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Exploratory Tests on Sting Interference at a Mach Number of 6.8

by

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LONDON: HER MAJESTY'S STATIONERY OFFICE

1961

THREE SHILLINGS NET

U.D.C. No. 533.6.071.4 : 533.6.011.55

C.P. No. 566

October, 1960

EXPLORATORY TESTS ON STING INTERFERENCE AT A MACH NUMBER OF 6.8

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SUMMARY

Tests with slender models at zero incidence showed that if the length of a supporting sting has to be kept short, it is desirable for transition to occur upstream of the base of the model, if interference effects are to be avoided. This type of flow corresponds to full-scale hypersonic vehicles operating at moderate altitudes. In addition it was found that there was no advantage to be gained in using a small diameter sting.

If the case of complete laminar flow over a hypersonic vehicle becomes of interest, which may happen if extreme altitudes are considered, greater interference problems would arise, and longer stings would be needed.

Previously issued as R.A.E. Tech. Note No. Aero. 2721 - A.R.C. 22,539.

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1 INTRODUCTION

The future programme of the 7" × 7" hypersonic tunnel includes tests on a variety of slender shapes, such as cones and delta wings. Force and pressure measurements will be made from zero incidence up to 30° incidence, and a sting mounting designed to give continuous coverage through this range is shown in Fig.1. The limited space available in the working section restricts the length of the sting support to about 3 in. for a model of 5 in. root chord; the requirement for electrical leads or pressure tubes to be carried internally through the sting, and the need for adequate sting rigidity, result in the diameter of the sting needing to be not less than about 3/8 in. Also, the junction of the downstream end of the sting with its mounting is quite bluff.

It was thought that a sting mounting of the proportions described above might affect the flow round slender models, and that it would be prudent to make some exploratory tests on sting interference effects with equipment and models already to hand, before the design of models and sting supports for future tests was finalised. This Note describes some tests made with a simple rig, using two delta wing models already available from previous flow visualisation experiments, and a simple cone model specially made for the present tests.

2 DESCRIPTION OF MODELS

Drawings of the two slender delta wings available from earlier experiments are given in Fig.2. It should be noted that these wings had a small hole drilled in each leading edge*. These holes proved useful in that they encouraged transition on the models, and therefore a turbulent wake, which was the main flow condition to be investigated. Another model, a smooth cone of the same "thickness/chord" ratio as the delta wings was also tested; with this model an all-laminar boundary layer could be expected at zero incidence, with transition occurring either at, or downstream of, the trailing edge. This was the second flow condition to be investigated.

All the models could be fitted with stings of diameters ranging from 3/16 in. to 3/8 in., which gave ratios of sting diameter to base thickness (d/t) of from 0.3 to 0.6. On the largest sting, an axisymmetric "windshield" (Fig.2(c)) could be positioned anywhere along its length, to give a free length of sting between the base of the model and the windshield of up to 4 in. This windshield had a greater frontal area than the end of the sting support shown in Fig.1 (which in front view is elliptical in shape), and was therefore likely to cause greater interference effects.

3 DESCRIPTION OF TESTS

The models were fitted to long stings which, in turn, were mounted on a larger sting support, which could be traversed in a fore and aft direction in the working section. In this way, any part of the model and sting assembly could be brought opposite the windows of the working section. Using the Schlieren apparatus, one photograph of the flow over the model was obtained, and then, with the sting assembly traversed further upstream, a second photograph was obtained of the wake behind the model. The two photographs were then joined to give a complete picture of the flow round the model and sting, as shown in Figs.6, 7, 9 and 10. The variation of Mach number along the axis of the working section is small, so no appreciable error should be involved in using this technique.

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* These holes connected with a duct inside the model, through which water had been introduced into the airstream.

The main series of tests was made with the models nominally at zero incidence. Some slack in the mounting system resulted in the models settling at a small incidence when the tunnel was running, but it is considered that this does not affect the qualitative interpretation of the flow photographs. A limited number of tests was made with the smaller of the two delta wings, mounted on various stings, at an incidence of 20°.

4 DISCUSSION OF RESULTS

4.1 General

In the 7" × 7" hypersonic tunnel, the maximum Reynolds number obtainable at a Mach number of 6.8 is about 6×10^{6}/ft, and hence there is a tendency for all-laminar boundary layers to be obtained on slender models at zero incidence. However, transition can generally be triggered by roughening the model surface. Full-scale hypersonic vehicles at very high altitudes would operate at Reynolds numbers sufficiently low for all-laminar boundary layers to exist, but at lower altitudes some turbulent flow on their surfaces can be expected. The situation is illustrated in Fig.3, where a Reynolds number of 5×10^{6} for transition at the trailing edge is assumed.

The separated flow pattern downstream of a body depends on Reynolds number and transition location (as well as on body shape and Mach number). Fig.4 shows two types of flow pattern that may occur. At low Reynolds numbers, with transition occurring in the wake, a long cavity region of low energy flow exists behind the body; at high Reynolds numbers, with transition occurring on the body, the flow is able to expand rapidly round the base of the body, and a short distance downstream of the base there is a recompression, which is the origin of the trailing shock wave. Different base pressures will result from these different flow patterns, and Fig.5(a) is a typical plot from Ref.1 of the variation with Reynolds number of pressure on the base of a body. If one defines a "critical sting length" such that a sting length less than critical affects the base pressure, it has been found that the variation of critical sting length with Reynolds number is similar to the base pressure variation[1]. Thus when Reynolds numbers are low enough for transition to occur in the wake, the critical sting length varies rapidly with Reynolds number, and is in general higher than the critical sting length associated with the flow where transition occurs on the model. This is shown in Fig.5(b).

So, if sting lengths have to be kept short, it seems desirable to aim for transition to occur upstream of the base of the model. For this reason, the present series of tests concentrated mostly on the case where a turbulent wake was obtained behind the model. However, a few tests were made with the flow over a model completely laminar, a state which might be encountered when aiming to reproduce conditions appropriate to flight at great altitudes, and some indications are given of the interference problems introduced with this type of flow.

4.2 Effect of sting diameter

For these tests long stings were used, and it is considered that for the cases where turbulent wakes behind the models were obtained, no interference effects from the traverse-sting support occurred at the model position.

The set of photographs in Fig.6 shows the larger delta model at zero incidence, supported by stings of various diameters. On this model, transition was upstream of the base, triggered by the holes in the leading edges of the wing; this can be seen in the Schlieren photographs*. For all but

* It should be noted, though, that the Schlieren photographs show the situation only at the plane of symmetry of these three-dimensional models. It does not necessarily follow that the boundary layer was turbulent over the whole span.

the smallest diameter sting, the wakes behind the model were of one type, with the flow expanding rapidly round the base of the model to re-attach on to the sting a short distance downstream; at this position, there was a recompression of the flow and a trailing shock was formed. (The flow separation at the downstream end of the sting was due to the proximity of the blunt end of the traverse-sting support.)

The type of wake obtained when the ratio of sting diameter to base thickness of the model was 0.3 is difficult to interpret, but appears to fall between the pattern obtained with larger diameter stings, and that obtained with a small diameter sting on the cone model, shown in Fig.7. It is possible that the wake was unsteady, and tended to oscillate between the two basic types of wake.

Experiments at supersonic Mach numbers have shown that, with a turbulent wake, base pressure decreases steadily with increase of sting diameter, until the sting diameter becomes about 0.8 times the base diameter of the model. Results from Refs.2 and 3 are plotted in Fig.8. This effect is due to the flow over the base of the model being more nearly two-dimensional in character with the larger sting diameters, and it seems likely that similar conditions existed at the Mach number of the present tests. As a closed turbulent wake associated with a low base pressure is likely to be more stable than one with a higher base pressure (which is closer to the laminar wake condition) there is therefore nothing to be gained from using a very small diameter sting.

4.3 Effect of windshield position

The effect of the windshield on the turbulent wake behind the larger of the delta models is shown in Fig.9. The windshield caused a separated flow region on the sting, but for sting lengths greater than the windshield diameter there was no evidence of this separation interfering with the re-attachment of the flow on to the sting immediately behind the model. According to Crocco and Lees[4], disturbances downstream of this re-attachment cannot affect the flow upstream, and it would appear, therefore, that the pressure on the base of the model will be unaffected by the presence of the windshield so long as the sting length is greater than the windshield diameter. The length of sting available on the sting mounting shown in Fig.1 should therefore be sufficient to avoid interference effects.

Although not checked in the present tests, it is likely that a windshield in an unclosed laminar wake would have greater influence upstream than in the case of a turbulent wake, and a greater length of sting would be required to obtain interference-free flow over the base of the model.

4.4 Effect of sting diameter with model at incidence

For the few tests at an incidence of 20°, the smaller of the delta models had to be used to keep the lift load sufficiently low. Results are given in Fig.10, and it can be seen that almost the same flow pattern was obtained with all stings, ($0.4 \leq d/t \leq 0.6$). One small difference was that the lower trailing shock moved further away from the sting axis with increase of sting diameter, and interfered with the bow shock wave slightly earlier. No upstream effect of the stings on the flow over the model was apparent. As there was no indication of particular difficulties arising in the incidence case, no other tests were made at the time. However, further tests will be made at a later date (see Section 6).

5 CONCLUSIONS

Although much remains to be done before a complete understanding of sting interference effects is obtained, the main conclusion to be drawn from these exploratory tests is that, if sting lengths have to be kept short, it is desirable to aim for transition to occur upstream of the base of the model so that a turbulent wake is formed. This type of flow corresponds to full-scale hypersonic conditions at moderate altitudes. If wind tunnel tests are required on models with laminar wakes, to reproduce full-scale conditions at great altitudes, greater sting lengths will be required.

For models with which a turbulent wake is obtained:-

(i) There is no advantage to be gained in using a small diameter sting; in fact, there is some evidence to show that a relatively large sting diameter gives a more stable wake.

(ii) The length of sting available on the sting mounting designed for the 7" × 7" hypersonic tunnel should be sufficient to prevent interference effects arising from the blunt end of the sting mounting.

(iii) In the few tests made with a model and sting support at incidence, the flow pattern on the model was not affected by sting diameter in the range $0.4 \leq d/t \leq 0.6$.

6 FURTHER WORK

The future programme for the 7" × 7" hypersonic tunnel includes axial force measurements on a variety of slender shapes over a wide incidence range, and base pressure measurements will have to be made. It will then be possible to relate these pressures to the flow patterns observed in the wake of the models, and to obtain the effects of sting diameter quantitatively.

If the case of complete laminar flow over a hypersonic vehicle becomes of interest, which may happen if extreme altitudes are considered, the regions of rapidly changing base pressure and critical sting length with Reynolds number (Fig.5) will become more important, and further experiments will have to be made.

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4	Crocco, L. Lees, L.	A mixing theory for the interaction between dissipative flows and nearly-isentropic stream. J. Ae. S., Vol.19, No.10, October, 1952.

WT.2078. C.P.566 K3. Printed in England.

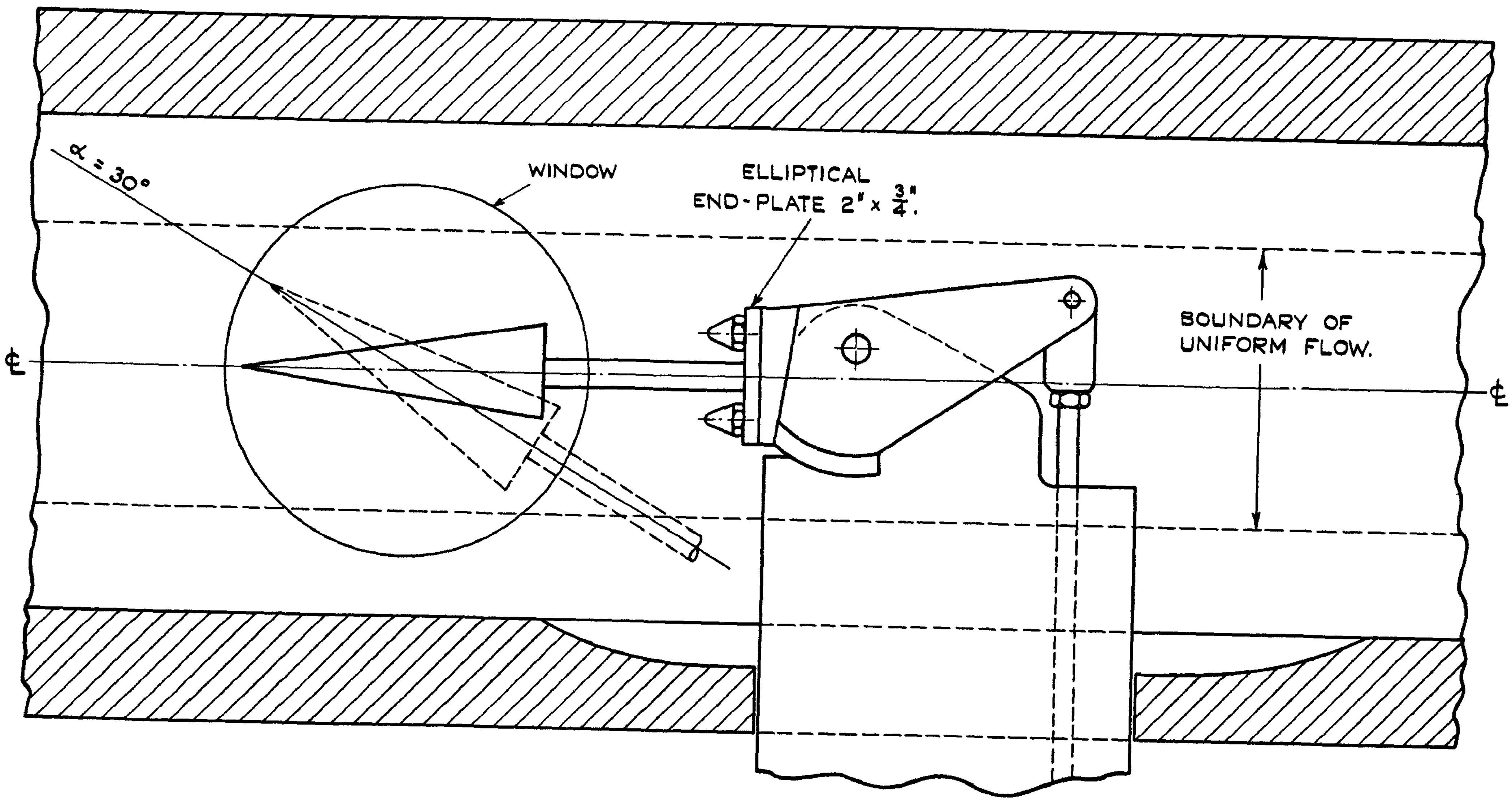


FIG. 1. STING SUPPORT MECHANISM FOR 7" x 7" HYPERSONIC TUNNEL.

SCALE : 1/2 FULL SIZE

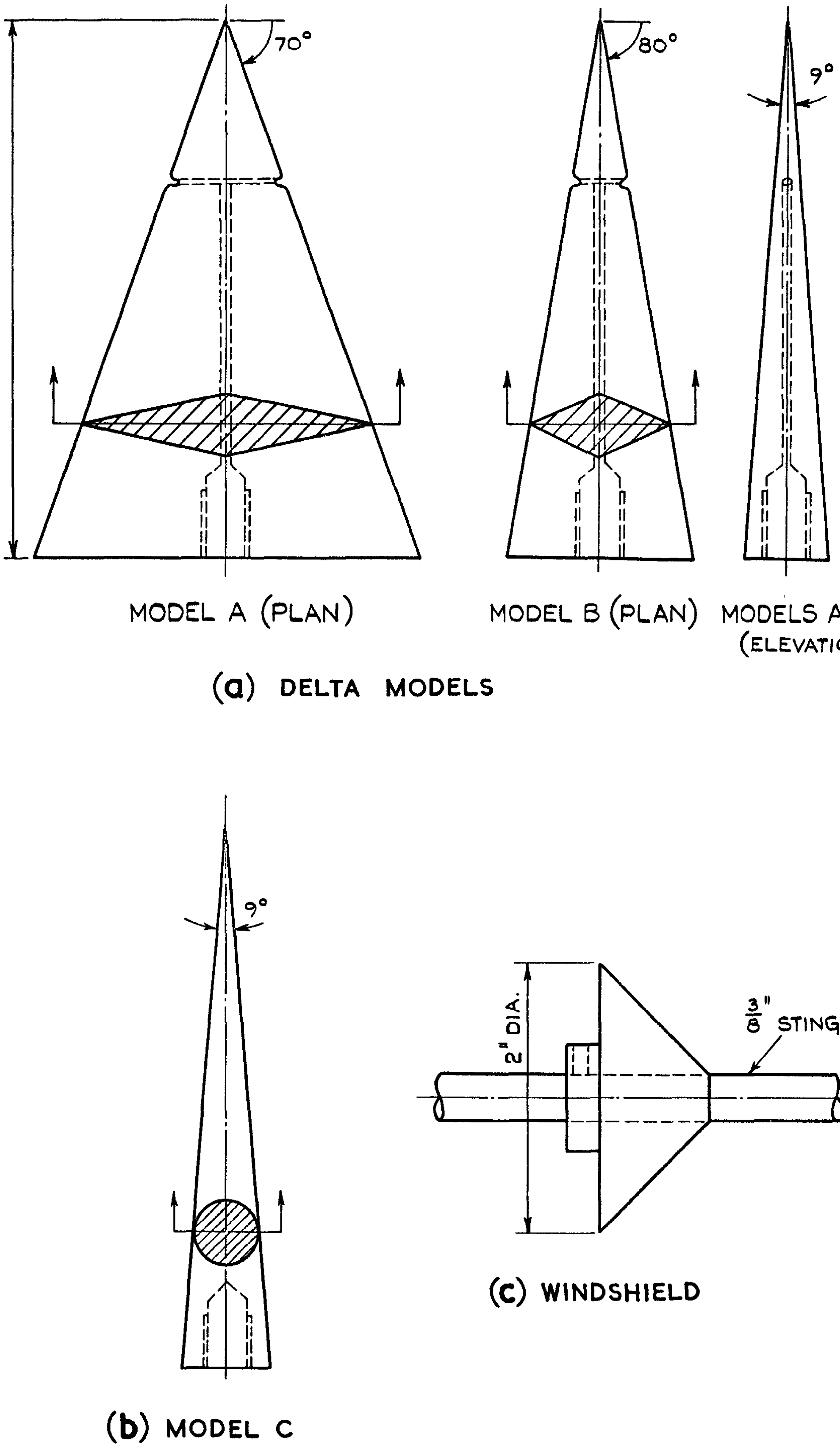


FIG. 2. DETAILS OF MODELS.
SCALE: FULL SIZE

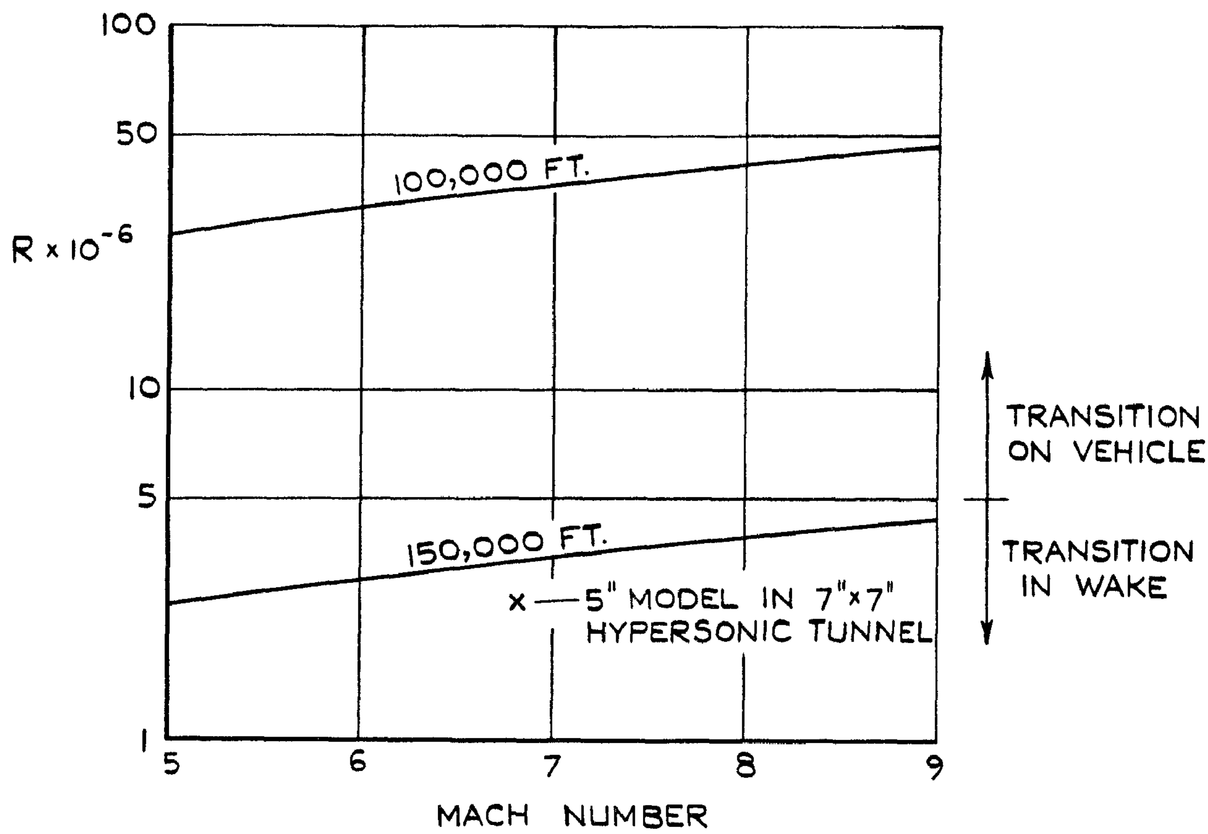


FIG. 3. REYNOLDS NUMBER vs MACH NUMBER FOR VEHICLE OF LENGTH 50 FT.

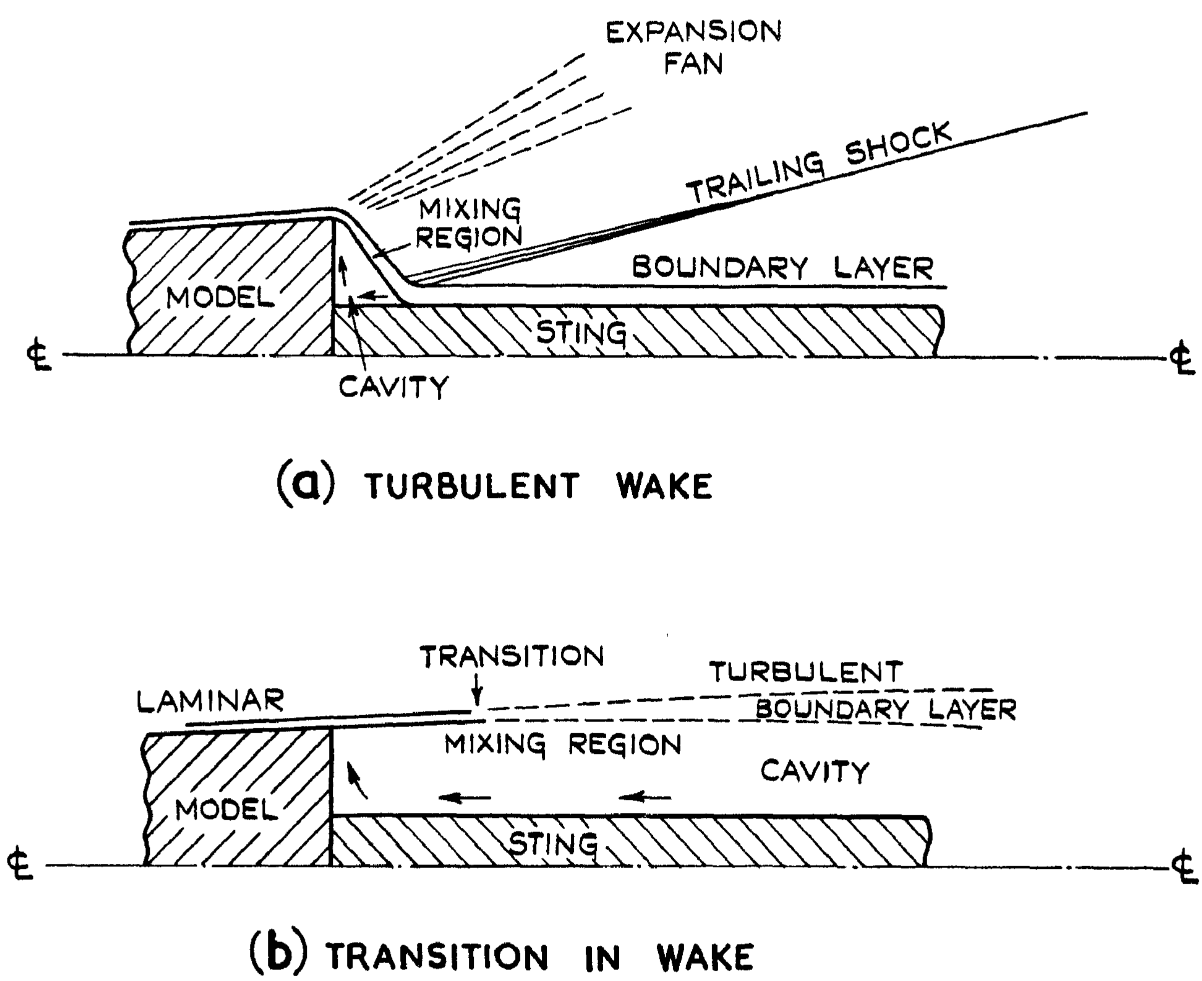
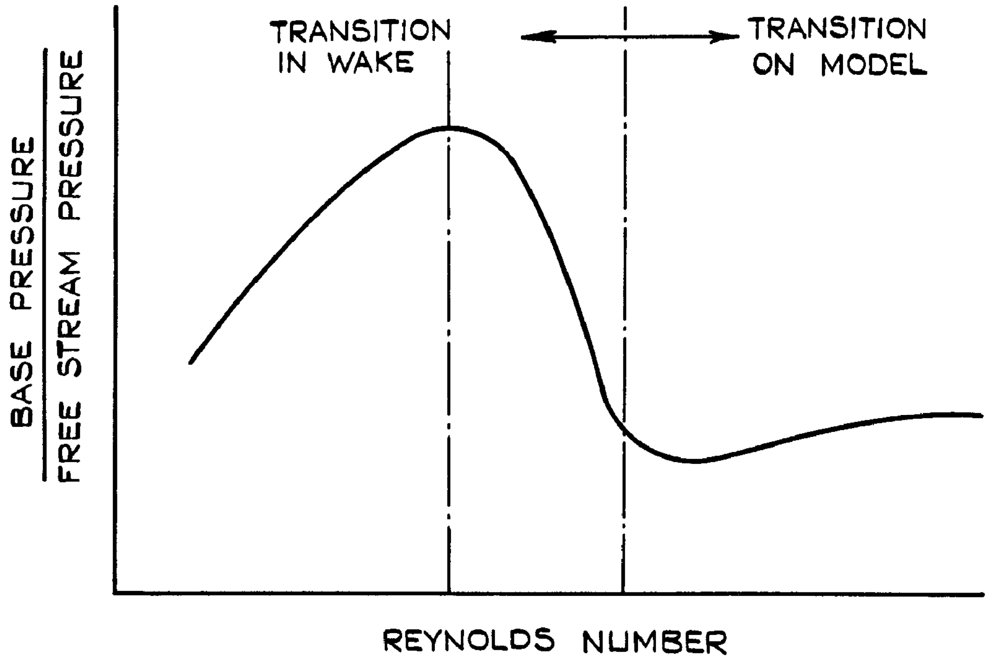
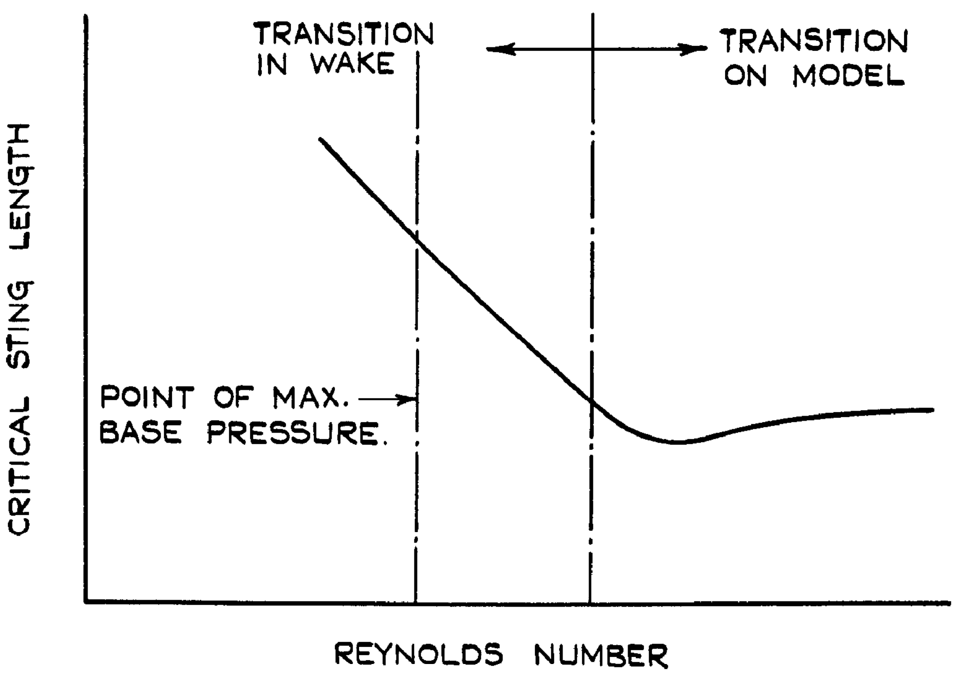


FIG. 4 (a & b) TYPICAL FLOW PATTERNS IN WAKE.

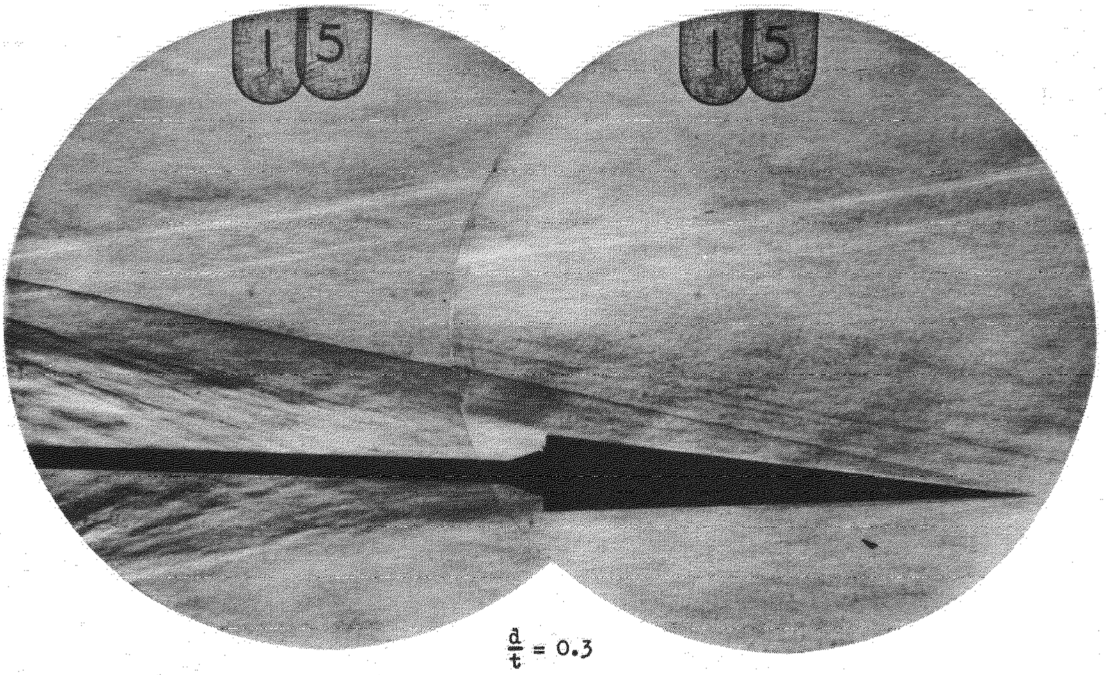


(a) BASE PRESSURE VARIATION

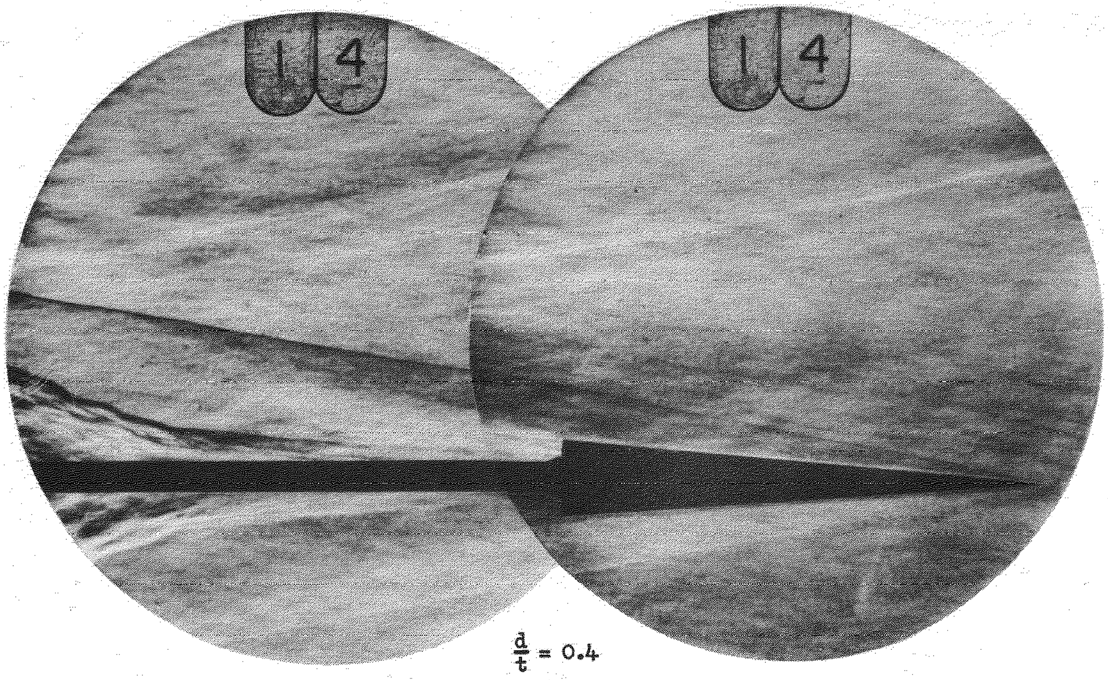


(b) CRITICAL STING LENGTH VARIATION

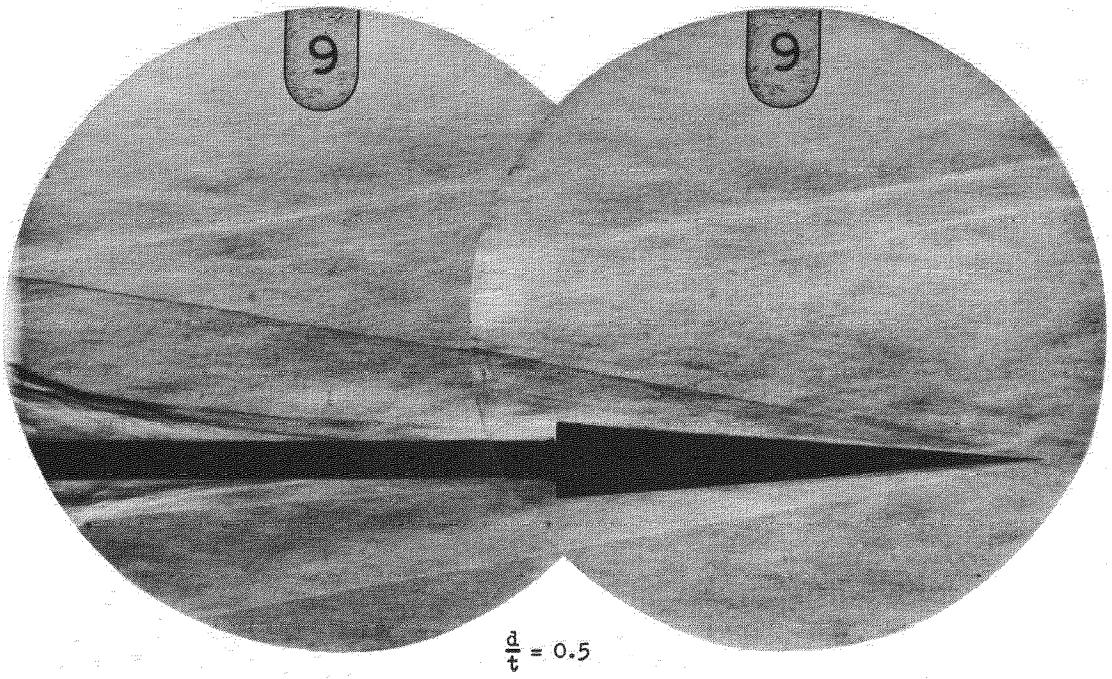
FIG. 5 (a & b) TYPICAL VARIATION OF BASE PRESSURE RATIO AND CRITICAL STING LENGTH WITH REYNOLDS NUMBER (FROM REF. 1)
(SUPERSONIC MACH NUMBER)



$\frac{d}{t} = 0.3$



$\frac{d}{t} = 0.4$



$\frac{d}{t} = 0.5$

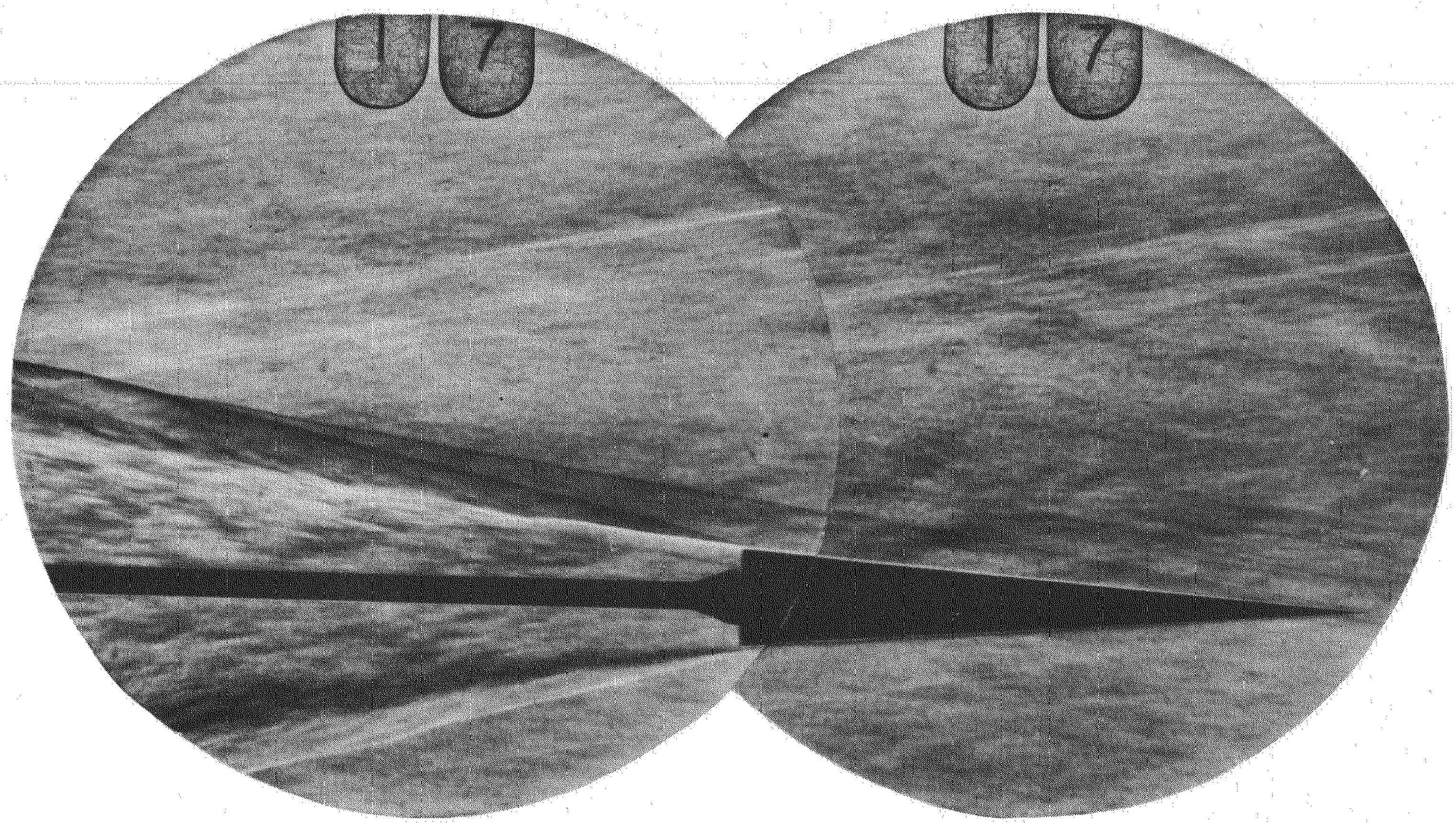


FIG. 7. MODEL 'C' (CONE)

$\alpha = 0^{\circ}$. Sting diameter/model base diameter = 0.3. $R = 2 \times 10^{6}$

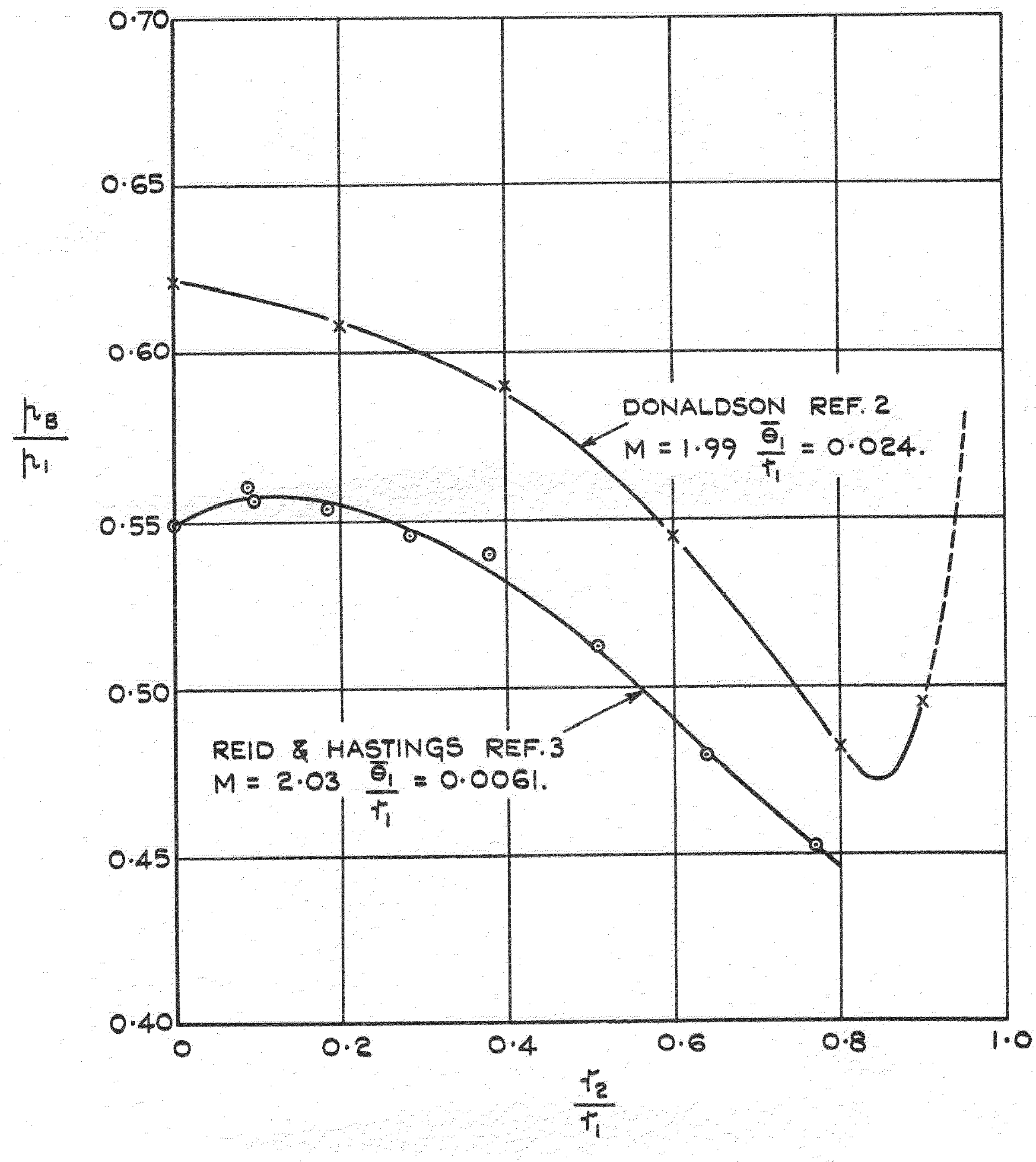
r_1 = BODY RADIUS

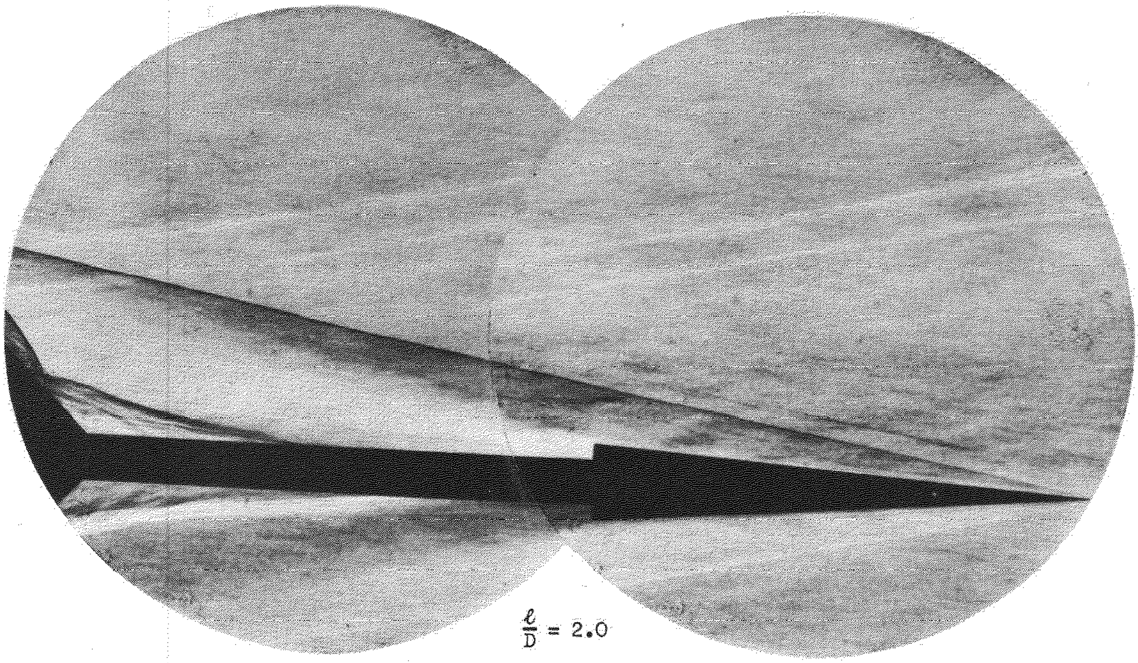
r_2 = STING RADIUS

p_B = BASE PRESSURE

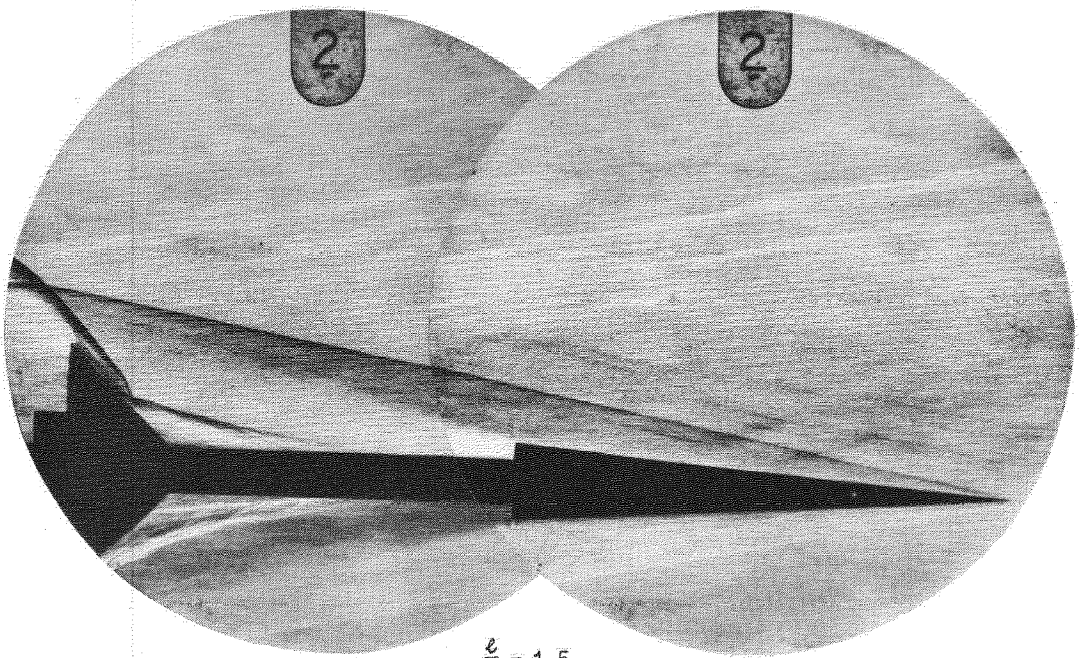
p_1 = FREE STREAM PRESSURE

$\bar{\theta}_1$ = MEAN MOMENTUM THICKNESS

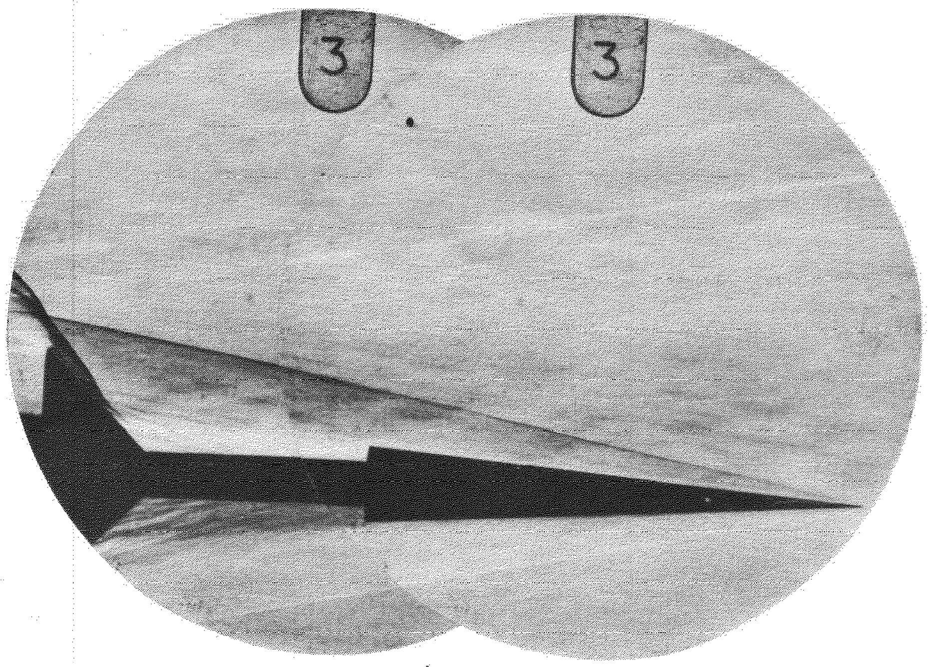




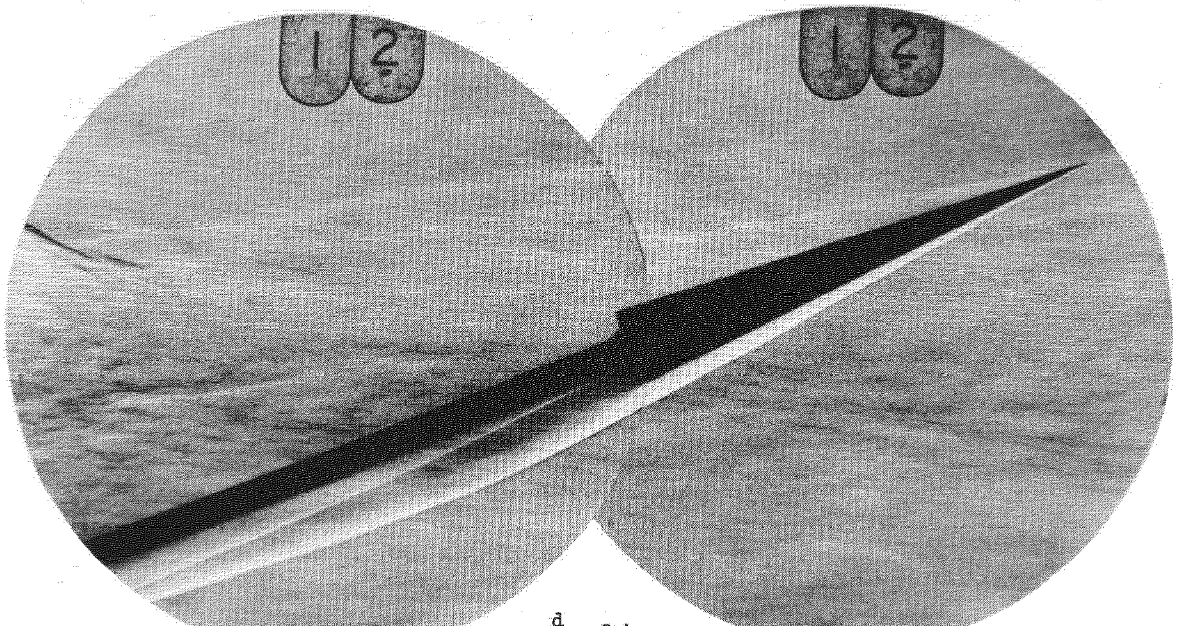
$\frac{\ell}{D} = 2.0$



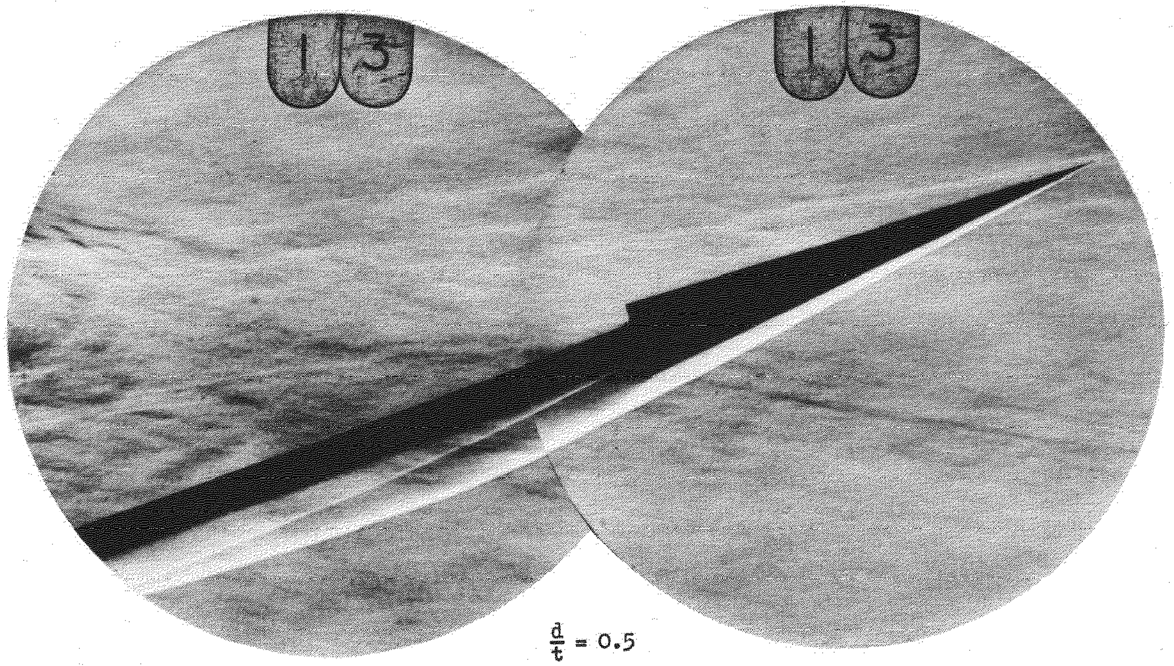
$\frac{\ell}{D} = 1.5$



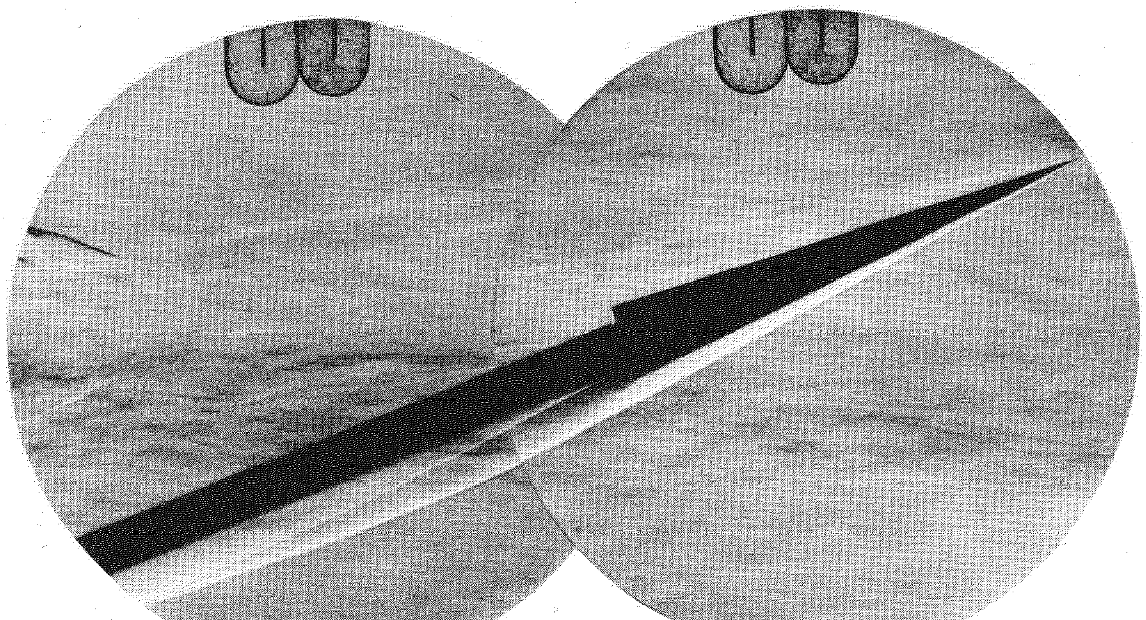
$\frac{\ell}{D} = 1.0$



$\frac{d}{t} = 0.4$



$\frac{d}{t} = 0.5$



$\frac{d}{t} = 0.6$

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