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Further Tests with a Variable Ramp Intake Having a Design Mach Number of 2.2

By

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Further tests with a variable ramp intake having a design Mach number of 2.2

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SUMMARY

Results are reported of tests on a two-dimensional combined external/internal compression intake having a design Mach number of 2.2. The particular parameters investigated in the tests now reported are:-

(a) the design of the boundary layer bleed slot

(b) the terminal supersonic Mach number

(c) the free stream Reynolds number.

The maximum pressure recovery obtained at the design Mach number was 88½ per cent with 3 per cent bleed at a Reynolds number, based on free stream conditions and intake capture height, of 3.25×10^6.

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Replaces N.G.T.E. Note No. NT.506 - A.R.C. 24,599

CONTENTS

ILLUSTRATIONS

1.0 Introduction

Some further tests are reported on the two-dimensional variable ramp intake described in Reference 1. The intake has a design Mach number of 2.2, and features combined external/internal compression in conjunction with boundary layer bleed from the ramp surface at the throat. The present paper describes tests with

(a) different forms of boundary layer bleed slot

(b) a reduction of the terminal supersonic Mach number

(c) a 3/1 range of free stream Reynolds number.

The work was carried out in Cell 1 of the Engine Test Facility at N.G.T.E.

2.0 Description of the model

2.1 General

The only difference of note from the description given in Reference 1 lay in the detailed geometry around the bleed slot. In order to facilitate investigation of the effect of bleed slot geometry on intake performance a recess was cut into the ramp into which blocks carrying different forms of bleed slot could be fitted. This detail is shown in Figure 1, which also shows the arrangement of the model.

The intake capture height and span were respectively $2\frac{1}{2}$ and $3\frac{1}{2}$ in., thus giving a capture plane aspect ratio of 1.4. "Starting", in the sense of establishing supersonic flow, could be achieved either by retracting the cowl backwards along the line AB in Figure 1, or alternatively by lowering both the ramp and one wall of the subsonic diffuser. The subsonic diffuser wall and the ramp could be positioned independently of each other - the ramp by pivoting about the point X in Figure 1 and the wall of the subsonic diffuser by pivoting about the position Y. Thus it was possible to obtain different throat bleed openings (in the sense of varying the extent of the ram scoop effect) for fixed positions of either the diffuser or the ramp. The bleed was not throttled. It discharged into a plenum whence it was removed through two ducts acting as measuring lengths and containing pitot tubes and static tappings. In practice the bleed mass flow in any particular intake build was varied by moving the position of the diffuser tip whilst the ramp position remained fixed. "Desynn" indicators were used to show the positions of the movable components.

Figures 2 and 3, reproduced from Reference 1, show respectively the method of mounting the intake in the test cell and two photographs of the assembled model.

The longer of the two subsonic diffusers described in Reference 1 was used in the present tests. A sketch of this diffuser is shown in Figure 4. Earlier tests[1] had shown that the performance of the intake was not compromised by fitting a shorter subsonic diffuser approximating closely to a practical installation.

2.2 Bleed geometries

These are shown in Figure 5. The design shown in Figure 5(c) was suggested in Reference 1. It appeared to offer a possible method of cleaning up the side wall secondary flow without introducing an expansion in the mainstream too far ahead of the normal shock.

In order to reduce vibration during tests at high Reynolds numbers the original subsonic diffuser tip was replaced by a stiffened version after preliminary tests had shown that the performance of the intake was not adversely affected. A lip with a rounded edge was also used. These details are also shown in Figure 5.

2.3 The shock patterns

The "design" shock pattern features two external oblique shocks each of 7° strength and focussed on the cowl tip, followed by a 10° internal oblique shock falling on the lip at the entrance to the subsonic diffuser. For a free stream Mach number of 2.2 this shock pattern theoretically gives a terminal supersonic Mach number of 1.38.

The terminal supersonic Mach number could be reduced during any test by adjusting the variable geometry, although as an incidental some spillage also occurred with the modified configuration. It is seen from Figure 1 that increasing the ramp deflection angle δ increases the strength of the second oblique shock. The internal oblique shock is correspondingly strengthened, and hence the Mach number upstream of the normal shock simultaneously reduced. A rearwards movement of the cowl tip was then necessary in order to (a) maintain the correct positioning of the internal oblique shock on the bleed slot knife edge and (b) ensure that the flow from the point of focussing of the two external oblique shocks (presumably containing a vortex sheet by virtue of the dissimilar supersonic compressions at this point) passes externally over the cowl and not into the intake. In practice, for the experimental range of terminal supersonic Mach numbers extending from 1.39 to 1.29, it was found that very little movement of the cowl was required. The maximum rearwards movement in the present tests was 0.35 in., corresponding with a calculated spillage over the cowl of a little less than 4 per cent of the intake capture flow. If desired in a future intake the shock patterns produced in this manner could be readily reproduced without spillage over the cowl by suitably modifying the dimensions of the ramp.

3.0 Test procedure

Prior to running the tunnel the "Desynn" indicators were calibrated to show the positions of the ramp and subsonic diffuser, and hence the bleed opening. The position of the diffuser tip was defined by its distance measured from the internal surface of the cowl, and that of the ramp by the size of slip gauge which fitted the bleed opening as in Figure 6.

The most convenient starting procedure was to open the throttle at the exit from the subsonic diffuser and translate the cowl rearwards. The ramp and diffuser tip were set at predetermined positions whilst the cowl was returned forwards until the internal oblique shock from the cowl tip, when viewed through a Schlieren apparatus, impinged on the lip at the entrance to the subsonic diffuser. The bleed mass flow in any particular intake build was varied by moving the position of the diffuser tip whilst the ramp position remained fixed. The terminal supersonic Mach number was varied by changing the ramp position as described in Section 2.3.

Testing was normally carried out with a nozzle inlet total pressure of 40 in.Hg abs, which gave a Reynolds number, based on free stream conditions and intake capture height, of approximately 1×10^6. In addition some tests were made at an inlet total pressure of $4\frac{1}{2}$ atm abs, which gave a test Reynolds number, defined as previously, of 3.25×10^6. Prior to the high pressure tests the tunnel was "started" at approximately 40 in.Hg abs in order to reduce the transient pressures on the model.

4.0 Results and discussion

4.1 Tests with different forms of bleed slot

During the tests it was noted that the bleed slot featuring the rounded tip initiated a marked unsteadiness in the throat flow, the terminal shock pulsating in a random manner to and fro in the entrance to the subsonic diffuser. Figure 7 shows that as a result of this instability the pressure recovery with a given bleed and ramp angle could vary by as much as 4 per cent, the variation being related to the transient position of the normal shock.

On the other hand all the bleed slots featuring a pointed tip provided a steady throat flow in which it was possible to stabilise the normal shock immediately downstream of the bleed. A consequence was that the tests with pointed tips defined, to within a scatter of about 1 per cent on pressure recovery, a unique relationship between pressure recovery and bleed for a given ramp angle. Some typical results are shown in Figure 7. Considering the Figure, together with the previously demonstrated advantage of the step bleed over the ram scoop type of slot, it would appear at the present stage of the investigation that the particular intake tested is not sensitive to detail variations in the bleed geometry provided that (a) the entrance to the subsonic diffuser features a sharp lip and (b) a sharp expansion is provided a small distance upstream of the entrance to the bleed slot, the expansion being positioned so as to make the bleed opening intermediate between "ram scoop" and "flush". A rounded lip may, however, prove satisfactory when used with a flush bleed as opposed to the part ram scoop/part flush type of slot used in the present tests. For example a flush bleed coupled with a throttle in the bleed duct might allow the establishment of what would effectively amount to a free streamline interface across the entry to the bleed slot, and avoid any potential disturbance from a rounded lip. An apparent advantage of such an arrangement when located downstream of the normal shock is that the high static pressure at the slot entrance would allow a high bleed pressure recovery.

4.2 Tests aimed at determining the effect on intake pressure recovery of reducing the terminal supersonic Mach number

The experimental technique for strengthening the oblique shock pattern in order to reduce the terminal supersonic Mach number has been described in Section 2.3. Results are presented in Figures 8, 9 and 10. Figure 8 shows for bleed flows of less than approximately 3 per cent a general raising of the pressure recovery/bleed flow characteristic as the ramp deflection angle is increased. As will be shown later, the increase in pressure recovery with ramp angle for a given bleed corresponds closely with the increase in theoretical shock recovery. With bleed flows greater than 3 per cent the picture is complicated by the increasing projection of the subsonic diffuser tip into the mainstream (i.e., by the bleed slot becoming more of a ram scoop and less of a flush slot), and a resultant tendency of the throat flow to deteriorate towards the pattern noted in the earlier tests with a ram scoop bleed[1]. Hence the measured pressure recoveries do not rise continuously with ramp angle as simple theory would indicate.

Although the curve drawn in Figure 8 for a ramp angle of 6.5° suggests increases in pressure recovery for increases in bleed beyond 4½ per cent, the bulk of the evidence supports the view that for a Reynolds number of approximately 1×10^6 the maximum pressure recovery occurs with between 4 and 5 per cent bleed from the ramp surface. The maximum pressure recovery recorded at this Reynolds number was 88.1 per cent with 4½ per cent bleed.

Static pressure distributions along the cowl surface are plotted in Figure 9. The region of interest is that covering the first 2 in. back from the cowl tip: further back, as was noted in Reference 1, the pressure distributions indicate the disturbance caused at the cowl surface by the flow pattern at the bleed entry. When the ramp deflection angle was increased from 5.9° to 6.5° it was found necessary to translate the cowl rearwards slightly, as discussed in Section 2.3, so that the internal oblique shock continued to focus on the subsonic diffuser tip; hence the step in the dashed line indicating the plane of the subsonic diffuser entrance. The increase of cowl static pressure as the oblique shock pattern is strengthened is clearly shown. More interesting perhaps are the high static pressures near the cowl tip. With a ramp deflection angle of 5.2° the cowl static pressure rises steeply downstream of the first static tapping (0.25 in. downstream from the cowl tip) but subsequently falls and levels out at 1¼ in. downstream from the cowl tip. Increases in the ramp deflection angle, plus probably also the rearwards translation of the cowl, gradually eliminate the measurement of an initial rise in static pressure, but at all ramp deflection angles the plots exhibit the fall in pressure to a very roughly steady level.

Without either flow visualization or extensive instrumentation in the region of the cowl tip the precise cause of the high static pressures occurring on the forward portion of the cowl is uncertain. However, the apparent forward movement of the pressure distributions plotted in Figure 9 with increases of ramp deflection angle and probably also rearward translation of the cowl suggests the possibility of the form of pressure distribution being associated with impingement of the second external shock on the cowl surface some distance downstream of the tip. Studies of theoretical shock patterns have emphasised the uncertainty involved in endeavouring to deduce the nature of the flow pattern adjacent to the cowl from the observed position of the internal oblique shock adjacent to the subsonic diffuser tip. However, if the suggested explanation for the form of pressure distribution is correct then the two principal consequences would seem to be:-

(a) the possibility of the initial pressure rise - observed most particularly with a ramp angle of 5.2° - causing premature turbulent flow in the boundary layer

(b) the possibility of a weak vortex sheet running downstream from the point of coalescence of the two oblique shocks originating on the cowl.

The associated losses however would probably be extremely small and unlikely to significantly influence the intake pressure recovery.

Figure 10 shows the influence of the terminal supersonic Mach number on the measured pressure recovery with a constant 3 per cent bleed. The position on the cowl to which the Mach numbers plotted on the abscissa refer is shown in Figure 9. Over the experimental range of terminal supersonic Mach number and at the lower of the two test Reynolds numbers the "extra-to-shock" losses remain constant at about 7½ per cent of the free stream total pressure. In Reference 1 the introduction of side wall bleed at the throat is shown to reduce the "extra-to-shock" loss by between 1 and 2 per cent, whilst a Reynolds number effect indicated by the spot point on Figure 10, is discussed in the following Section.

4.3 The effect of Reynolds number on intake performance

Figure 8 shows that, for equal ramp deflection angles and bleed flows, raising the test Reynolds number from 1×10^6 to 3.25×10^6 increased the pressure recovery by roughly 1½ per cent. The extension of the line joining the two points obtained at $R_e = 3.25 \times 10^6$ is shown dotted because an instrumentation failure prevented bleed measurement after the point showing 88½ per cent recovery with 3 per cent bleed. However, it was noted that with larger bleeds (regulated by raising the subsonic diffuser tip) the pressure recovery fell. The same increase of Reynolds number reduces the throat bleed for maximum pressure recovery from between 4 and 5 per cent to 3 per cent. At the higher Reynolds number Figure 10 shows that with 3 per cent bleed from the ramp surface the "extra-to-shock" loss is reduced to just over 5½ per cent.

5.0 Future development

Coupling the Reynolds number effect with that of side wall bleed suggests the possibility of reducing the "extra-to-shock" losses to about 4 per cent on pressure recovery. Extrapolating from the point on Figure 10 obtained at $R_e = 3.25 \times 10^6$ along a slope parallel to the curve obtained at $R_e = 1 \times 10^6$ suggests a recovery of 89½ per cent at the higher Reynolds number with a terminal supersonic Mach number of 1.29 and 3 per cent bleed. Addition of side wall bleed should thus render feasible pressure recoveries of a little over 90 per cent. The prospect of the intakes of a proposed supersonic transport aircraft giving the same recovery is enhanced by the higher free stream Reynolds number obtained at $M = 2.2$ at 60,000 ft. The Reynolds number based on a 3 ft intake capture height is then approximately 5.5×10^6.

6.0 Conclusions

A two-dimensional intake having combined external/internal compression has given a maximum pressure recovery of 88½ per cent at a free stream Mach number of 2.2 and at a Reynolds number of 3.25×10^6. The accompanying bleed flow was 3 per cent, taken from the ramp surface at the throat.

Tests with different forms of ramp bleed have suggested that the model described here is not sensitive to detail variations in the bleed geometry provided that (a) the entrance to the subsonic diffuser features a sharp lip and (b) a sharp expansion is provided a small distance upstream of the entrance to the bleed slot.

Reducing the terminal supersonic Mach number from 1.39 to 1.29, and thus increasing the overall shock recovery, produced an exactly equivalent increase in the measured pressure recovery.

Increasing the test Reynolds number by a factor of approximately 3 reduced the bleed for maximum pressure recovery from a little over 4 per cent to 3 per cent. With 3 per cent bleed the pressure recovery was increased by a little over 1½ per cent as the test Reynolds number was increased over the experimental range.

With further development pressure recoveries of over 90 per cent should be possible.

REFERENCES

No.	Author(s)	Title, etc.
1	M. C. Neale P. S. Lamb	Tests with a variable ramp intake having combined external/internal compression, and a design Mach number of 2.2. A.R.C. C.P. 805 August, 1962

BASIC ARRANGEMENT OF THE MODEL

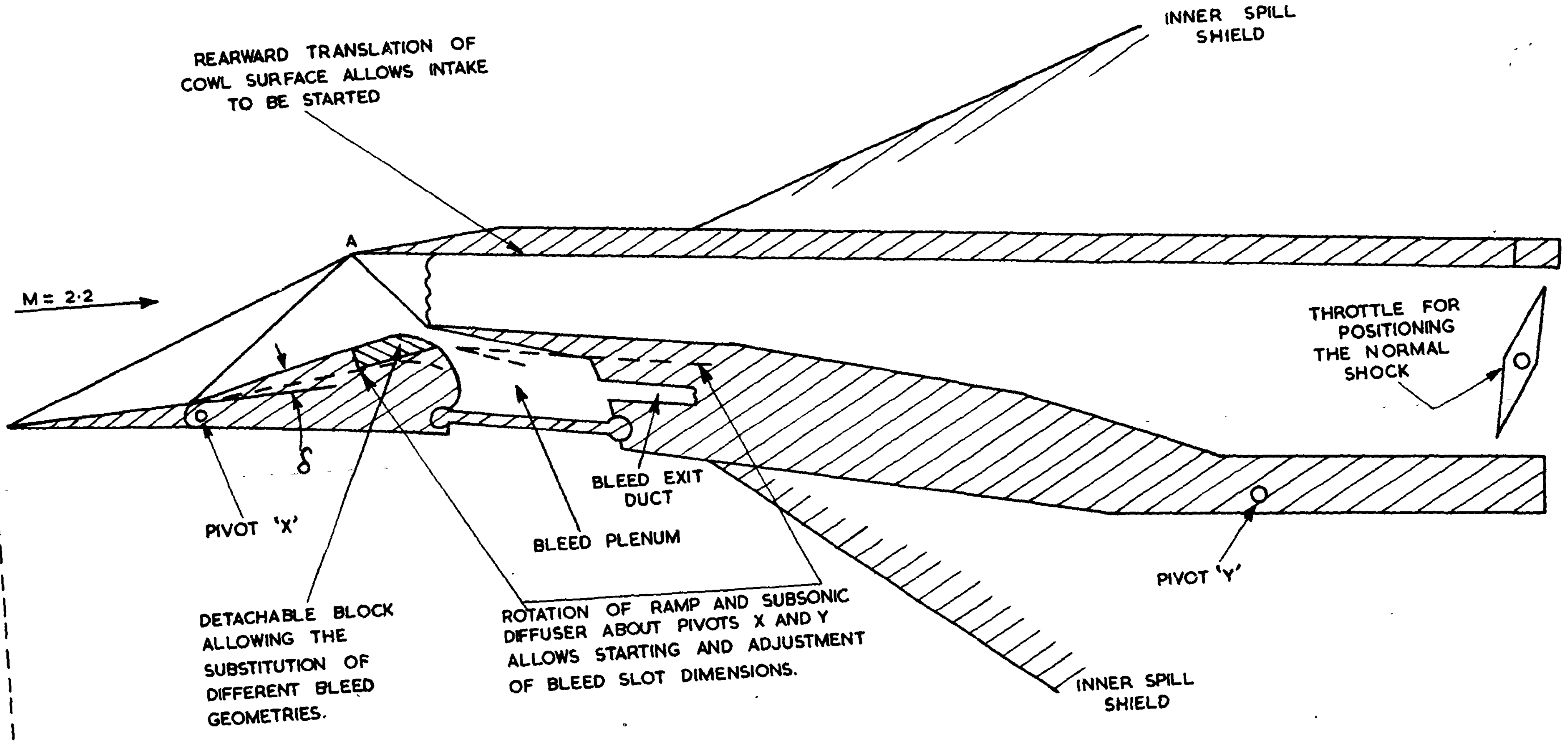


FIG. 1.

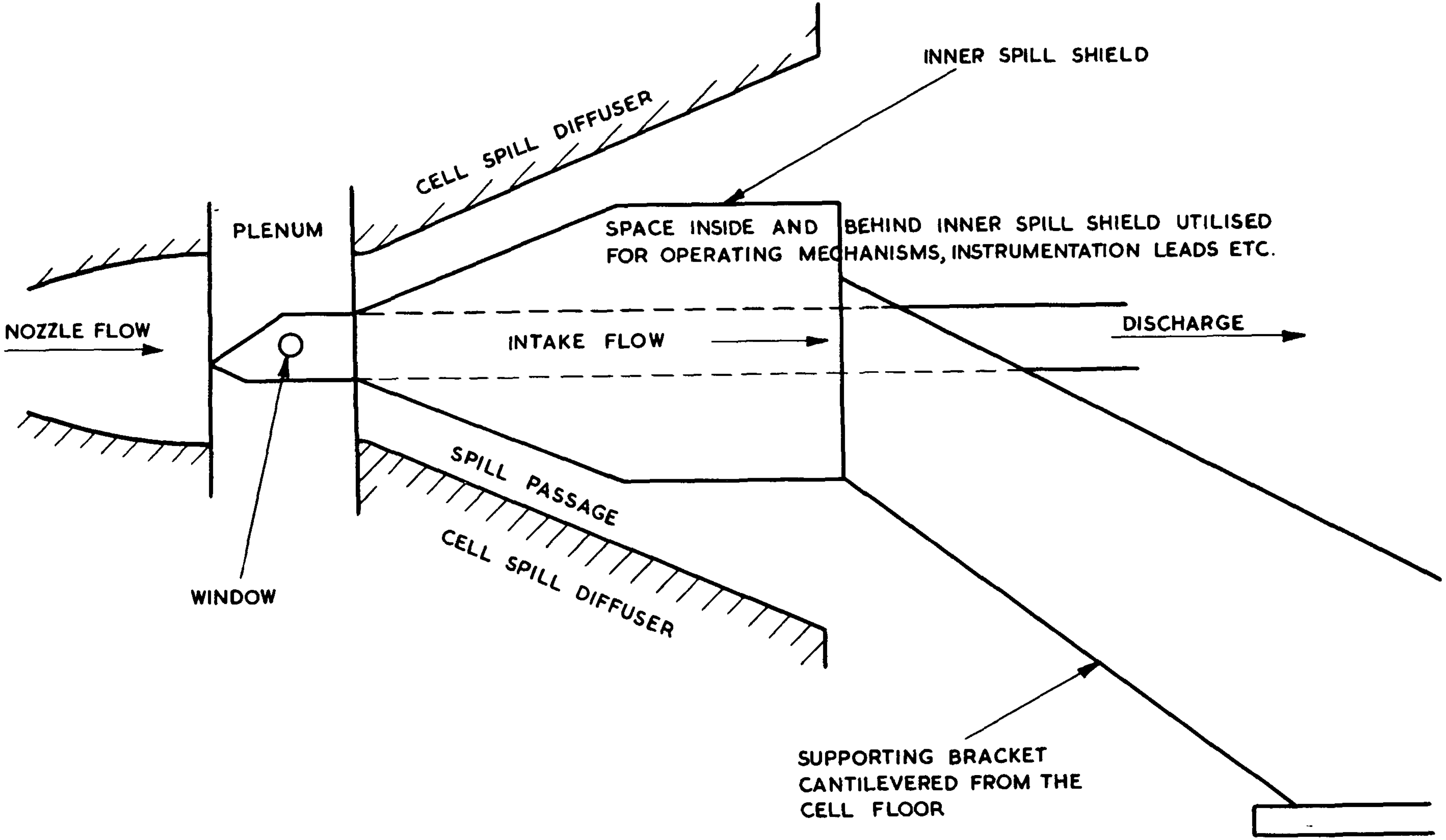
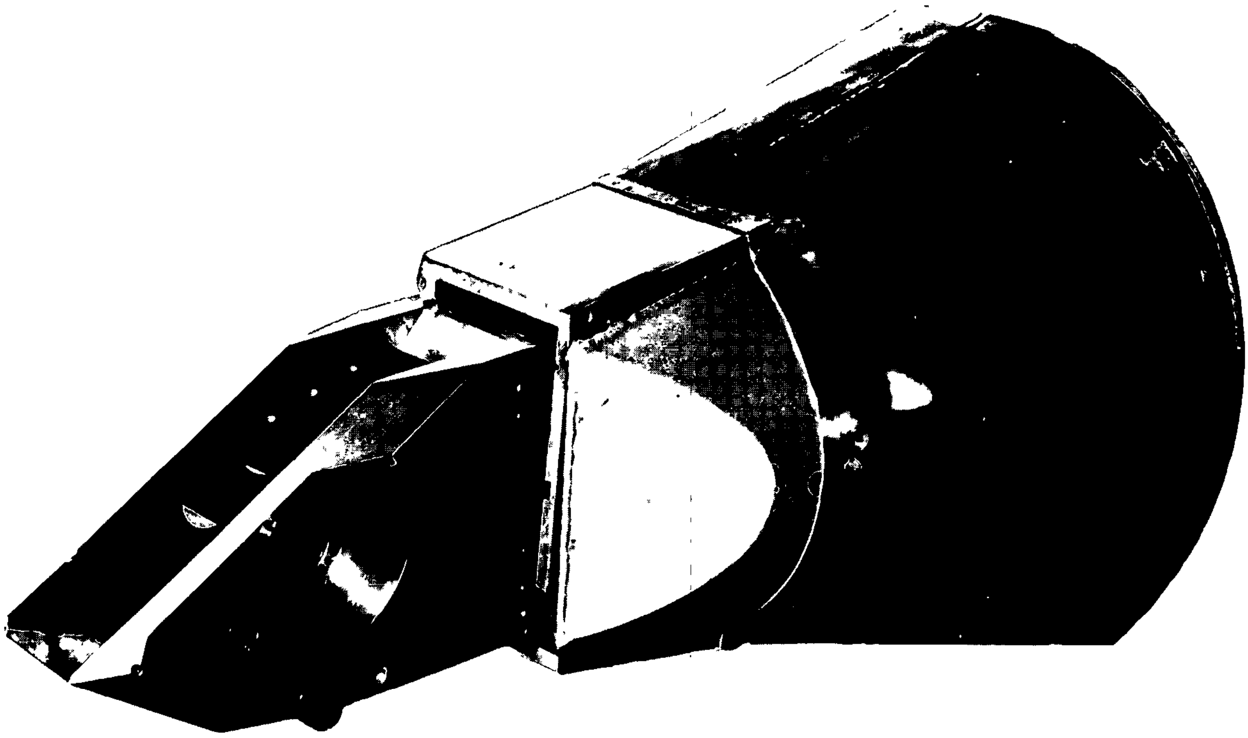


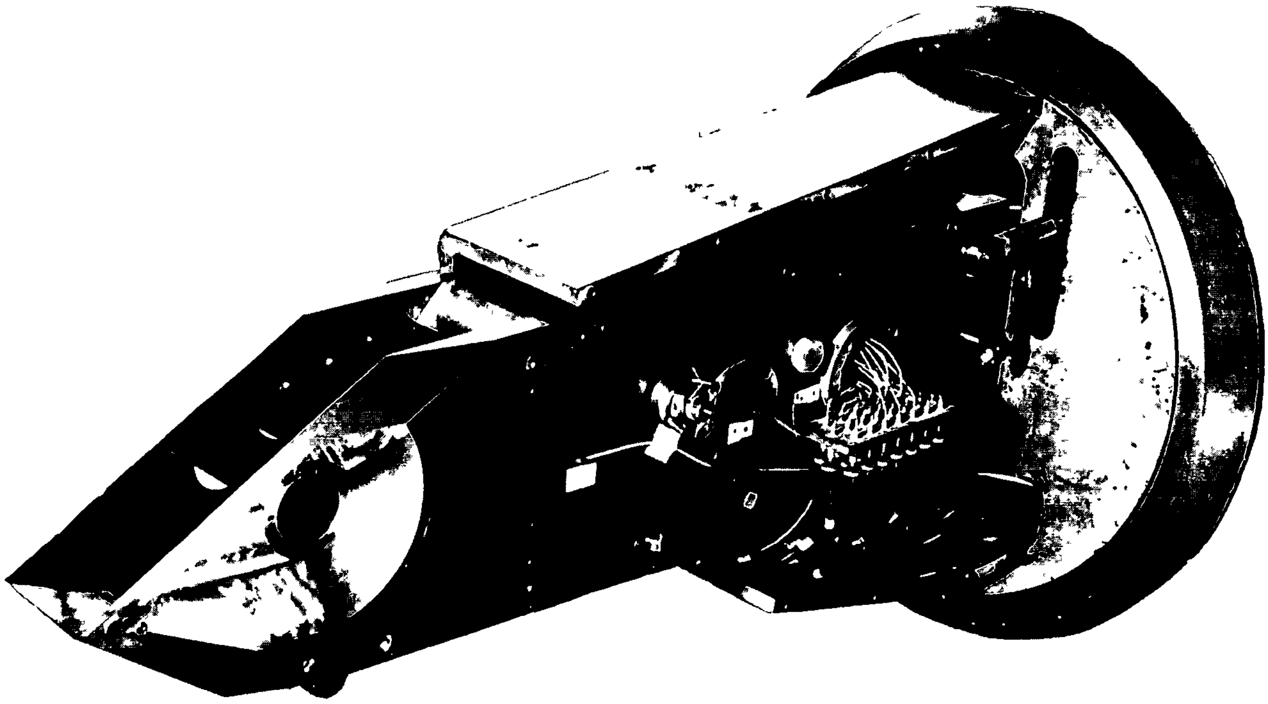
FIG. 2.

THE MODEL MOUNTED IN CELL 1

FIG. 3



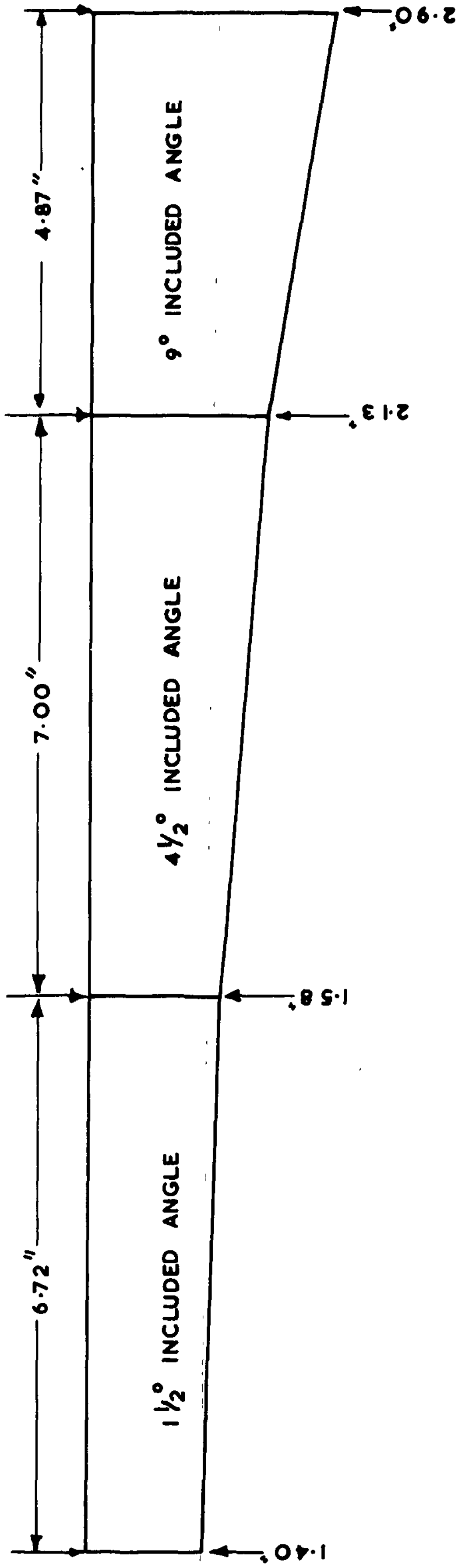
(a) THE MODEL ASSEMBLED AND READY FOR TESTING



(b) THE MODEL WITH THE INNER SPILL SHIELD REMOVED

PHOTOGRAPHS OF THE MODEL

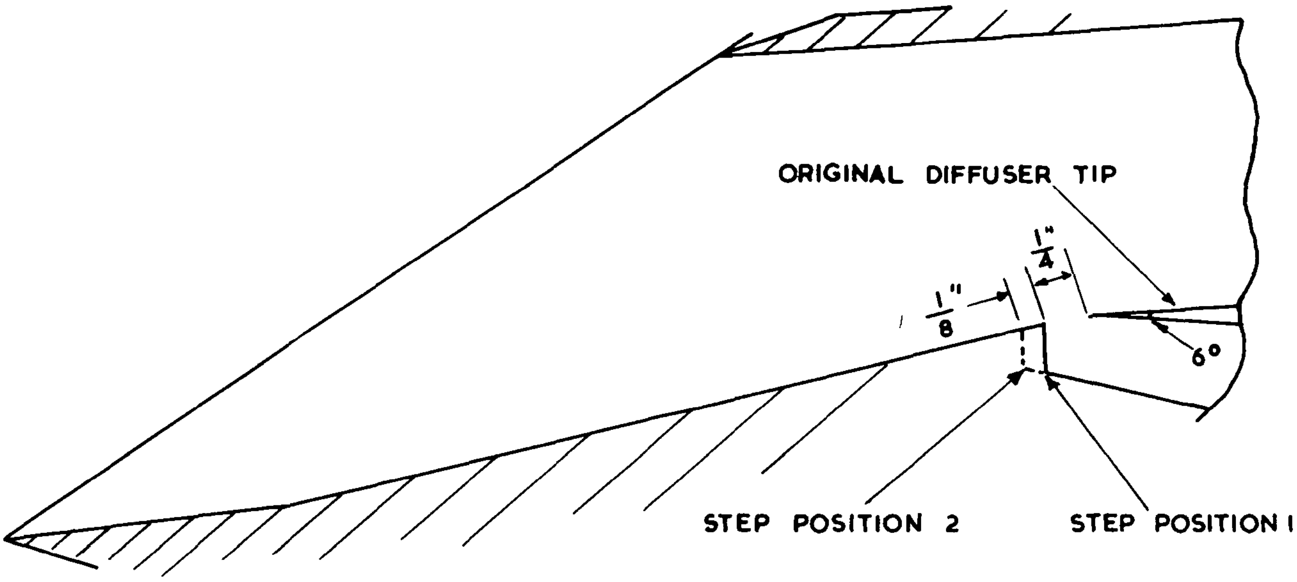
FIG. 4



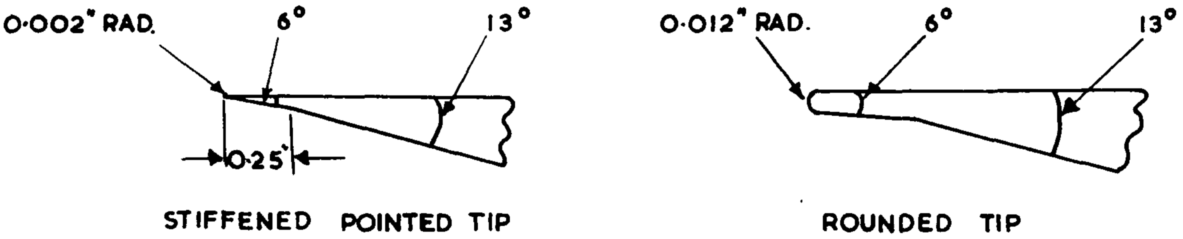
MACH NUMBER BEHIND NORMAL SHOCK ASSUMED IN THE DESIGN TO BE APPROXIMATELY 0·8

SUBSONIC DIFFUSER.

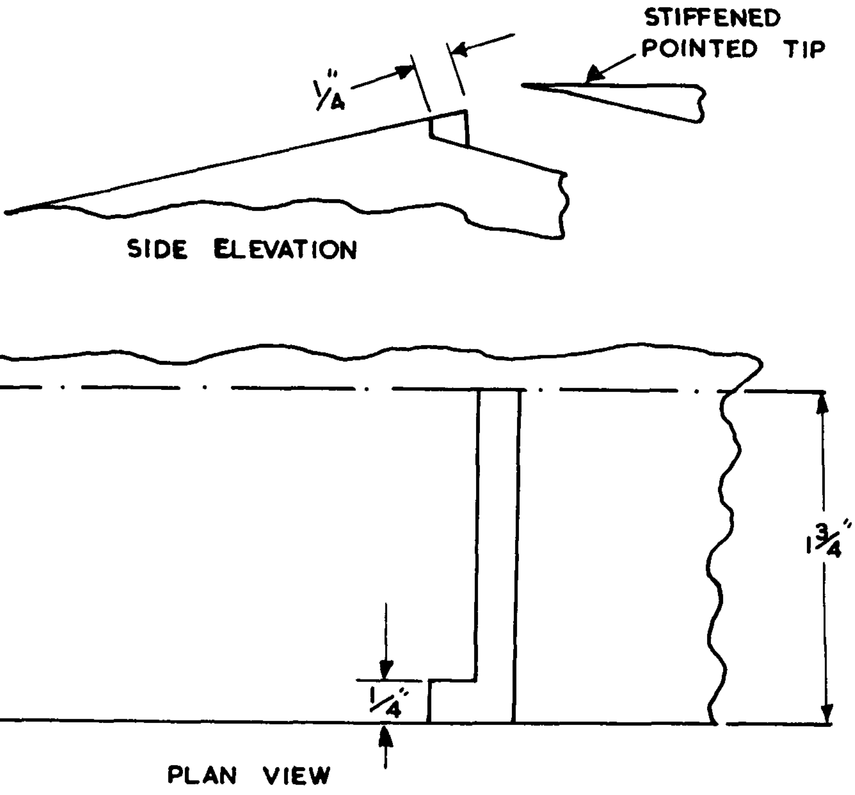
FIG. 5



(a) STEP BLEED POSITIONS



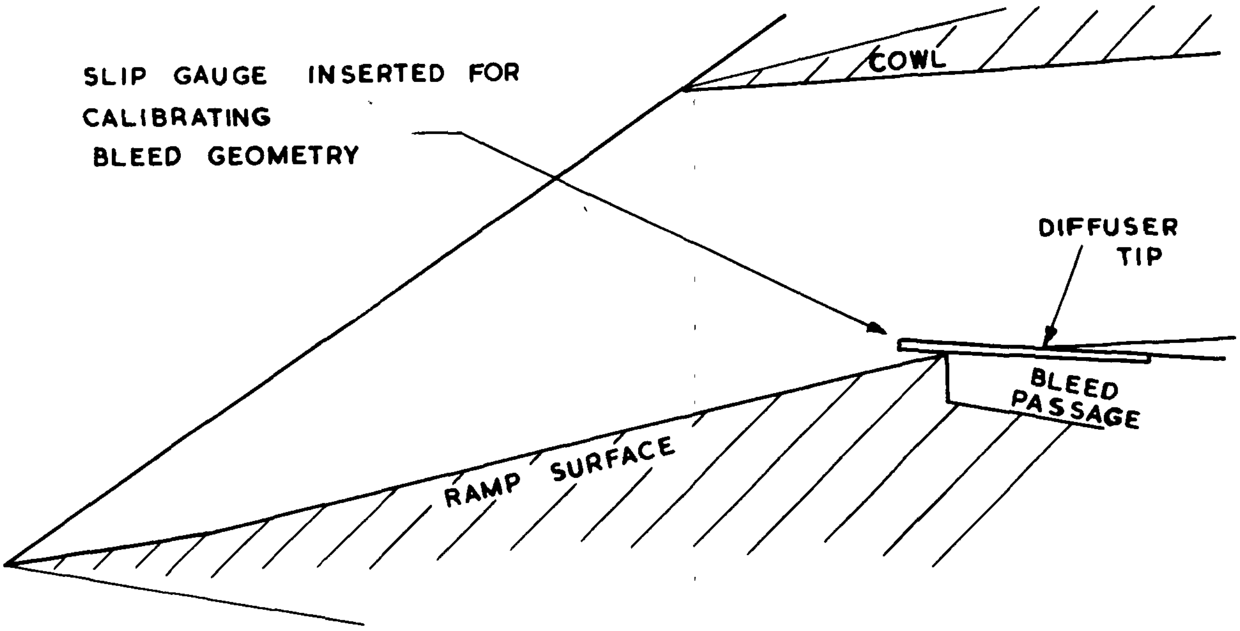
(b) ALTERNATIVE SUBSONIC DIFFUSER TIPS



(c) MODIFIED STEP BLEED

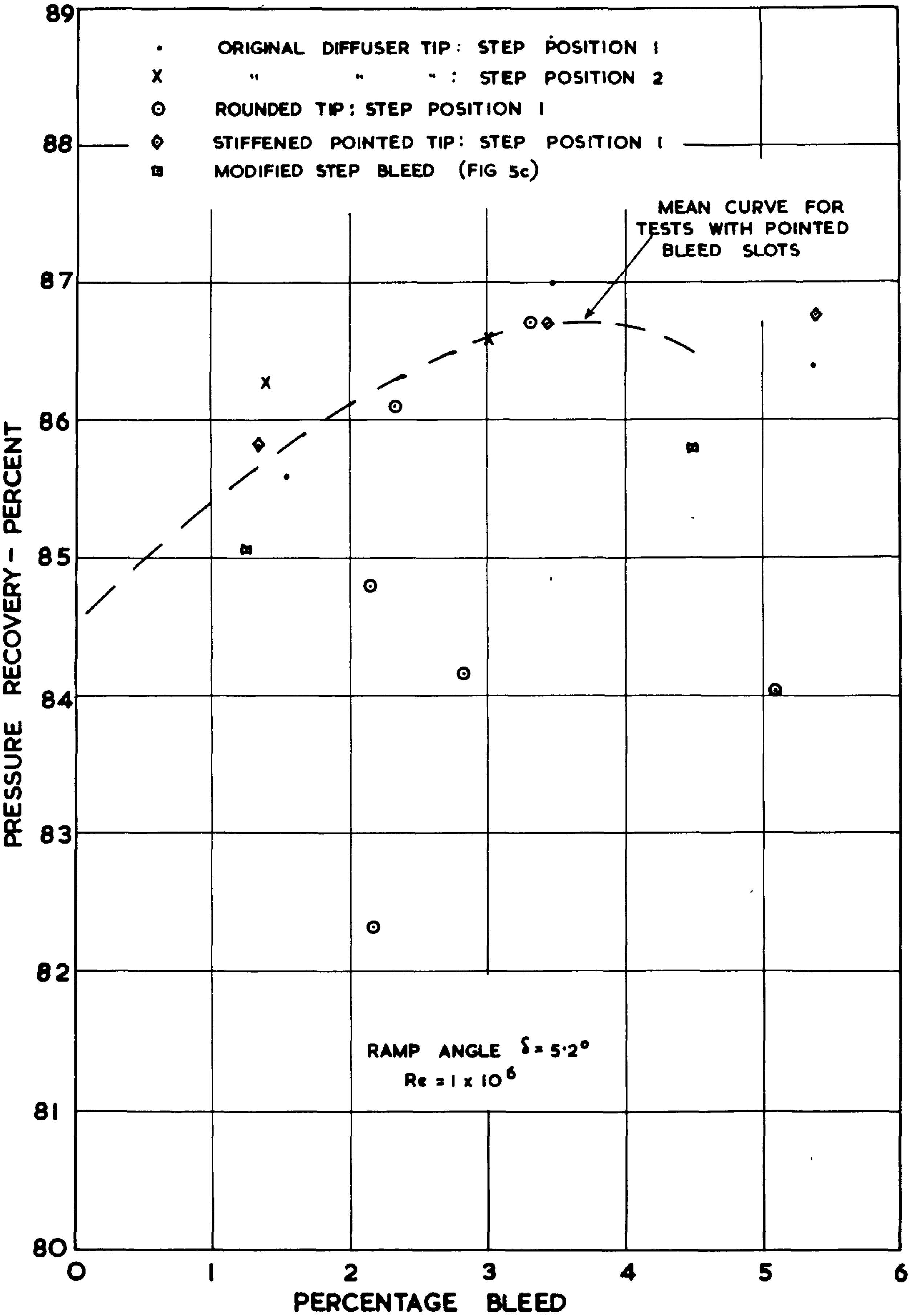
BLEED GEOMETRIES.

FIG. 6



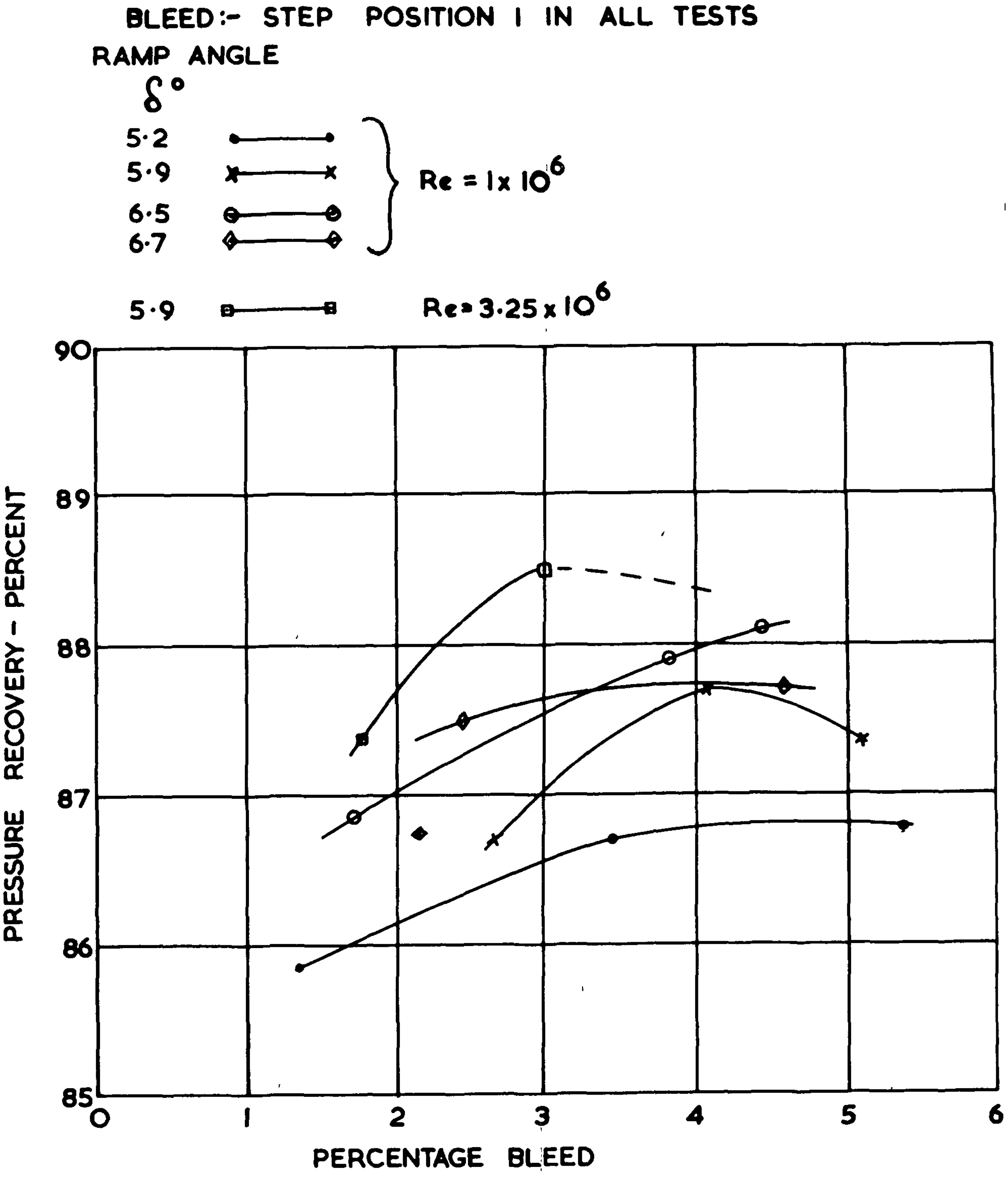
CALIBRATION OF BLEED GEOMETRY.

FIG. 7



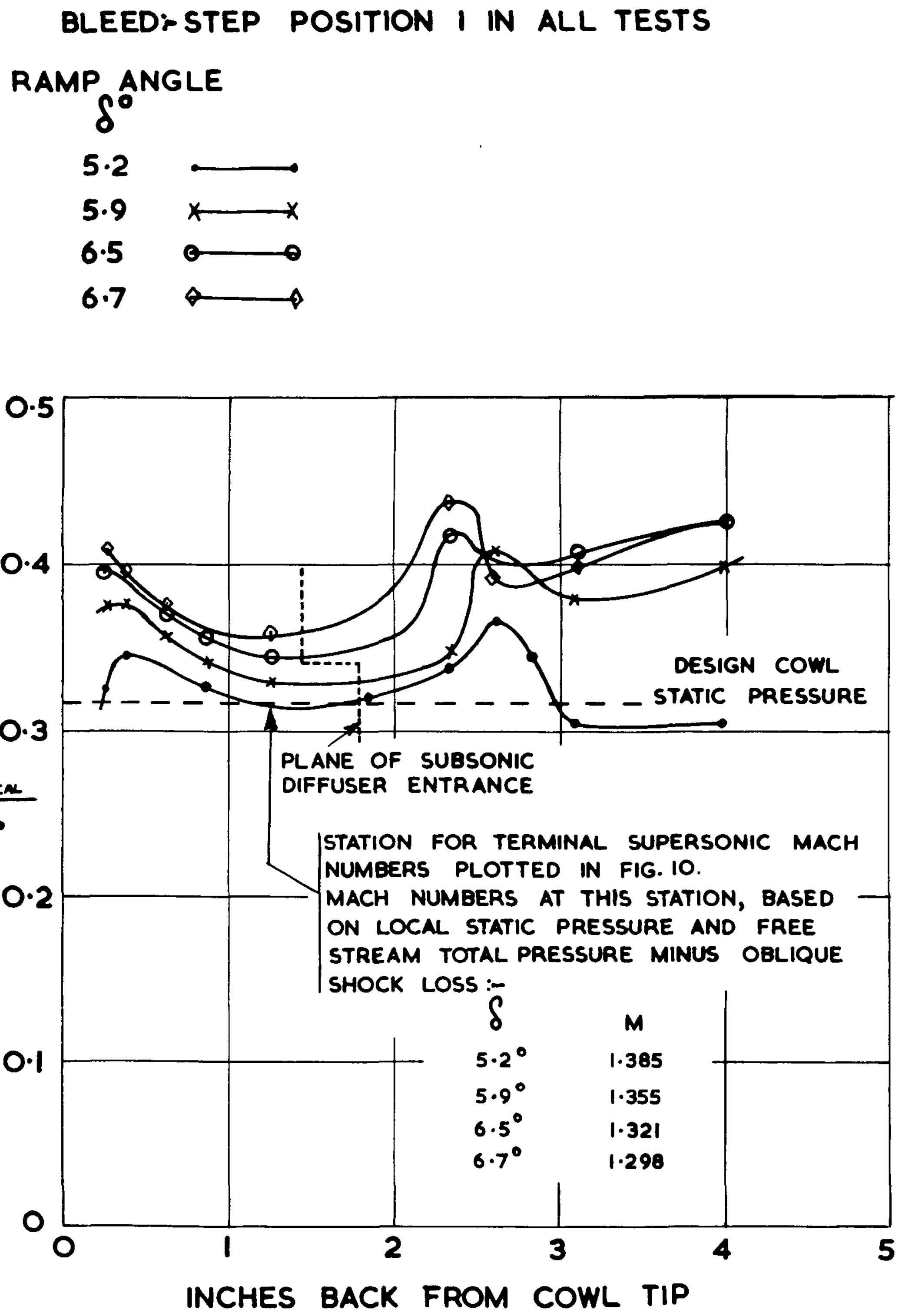
EFFECT OF BLEED GEOMETRY ON INTAKE PRESSURE RECOVERY.

FIG. 8



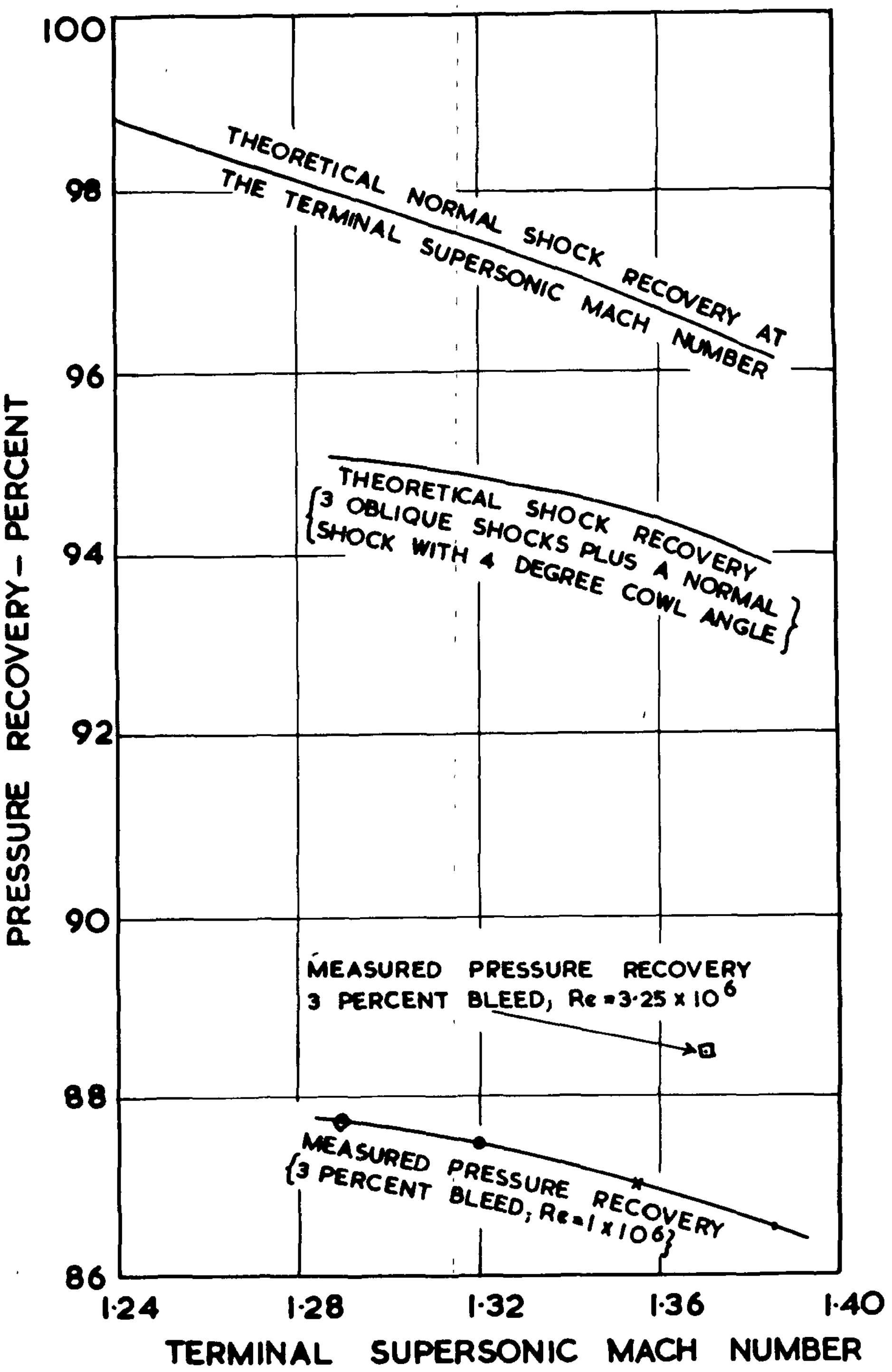
EFFECT OF RAMP ANGLE AND BLEED FLOW ON PRESSURE RECOVERY

FIG. 9



EFFECT OF RAMP ANGLE ON COWL STATIC PRESSURES (INTAKE SUPERCRITICAL)

FIG. 10



EFFECT OF TERMINAL SUPERSONIC MACH NUMBER ON PRESSURE RECOVERY.

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