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Vortex Breakdown—Some Observations in Flight on the *HP 115* Aircraft

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Summary

A technique for observing flow in vortex cores in flight is described and the results of flight tests to study vortex breakdown using the *HP 115* aircraft are presented.

* Replaces R.A.E. Technical Report 71177—A.R.C. 34 400.

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1. Introduction

Water tunnel studies[1] on models of highly swept wings with sharp leading edges have shown that at some position along the vortices associated with the flow past such wings a radical change in the nature of the flow can occur. The vortex expands radially and the line of the core takes on a spiral shape. The phenomenon is usually described as 'vortex breakdown', and the initial appearance is downstream of the wing. As incidence is increased the position of breakdown moves upstream and may occur forward of the trailing edge at sufficiently large angles of incidence.

Because of the current interest in slender wings and in the turbulence in their wakes, it was decided to see if vortex breakdown could be identified in flight behind the *HP 115* research aircraft. This Report describes the experimental technique used and the results obtained during tests in 1964 and 1965 at the Royal Aircraft Establishment, Bedford.

2. The *HP 115* Aircraft

This aircraft was specifically designed and constructed to investigate the low speed handling problems of slender winged aircraft. It has a wing of triangular planform with rounded tips, a leading edge sweep of 76 degrees, and an aspect ratio of 0·92. The wing has a biconvex circular arc section with a constant thickness/chord ratio of 0·06, and the leading edges are effectively sharp, having a radius of 0·1 inch. Large full-span elevons are fitted, it being considered at the design stage that separate elevators and ailerons might introduce control problems if the vortex should cross the chordwise elevator–aileron boundary. The general arrangement of the aircraft is shown at Fig. 1.

From the available wind tunnel data[2,3] on models having a general resemblance to the *HP 115* wing planform (but not wing section shape) it was estimated that the incidence at which vortex breakdown would occur at the trailing edge would be about 35 degrees at an indicated airspeed in the region of 45–50 kn, although the performance of the aircraft was such that this speed would be associated with a high rate of descent. Angles of incidence of this order are well outside the capabilities of conventional aircraft, and at the time when the trials were planned, had not been reached by the *HP 115*. Previous flight experience with the aircraft at speeds down to about 60 kn had shown that it was remarkably docile with no insuperable handling problems, and as a preliminary to the flow visualization tests, a number of flights was made at progressively lower speeds: these showed that the aircraft remained fully controllable in the incidence and speed range required (35 degrees and 45 kn, indicated). It was found however, that there was a marked reduction in the turbulence threshold required to initiate the Dutch roll at these airspeeds and angles of incidence. It was possible to damp out this oscillation quite rapidly by forward movement of the control column, thus reducing incidence, but it meant that very calm conditions had to be chosen for the flow visualization trials.

3. Flow Visualization Technique

In order to make the flow visible, coloured smoke was injected into the airstream at the predicted position of the vortex core, close to the intersection of the wing leading edge with the fuselage side.

The smoke generating system is shown in Figs. 2 and 3. It consisted of a chemical cartridge adapted from a marine distress signal, a tar trap, and a pipe to direct the smoke into the vortex core. The cartridge, which was ignited electrically using a switch in the cockpit, produced dense orange smoke for approximately 30 seconds. Longer duration cartridges (60 and 120 seconds) were tested but did not produce sufficiently dense smoke for photographic purposes.

A test firing of the cartridge before it was installed on the aircraft showed that the smoke was accompanied by a considerable quantity of soot and tarry material and it was thought advisable to remove as much as possible of these undesirable products of combustion to reduce contamination of the airframe and engine.

The cartridge was therefore mounted so that the smoke from it first entered a can containing baffles which reversed the flow twice (Fig. 2). At the forward end of this can a one inch (internal) diameter pipe led the smoke over the leading edge and into the vortext core (Fig. 3). Some preliminary flight tests were required before a satisfactory location for the pipe exit was obtained.

The trap removed an estimated 75 per cent of the tar, and as a first attempt, was considered reasonably satisfactory. The untrapped tar was, however, sufficient to cause some inconvenience, and for future experiments an improved design would be desirable. Possible modifications could be a larger number of baffles and an increase in length of the trap to promote cooling and condensation of the tar. The untrapped tar was deposited on the wing upper surface and also on the engine compressor blades. Removal of the deposit from the wing was facilitated by applying a thin coat of lanolin to the upper surface before each flight. The contamination of the engine was not entirely unexpected since it seemed inevitable that some denser particles of the smoke emission would escape from the vortex core and might find their way into the engine intake. The degree of contamination was however, greater than expected, and sufficiently serious to require a cleaning treatment after each flight.

4. Flight Test Technique

On each flight one smoke canister was carried under each wing. For straight runs the cartridges were fired individually so that two airspeed conditions could be observed, while for the examination of the effects of sideslip, both cans were fired together and sideslip progressively increased and reduced. The resulting flow patterns were observed from a chase aircraft and photographed with a handheld 16 mm cine camera. For most of the flights the chase aircraft was an *Auster AOP Mk 9* but on a few occasions a *Whirlwind* helicopter was employed. Most of the flights were made in the speed range 45–65 kn ias and in these conditions the rate of descent of the *HP 115* was of the order of 1000 ft per minute (5 metres per second). Considerable skill on the part of the chase aircraft pilot was required to maintain a suitable observation position relative to the target aircraft.

5. Qualitative Results

Some preliminary flights were necessary to establish the optimum position of the smoke ejection pipe (as evidenced by the slight kink in the pipe to be seen in Fig. 3) and once this had been obtained the vortex core was clearly defined by the injected smoke, as shown in Fig. 4. Prior to breakdown, the smoke was confined to a compact cylindrical zone of almost constant diameter for several aircraft lengths downstream of the trailing edge. Vortex breakdown was observed to occur at up to three or four aircraft lengths downstream of the trailing edge, moving upstream as incidence was increased. Fig. 5 shows a typical extract from the cine film record, the incidence in this case being 28 degrees and the burst position $0{\cdot}6\ C_0$ (C_0 = wing centre line chord) downstream of the trailing edge. The form of the breakdown was similar to that described by other authors[1], namely an increase in the core diameter and an apparent reduction in axial velocity. The concentrated smoke in the vortex core appeared to separate into a number of filaments at breakdown, each of which followed a spiral path, as may be seen in Figs. 5 and 6 (the latter shows a sideslip condition). On some flights it was not possible to detect these filaments until a considerable distance downstream of the onset of breakdown; on these occasions the burst vortex had an appearance consistent with an envelope of the separate filaments. An example of this may be seen in the starboard smoke trail in Fig. 7. Fig. 8 is of particular interest. In this case the aircraft was sideslipping to port, and the breakdown position is consequently nearer to the trailing edge of the port wing than to that of the starboard wing. The starboard smoke trail however, is showing a spiralling motion of the whole core prior to breakdown, as observed by Lambourne and Bryer (Fig. 4 of ref. 1).

When the aircraft was sideslipped, the breakdown positions moved rapidly, stabilizing closer to the trailing edge of the advancing wing, and further downstream of the opposite wing[4]. This is shown in Figs. 6 to 8.

On all flights, a vertical change in direction was observed as the core passed over the trailing edge, when the core direction returned approximately to that of the free stream. Fig. 7 shows this occurring in flight, while Figs. 9 and 10, taken in the course of the work described in Ref. 5, show this on a model of the *HP 115* in the R.A.E. 13 ft × 9 ft wind tunnel.

6 Quantitative Results

The variation of breakdown position with incidence is shown in Fig. 11. The position of the breakdown was estimated from the cine films, and the incidence determined from the *HP 115* instrumentation records. These results were principally derived from straight flight, but a few results from sideslip conditions are also plotted. The latter must be treated with reserve because of doubts as to the validity of the sideslip vane calibration at the large angles of incidence.

The results for straight flight were obtained over a range of incidence from 24 to 37 degrees, with corresponding breakdown position varying from about 1·8 centre line chords aft of the trailing edge to 0·1 centre line chords forward of the trailing edge. The recorded values of sideslip varied from 3·6 to 5·5 degrees; the true values were probably somewhat less. The scatter in the results may be partly ascribed to uncertainty in defining the precise position of the burst from the cine film image, and to correlating the film and instrumentation records.

Fig. 12 shows a comparison of the results obtained in straight flight with those obtained from wind tunnel tests on a model of the *HP 115*[5] and on one of the delta wing models of Ref. 2. The model used in the latter tests was a plano-convex delta wing with 76 degrees leading edge sweep and a constant thickness chord ratio of 0·06. Both sweep and thickness chord were thus the same on this model as on the *HP 115*. Two curves for breakdown position are shown according to whether the convex surface or flat surface was uppermost. The *HP 115* model results show breakdown occurring further aft than in flight at angles of incidence below 31 degrees whilst the results from the delta wing models at angles above 36 degrees were consistent with those from flight within the accuracy of the tests. It should be noted that earlier model tests[1] had shown that upward deflection of the trailing edge makes the breakdown point move forward and, since the *HP 115* model tests were made with controls undeflected while an up-elevon setting of about 20 degrees was required in flight, there is a qualitative explanation for the discrepancy in the results in the lower incidence range.

7. Pilot Comment

In straight flight at high incidence no undue difficulty was experienced in flying the aircraft in spite of the lack of forward view. On several occasions pilots reported that turbulence had initiated the Dutch roll but that the degree of rolling could be limited by instinctive lateral control movements or by reducing incidence. The comment made after the flight in which the highest incidence was achieved (37 degrees) was "The aircraft seems to be stick fixed unstable at indicated airspeeds below about 46 to 47 kn (approximately 36 degrees) and it is correspondingly difficult to ensure both a stable airspeed and minimum stick input at the same time. Very still air is needed for runs at these speeds, as the slightest disturbance sets off the unstable Dutch roll. Despite these comments the aircraft remains easy to control, and instinctive corrections to the Dutch roll oscillations will limit the degree of rolling with no sensation of being near an aircraft limit of controllability."

Although on this flight the vortex breakdown was forward of the trailing edge, no effect was felt by the pilot.

When sideslip was applied, there was a marked deterioration in the handling; only small values of indicated sideslip (approximately 5 degrees) could be achieved at incidences of about 30 degrees before encountering elevon buffet. On one flight the pilot commented as follows "On a dummy run (i.e. not filmed or recorded) at lower speed—48 kn—some evidence of flow breakdown was felt at the rear of the aircraft when slipping with maximum aileron. The aircraft in this condition was not steady and had a small pitching, rolling and yawing motion. The general feel of the aircraft was not pleasant." The incidence in this case would have been about 34 degrees, the sideslip angle approximately 5 degrees, and the breakdown position was probably forward of the trailing edge.

8. Conclusions

(1) Vortex breakdown has been shown to occur in flight, and the general characteristics of the flow associated with such breakdown are similar to those observed on models in wind and water tunnels.

(2) The position of breakdown moves upstream with increasing incidence in straight flight and with increasing sideslip at constant incidence.

(3) The relation between burst position and incidence derived from flight tests is consistent with that obtained in model tests; part of the difference between flight and model test results may be attributed to elevon deflection in the flight case.

(4) Occurrence of vortex breakdown within $\pm 0{\cdot}1$ root chord of the trailing edge in straight flight caused no increase in handling problems on the *HP 115* aircraft. With vortex breakdown close to the trailing edge in sideslip conditions, some deterioration in stability took place.

ADDENDUM

Some Further Analysis of the Results in Relation to the Results of Some Subsequent Tests

By R. L. Maltby

During a subsequent series of tests[6] to investigate wake turbulence in the far field behind the *HP 115*, some further measurements were made of apparent vortex breakdown at lower angles of incidence. The breakdown measured in these tests occurred at a distance of the order of 10 chords behind the wing apex.

Fig. 13 shows the results on a logarithmic plot. The points from Fig. 11 are plotted as the solid symbols and those from the later tests as open circles. The point at an incidence of about 18 degrees was well established but those at the smaller angles were difficult to define because the character of the apparent breakdown was more diffuse. The remaining points to the right of the diagram are from the tunnel tests[2] on a delta wing having an aspect ratio of one. It should be noted that this was not a cropped delta wing like the *HP 115* nor was it tested with trimming controls deflected.

The plot shows that, except for the two points at the lowest angles of incidence, all the results lie close to a straight line. The slope of the line indicates that the position of breakdown varies with $\alpha^{-5/2}$. The three points at the lowest angles could be said, with less conviction, to lie on another straight line indicating breakdown position to vary with α^{-1}. The change in appearance of the breakdown at about 8 chords downstream probably indicates that a different mechanism is causing breakdown which would be consistent with a change of slope.

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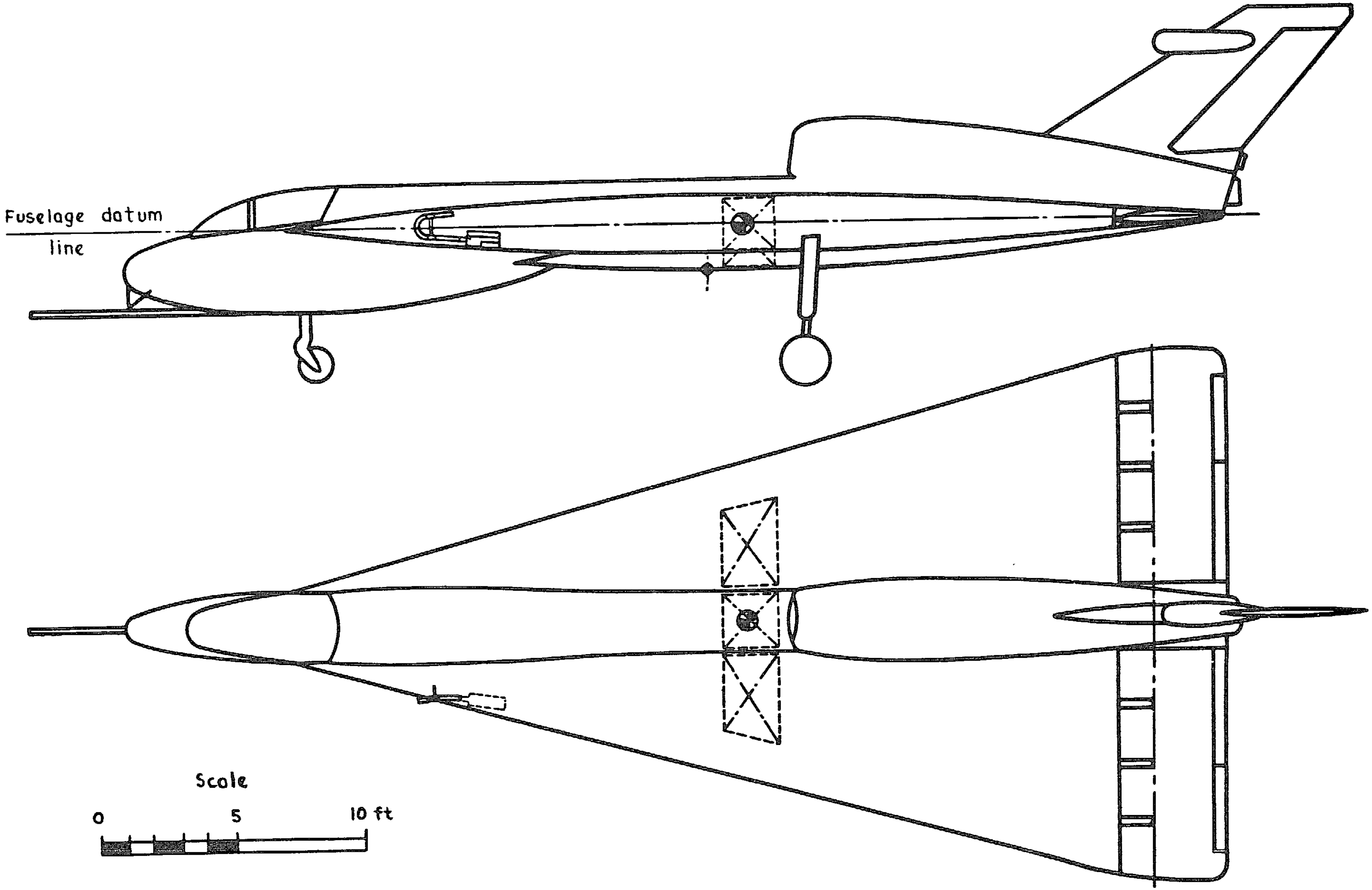

FIG. 1. General arrangement of Handley-Page *HP 115*.

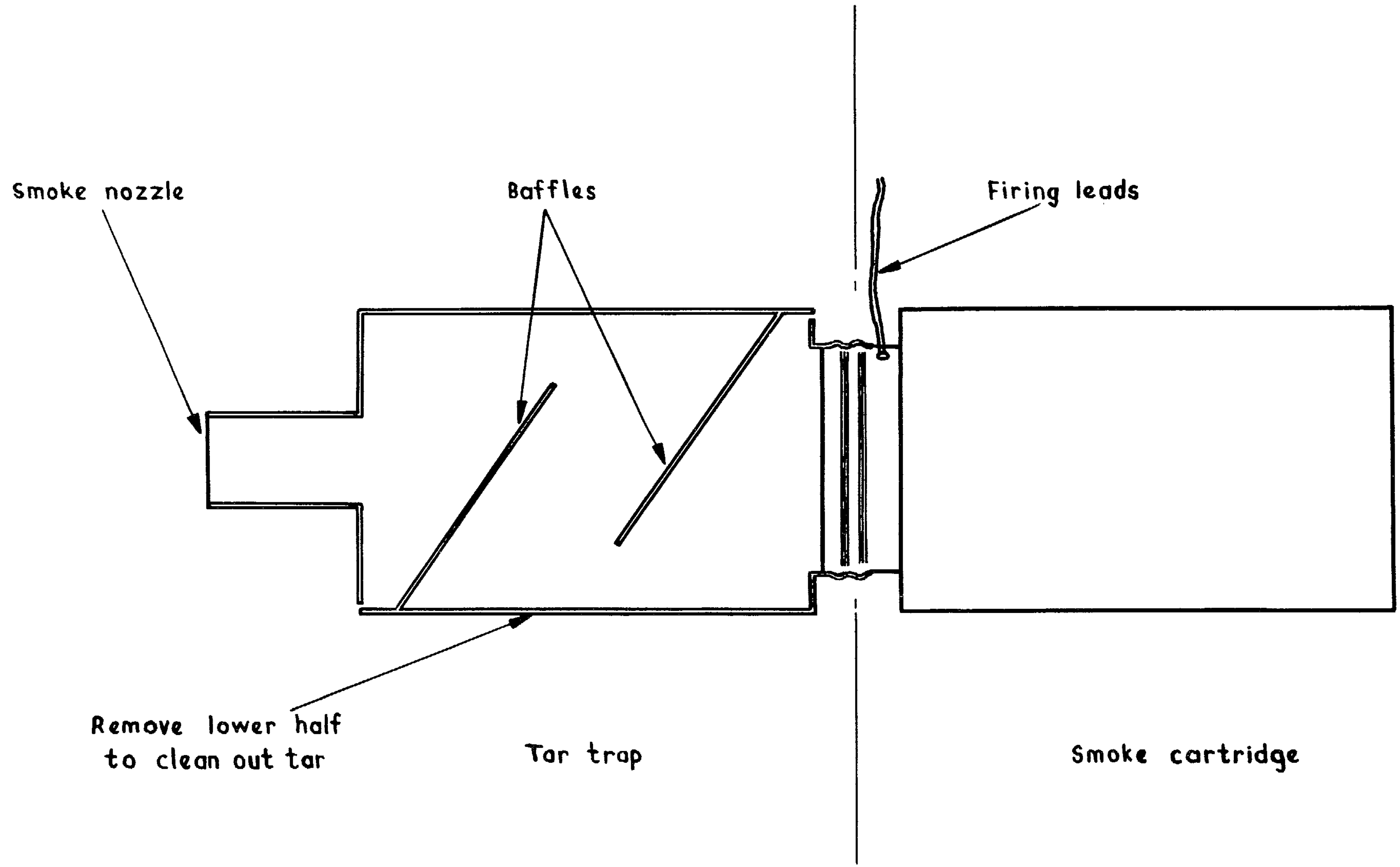

FIG. 2. Smoke cartridge and tar trap.

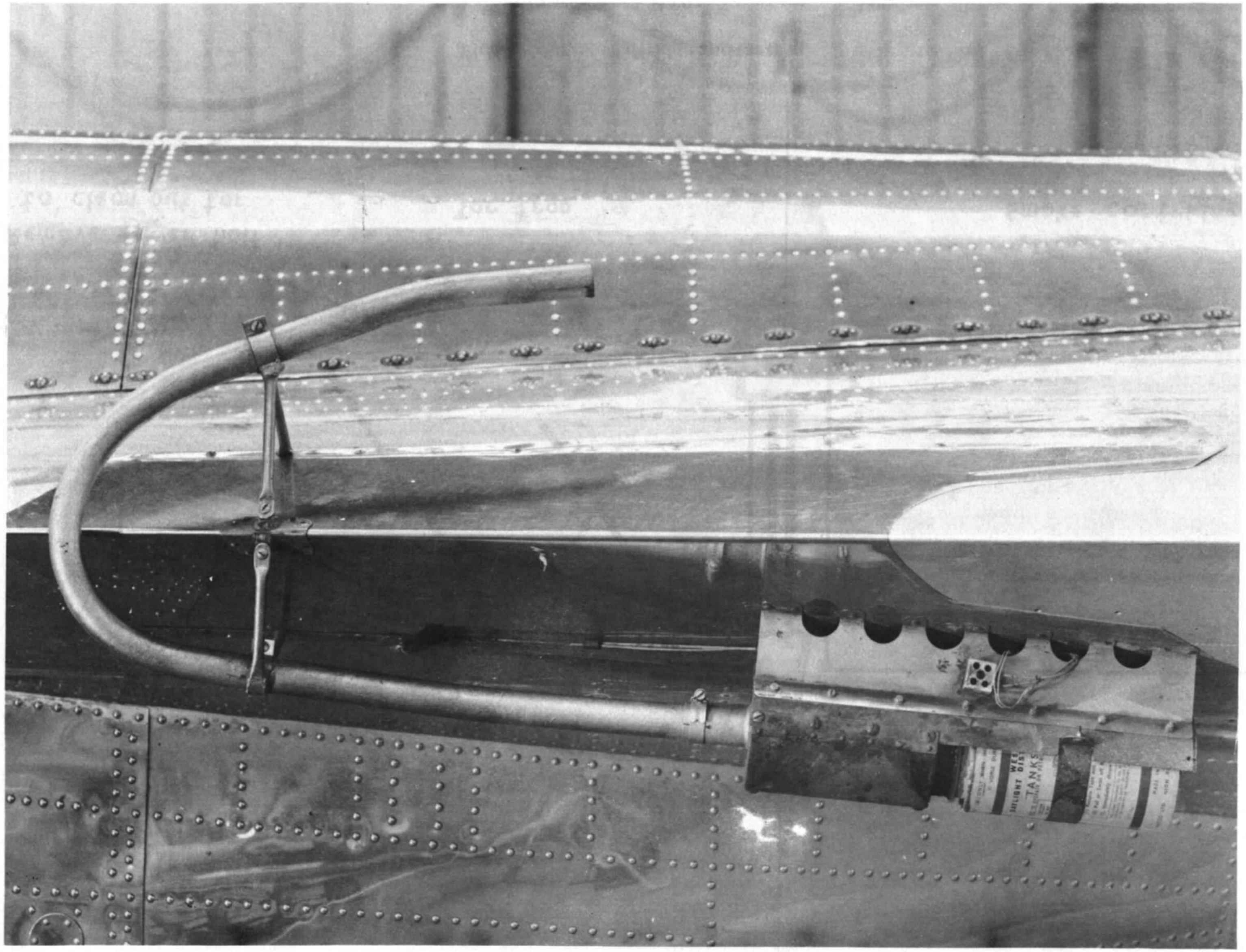

FIG. 3. Smoke generating system on *HP 115*.

FIG. 4. Vortex core flow visualisation.

FIG. 5. Vortex breakdown at 28° incidence (extract from cine film).

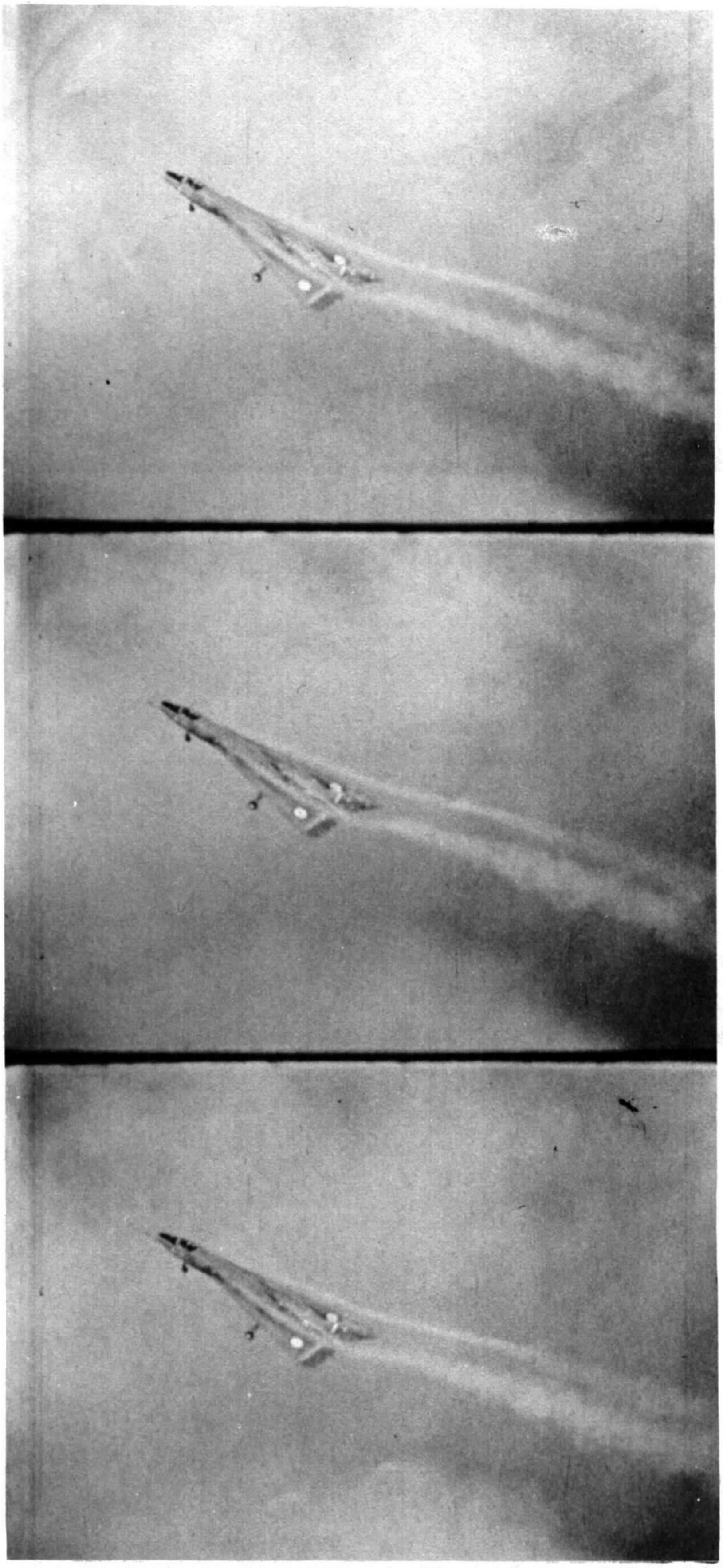

FIG. 6. Vortex breakdown at 30° incidence while sideslipping to port (extract from cine film).

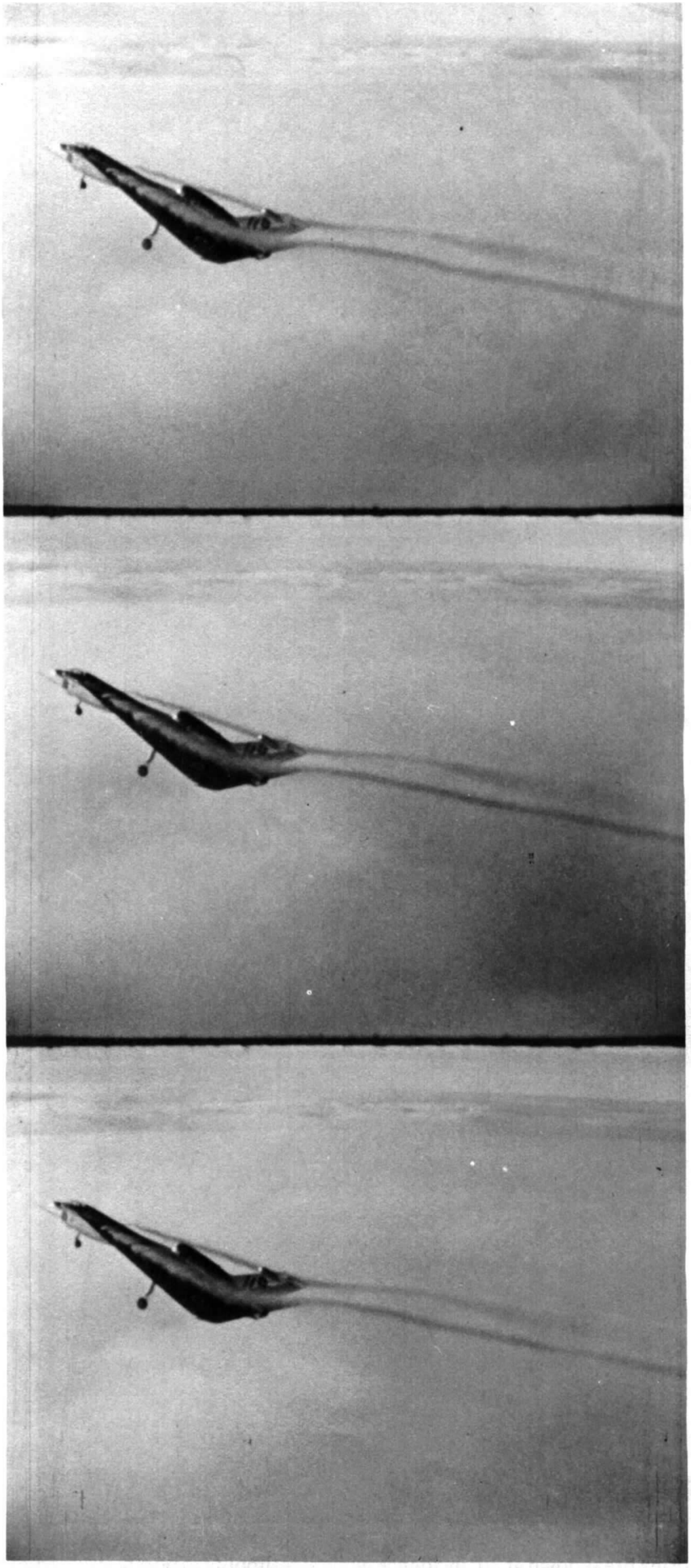

FIG. 7. Vortex breakdown at 28° incidence while sideslipping to starboard.

FIG 8. Vortex breakdown at 26° incidence while sideslipping to port.

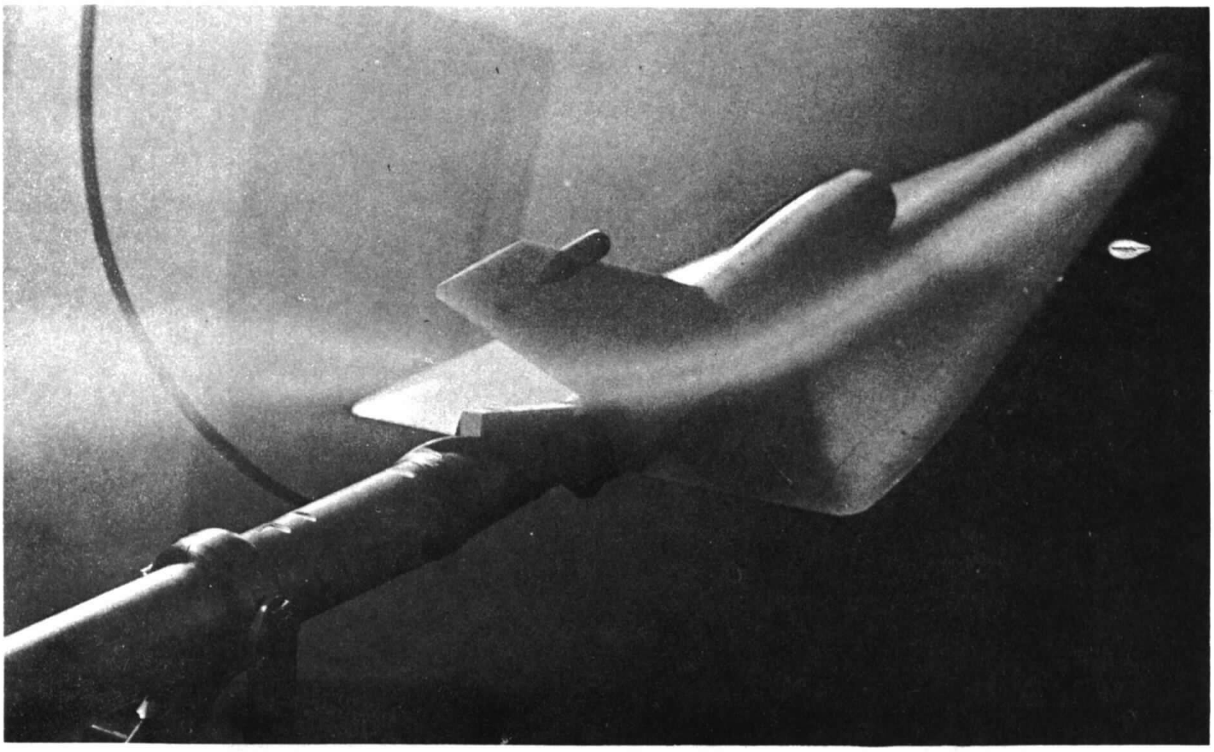

FIG. 9. Vortex breakdown on wind tunnel model at 29·4° incidence.

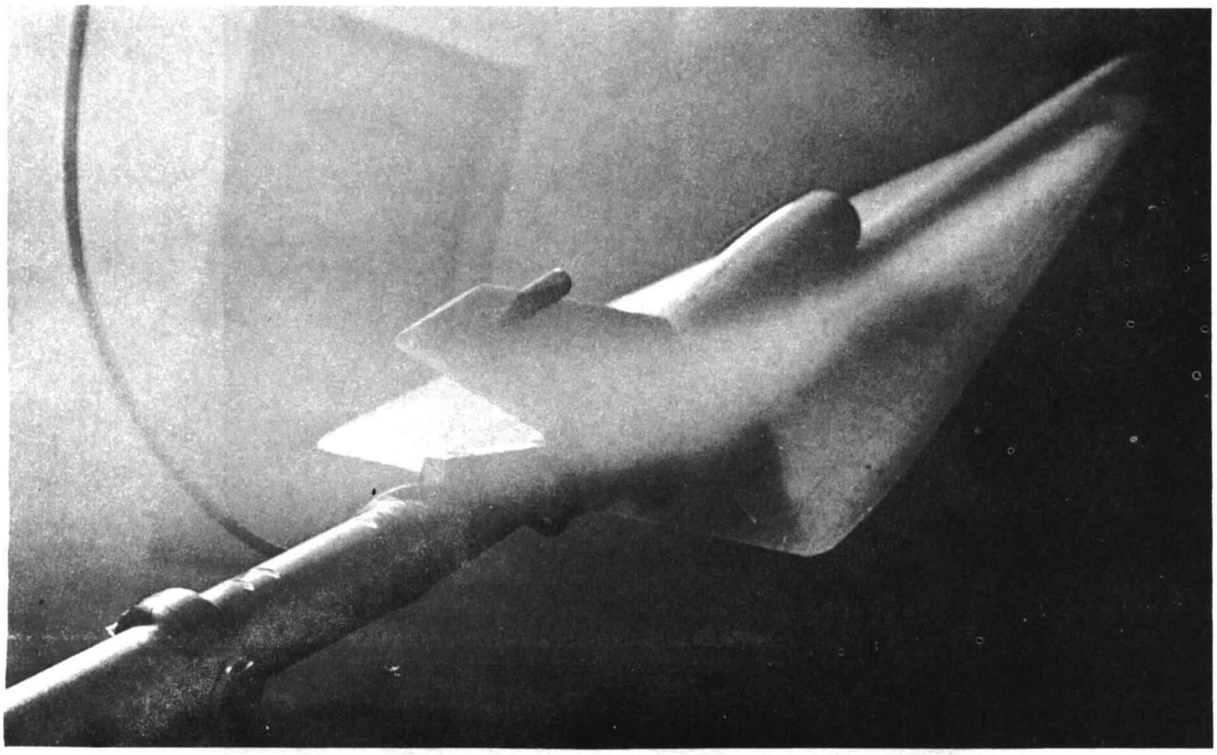

FIG. 10. Vortex breakdown on wind tunnel model at 33° incidence.

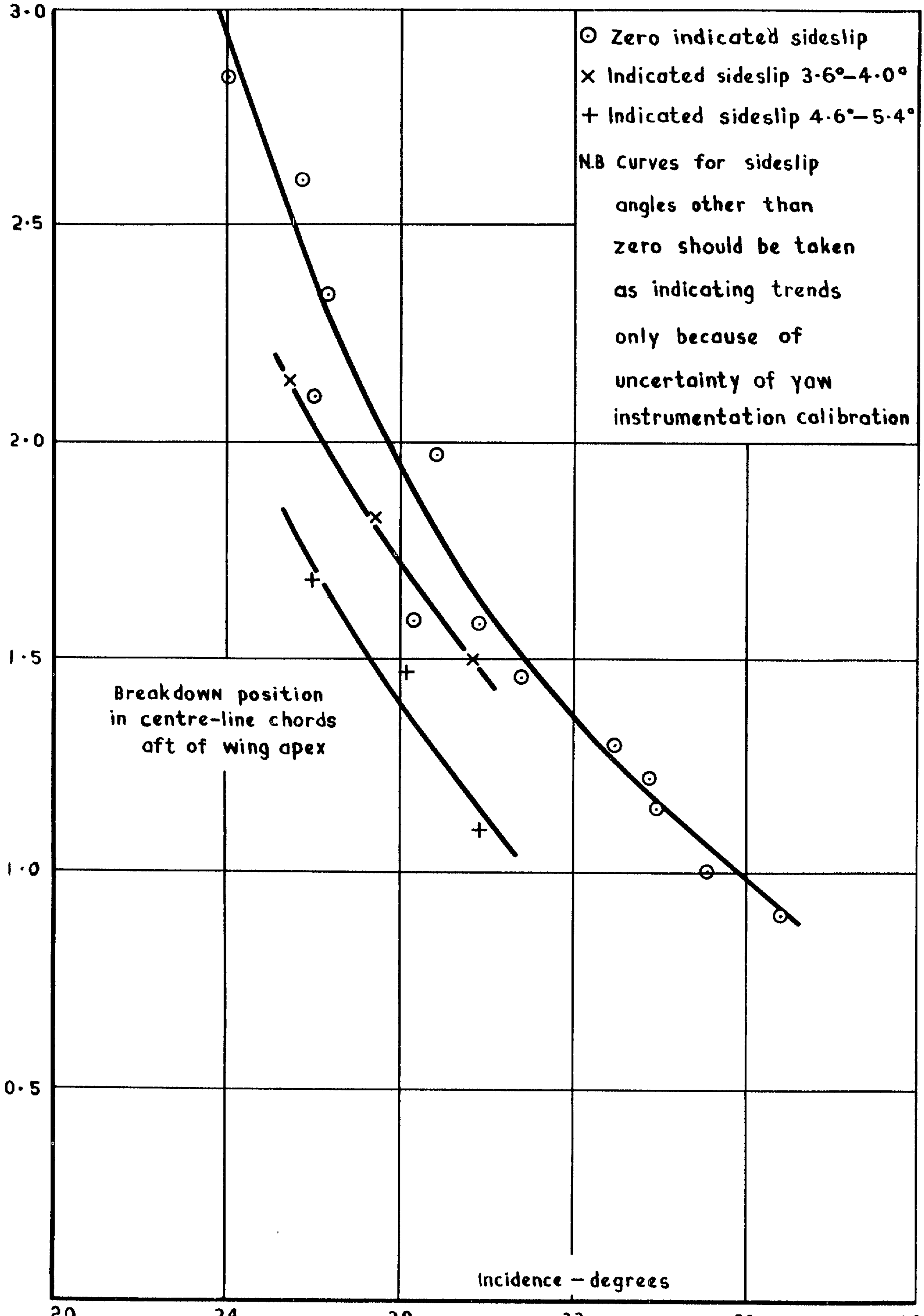

FIG. 11. Breakdown position as a function of incidence.

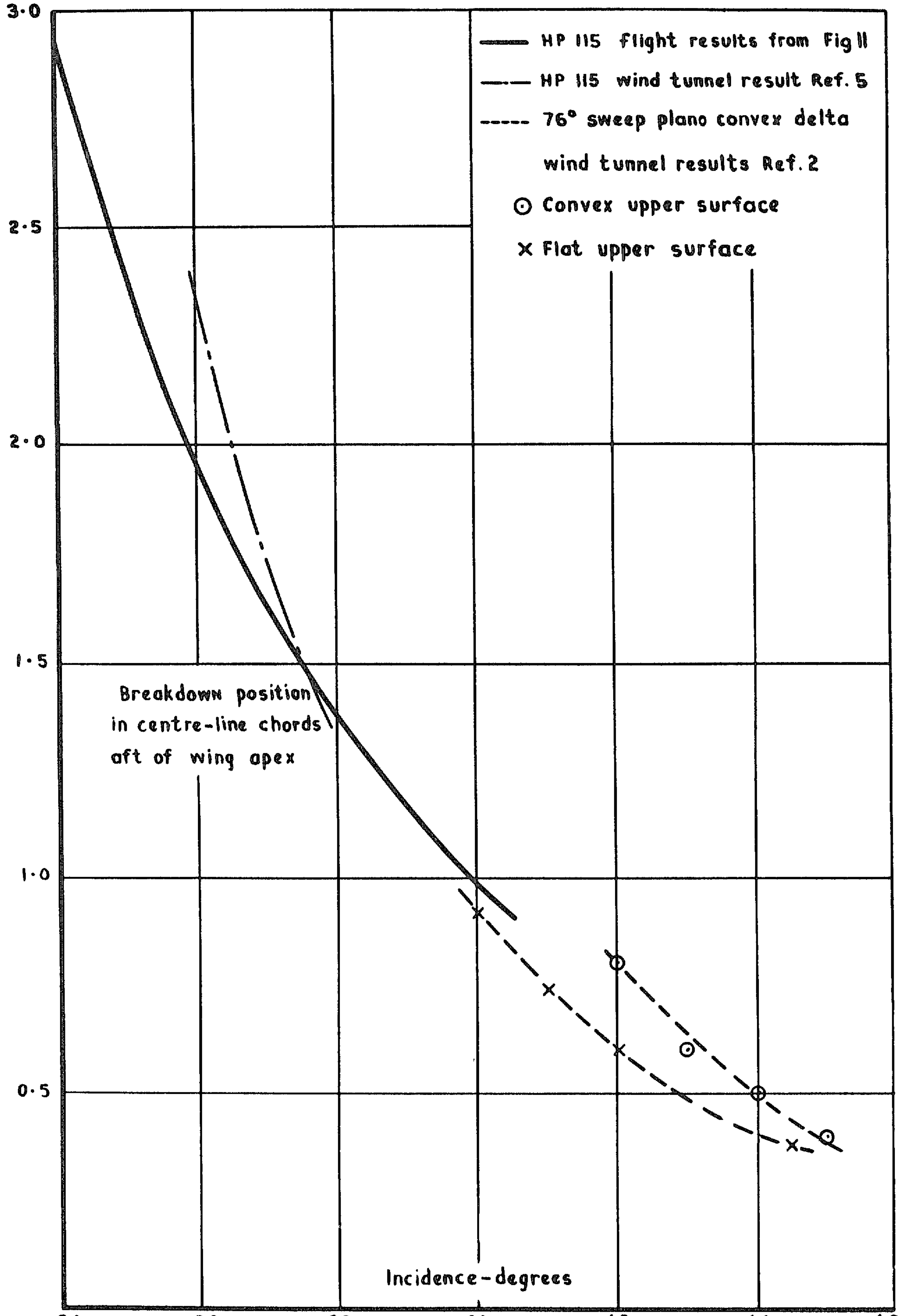

FIG. 12. Comparison of flight and wind tunnel results.

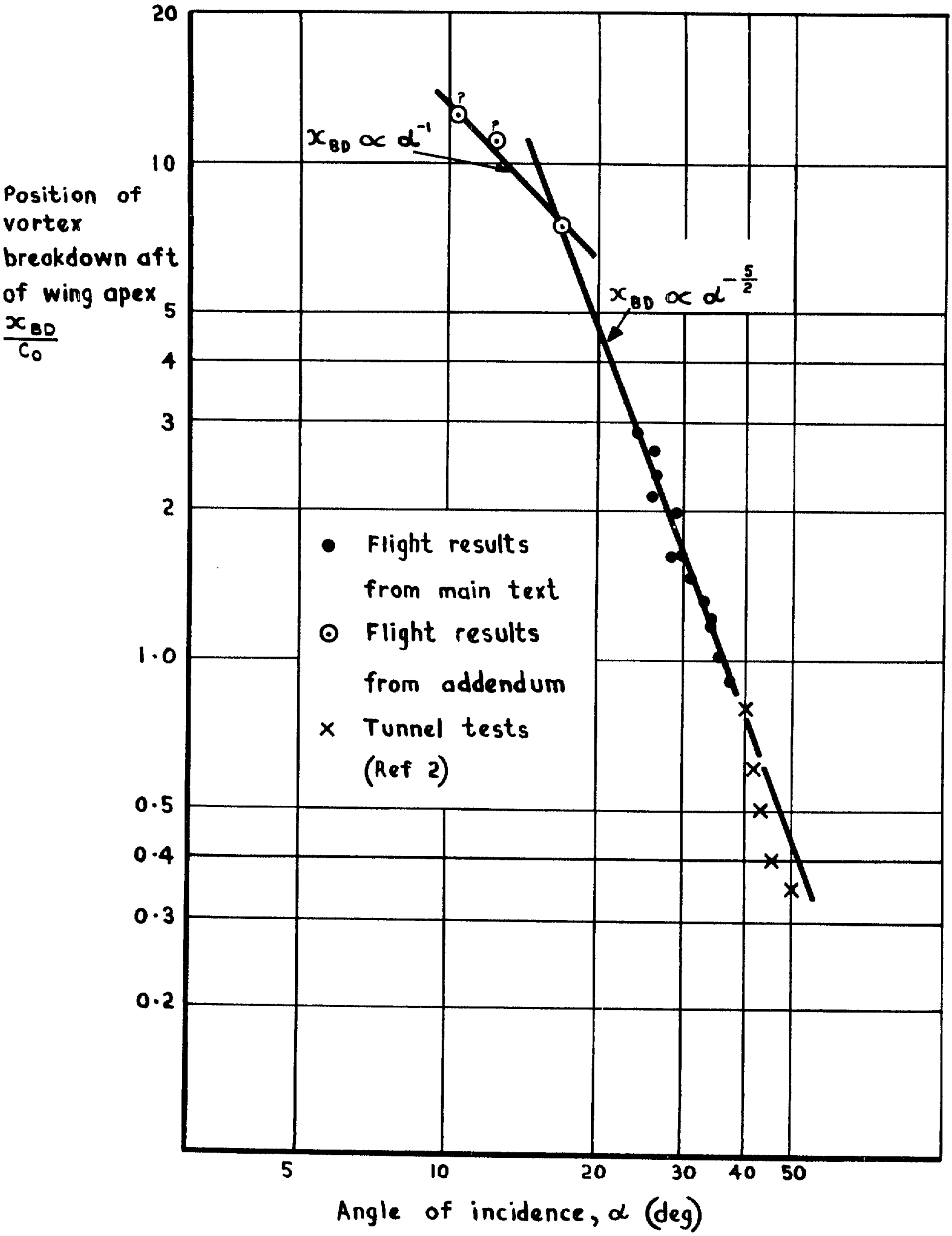

FIG. 13. Breakdown position as a function of angle of incidence (logarithmic plot).

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