright-Patterson AFB, Ohio some oil flow studies were performed on the turret/fairing assembly (Fig. 15). The flow patterns correspond well with small scale oil flows. However, flow details are not apparent due to the higher viscosity oil used and its sparse application. A closeup of the cutout region (Fig. 16) shows attachment only one turret diameter downstream from the fairing leading edge.

i. The A.L.L. Cycle III/IV fairing was used in conjunction with a similar on-gimbal turret in a test in support of the B-52 Short Range Applied Technology (SRAT) program. The test was conducted during August-September, 1978 in the AFFDL/TGF.[7] Oil flow studies were made with the turret/fairing assembly mounted just upstream of the large vertical stabilizer (Fig. 17). Flow patterns on the turret and fairing are similar to previous ones. The only observable differences are a spreading of the turret/fairing wake and larger flow separation at the rear of the fairing/fuselage juncture.

j. Finally a test was run from April to May, 1979 in the AFFDL/TGF in support of the Advanced Airborne Demonstrator (AAD) program.[8] Flow visualization was by oil and detailed photographs were obtained. An interesting look at the flow about an on-gimbal turret mounted to fuselage (Fig. 18a) shows the double vortex pattern behind the turret. The turret cavity is at 60 degrees azimuth to the wind axis, hence the downstream location of the lower vortex member. Separation on the turret is distinct as well as the wake formation and spreading. The coelostat turret (Fig. 18b) exhibits the same flow patterns except for the location of the vortex pair on the turret itself and a less divergent wake.

The coelostat turret plus an aft fairing (Fig. 19a) with cutout region and small radius leading edges show the retention of the vortex pair. In

addition flow separation off of the leading edges and at the rear of the fairing exists. Partially filling the cutout region (Fig. 19b) and increasing the radii of the leading edges eliminates flow separation. However, there still is separation at the fairing trailing edge.

III CONCLUSION

Although all six methods of flow visualization have been used in the A.L.L. wind tunnel testing program it is perhaps easy to state that the most useful, in terms of the amount of information gained as well as the minute flow details revealed, have been the oil flow and schlieren photography. Tuft studies are helpful but too coarse to reveal the small detail of any large scale structures. Their use should be restricted to determining separated flow regions and unsteady flow regions.

Encapsulated liquid crystal use should probably be restricted to determination of transition location and shock location.

Sublimation techniques, again being of a coarse nature, are best used to reveal the location of regions of high heat transfer as in vortices.

Shadowgraph photography produces results identical to schlieren photography but its application is more restricted than that of schlieren.

Finally oil flow and schlieren photography are easy methods to apply. Large quantities of data can be collected by these methods and the flow details are exceptionally clear.

REFERENCES

1. Van Kuren, J.T. and Golden, W.J. "Transonic Ten Pin Test Phase I - Basic Flow Studies and Preliminary Propagation Results, "AFFDL-TM-75-87-FX, December, 1972 revised June, 1975.

2. Van Kuren, J.T. and Otten, L.J., "Acoustic Phenomena of Open Cavity Airborne Cassegrainian Telescopes, "AFFDL-TM-73-54-FX, May, 1973.

3. Van Kuren, J.T. and Conner, W.R., "Transonic Ten-Pin Test Phase II-Configuration Studies and Open Port Pressure Fluctuations, "AFFDL-TM-73-159-FXM, September, 1972.

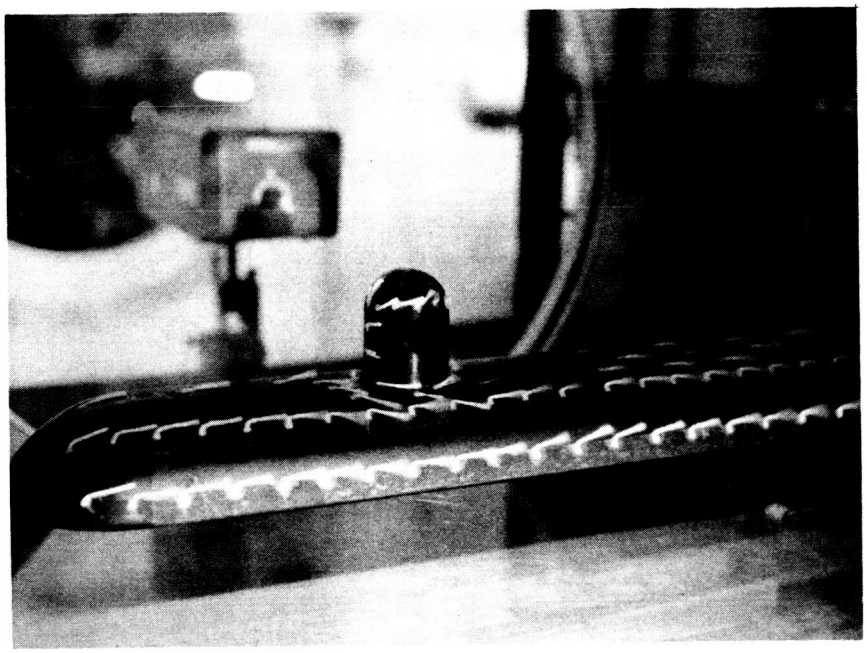
4. Van Kuren, J.T. and Conner, W.R.,"Fairing Design for Fuselage Mounted Turret in Transonic Flow, "AFFDL-TM-73-115-FXM, September, 1973.

5. Van Kuren, J.T., Unpublished Data.

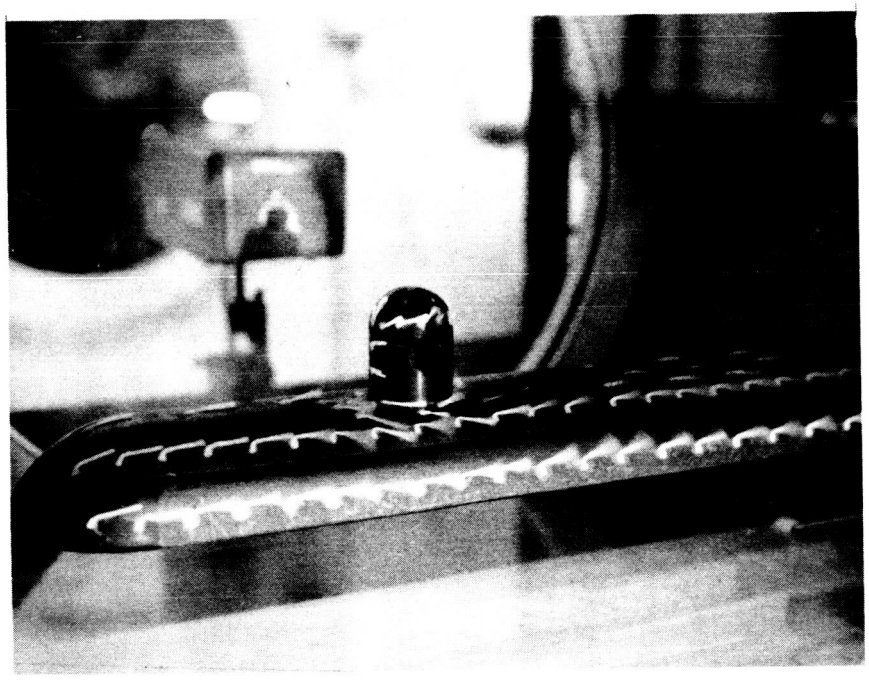
6. Otten, L.J., Unpublished Data.

7. Thomas, J.P., "Test of Turret/Fairing Configurations for the B-52 SRAT Program", AFFDL-TM-FXM-79-21, February, 1979.

8. Walterick, R.E., Unpublished Data.



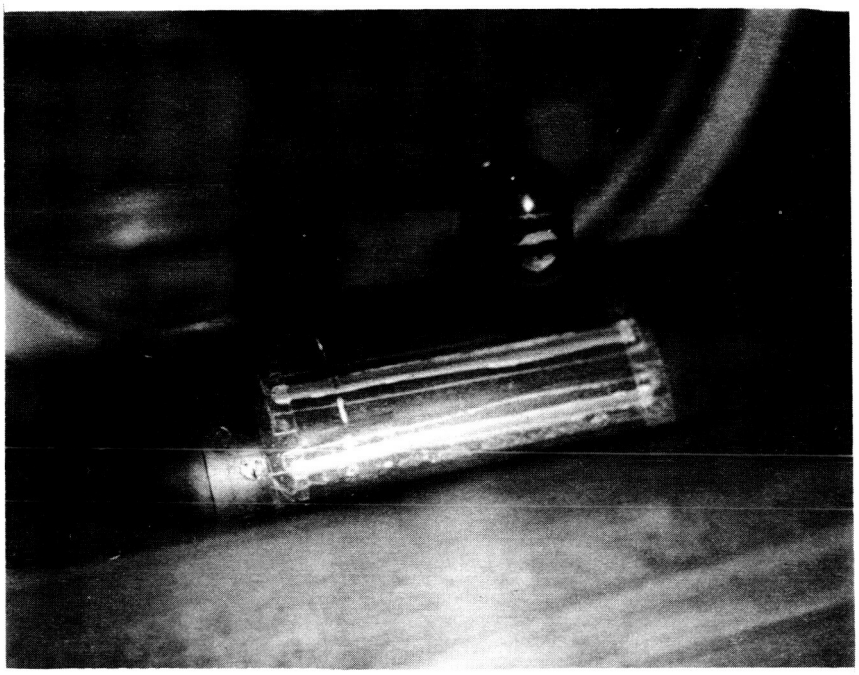
$M_\infty = 0.55$



$M_\infty = 0.60$

FIGURE 1
ON-GIMBAL TURRET TUFT FLOW

$M_\infty = 0.55$



$M_\infty = 0.65$

FIGURE 2
ON-GIMBAL TURRET LIQUID CRYSTAL RESULTS

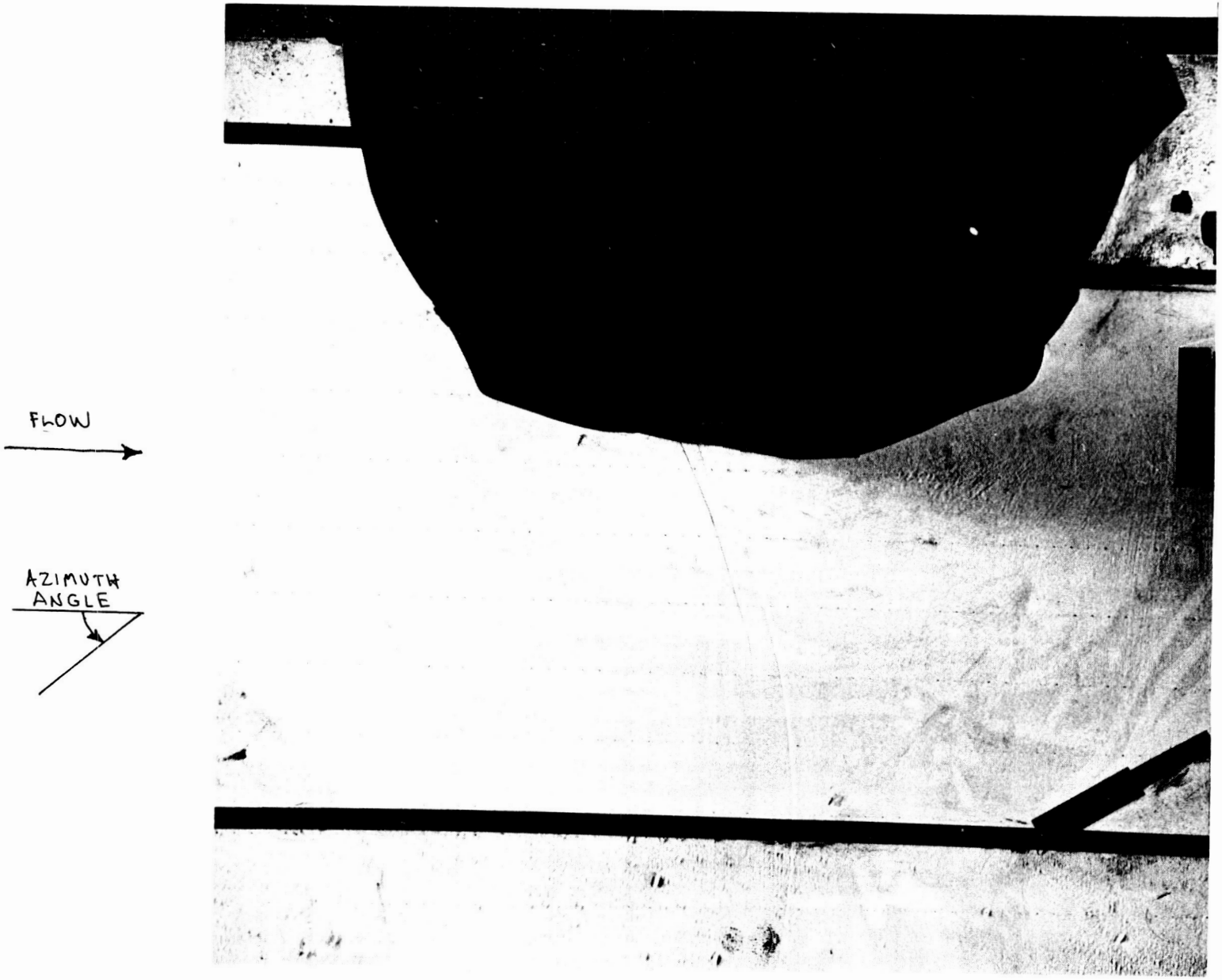


FIGURE 3
ON-GIMBAL TURRET SHOCK PATTERN, $M_\infty = 0.75$

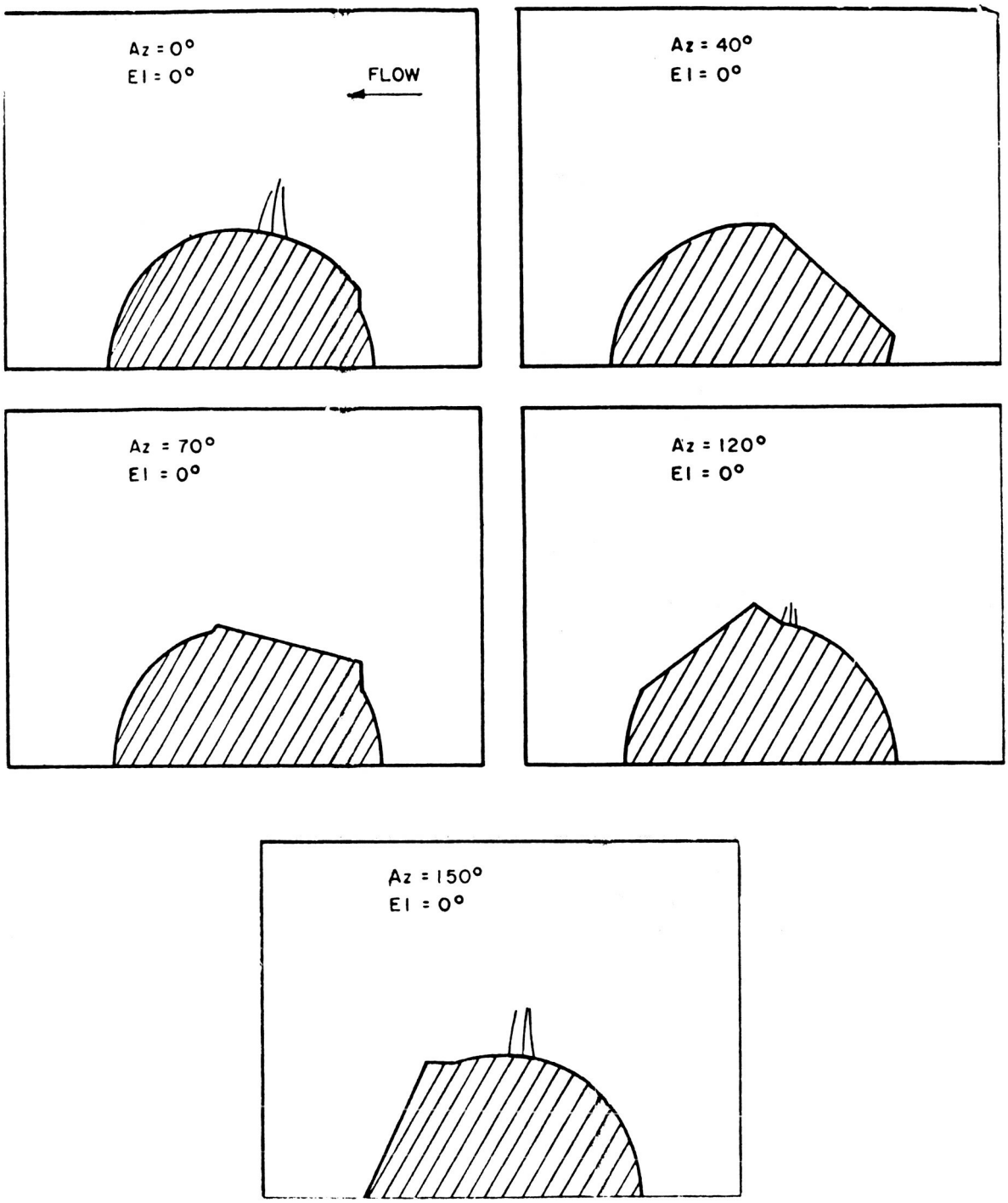


FIGURE 4

ON-GIMBAL TURRET SHOCK PATTERN
VARIATION WITH AZIMUTH ANGLE, $M_\infty = 0.75$

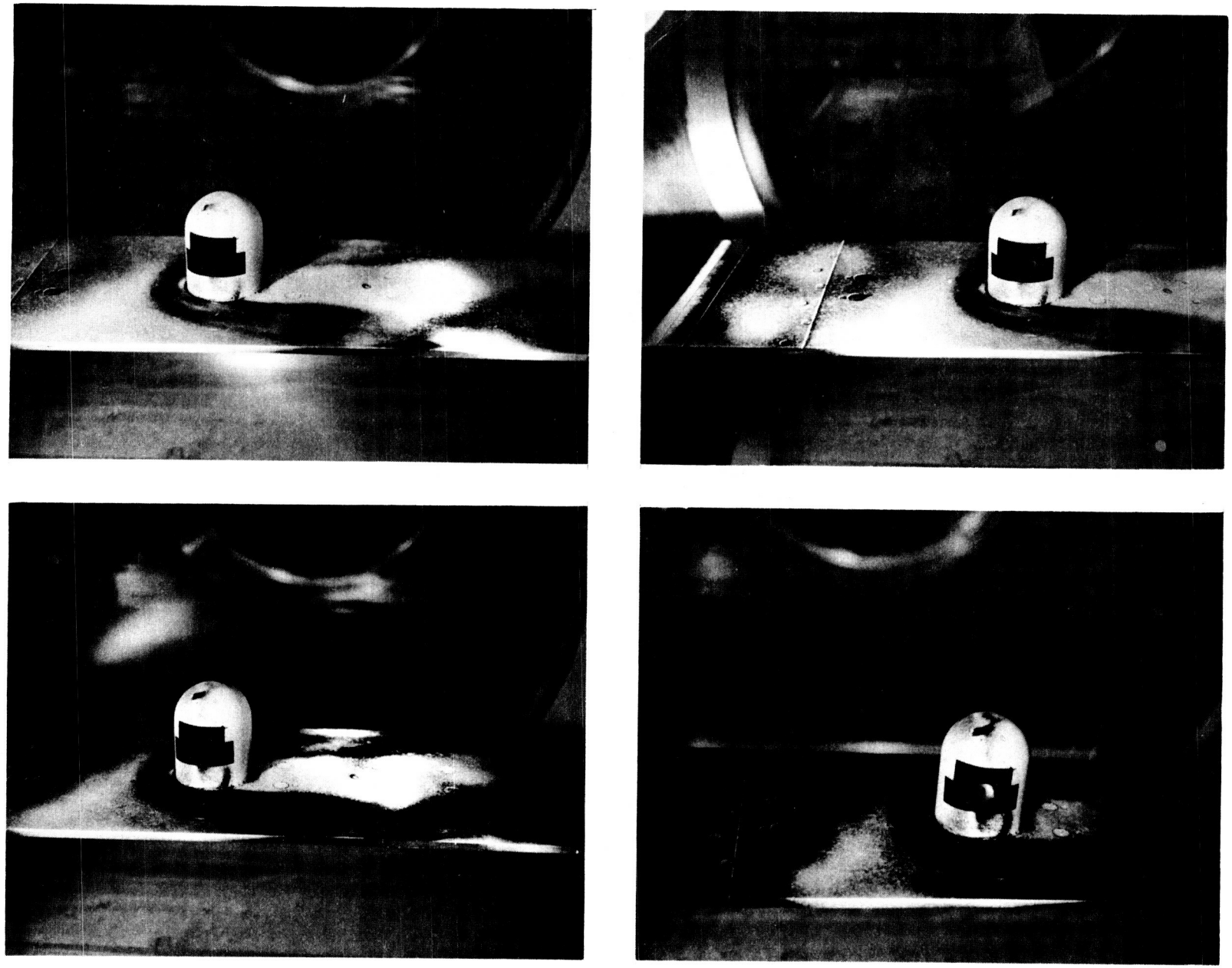


FIGURE 5

ON-GIMBAL TURRET SUBLIMATION, $M_\infty = 0.75$

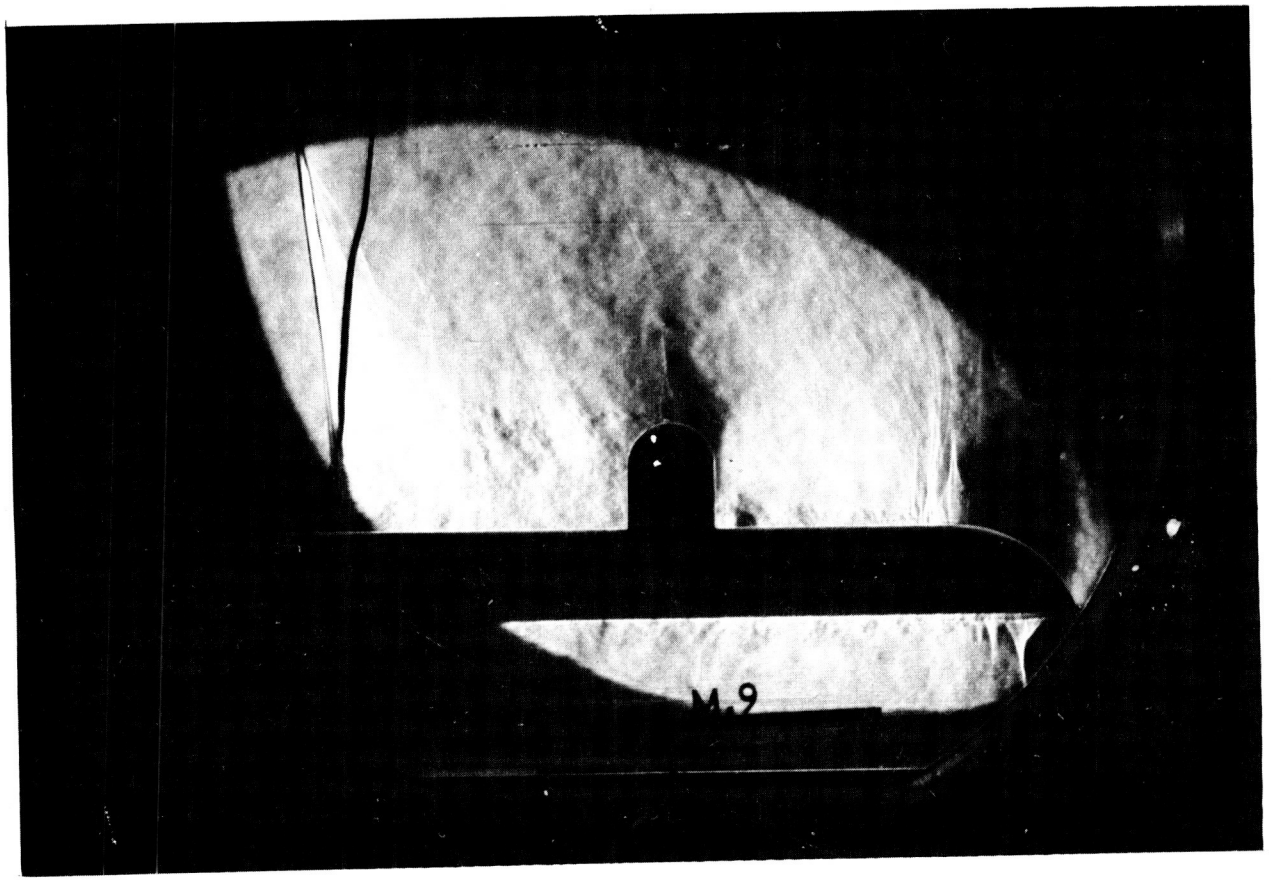
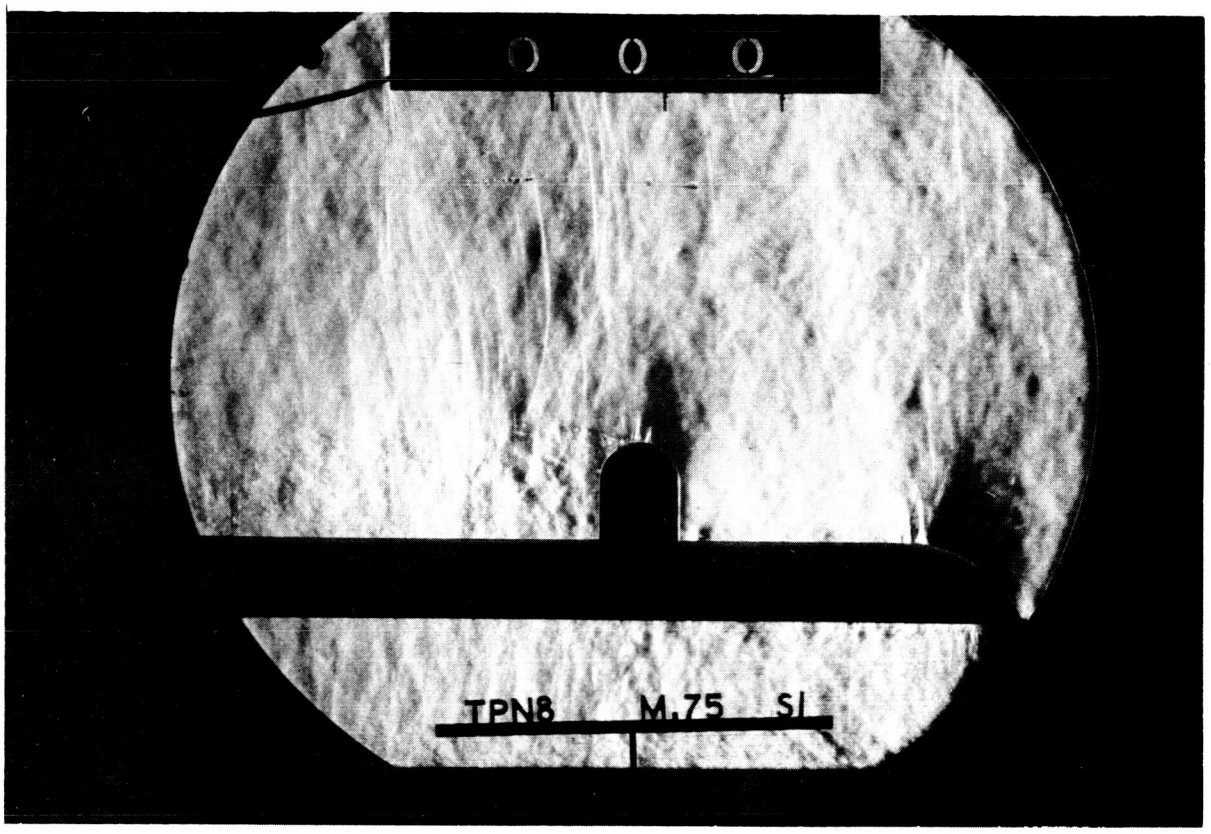


FIGURE 6
ON-GIMBAL TURRET SCHLIEREN PHOTOGRAPH, $M_\infty = 0.90$



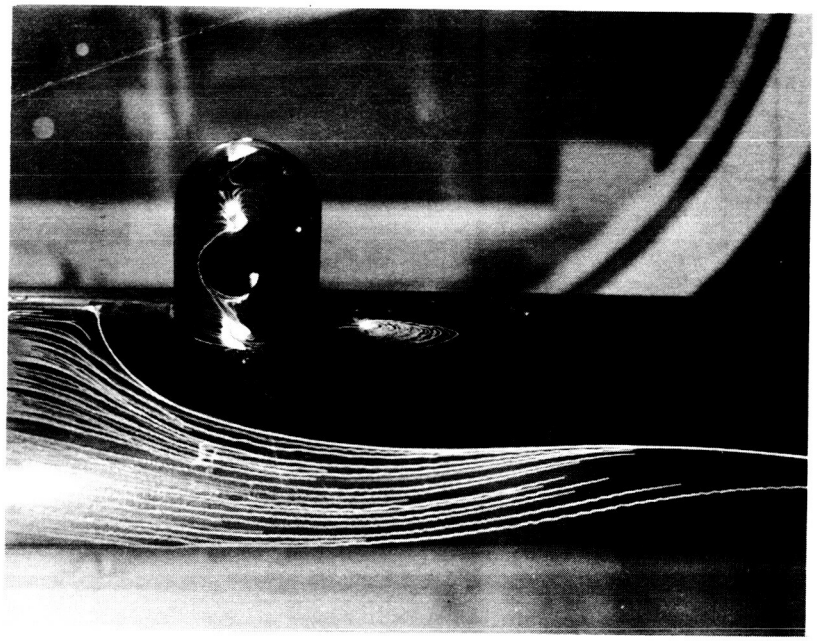


FIGURE 7

ON-GIMBAL TURRET SCHLIEREN AND

OIL FLOW PHOTOGRAPHS, $M_\infty = 0.75$

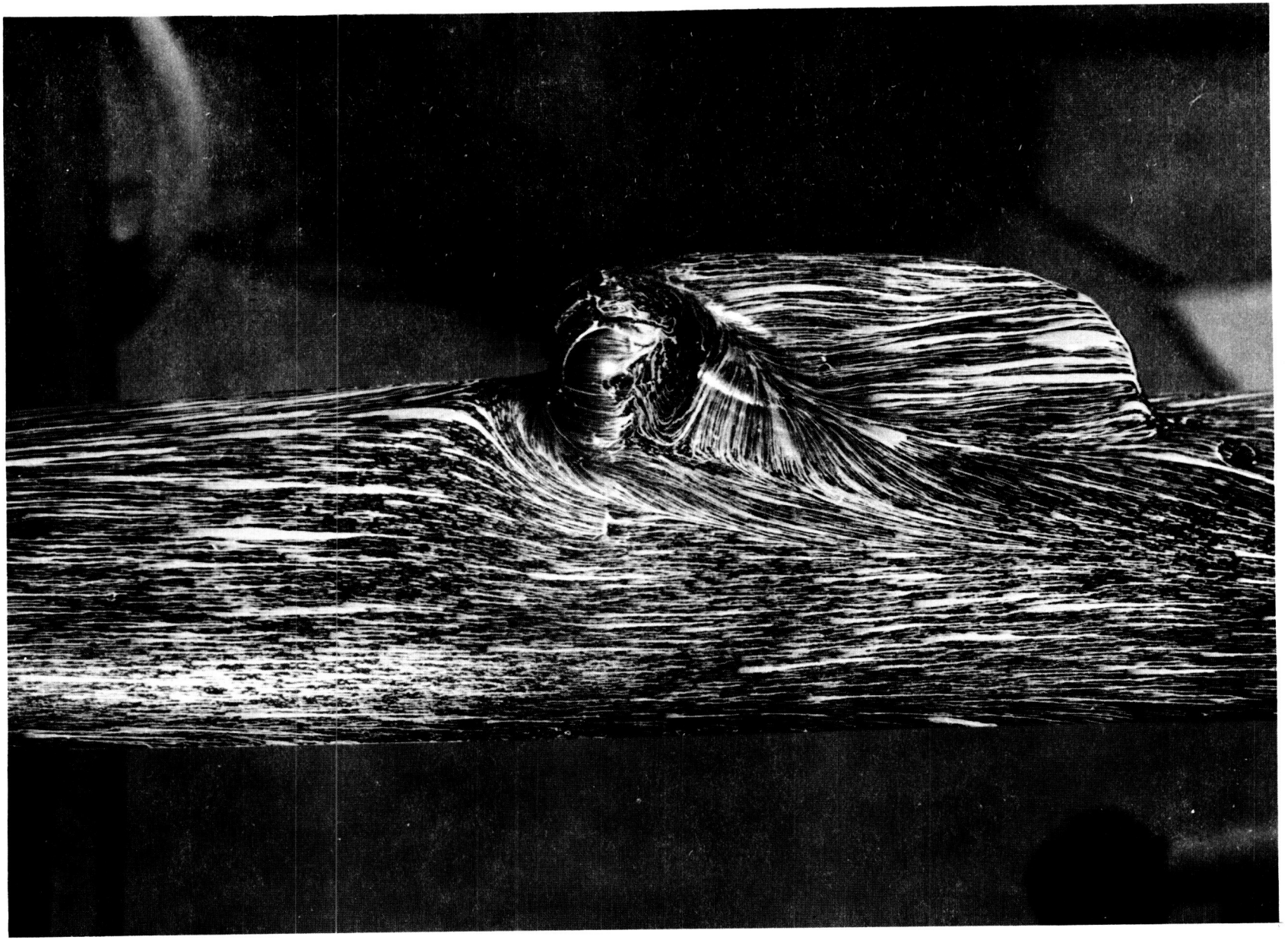


FIGURE 8

OIL FLOW VK-6 FAIRING, $M_\infty = 0.66$

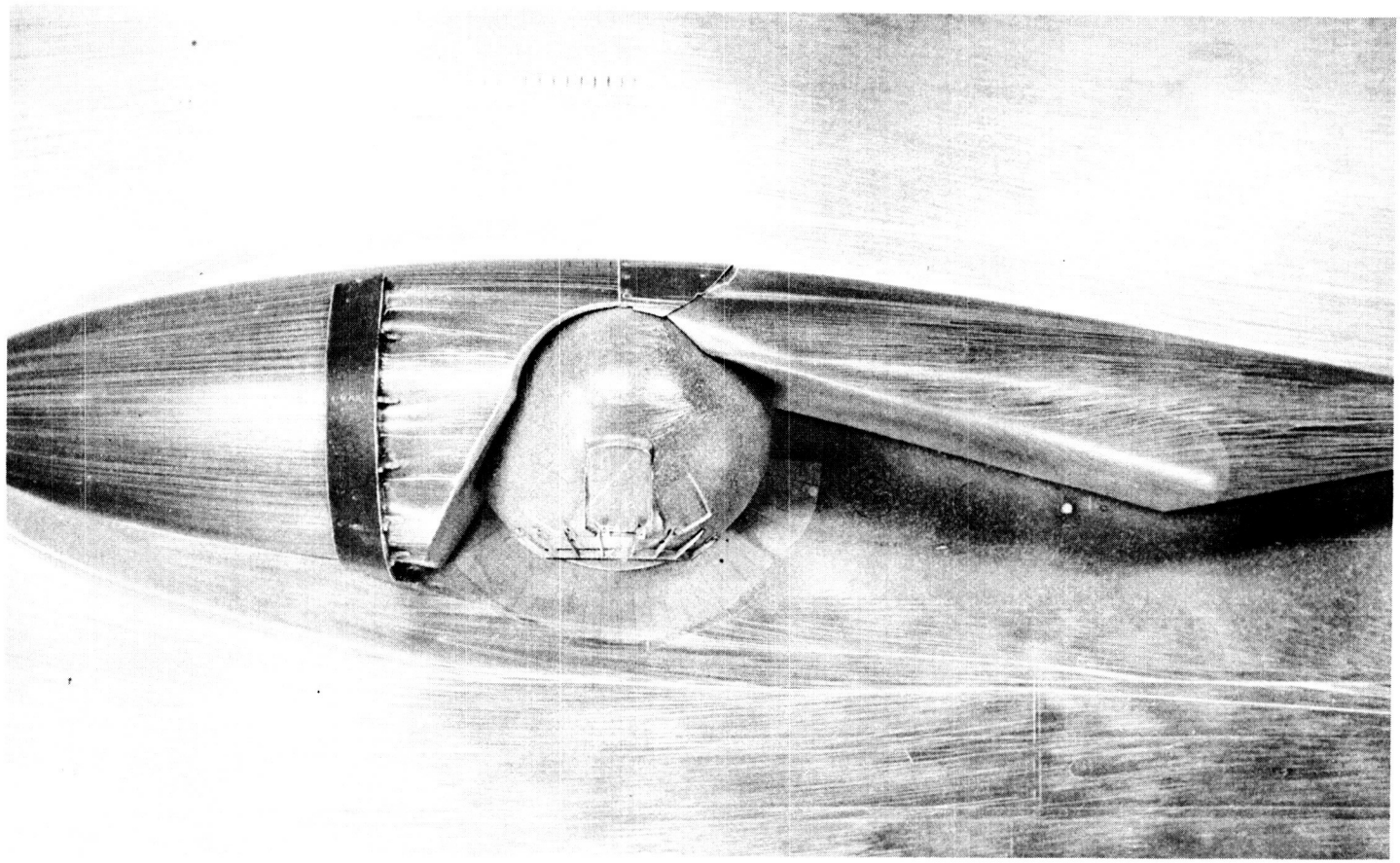


FIGURE 9
GENERAL DYNAMICS CYCLE II TURRET/FAIRING OIL FLOW

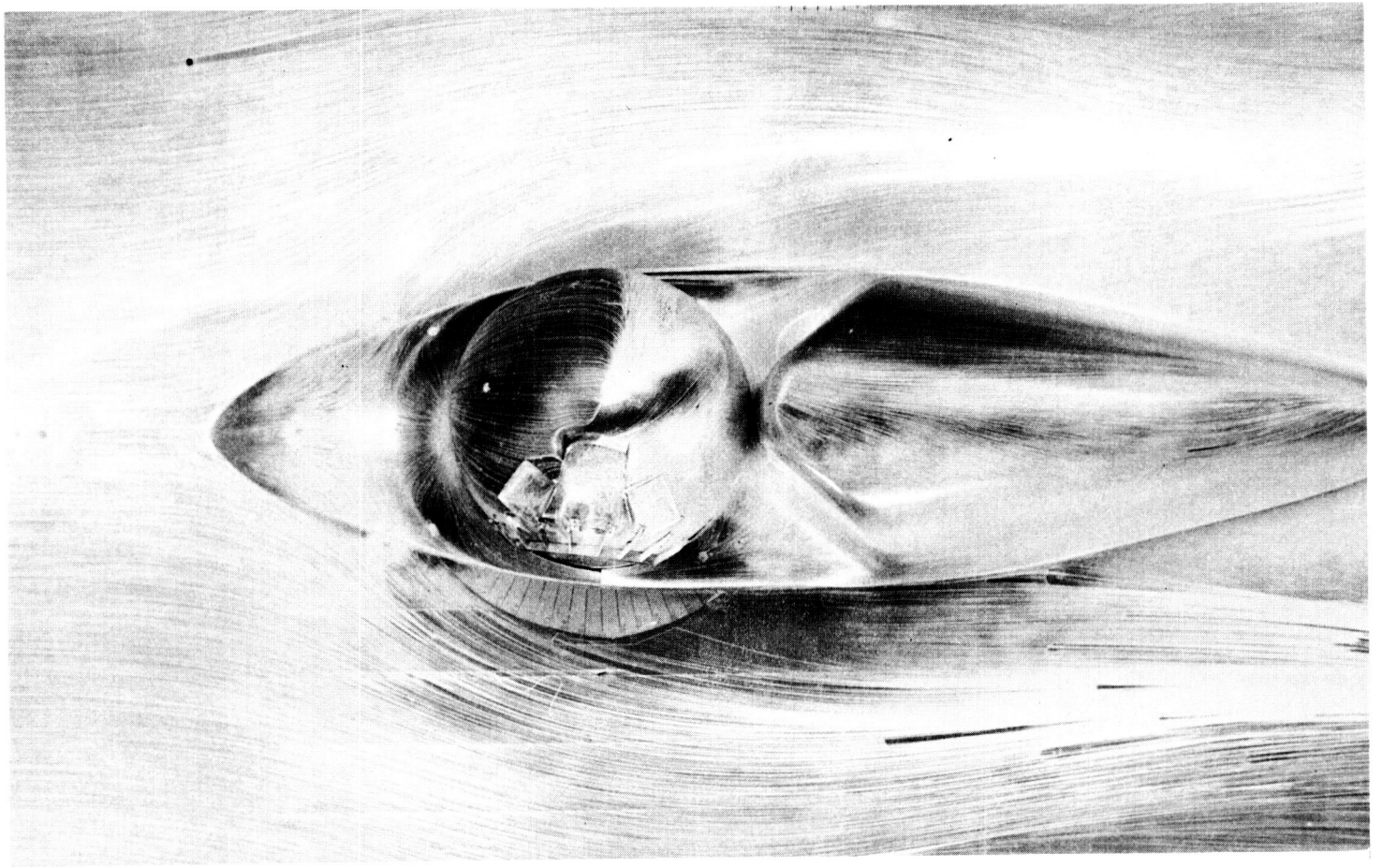
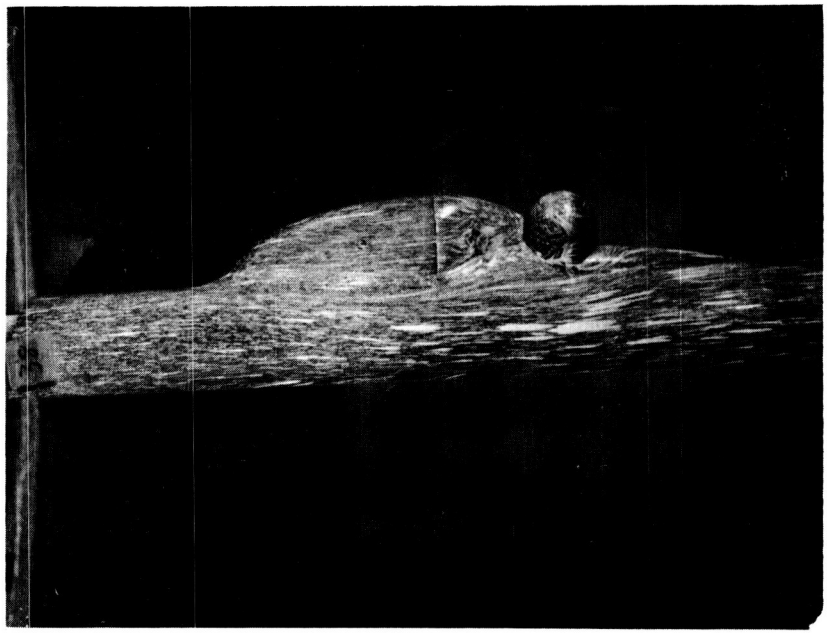
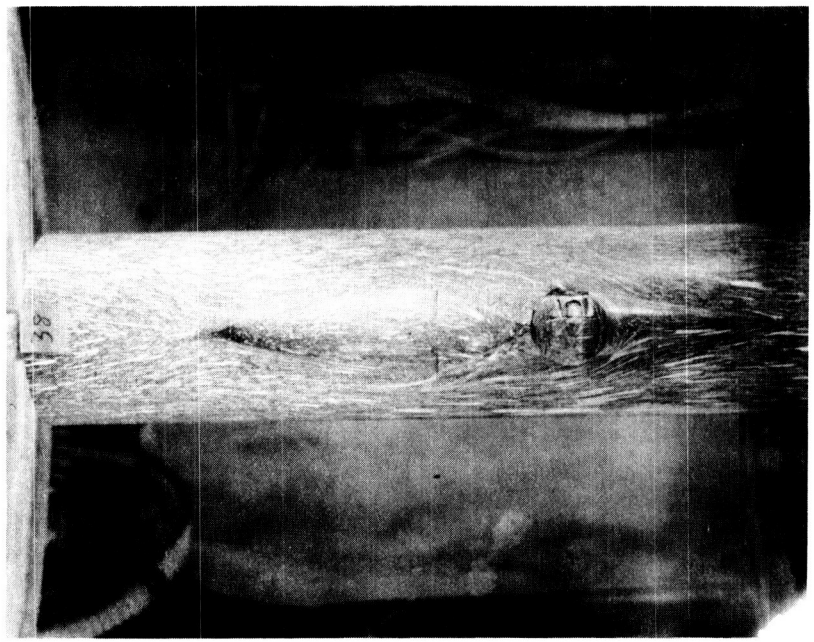


FIGURE 10
AFFDL T-2 FAIRING OIL FLOW





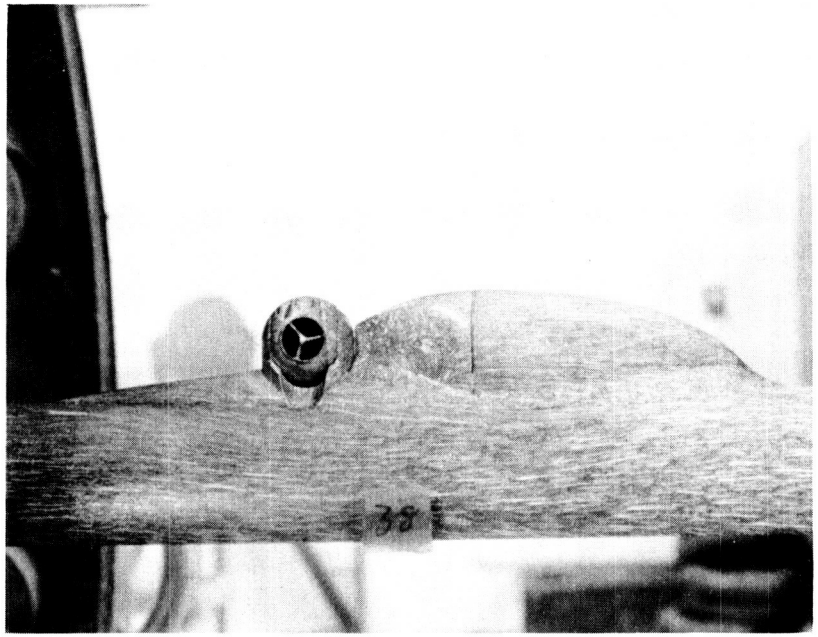


FIGURE 11
OIL FLOW CYCLE III/IV FAIRING, $M_\infty = 0.77$

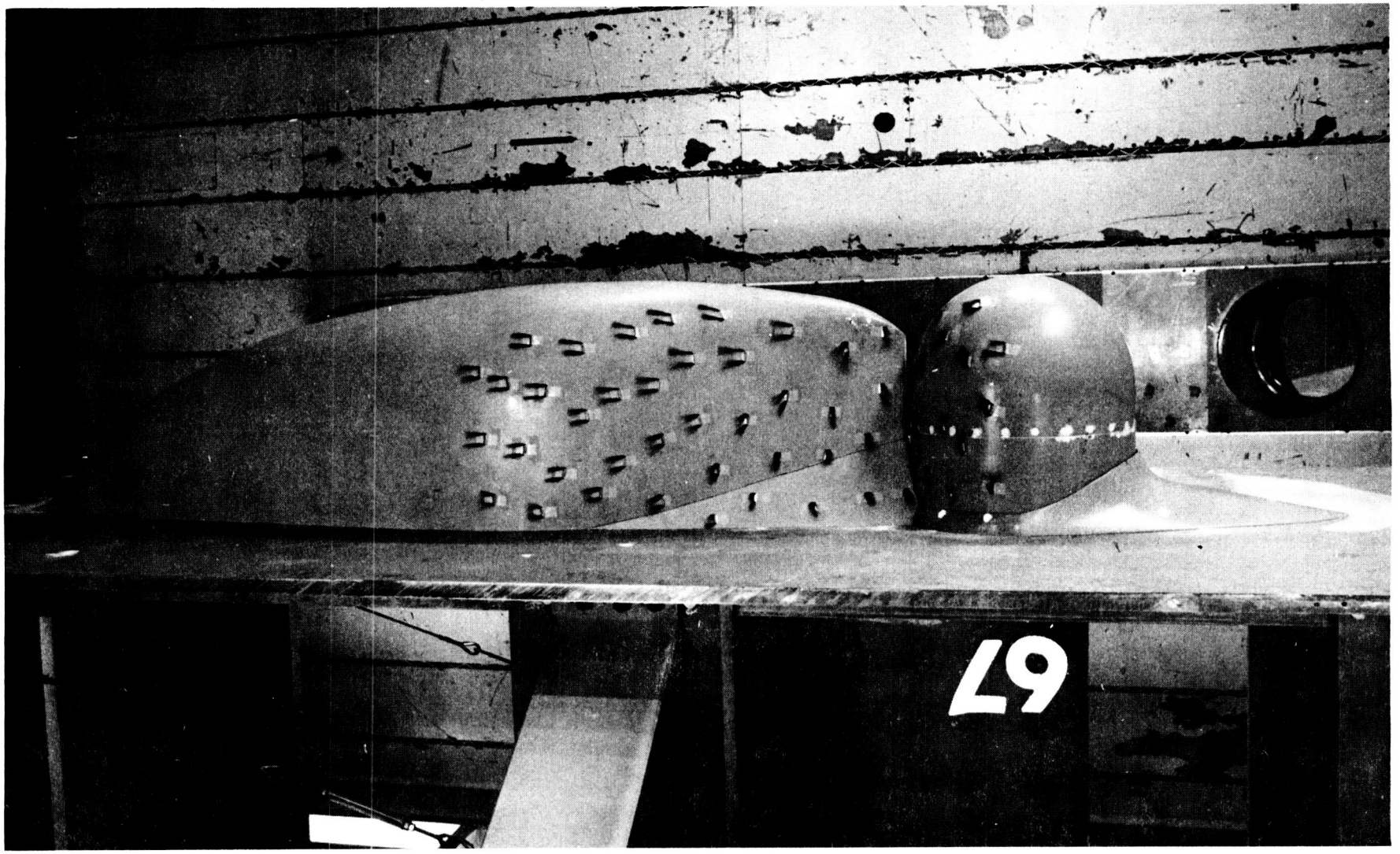


FIGURE 12
TUFT FLOW CYCLE III/IV FAIRING, $M_\infty = 0.50$

$M_\infty = 0.5$

$Re/L = 2.35 \times 10^6 \quad FT^{-1}$

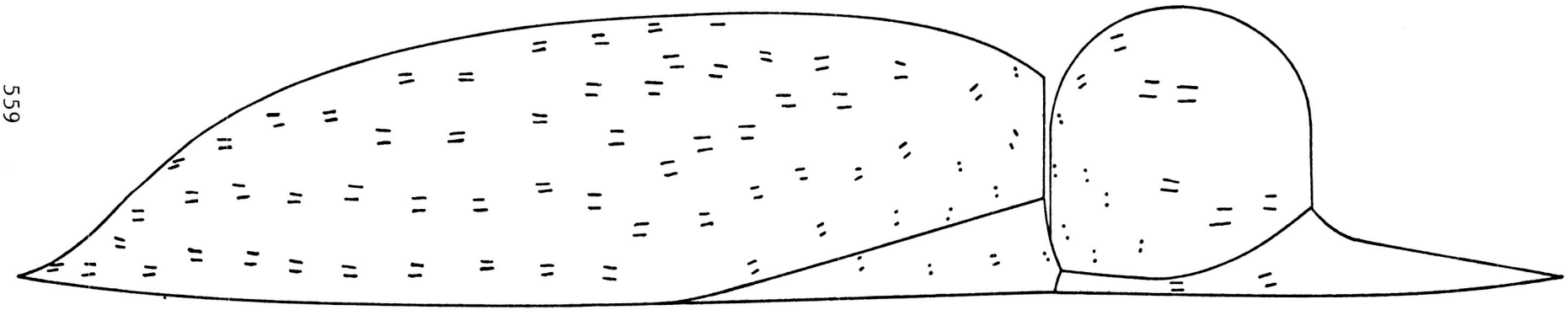


FIGURE 13

A.L.L. 3/10ths SCALE MODEL TUFT DIAGRAM

FIGURE 14
FULL SCALE FLIGHT TUFT FLOW

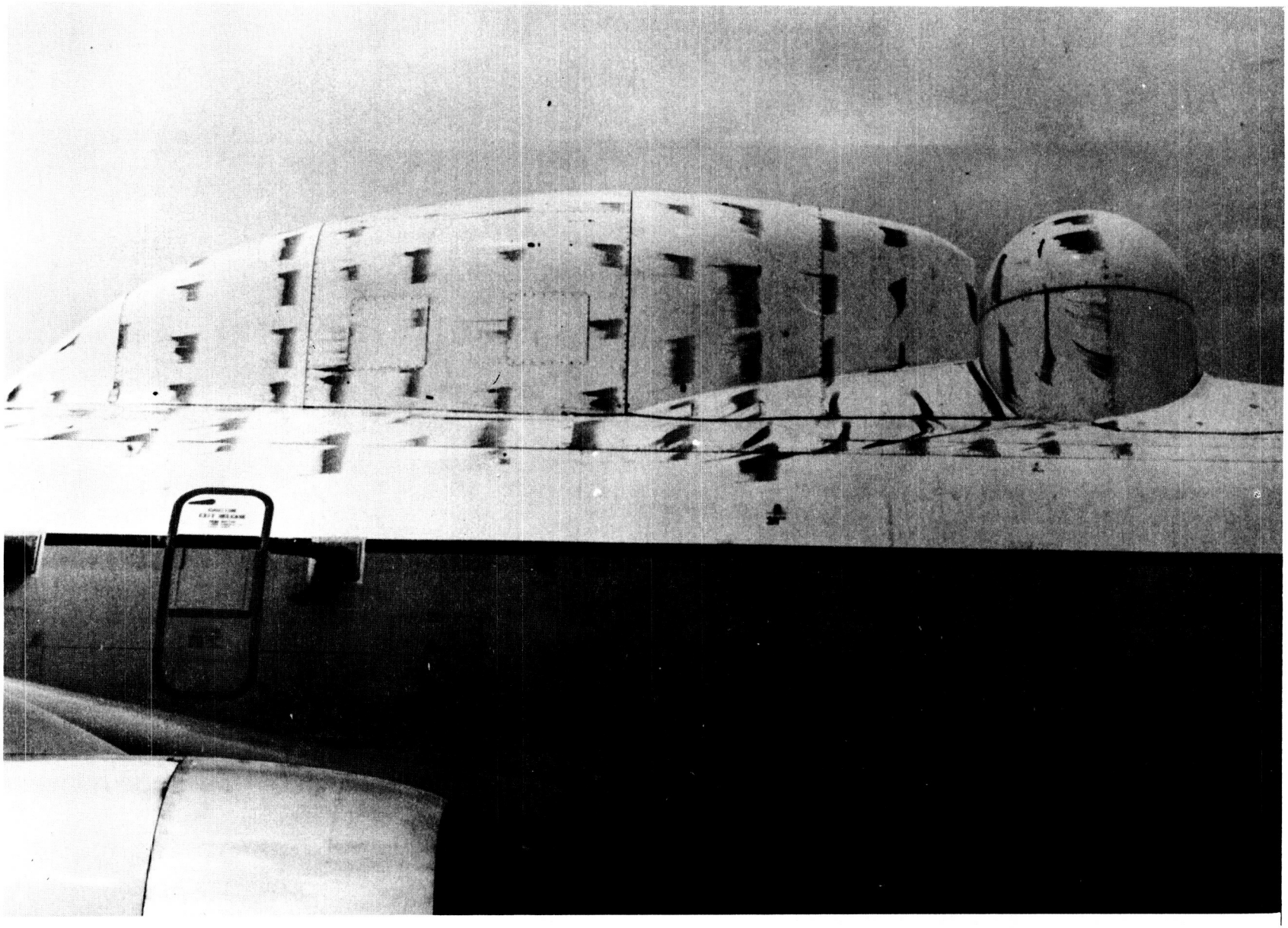


FIGURE 15
FULL SCALE FLIGHT OIL FLOW

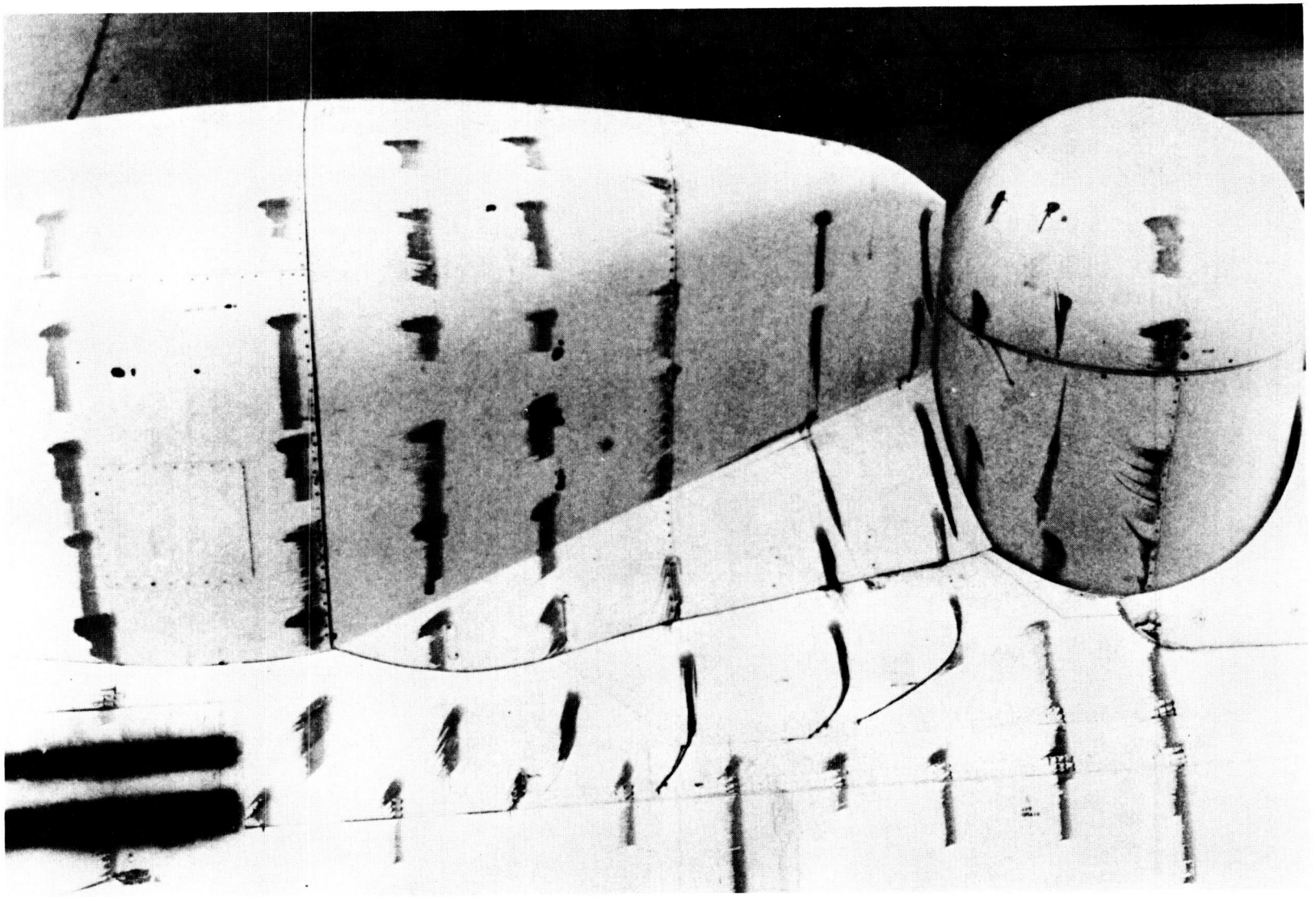


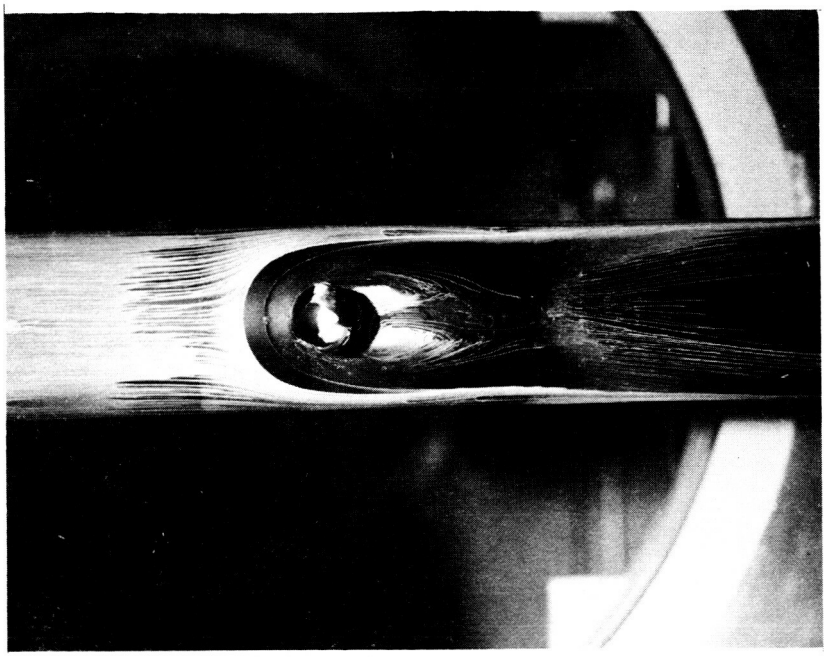
FIGURE 16
FULL SCALE FLIGHT OIL FLOW, CLOSEUP CUTOUT REGION

$M_\infty = 0.55$

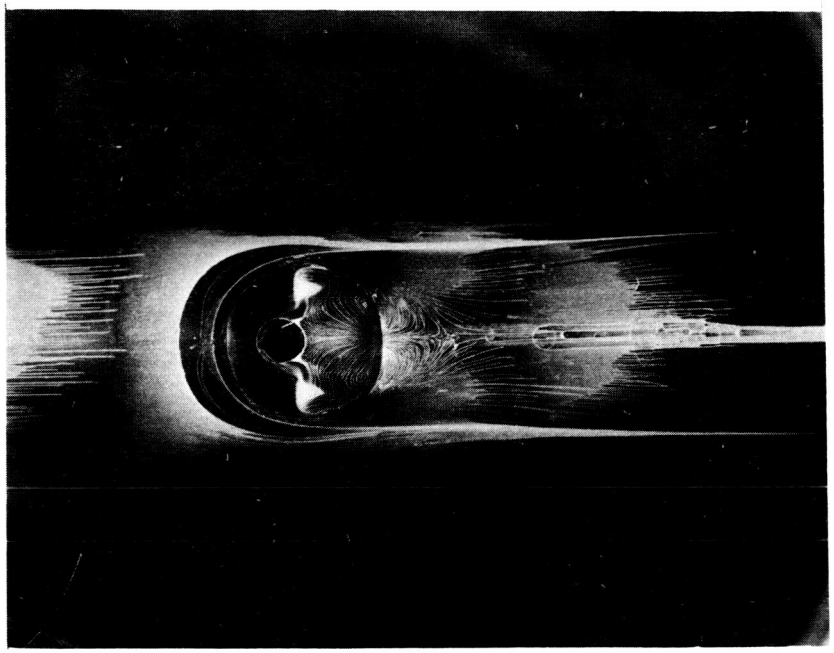
$M_\infty = 0.70$

FIGURE 17

B-52 SRAT/CYCLE III/IV FAIRING OIL FLOW

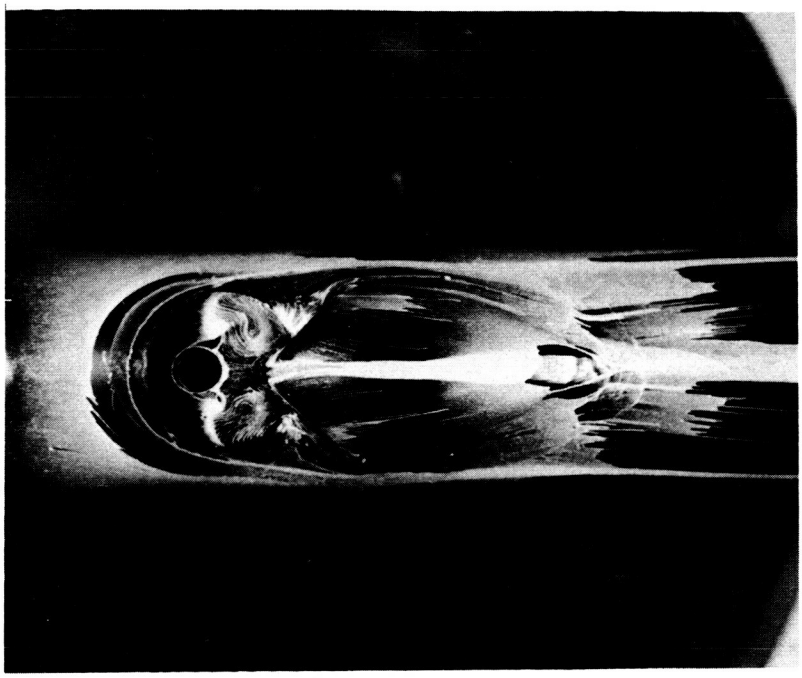


a.
ON-GIMBAL TURRET

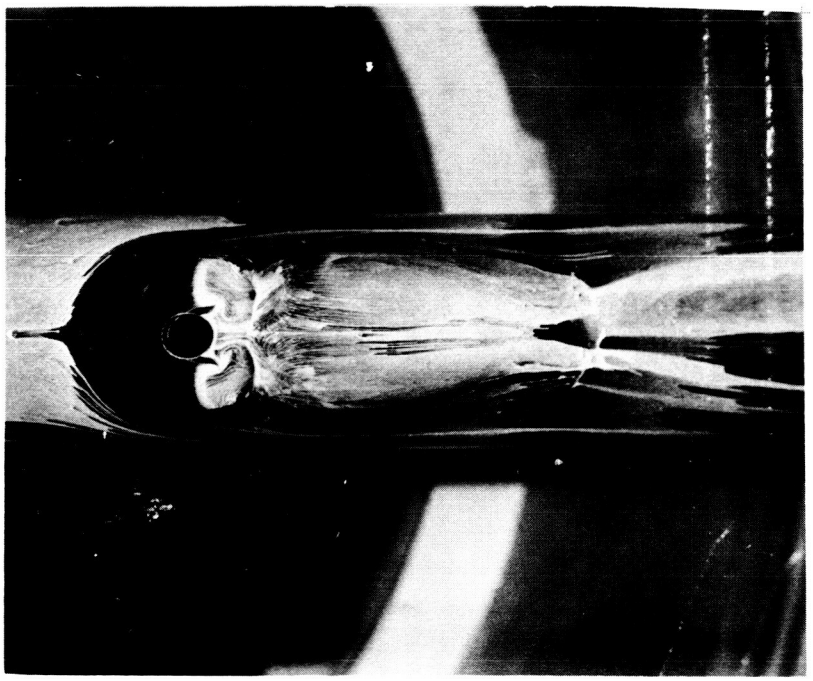


b.
COELOSTAT TURRET

FIGURE 18
TURRET OIL FLOWS, $M_\infty = 0.75$



a.
FULL CUTOUT



b.
CUTOUT PARTIALLY FILLED

FIGURE 19
COELOSTAT TURRET/FAIRING OIL FLOW, $M_\infty = 0.75$