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# Tests of a Blow-Away Jet Debris Guard Applied to a Supersonic Turbojet Intake

*By*

*G.T. Golesworthy*

LONDON: HER MAJESTY'S STATIONERY OFFICE

1961

PRICE 5s 6d NET

C.P. No.561

U.D.C. No. 621-757:621.438-225.12

# Tests of an aerodynamic debris guard for a supersonic turbojet intake

- by -

G. T. Golesworthy

## SUMMARY

It is well known that objects can be drawn into the intakes of turbojet engines during ground running by vortices generated by the action of wind on the flow into the intake. It has previously been shown that, with a simple intake, these vortices can be prevented from forming by directing a jet of compressed air downwards on to the ground beneath the intake.

The present tests were made to investigate the degree of protection afforded by a jet screen, or blowaway jet, to the more complex intake of a typical supersonic turbojet, for which additional inlets are necessary to enable the engine flow requirements to be met when running on the ground. The intake tested had, in addition to its centrebody nose inlet, a ring of breather ports and a ring of spill ports spaced back along the cowling. The object of the investigation was to discover to what extent these additional inlets modified the basic vortex pattern, and the screening system required for protection.

The nose inlet was relatively easy to protect with a single nozzle of rose (i.e. multiple hole) form which passed an airflow of the order of 0.14 per cent of the main flow. When directed to strike the ground beneath the inlet any vortex there was readily destroyed.

Protection of the rearward ports proved more difficult owing to the mobility of the vortex that formed. For the two alternative builds, viz., breather ports open, and breather plus spill ports open, a complex jet array was developed consisting of jets from four divergent nozzles. This gave satisfactory protection but required a total of 0.3 to 0.4 per cent of the main airflow.

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Previously issued as N.G.T.E. Memo. M.327 - A.R.C.21,242.

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## 1.0 Introduction

A survey of operational damage to turbojet engines in the United States in 1954 and 1955 has shown that over 40 per cent of engines failing in service did so because of the ingestion of maintenance and airfield debris into the intake[1]. Similar British experience has not been published but more general and unofficial figures have suggested a figure of about 20 per cent.

The greatest risk to an engine occurs while it is running on the ground. References 2, 3 and 4 state that the airflow into an intake will not, unaided, pick up objects, but a cross wind blowing on to the intake, or some other asymmetry of the external airflow, may cause a vortex to form. The vortex can raise into the air any debris that it strikes as it moves over the ground beneath the intake. The pick-up is caused by the high local air velocities and suctions generated which produce a lifting and a drag force upon an object on the ground. Away from the vortex core the horizontal component of force generally exceeds the vertical so that objects on a smooth surface are usually blown clear of the intake by the outer region of the vortex. If, however, an object should be restrained in a crack or by other ground contours so that it is not blown clear by the outer region of the vortex, and if, eventually, the vortex should pass over it, the horizontal component of force will become small and the vertical force large and the object could rise almost vertically. Once in the air in front of the intake, the object is likely to be drawn in, with resultant damage to the engine.

It is easy to fit an engine with some form of mesh screen during ground testing, but it is much more difficult to provide a satisfactory mechanical screen for operational use ensuring protection until the aircraft is clear of the ground. The problems are the weight, the performance loss and the anti-icing problem for a fixed screen, while a retractable screen must also retain any debris that has been collected[3].

A screening system that is coming into prominence in the United States, particularly for the Douglas DC 8 jet transport, is one in which a small air jet is directed below the engine intake[5,6]. The jet spreads radially on reaching the ground and severs the attachment of the vortex core to the ground.

Since a vortex must end either on itself or a solid surface, the severing of the attachment of the vortex will cause it to collapse, as the jet will then be able to supply the core with air at sensibly atmospheric pressure.

In the tests with which this Report deals, the screening problem was complicated by the configuration of the intake, which was of the supersonic centrebody type and which had a ring of breather ports and a ring of spill ports spaced back along the cowling. Both of these rings of ports could be open during ground running.

## 2.0 Apparatus

The model intake (Figure 1), of mixed wood and metal construction, was a $\frac{1}{4}$ scale version of a proposed aircraft intake. The breather port doors on the model were controlled by a locking mechanism, but as this proved unsatisfactory a blanking plate was used instead. A similar blanking plate was used for the spill ports.

Because it was desired to use an existing suction line a false "ground" was needed so that the scale height of the intake could be maintained. A hardboard platform, approximately 8 ft 6 in. square, was therefore erected $13\frac{1}{4}$ in. (1.92 cowl lip diameters) below the intake centre line.

The jet screen can best be visualized from the photographic illustrations of the rig and its operation. The simple arrangement consisted of a horizontal pipe with a tee piece and nozzle mounted below the intake as in Figures 1, 10 and 12. A more complex version (Figure 15) utilized two pipes each with two tee pieces, these latter accommodating the nozzles. The pipes were supplied with compressed air at pressures of up to 80 lb/sq.in.abs., the pressure being read on a gauge mounted adjacent to the intake. Rotation of the pipes allowed variation of the jet direction fore and aft. The nozzles were formed in $\frac{1}{2}$ in. B.S.P. plugs. Parallel nozzles were drilled in the plugs ranging in diameter from 0.050 to 0.175 in. in steps of 0.025 in. with two further nozzles of 0.250 and 0.375 in. diameter. In addition rose nozzles, as in Figure 2, were made having areas equivalent to single nozzles of 0.060, 0.100 and 0.175 in. in diameter and also divergent nozzles (Figure 3) of 0.1 in. throat diameter.

The ambient wind was provided by two fans of 3 H.P. and $\frac{3}{4}$ H.P. As these were fixed speed units, control of the airflow was obtained by blanking the inlets. Typical wind gradient plots measured 6 in. above the false ground are shown in Figures 4 to 7. It can be seen that a wind jet was produced having a peak velocity of about 30 ft/sec tapering off to 2 to 3 ft/sec in 4 to 5 ft.

### 2.1 Flow visualization

The "water whirl" technique as described in Reference 5 proved the most satisfactory method of flow visualization for general testing. For this a metal tray 2 ft 6 in. square was set in the false ground below the intake, and filled with water to half an inch from the top prior to running. As it was found that the level could be reduced rapidly during operation the initial procedure for maintaining it, hand filling, was later replaced by a system using a small continuous supply. The presence of a vortex was indicated by the formation of a miniature water spout, up to about 4 in. high, on the surface of the water. The top of this would continually burst, centrifuging water outwards, some of which passed into the intake (Figures 10, 13 and 15). The disturbance set up created a complicated and violent reflected wave system on the surface of the water.

The effect of the blowaway jet as its pressure and hence mass flow was increased was first to decrease the size of the waterspout, and then when it had been reduced to about half size, to cause increasing interruptions in its formation. The final point of prevention was not well defined.

Smoke was used when it was desired to trace the airflow into the intake, and could be made to show the core of the vortex or the helical path of the airflow around it. The smoke was kerosine vapour produced in a generator similar to that described in Reference 7.

## 3.0 Procedure

Experience showed that a reliable way of forming the largest possible vortex was first to position the blower so that its jet centre line was offset 2 to 3 ft from the port under investigation and then to increase the wind strength, by unblanking the blower inlet, until the vortex size had increased to a maximum. Any further increase caused growing interruptions in the vortex formation. The offset was then adjusted slightly to see if any improvement could be obtained. This was the procedure usually adopted.

The main intake configurations investigated were:-

(i) the nose inlet alone open

(ii) the nose inlet and breather ports open

(iii) all ports open

(iv) the lower breather and spill ports blanked off.

In the initial testing the effectiveness of the various nozzles was compared using the intake with the nose and breather ports open. Because of the results obtained the rose and divergent nozzles were used in all subsequent tests, where the object was to protect the three main configurations over the whole intake airflow range.

In order to assess the effect of the blowaway jet on solid objects the water tray was blanked off, and a number of small aluminium washers placed beneath the intake. Ground contours were obtained by placing some $\frac{1}{2}$ in. square section iron bars on the blanking plate and spaced about 1 in. apart. This arrangement was intended to represent the effect of the joints in runway paving.

## 4.0 Results

### 4.1 General

In the intake configurations investigated it was impossible to form more than one powerful vortex at a time. It would seem that the airflows set up prevent the formation of any further vortices close to an established one. Disruption of a vortex is provided most economically when the blowaway jet provides just enough mass flow to balance the low pressure region in the core of the vortex. This condition is difficult to achieve because the vortex moves about beneath the intake, whereas the blowaway jet provides a relatively inflexible airstream.

The movement of the vortex from a position directly beneath the intake appeared to have three components:-

(i) a basic wander

(ii) a set downwind

(iii) an offset across the wind.

The basic wander covered an area on the ground of up to about 3 in. x 3 in. for a vortex formed from the nose inlet, 3 in. x 6 in. wide for a breather inlet vortex and 6 in. x 6 in. for a vortex common to the breather and spill ports. The downwind set and the across wind set (these appear to be due respectively to a drag effect and a Magnus effect, each acting on the core of the vortex which, when curved, would seem to be able to sustain a sideways force) combine to give the vortex a diagonal offset. Together these movements produce a total area to be protected of about 6 in. x 6 in. for a vortex originating from the nose inlet, 6 in. x 12 in. wide for a vortex from the breather ports and 10 in. x 12 in. wide for a vortex originating from the breather and spill ports.

The parallel nozzles were not very effective because of the inflexibility of the air jet they produced but, of the range of nozzle sizes tried, the 0.1 in. diameter seemed the best. If the jet could be directed into a comparatively stationary vortex, as occurred at the lower intake mass flows, the vortex would be destroyed, but often the vortex would form to one side of the jet strike area and then the disturbance caused by the jet striking the water would be added to that caused by the vortex. (However, it appeared from a test, using solid objects, that the jet throw-up problem may not be as serious as the water tray indicates.) In an attempt to produce a jet with a greater spread, the rose and divergent nozzles were tried and found to be a great improvement; the strike area was increased and hence, for a given mass flow, the pressure exerted on the water was reduced so that water throw-up troubles decreased. Conversely the mass flows could be increased considerably over those permitted by a parallel nozzle before throw-up troubles again became apparent. In one instance an increase of mass flow of 40 per cent for a rose nozzle and 100 per cent for a divergent nozzle was recorded before similar throw-up troubles were obtained. Of the rose nozzles the 0.1 in. equivalent diameter was the most effective so this diameter was used for the divergent nozzles.

Thus, in general, the parallel nozzles were sometimes successful under the easier conditions occurring at the lower intake flows, but the rose or divergent nozzles, because of their greater strike area and usable mass flow, were a more reliable safeguard. From the foregoing it will also be realized that jet aiming was not at all critical so long as the jet struck the ground somewhere beneath the inlet to be protected.

### 4.2 Nose inlet only

The nose inlet by itself produced a strong consistent vortex over a wide variation of wind direction, except when the supporting structure at the back of the intake obstructed the wind flow.

The effectiveness of various types and sizes of nozzles in preventing or destroying the vortex is shown in Figure 8. Points are shown for tests with the inlet accepting 75 per cent and 57 per cent respectively of the full intake mass flow (choking occurring at 77 per cent of the full mass flow with only the nose inlet open). The parallel nozzle results shown for 75 per cent mass flow are of little practical interest as the jets required very careful setting up for the wind direction being used and even then exhibited intermittent water throw-up troubles. At 57 per cent mass flow the parallel nozzles (provided they were very carefully set up) were effective in preventing the vortex, as the latter appeared to be nearly stationary and less offset.

With 75 per cent mass flow passing through the intake the 0.1 in. divergent nozzle did not have as great a margin between vortex prevention and water throw-up as was exhibited by the 0.1 in. rose nozzle. Because of this the rose nozzle was used for the test of protection over the intake mass flow range, of which the results are shown in Figure 9, where $Q_A$ is the intake mass flow and $Q_{A_b}$ the jet mass flow. The percentage of the intake mass flow required by the blowaway jet to prevent vortex formation over the intake operating range can be seen together with the pressure required across the nozzle. The jet mass flow needed for this nose inlet configuration agrees reasonably well with the amounts quoted in Reference 6 for set pressures of 4 atmospheres or above, but not with the amounts suggested for low jet pressures. Below 25 per cent mass flow the vortices formed are very small and would not appear to be a danger to the intake. Figure 10 shows the effect of the blowaway jet on a vortex formed at 70 per cent mass flow.

### 4.3 The nose inlet and the breather ports

With this build it was possible to produce, by varying the wind direction, either a nose inlet vortex or a breather vortex. On some occasions it was also possible to produce two very weak vortices, especially when the wind was light.

The nose vortex was similar to, though rather weaker than, that formed when only the nose inlet was opened.

The results obtained using various nozzles are shown in Figure 11 and it can be seen that only some of the parallel nozzles were of use even at the lower mass flows. The rose nozzle of 0.1 in. equivalent diameter was again found to have a larger operating margin than the divergent nozzle, and so was used for the intake mass flow range test, for which the results are shown in Figure 12. The photographs in Figure 13 illustrate the effectiveness of the jet.

The vortex obtained beneath the breather port was smaller and more mobile than the nose inlet vortex. The reason for the mobility was that, whereas the nose vortex core issued from the same area of the nose inlet, the breather vortex core oscillated between the two available breather ports on the underside of the cowling. Because of this mobility it was very difficult to stop the formation of the breather vortex. The parallel nozzles were quite useless at full flow conditions. At first it was thought that the 0.1 in. divergent nozzle passing 0.1 per cent of the main airflow, was operating successfully, but later tests where the wind direction was varied while the nozzle conditions remained constant showed that the jet could only prevent vortices forming in about 70 per cent of the possible formation area. With this vortex it was also found that the 0.1 in. rose nozzle caused water throw-up at lower jet mass flows than did a 0.1 in. divergent nozzle. This is at variance with the results obtained from the nose inlet vortex. A possible explanation is that the closer proximity of the water surface to the nozzle outlet does not allow the individual jet streams of a rose nozzle to mix sufficiently with the surrounding air.

In order to destroy vortices forming towards the sides of the possible formation area two divergent nozzles were used, one being placed $2\frac{1}{2}$ in. each side of the vertical centre line, beneath the intake, and directed parallel to the centre line to strike the water below the breather ports. Unfortunately the vortex tended to form ahead or astern of the jet strike areas, and either to the sides or between them.

The next stage used four divergent nozzles in two laterally disposed pairs, spaced $2\frac{1}{2}$ in. each side of the centre line, and 3 in. ahead and astern of the breather ports. The jets were adjusted to impinge upon each other, about 1 in. above the ground, below the two lower breather ports. This increased the lateral spread at the expense of the axial, and proved successful in preventing vortex formation over the whole area.

The intake had originally been mounted with the two lowest breather ports equally spaced either side of the undersurface centre line, i.e. "off" centre. It was later suggested that rotation of the intake, so that a single port would be on the centre line, i.e. "on" centre, might improve the situation by stabilizing the vortex on the central plane and hence reducing the area requiring protection. This modification considerably strengthened the vortex but reduced its lateral travel, but unfortunately made it more difficult to prevent.

The results obtained with the four jet array are plotted in Figure 14, where the air requirements and jet pressure are shown against the intake mass flow for both the "on" centre and "off" centre configurations. The curves show that the strengthening of the vortex caused by rotating the intake to the "on" centre configuration more than offsets its reduced wander. In addition the vortex produced in the "off" centre configuration became weak below about 50 per cent intake mass flow.

Figure 15 illustrates the effect of the four jet array on a vortex formed below the breather ports in the "on" centre configuration.

### 4.4 All ports open

With all the inlets open a single sustained vortex could be formed only beneath the breather and spill ports. Once this vortex was established it prevented the formation of a nose inlet vortex. Conversely, if the formation of the rearward vortex was prevented by the action of the blowaway jet or ceased during an adjustment of the conditions, a small and intermittent nose inlet vortex could be formed.

The core of this breather/spill port vortex oscillated between the two breather and the two spill ports on the underside of the model, and therefore covered a large area on the ground. This movement made the vortex very difficult to stop at full flow conditions when a single divergent nozzle using 0.1 per cent could only provide about 60 per cent protection, i.e. it only prevented vortex formation within its own strike area. The parallel nozzles performed as in the previous configurations and operated successfully only at part flow conditions.

The four jet array, as for the breather ports, was used with the nozzles spaced $2\frac{1}{2}$ in. either side of the centre line, two being ahead of the breather ports and two astern of the spill ports. The most successful arrangement was similar to that used in the breather inlet configuration where each forward jet impinged upon the after one, on the same side of the centre line, about 1 in. above the ground. The resultant pair of laterally disposed strike areas were arranged to be about midway between the breather ports and the spill ports.

It was found that it was easier to destroy the vortex formed in the "on" centre condition with this build as, although the vortex was stronger than the one formed in the "off" centre state, it was also very much less mobile. In the "off" centre build vortices could be formed at maximum intake flow conditions to one side of the jet strike area by a 45° head wind, even with the four jet array. However, as these vortices were both weak and outside the model diameter, they were not thought to be a danger to the intake. The results obtained over the intake operating range with a typical wind direction can be seen in Figure 16.

### 4.5 Blanking off the lower ports

This modification was tried and it was found that weak vortices could be formed, although they were outside the projected diameter of the model. Once the nose vortex became established, as generally happened regardless of wind direction, it prevented the formation of these small vortices.

An extension of the idea of blanking off the lower ports was one which suggested that they should instead be protected by a mesh screen. The reason for this was that, as mentioned in Section 4.4, in the all ports open condition a vortex formed preferentially beneath the breather and spill ports. If this happened it was reasoned that the nose inlet would not require protection and objects could not enter the rear ports because of the screens. Unfortunately, as can be seen in Figure 15, a vortex forming beneath the breather ports could project water, and therefore presumably objects, into the nose inlet. Hence the nose inlet would require some form of screen or bib, which raises the problems mentioned in the introduction.

### 4.6 Solid objects

Because of the throw-up troubles experienced with the parallel nozzles when the disturbance caused by the jet striking the water became comparable with that of the vortex, a test was carried out to study the effect using solid objects, small washers, instead of water.

When the test was begun it was apparent that the washers, unless restrained by some form of ground contours, would not be picked up as an approaching vortex would blow them away. This conclusion confirmed information given in Reference 5. Accordingly some $\frac{1}{2}$ in. square section bars were placed on the blanking plate beneath the nose inlet and spaced 1 in. apart. The washers were distributed between these bars and it was found that those that could not escape along them erupted into the air when overrun by the vortex. About one in ten would pass into the intake, not necessarily via the core, the rest were centrifuged outwards after pursuing a helical path around the vortex.

The effect of the blowaway jet, as produced by a parallel nozzle under a condition of no wind and hence no vortex present, was to cause the objects to be blown away or into the air, but none succeeded in entering the intake.

Hence it is concluded that the water throw-up effect may not represent as serious a practical problem as the experiment indicated, but as only one size and type of object was tried it is difficult to be definite.

### 4.7 Summary of results

The nose inlet by itself can produce a strong consistent vortex that requires a rose nozzle passing up to 0.14 per cent of the main airflow for its prevention.

In the nose inlet and breather ports configuration a vortex could be produced beneath either, depending upon the wind direction. The nose inlet vortex was very similar to that produced in the inlet condition, and required similar protection, i.e. a rose nozzle passing up to 0.1 per cent of the main airflow. Breather port protection was more difficult because of the mobility of the vortex. The successful system finally developed required four divergent nozzles passing a total of 0.3 to 0.4 per cent of the main airflow. Alteration of the breather port position by rotating the intake showed that an "off" centre port disposition is to be preferred.

With all the ports open a single very mobile vortex formed beneath the breather and spill ports. This required similar protection to that used for the breather ports but the "on" centre configuration was preferred.

Blanking off the lower breather and spill ports reduced the size of the rearward vortex.

No firm conclusion has been reached regarding the potential danger of throw-up caused by the blowaway jet but it seems unlikely to be serious.

## 5.0 Aircraft movement

Although all the tests described were performed with the intake stationary, it is felt that the effect of aircraft movement may reasonably be deduced from the results obtained. It has been explained in Section 3.0 that the wind strength and direction were adjusted to make the vortex strength a maximum. Any change from these conditions, such as would be caused by movement of the intake, would be equivalent to a change in the wind speed and could only result in decreased vortex size. Thus aircraft movement is not thought to present any additional problem.

## 6.0 Conclusions

(1) In a condition where the nose inlet alone is open a single nozzle of rose form passing a flow of the order of 0.14 per cent of the main airflow is required to disrupt the strongest vortex formed.

(2) In a condition where the nose inlet and the breather ports are open, a total of five jets is required. A single rose nozzle as in (1) above, passing up to 0.1 per cent, is needed to protect the nose inlet. An array of four divergent nozzles arranged around the lowest ports and passing up to 0.4 per cent provides protection for the breather ports.

(3) In a condition where all the ports are open five jets are required, arranged in substantially the same manner as (2) but with the rearward pair of divergent nozzles moved aft to allow for the location of the spill ports.

(4) Accurate jet aiming is not required.

(5) Rose or divergent nozzles are more effective than parallel nozzles.

(6) The pressure and hence size of nozzle shows no optimum although model sizes of 0.1 in. diameter and pressures of two atmospheres showed most promise.

(7) Blanking off the lower breather and spill ports or fitting them with gauze screens does not offer a complete solution.

(8) Aircraft movement is not thought to present any additional problem.

6(a) It will be appreciated that the full scale arrangement of the jet system and the mass flows to be applied, would depend on the matching of the intake port configuration to the operating conditions likely to be met when ground running the engine used.

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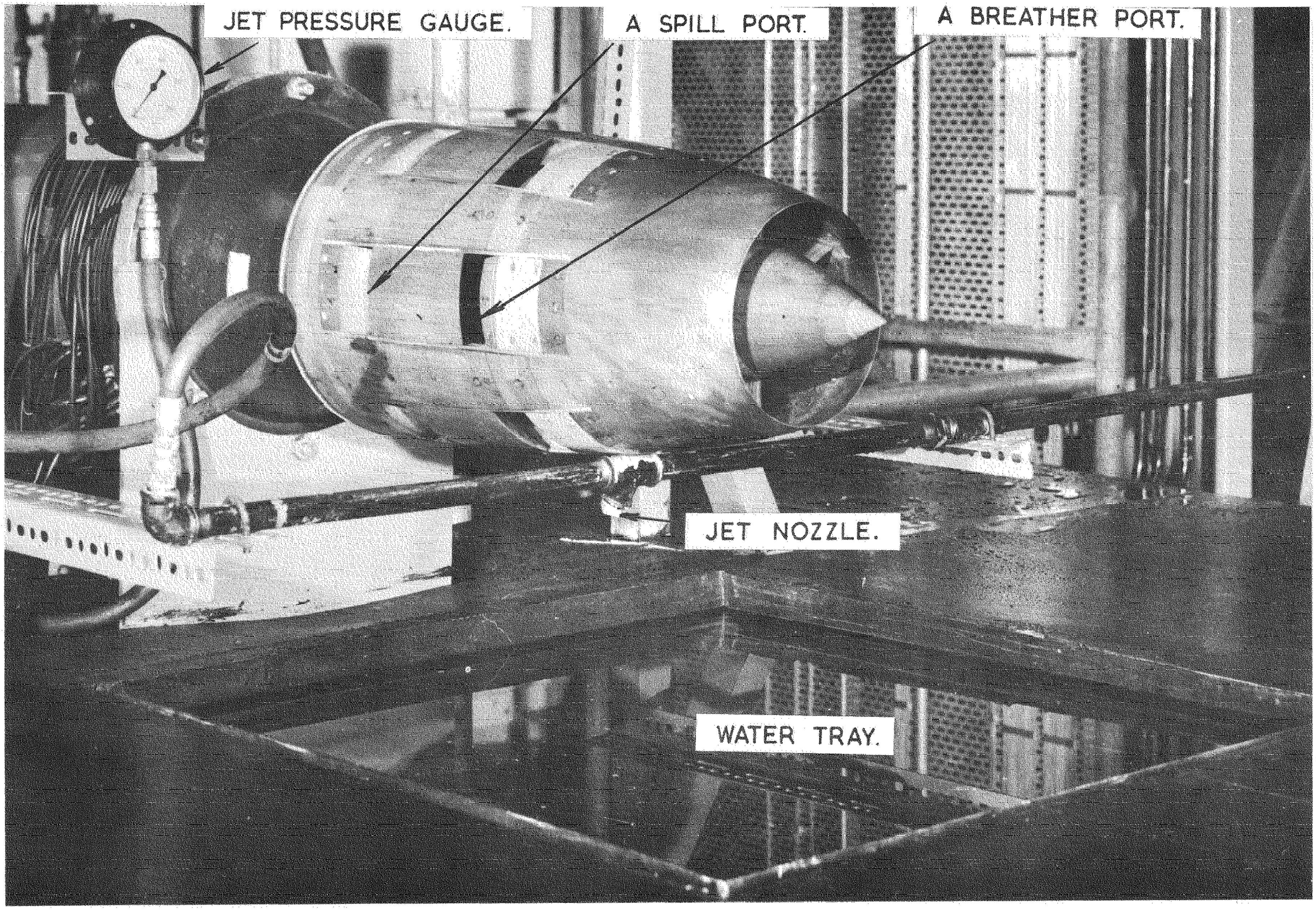
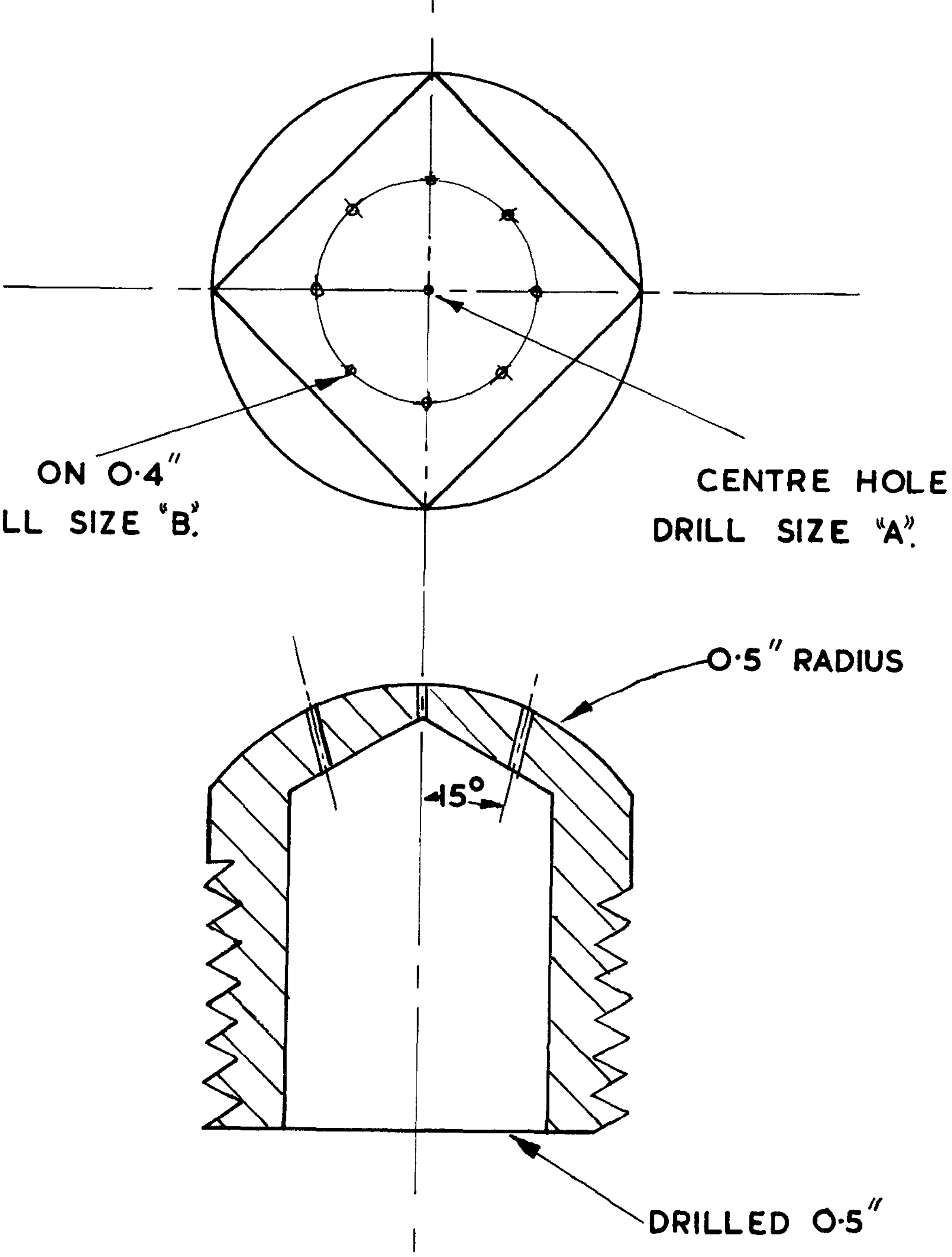

JET PRESSURE GAUGE.
A SPILL PORT.
A BREATHER PORT.
JET NOZZLE.
WATER TRAY.

FIG. 1

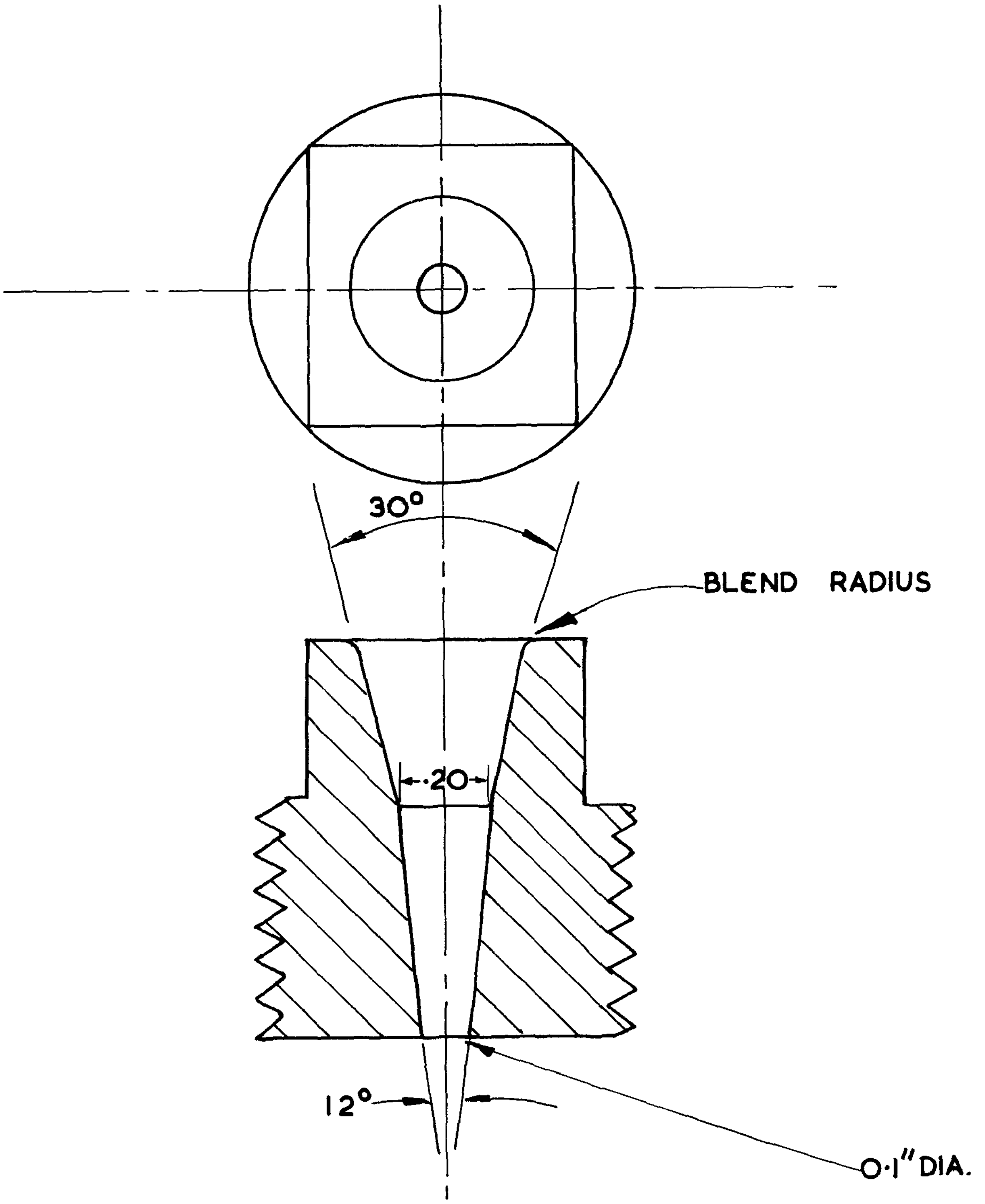
FIG. 2

| JET AREA EQUIVALENT TO | DRILL "A" SIZE | DRILL "B" SIZE |
|---|---|---|
| 0·062" DIA. | ·028" | ·020" |
| 0·10" DIA. | ·035" | ·033" |
| 0·175" DIA. | ·052" | ·046" |



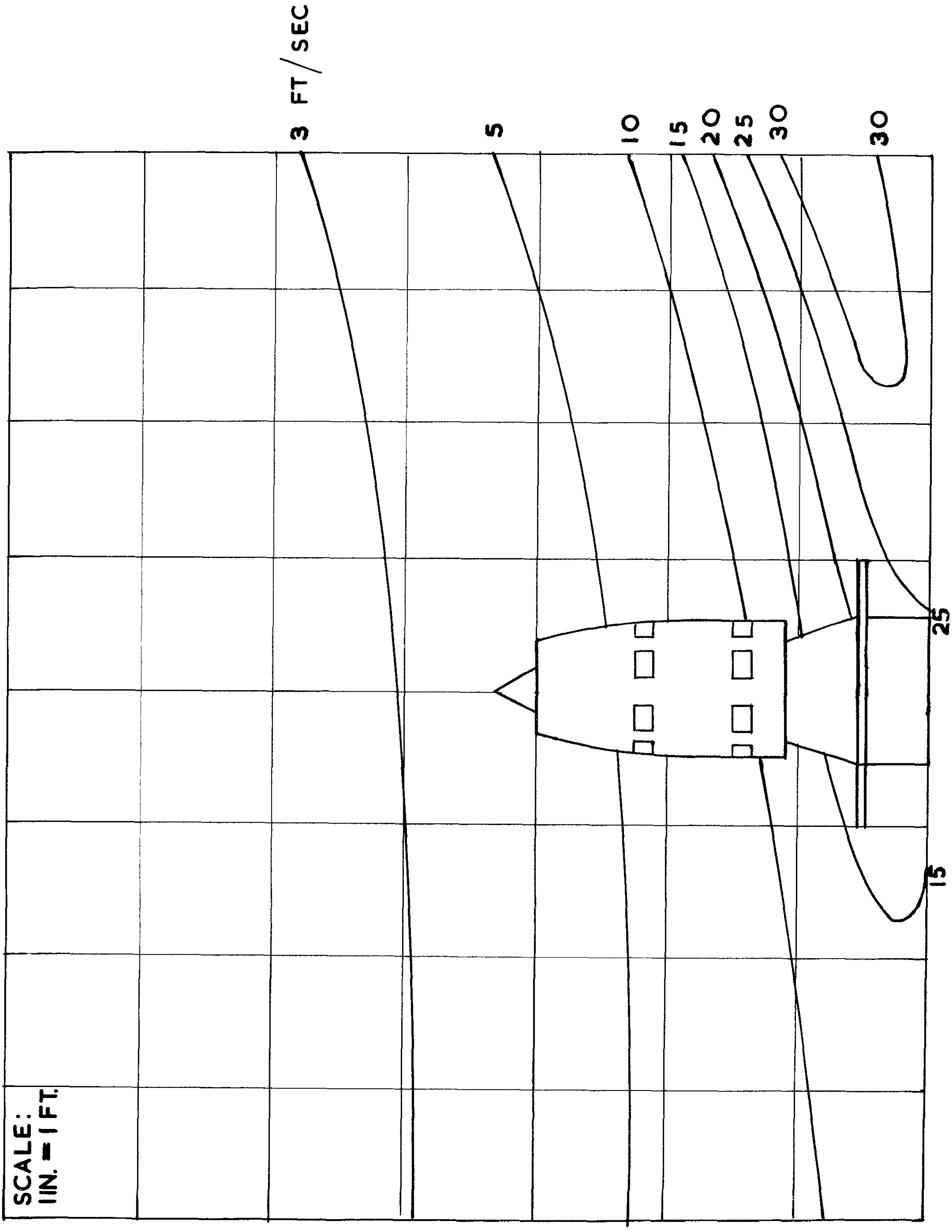
ROSE NOZZLES SHOWING ADAPTATION FROM 1/2" B.S.P. PLUGS

FIG. 3.



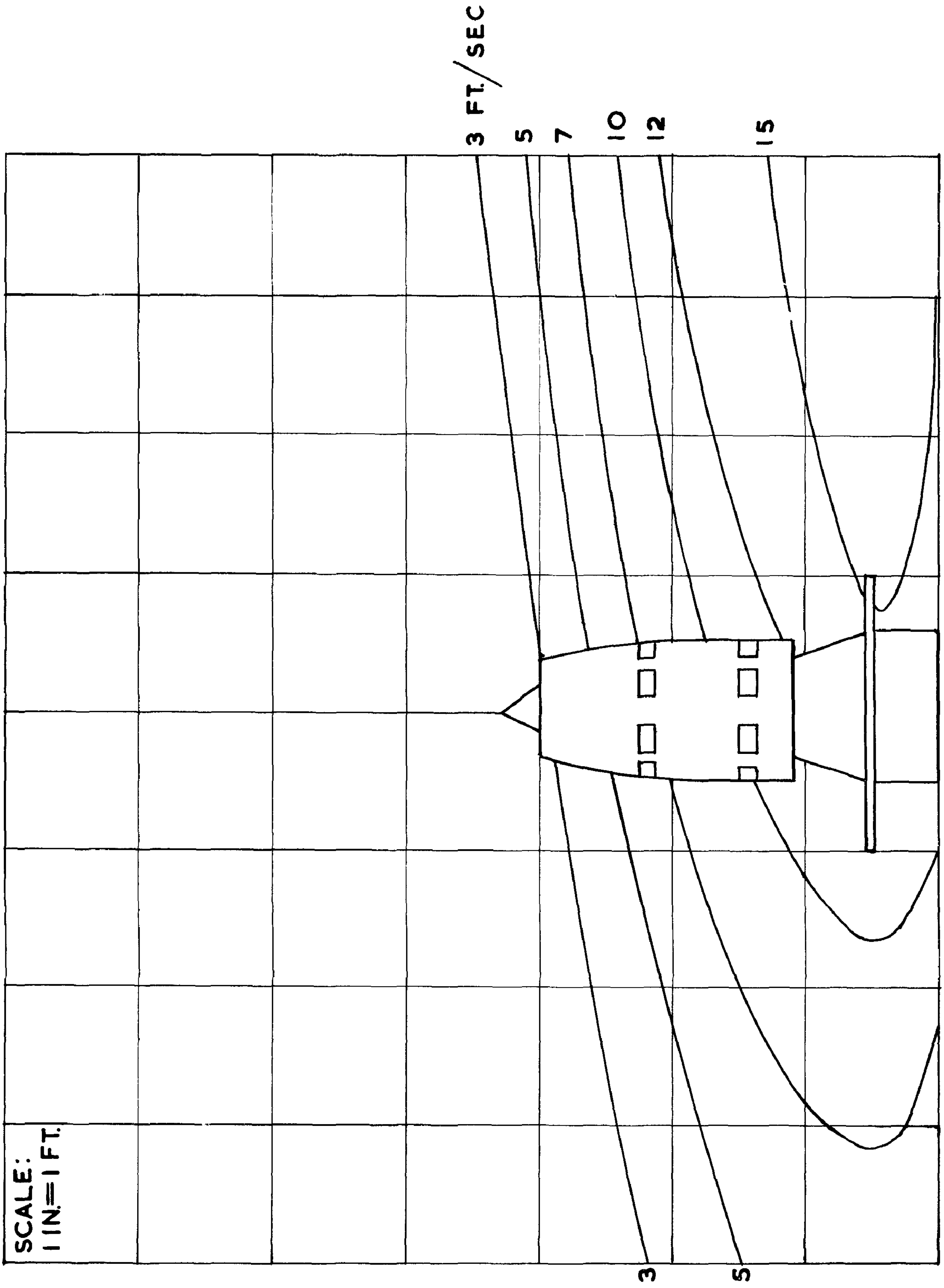
O·1" DIVERGENT NOZZLE ADAPTED FROM 1/2" B.S.P. PLUG

FIG 4



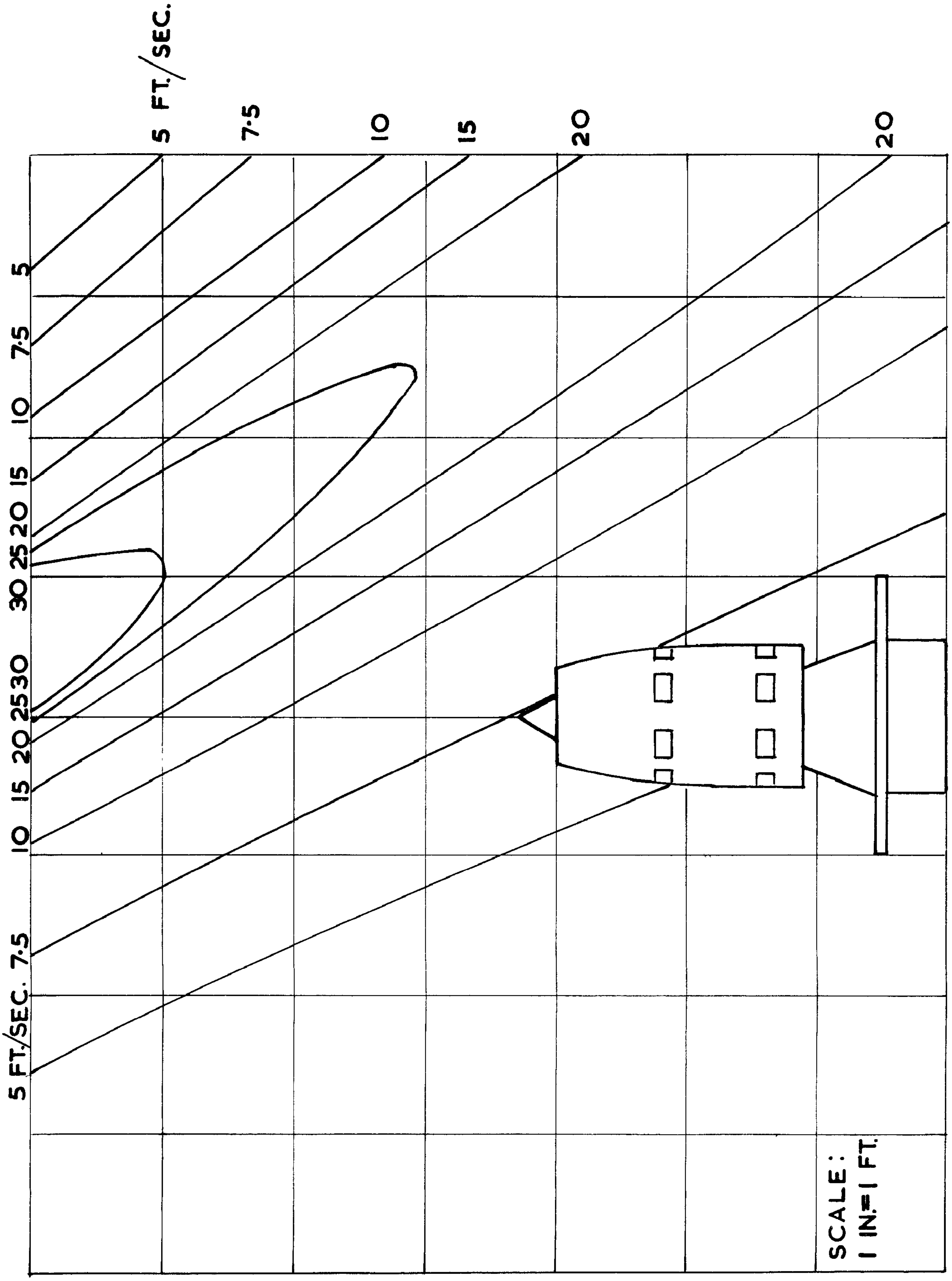
VELOCITY PROFILE AROUND INTAKE
GENERATED BY HALF OF 3 H.P. FAN
TO THE RIGHT OF THE INTAKE

FIG. 5.



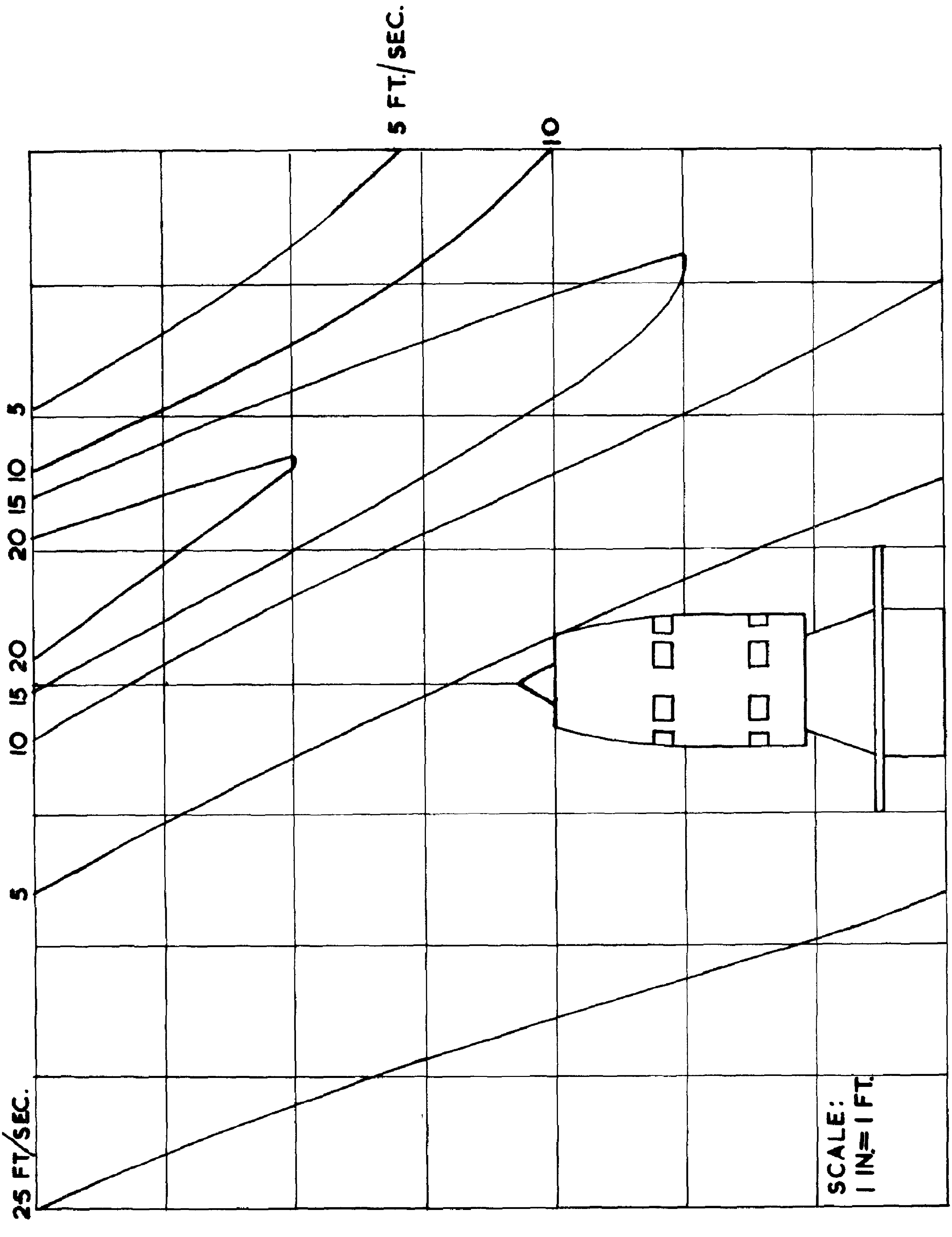
VELOCITY PROFILE AROUND INTAKE GENERATED BY ONE QUARTER OF 3 H.P. FAN TO THE RIGHT OF THE INTAKE.

FIG. 6.



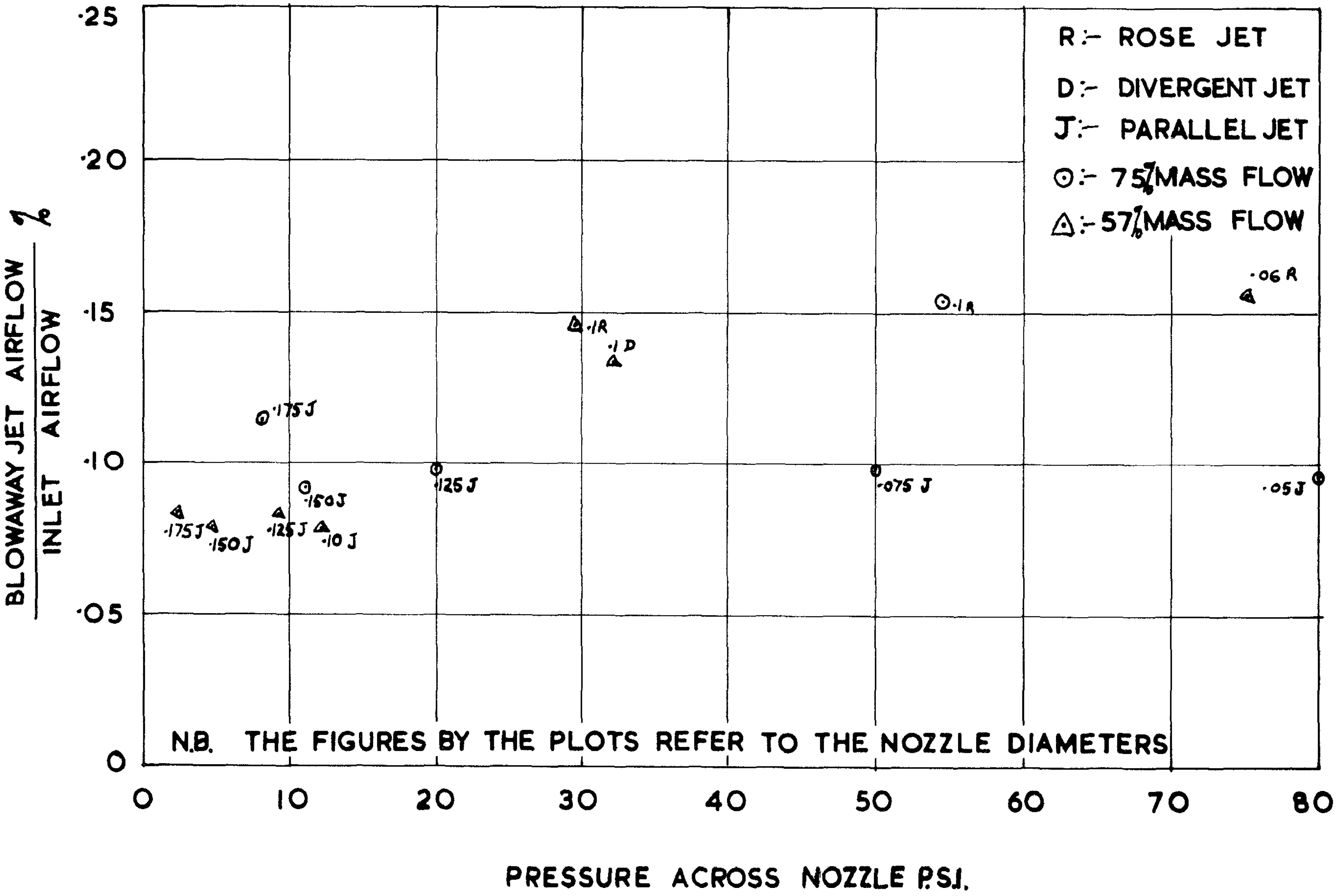
VELOCITY PROFILE AROUND INTAKE
GENERATED BY ¾ H.P. FAN AHEAD

FIG. 7.



VELOCITY PROFILE AROUND INTAKE GENERATED BY HALF OF ¾ H.P. FAN AHEAD OF INTAKE

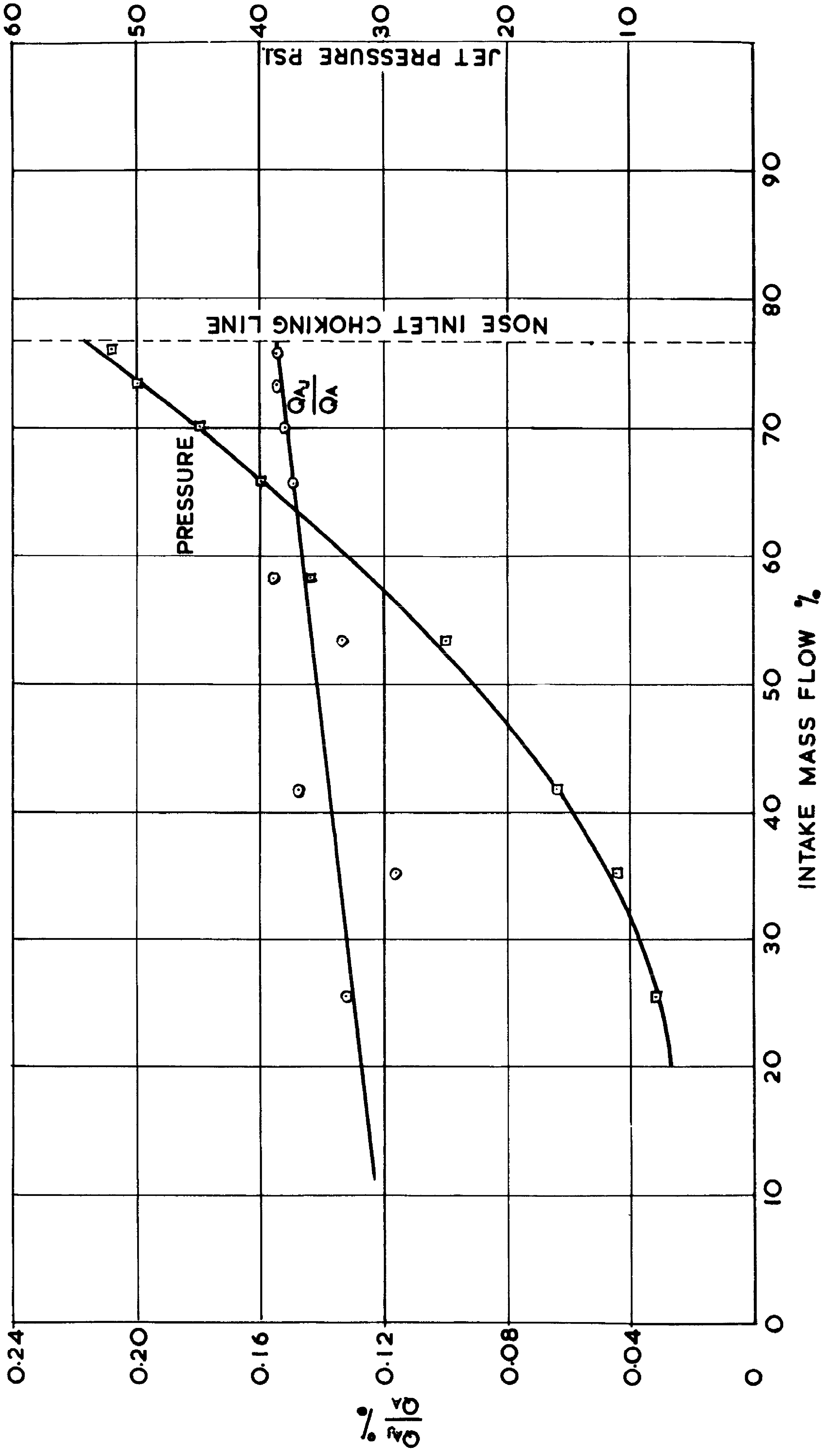
**BLOWAWAY JET CONDITIONS REQUIRED TO PROTECT NOSE INLET. OTHER PORTS BLANKED OFF.**



N.B. THE FIGURES BY THE PLOTS REFER TO THE NOZZLE DIAMETERS

FIG 8

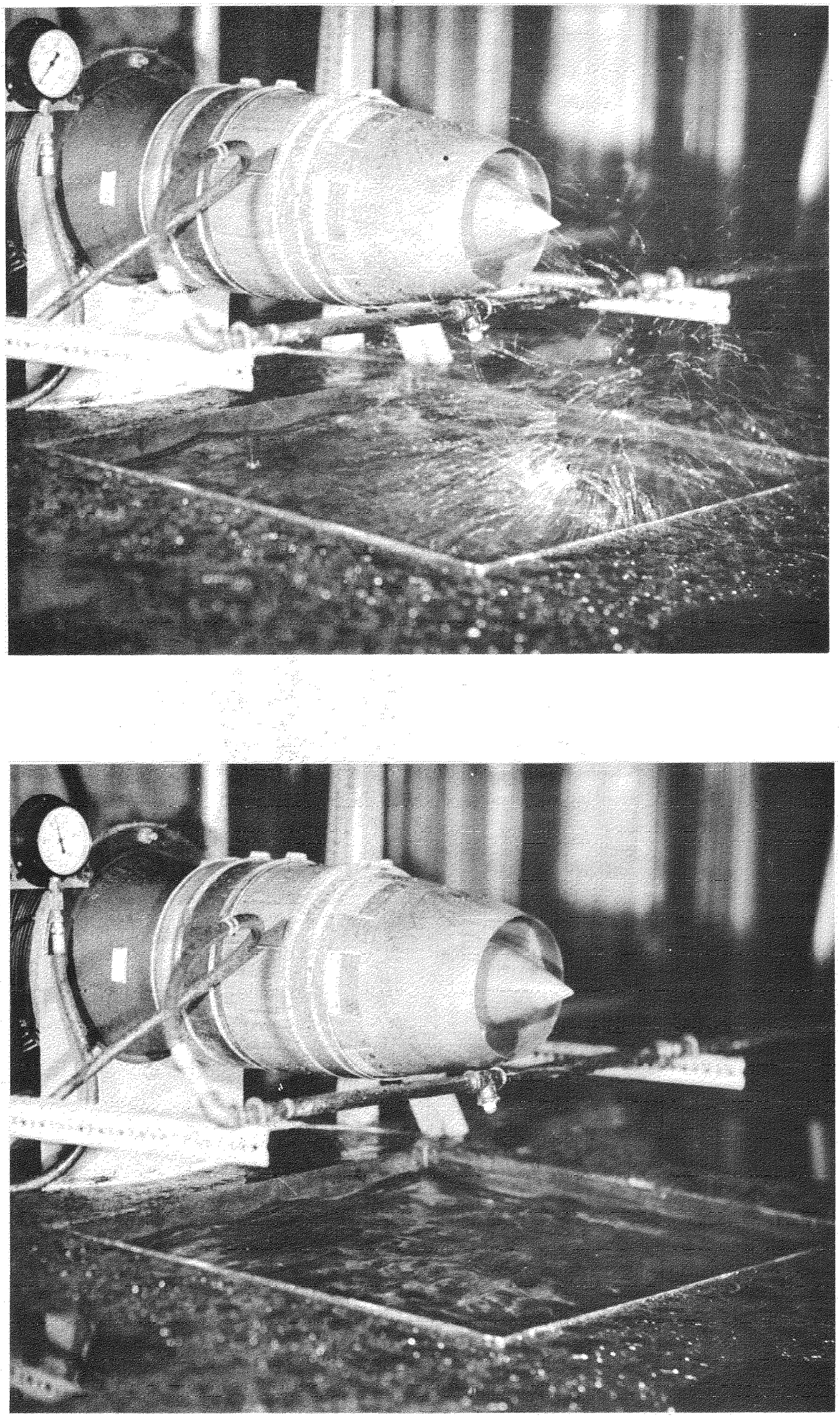
FIG. 9



NOSE INLET PROTECTION

USING ROSE JET

FIG. 10



# BLOWAWAY JET CONDITIONS TO PROTECT NOSE INLET WHEN THE BREATHER PORTS ARE OPEN

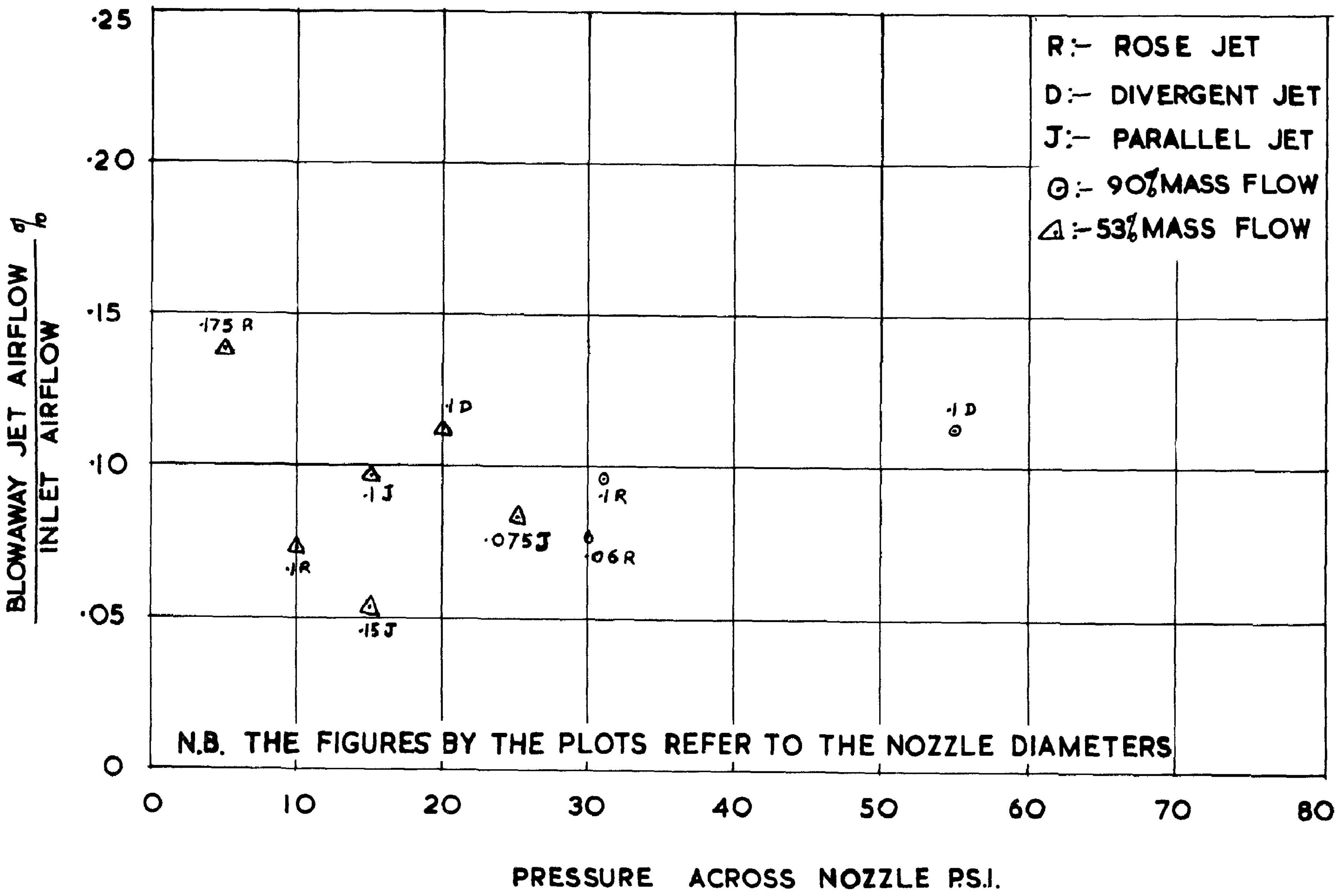
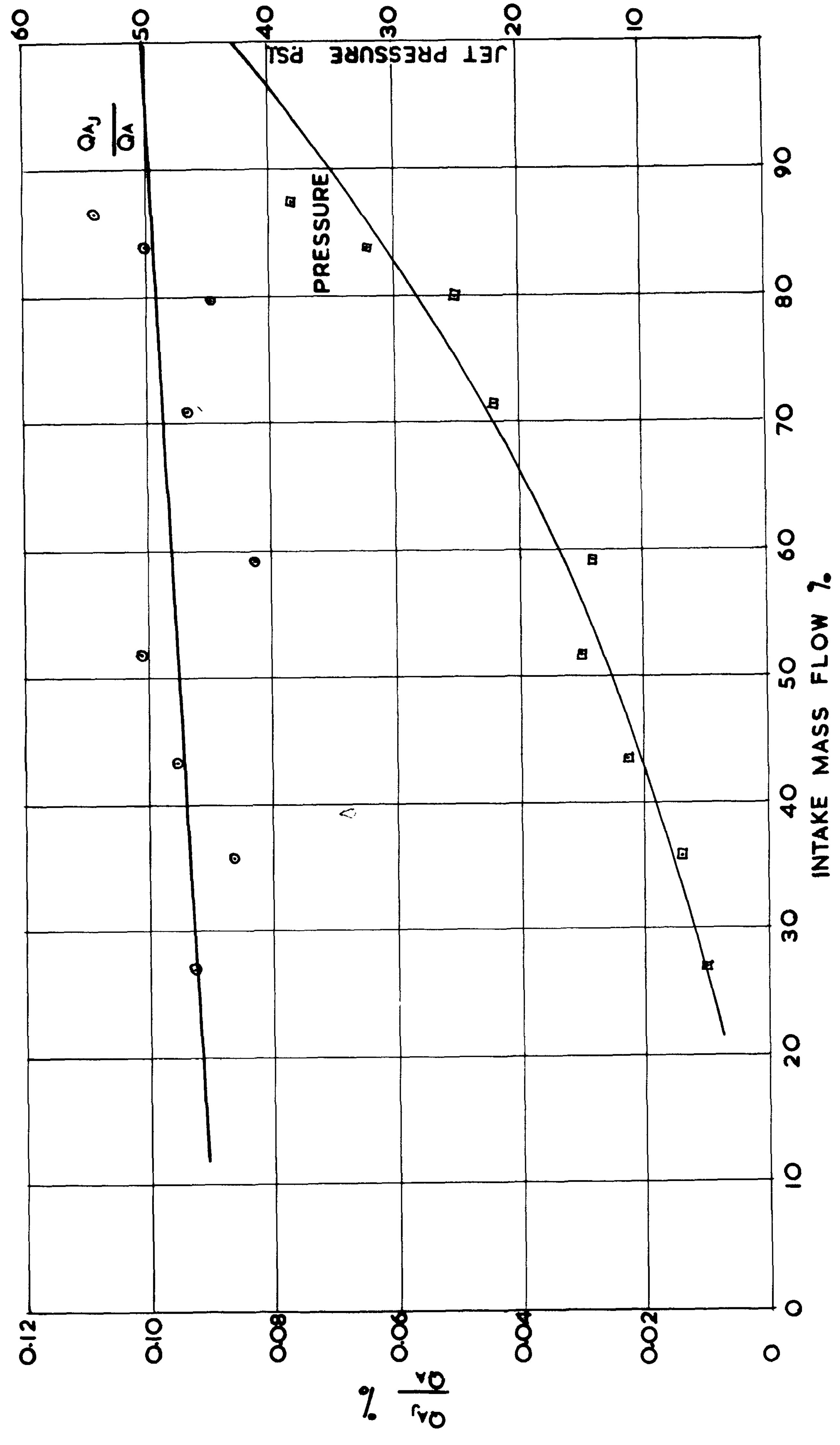


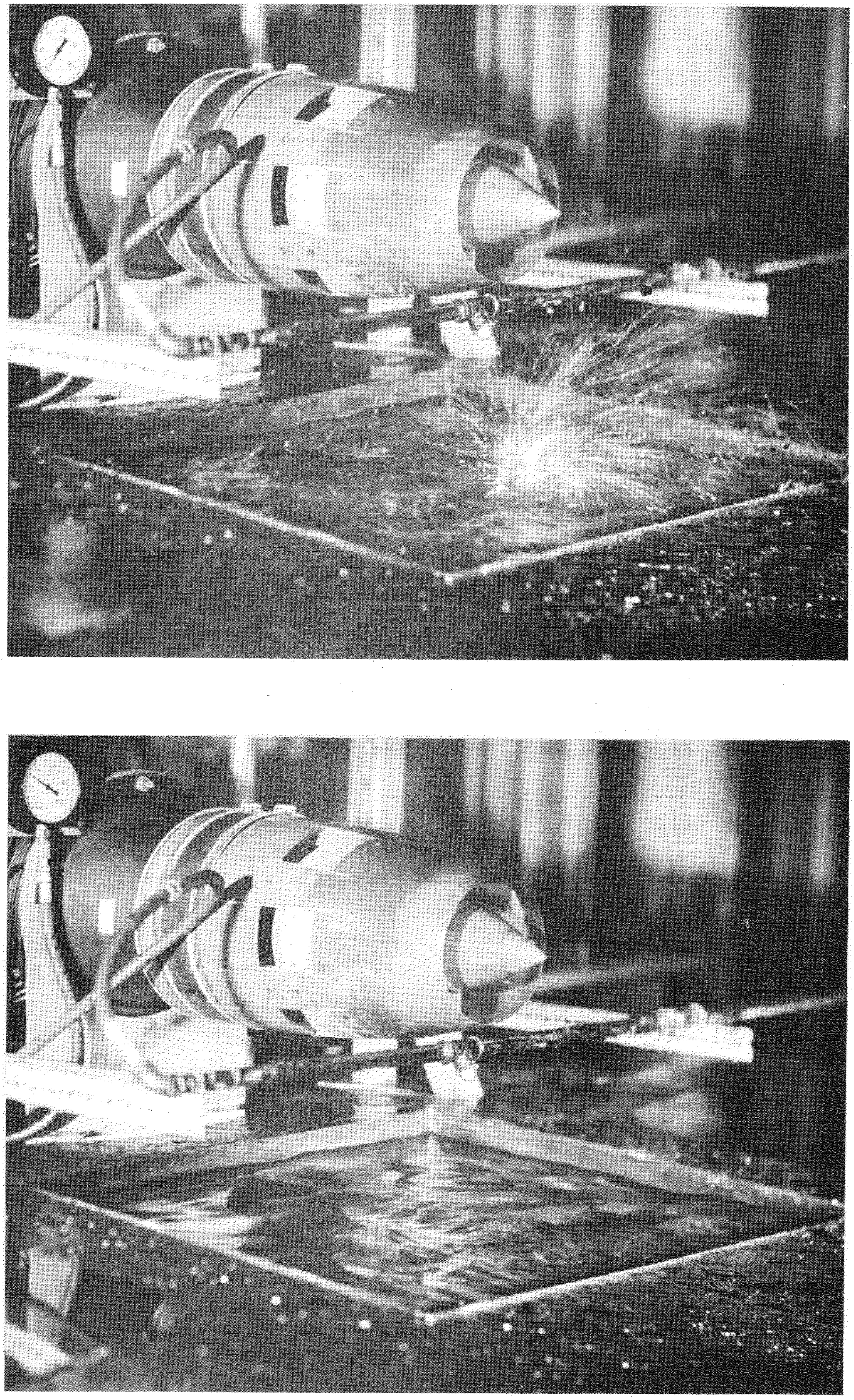
FIG.11

FIG. 12



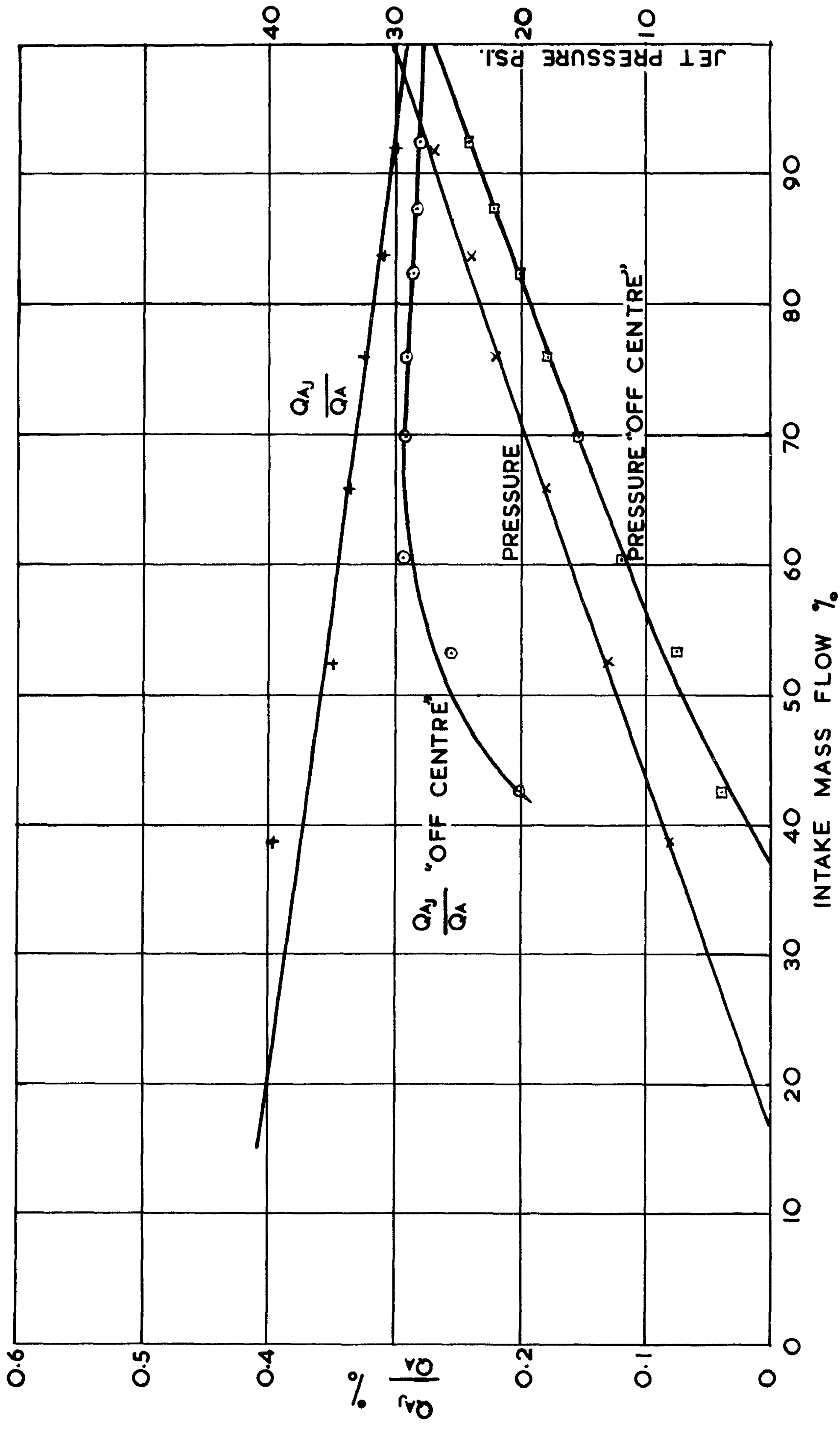
NOSE INLET PROTECTION, BREATHERS OPEN, USING ROSE JET

FIG. 13



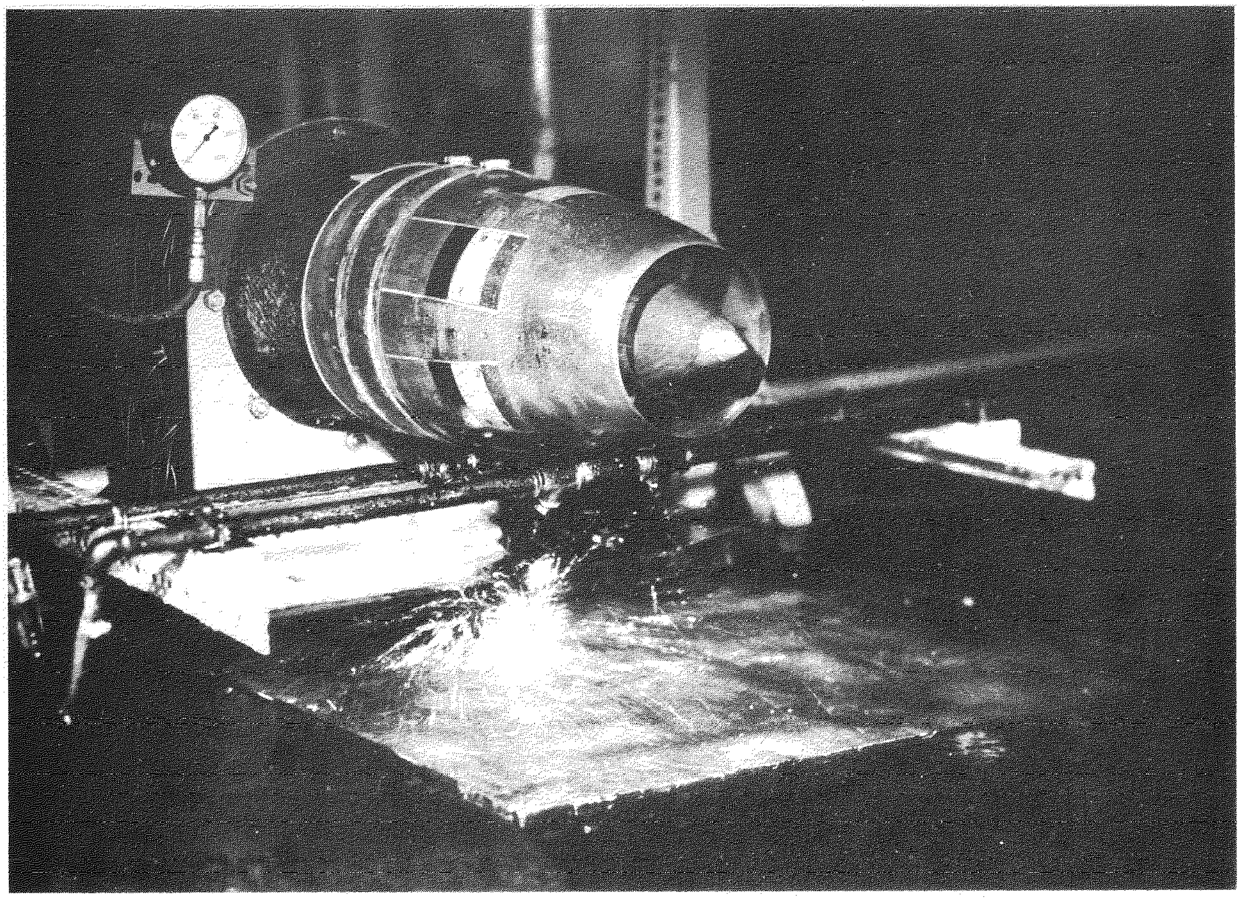
EFFECT OF BLOWAWAY JET USING ·09% OF

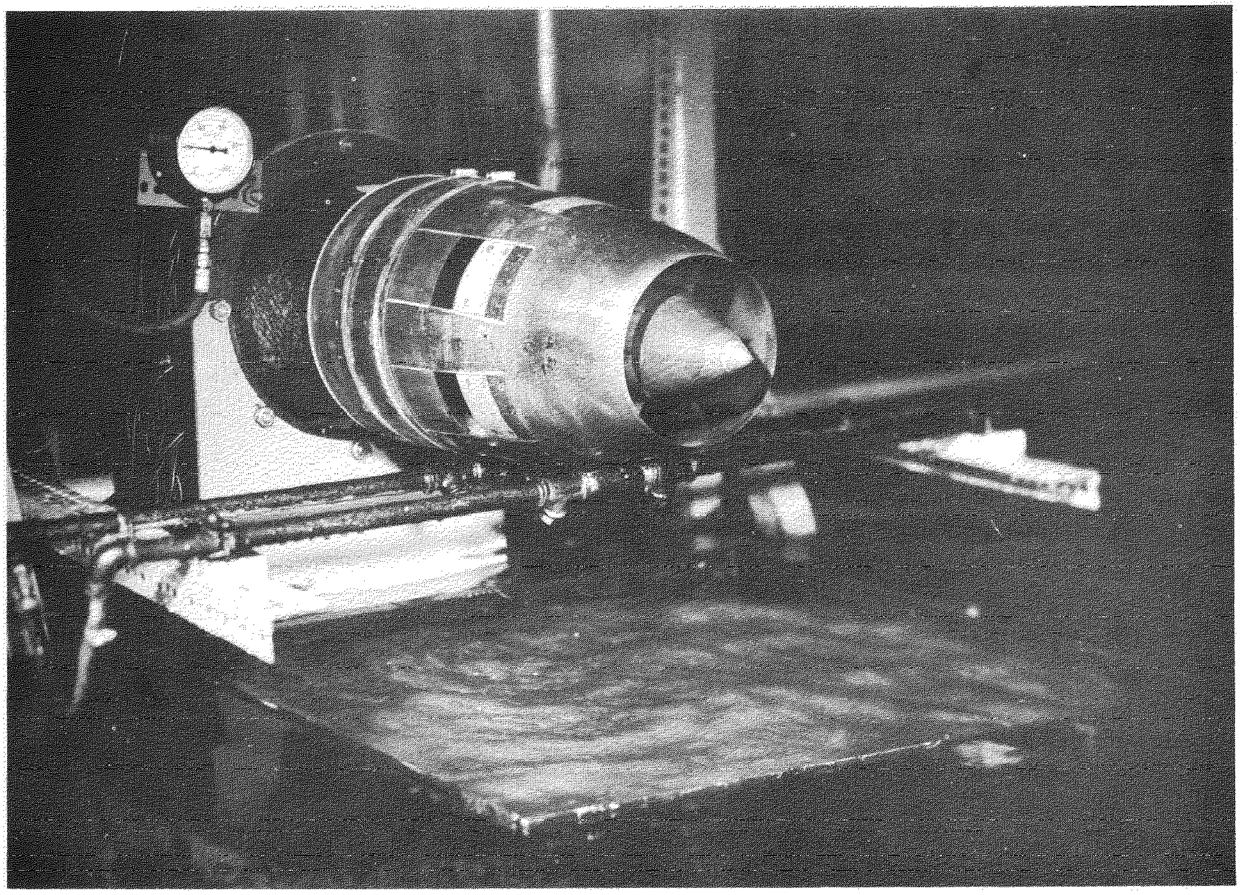
FIG. 14



BREATHER PORT PROTECTION USING 4 JET ARRAY AND WITH PORTS SPACED "ON" AND 'OFF' CENTRE

FIG. 15





## BREATHER AND SPILL PORT PROTECTION
## USING 4 JET ARRAY AND WITH PORTS SPACED
## "ON" AND "OFF" CENTRE

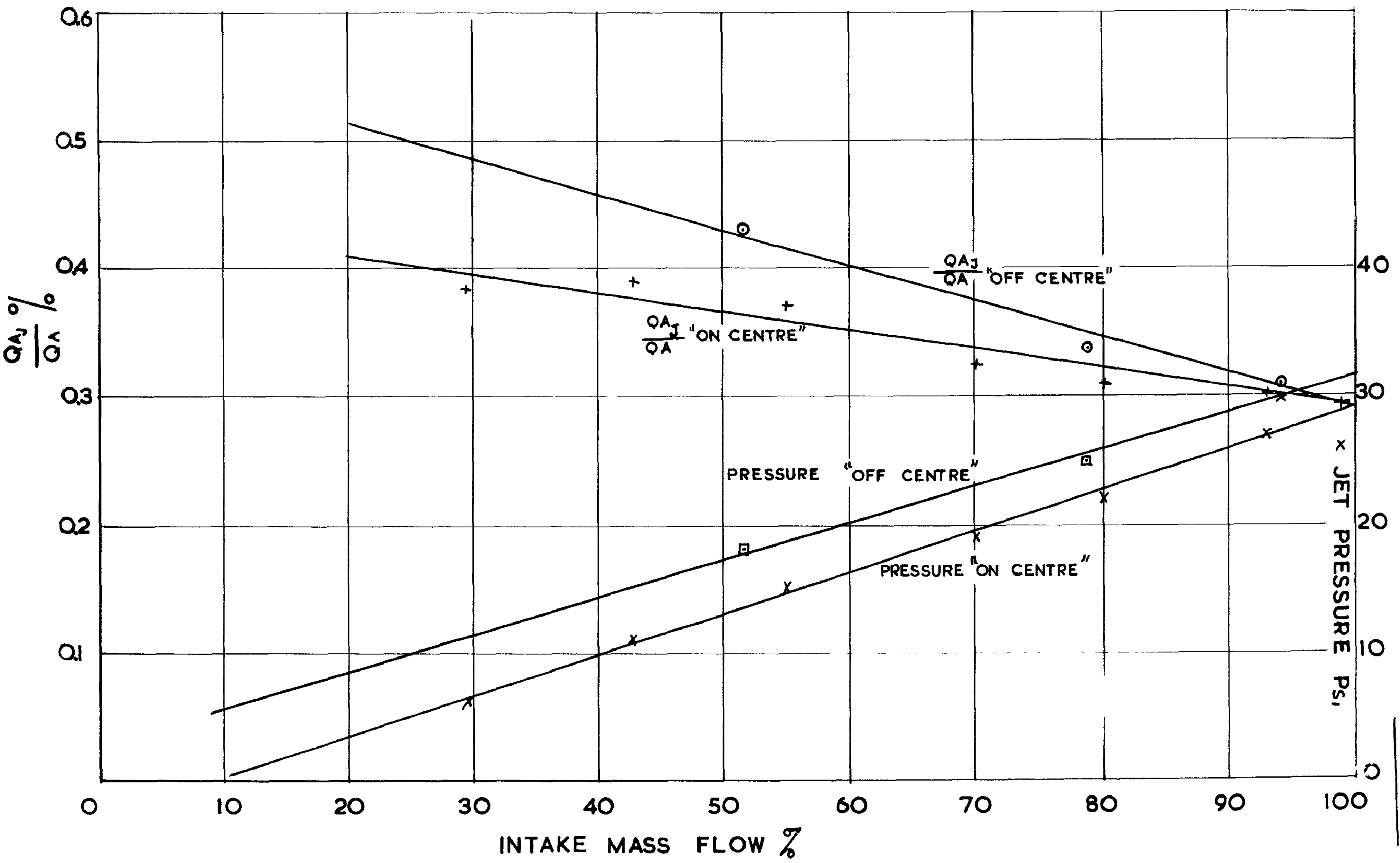


FIG. 16

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## TESTS OF AN AERODYNAMIC DEBRIS GUARD FOR A SUPERSONIC TURBOJET INTAKE

It is well known that objects can be drawn into the intakes of turbojet engines during ground running by vortices generated by the action of wind on the flow into the intake. It has previously been shown that, with a simple intake, these vortices can be prevented from forming by directing a jet of compressed air downwards on to the ground beneath the intake. The present tests were made to investigate the protection of a supersonic intake having, in addition to its nose inlet, a ring of breather ports and a ring of spill ports spaced back along the cowling.

P.T.O.

---

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P.T.O.

The nose inlet was relatively easy to protect with a single nozzle of rose (i.e. multiple hole) form which passed an airflow of the order of 0.14 per cent of the main flow. When directed to strike the ground beneath the inlet any vortex there was readily destroyed.

Protection of the rearward ports proved more difficult owing to the mobility of the vortex that formed. For the two alternative builds:- breather ports open, and breather plus spill ports open, a complex jet array was developed consisting of jets from four divergent nozzles. This gave satisfactory protection but required a total of 0.3 to 0.4 per cent of the main airflow.

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S.O. Code No. 23-9012-61