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Some Tests with a Variable Ramp Intake having Sidewall Compression and a Design Mach Number of 2.2

By

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Some tests with a variable ramp intake having sidewall compression and a design Mach number of 2.2

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SUMMARY

Results are reported of some tests aimed at determining the effect of sidewall compression in a "two-dimensional" intake having combined external/internal compression and a design Mach number of 2.2. Sidewall compression results from the chamfers that are necessary to provide thickness for the splitter plate separating the two units of a twin cell intake.

The results suggest that the maximum penalty likely to result from the introduction of sidewall compression will be about 1 per cent on pressure recovery. With further development the penalty may be eliminated.

*Replaces N.G.T.E. M.367 - A.R.C.25268

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ILLUSTRATIONS

1.0 Introduction

Earlier Notes[1,2,3] have described tests with a two-dimensional intake having combined external/internal compression and a design Mach number of 2.2. The test model used for this work had plane parallel sidewalls so that, neglecting viscous effects, the internal flow could be regarded as purely two-dimensional. Such an ideal is not possible in some current full scale proposals which envisage "boxes" of two or more intakes side by side. In these the necessity for developing some sidewall (or in this context "splitter plate") thickness entails the introduction of internal chamfers on the appropriate sidewalls. Thus for example, in a bank of three intakes, the central one might entail chamfers on both sidewalls, while the two outer intakes could, if desired, be designed with one sidewall chamfered and the other plane. The present Note describes some tests aimed at determining the effect of such chamfers on intake performance.

2.0 Description of the model

Detailed descriptions of the model are given in the earlier Notes mentioned above. The particular model used in the present tests incorporated ramp bleed only. The only additional point to be made here concerns the sidewall chamfers; Figure 1 shows the manner of their introduction into the intake. The internal chamfer angles, and the extent of the sidewall contraction, corresponded with what at the time of the tests were proposals for a full scale intake. Tests were made with both the long and the short subsonic diffusers that are shown in Figure 2. The instrumentation was identical with that used in Reference 2.

3.0 Test procedure

Testing was 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. Tests were made with a number of different values of the ramp angle (δ in Figure 1), and the position of the tip of the translating cowl was so adjusted that at all times the internal oblique shock, when viewed through Schlieren apparatus, impinged on the subsonic diffuser tip at the bleed slot. Figure 1 shows the method used for defining the cowl tip position. The bleed slot geometry was so arranged that the bleed flow was always between 3 and 4 per cent of the intake capture flow. In the light of the results of the initial tests, for some further work the bleed slot position was moved forward 0.14 intake capture heights relative to the position shown in Figure 1.

4.0 Results and discussion

It was first noted that with the intake running supercritically the portion of the internal oblique shock that could be seen appeared quite "clean". However, compared with the throat flow pattern obtained with plane sidewalls, the remainder of the Schlieren picture was not so clear, as may be seen in Figure 3. The appearance of waves additional to the internal oblique shock and its reflection presumably indicated the presence of increased three-dimensional effects. Nevertheless, as Figure 3(a) shows, this complication was not sufficient to prevent the focussing on the diffuser tip of what appeared to be the major spanwise portion of the internal oblique shock. Thus it was possible to use the same experimental techniques that had been evolved in the development of the intake with plane sidewalls.

Stabilisation of the normal shock at the entrance to the subsonic diffuser proved impossible. Over the full experimental range of ramp angles and corresponding cowl tip positions, and also with both lengths of subsonic diffuser, the maximum pressure recovery was obtained with the normal shock flitting to and fro in the general region of the entrance to the subsonic diffuser about a mean position indicated by the normal shock in Figure 3(b). Earlier tests with plane sidewalls would suggest a resultant penalty on pressure recovery of about 1 per cent. Attempts to move the normal shock further forward from the position shown always resulted in shock expulsion, which appeared to occur in the manner noted previously with the intake having plane sidewalls[3].

Experimentally it was found convenient to determine the performance of the sidewall compression intake at a number of different cowl tip positions, and subsequent comparisons with the performance of the intake with plane sidewalls[1,2,3] were initially made on the basis of the cowl tip position. It was found that for a given position of the cowl tip the ramp angles required to focus the cowl shock on the subsonic diffuser tip were smaller with sidewall compression than without. In other words, the introduction of sidewall compression effectively strengthened the oblique shock system. The pressure recoveries plotted against cowl tip position are shown in Figure 4. Some scatter may result from ignoring small changes of bleed, and perhaps from the projecting Araldite fillets with the cowl tip in downstream positions. However earlier work has shown that within the present range of bleed flow the rate of exchange between pressure recovery and bleed is very small and insufficient to upset the trends of the ensuing arguments. Figure 4 shows that for a given cowl position, and with the long subsonic diffuser, the introduction of sidewall compression entailed a penalty of about 2 per cent on pressure recovery, or rather more than the 1 per cent expected from the downstream position of the normal shock. The short subsonic diffuser reduced the pressure recovery by roughly a further 3 per cent, probably as a result of the normal shock not being stabilised at the diffuser entry. In the early tests with plane sidewalls[1] the pressure recoveries obtained with the short subsonic diffuser were not brought up to the levels obtained with the longer one until bleed slot development enabled the normal shock to be positioned on the diffuser tip.

Static pressure distributions along the cowl centre line throw valuable light on the performance of the intakes that were tested. The fall in static pressure rearwards from the tip that was noted in Reference 2 was much more pronounced following the introduction of sidewall compression, perhaps because of supersonic expansions at the downstream edges of the chamfers. Figure 5 shows that for a given cowl tip position the static pressures near the tip were almost unchanged. Subsequently however the static pressure in the sidewall compression intake fell at such a rate that at the plane of the throat the pressure was between 10 and 15 per cent less than that obtained with plane sidewalls. Hence the corresponding terminal supersonic Mach number was, in this comparison, greater with sidewall compression than without. It is shown in Figure 6 that the maximum theoretical shock recovery occurs with a terminal supersonic Mach number of 1.2; as the tests were made with terminal supersonic Mach numbers in excess of this value it follows from the upper curve in Figure 6 that the theoretical shock recovery of the sidewall compression intake was correspondingly lower. It thus appears that the deterioration in performance associated in Figure 4 with the introduction of sidewall compression results partly from the downstream position of the normal shock during critical operation, and partly from the reduction in the theoretical shock recovery. Any undesirable influence of possible supersonic expansions at the downstream edges of the chamfers might be removed by extending the chamfers rearwards to cover the full throat height. However the intake design would be considerably complicated by such a step. Moreover, the possibility of adverse repercussions on the aerodynamic performance would seem to be strong. (The apparent supersonic expansion between the cowl tip and the throat may also be associated with the previously observed deflection of the sidewall secondary flow along the line of the internal oblique shock towards the ramp bleed slot[1]. This could, perhaps, effectively reduce the thickness of the sidewall boundary layer on passing through the internal oblique shock, and thus induce an expansion in the mainstream.)

When the results are considered on the basis of terminal supersonic Mach number (Figure 6) it is seen that with the long subsonic diffuser the pressure recovery with plane sidewalls is only 1 per cent higher than with sidewall compression. This difference corresponds closely with the penalty of about 1 per cent on pressure recovery suggested as accruing from the downstream position of the normal shock in Figure 3(b). The lower performance of the sidewall compression intake with the short subsonic diffuser was noted in the discussion on Figure 4.

Figure 7 shows that over a range of ramp deflection angles the additional cowl retraction required for focussing the internal oblique shock in the sidewall compression intake approximately equals 0.14 intake capture heights. It can also be seen from Figure 7 that the additional retraction roughly corresponds with $1\frac{1}{2}^{\circ}$ of supersonic turning on the ramp which, when added to the corresponding deflection at the cowl tip, makes a total increase in the supersonic turning of 3°. The same angle, representing the effective compression generated by the internal chamfers, is obtained by comparing the curve obtained with plane sidewalls in Figure 5(a) with the curves for sidewall compression in Figure 5(c), where it can be seen that roughly the same static pressure at the subsonic diffuser entry plane (and hence on an earlier argument the same theoretical shock recovery) is obtained with the same ramp deflection angle. However the addition of sidewall compression raises the static pressure near the cowl tip from approximately 0.345 to 0.405 times the free stream total pressure, a rise equivalent to a flow deflection of 3°. The agreement between this figure and the internal chamfer angle in the free stream direction is probably restricted to the aspect ratio of the model under test, i.e., 1.4 based on the capture plane dimensions. It is thought unlikely to be a general result.

The aerodynamic mechanisms producing these effects are not at present clear, although earlier tests[4] would support the view that three-dimensional flows within the intake are prominent. It should be emphasised also that the tests were made at a Reynolds number of 1×10^{6}. However Reference 2 suggests that the results would be similar for the higher Reynolds numbers more appropriate to supersonic transport installations.

After the tests just discussed the position of the bleed slot was moved forward 0.14 intake capture heights, i.e., an amount equal to the observed forward displacement of the foot of the internal oblique shock. It was found that the pressure recoveries then equalled those obtained with the same cowl positions and ramp deflection angles in the intake with plane sidewalls. In other words, the forward movement of the bleed eliminated the additional cowl retraction previously required for shock focussing in the sidewall compression intake. Such a result was to be expected. The forward movement of the bleed may be regarded as designing the intake to take due account of the sidewall contraction.

The intake with the bleed slot moved forwards may also be compared with the intake having plane sidewalls in order to examine the effect of sidewall compression on the overall supersonic contraction ratio, here defined as:

$$\frac{\text{internal flow area immediately upstream of the bleed slot}}{\text{capture plane dimensions measured perpendicular to the free stream}} .$$

As would be expected from the preceding discussion, the ramp deflection angles were found to be equal when the cowl tips of both intakes were in the datum position. With the cowl tips so positioned, notwithstanding the change in the position of the bleed slot, the supersonic contraction ratio was slightly less in the sidewall compression intake, the difference between the two ratios being about 2 per cent. This difference implies that although the terminal supersonic Mach numbers, defined at mid span as previously, were equal, the mean throat Mach number based on the throat area was less in the sidewall compression intake than in the intake with plane sidewalls. The corresponding improvement in the theoretical shock recovery of the sidewall compression intake would amount to about 1 per cent. The failure to realise this potential improvement can be ascribed to the inability to stabilise the normal shock at the diffuser entry; it will be recalled that the earlier tests with plane sidewalls suggested that a penalty of about 1 per cent on pressure recovery resulted from the downstream position of the normal shock shown in Figure 3(b).

It would seem possible that the introduction of sidewall bleed in the sidewall compression intake might enable the normal shock to be positioned at the entrance to the subsonic diffuser. In Reference 3 it was found that introducing sidewall bleed into the intake with plane sidewalls improved the pressure recovery by 1 per cent for an unchanged total bleed flow. Thus the potential gain from sidewall bleed in the sidewall compression intake would appear to be the 1 per cent on pressure recovery noted in Reference 3 plus a further 1 per cent from the forward movement of the normal shock. The higher pressure recovery of the sidewall compression intake compared with the intake with plane sidewalls and the same ramp deflection angle would then correspond with the smaller supersonic contraction ratio of the former. If it is assumed that the ultimate performance of both types of intake is determined by some limiting supersonic contraction ratio, then provided sidewall bleed or some other form of control enables the normal shock in the sidewall compression intake to be stabilised at the throat, the maximum pressure recoveries of both intakes should be equal. The ramp deflection angle in the sidewall compression intake would then be somewhat smaller than in the intake with plane sidewalls, and the terminal supersonic Mach number based on the cowl static pressure at mid span in the diffuser entry plane, somewhat higher. The mean throat Mach numbers based on the contraction ratios would however be equal. A failure to stabilise the normal shock at the throat of the sidewall compression intake would apparently entail a penalty on pressure recovery of about 1 per cent.

5.0 Conclusions

The tests show that the introduction of sidewall compression in a "two-dimensional" mixed compression intake necessitates modification of the basic two-dimensional design.

In the initial tests the sidewall compression reduced the ramp deflection angle that was required in order to focus the internal oblique shock on the diffuser tip. The static pressure distribution along the internal surface of the cowl was also changed so that whilst, with a given ramp angle, the pressures on the centre line at the subsonic diffuser entry were unaltered, the pressures near the cowl tip in the sidewall compression intake were appreciably higher. In addition, it was found impossible to stabilise the normal shock at the subsonic diffuser entry in the sidewall compression intake.

In subsequent tests, with the throat position modified to allow for the presence of sidewall compression, the terminal supersonic Mach number based on contraction ratio was slightly less in the sidewall compression intake than in the intake with plane sidewalls, while the pressure recoveries were equal. The failure to achieve a correspondingly higher pressure recovery in the sidewall compression intake is ascribed to the inability to stabilise the normal shock at the subsonic diffuser entry.

It is suggested that if the ultimate intake performance is determined by some limiting supersonic contraction ratio then, provided it becomes possible to stabilise the normal shock in the throat, the performance of the sidewall compression intake should equal that of the intake with plane sidewalls. A failure to stabilise the normal shock in the throat would entail a penalty of about 1 per cent on pressure recovery.

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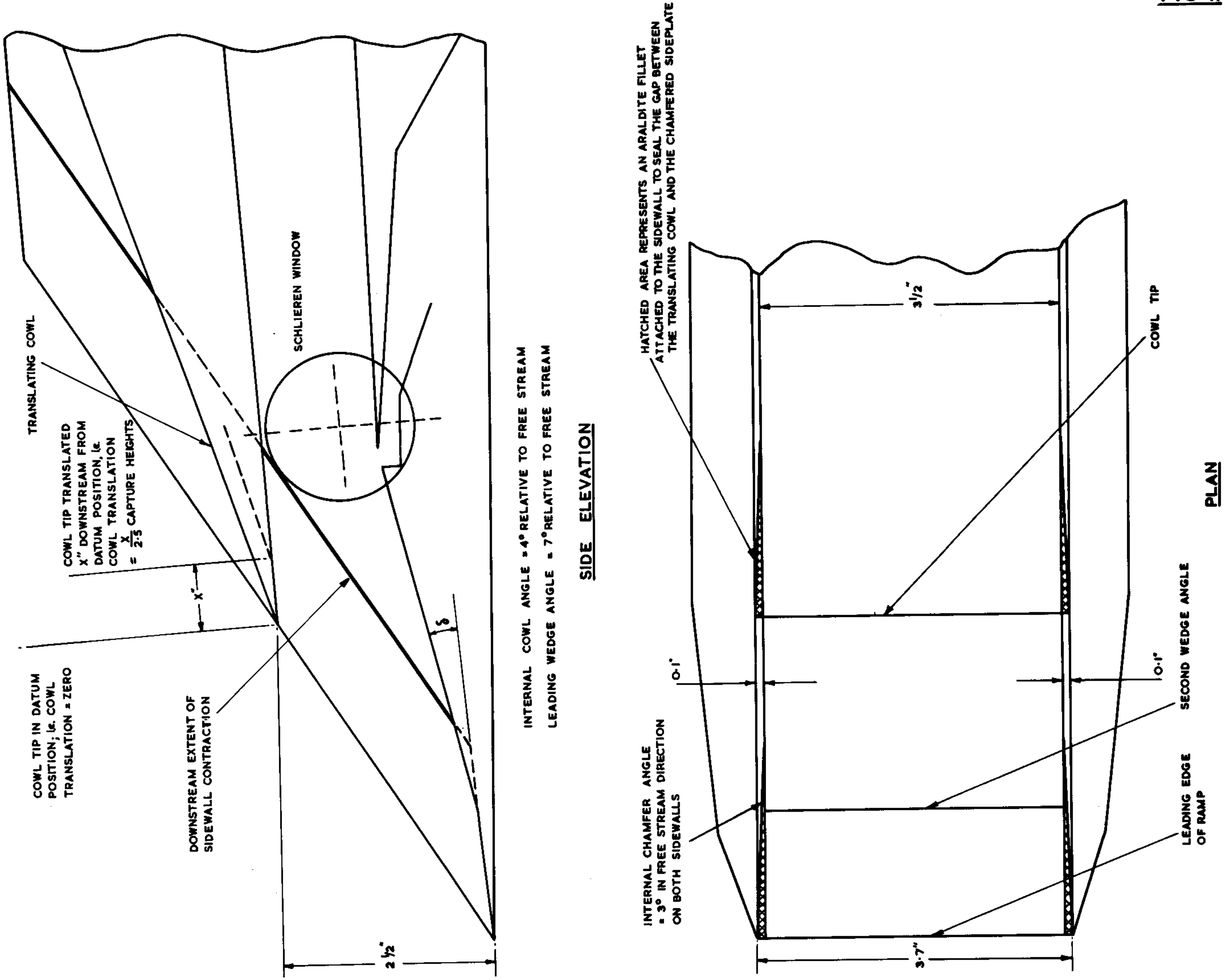
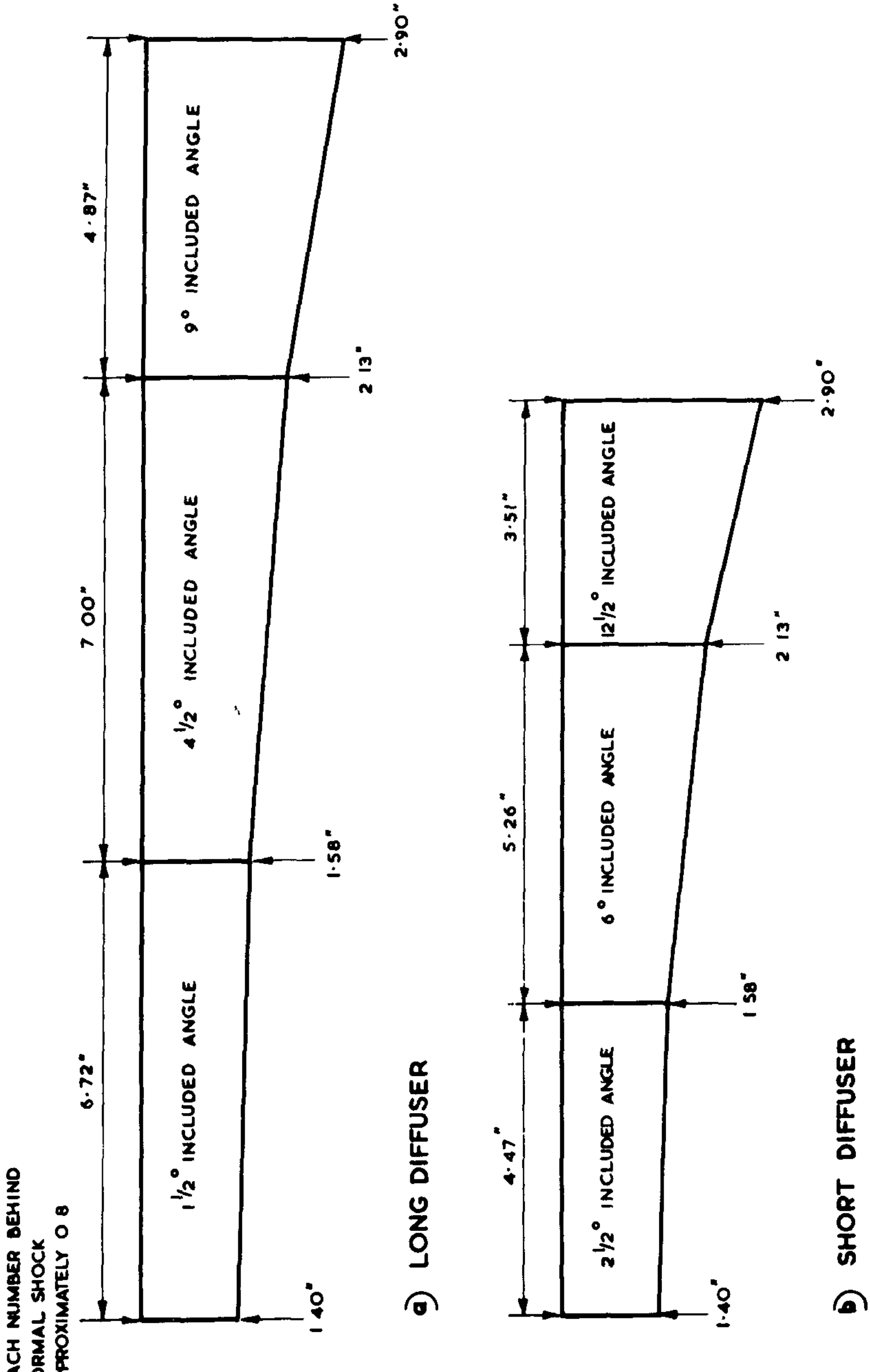
2	M. C. Neale P. S. Lamb	Further tests with a variable ramp intake having a design Mach number of 2.2 A.R.C. C.P.826 February 1963
3	M. C. Neale P. S. Lamb	More tests with a variable ramp intake having a design Mach number of 2.2 A.R.C. C.P.938 November 1963
4	M. C. Neale P. S. Lamb	Tests with a two-dimensional intake having all external compression and a design Mach number of 2.0 A.R.C. C.P.937 September 1963

FIG. I.



COMBINED EXTERNAL/INTERNAL COMPRESSION INTAKE WITH SIDEWALL COMPRESSION

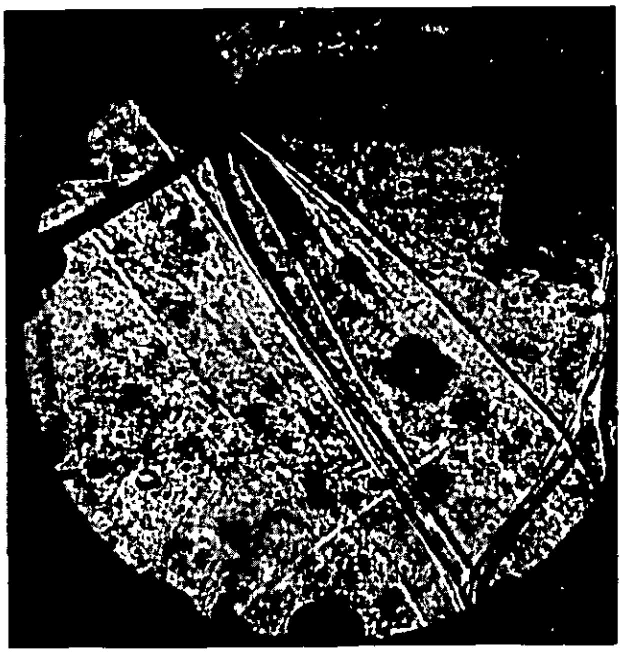
FIG. 2.



SCALE: ½ X FULL SIZE

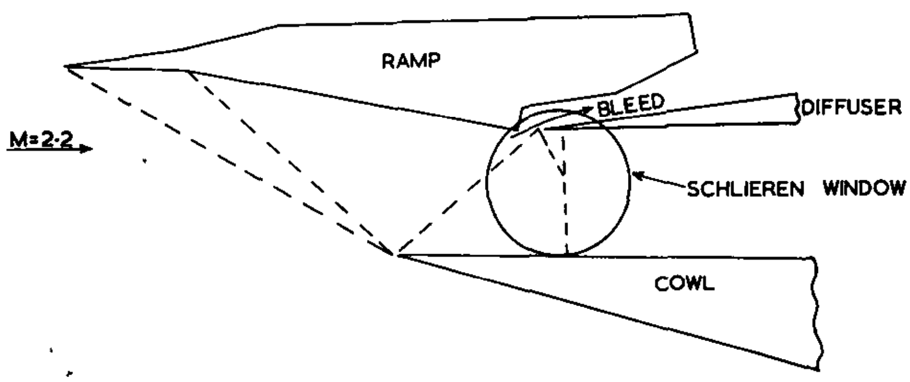
THE TWO SUBSONIC DIFFUSERS TESTED

FIG. 3



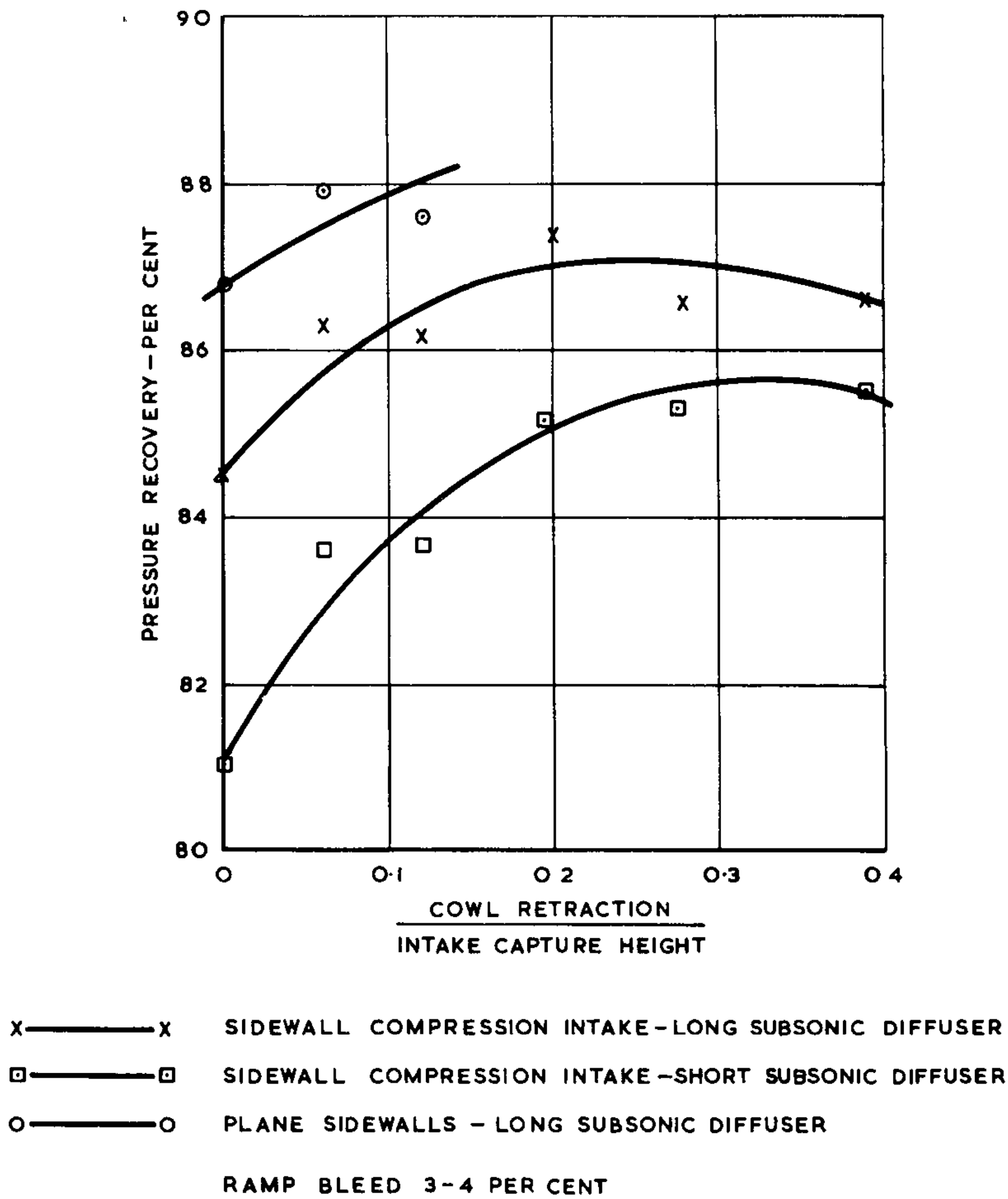
(a) INTAKE SUPERCRITICAL

(b) INTAKE CRITICAL



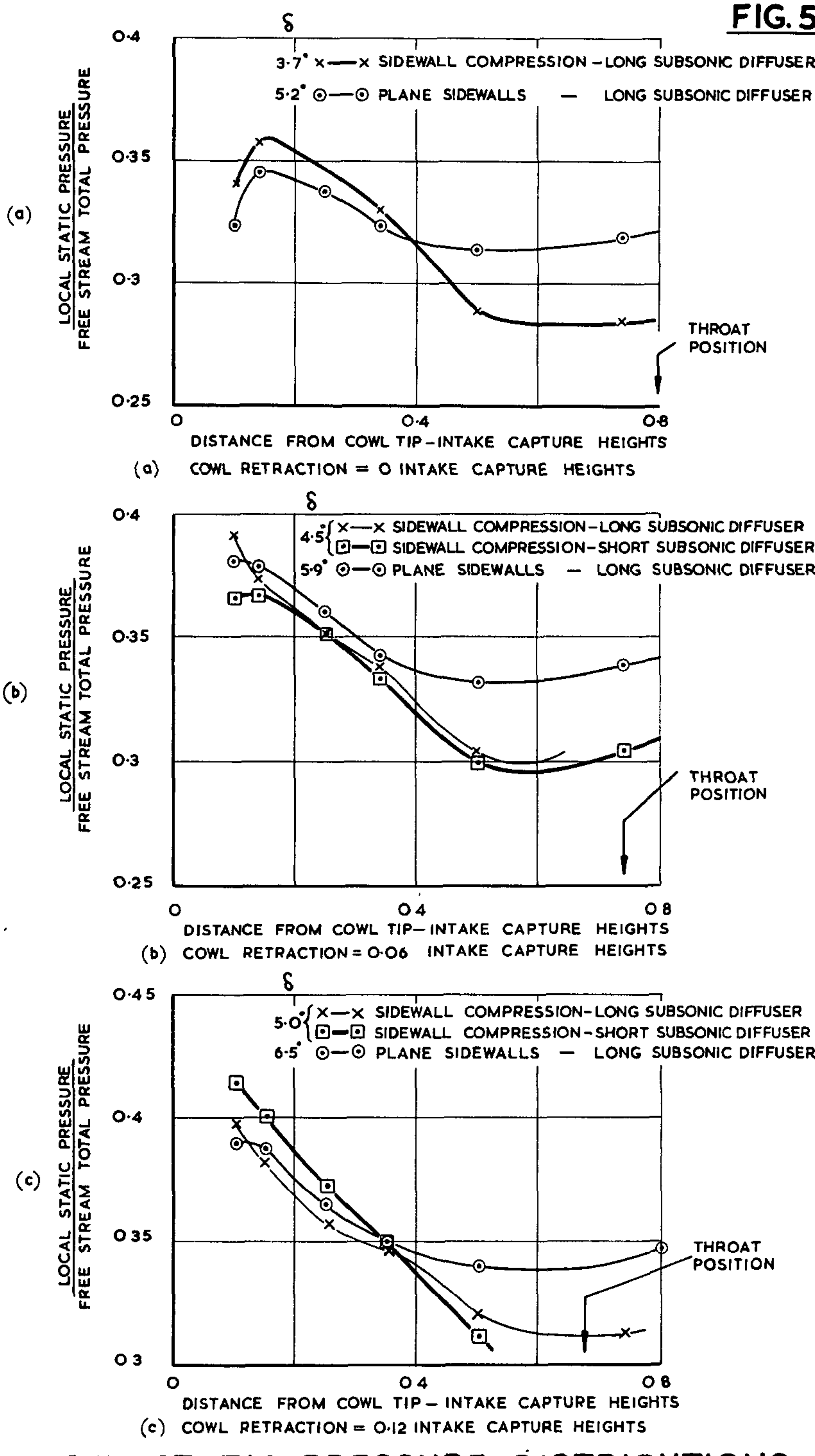
SCHLIEREN PHOTOGRAPHS OF THE THROAT FLOW PATTERN.

FIG. 4.



INTAKE PRESSURE RECOVERIES PLOTTED AGAINST COWL TIP POSITION

FIG. 5



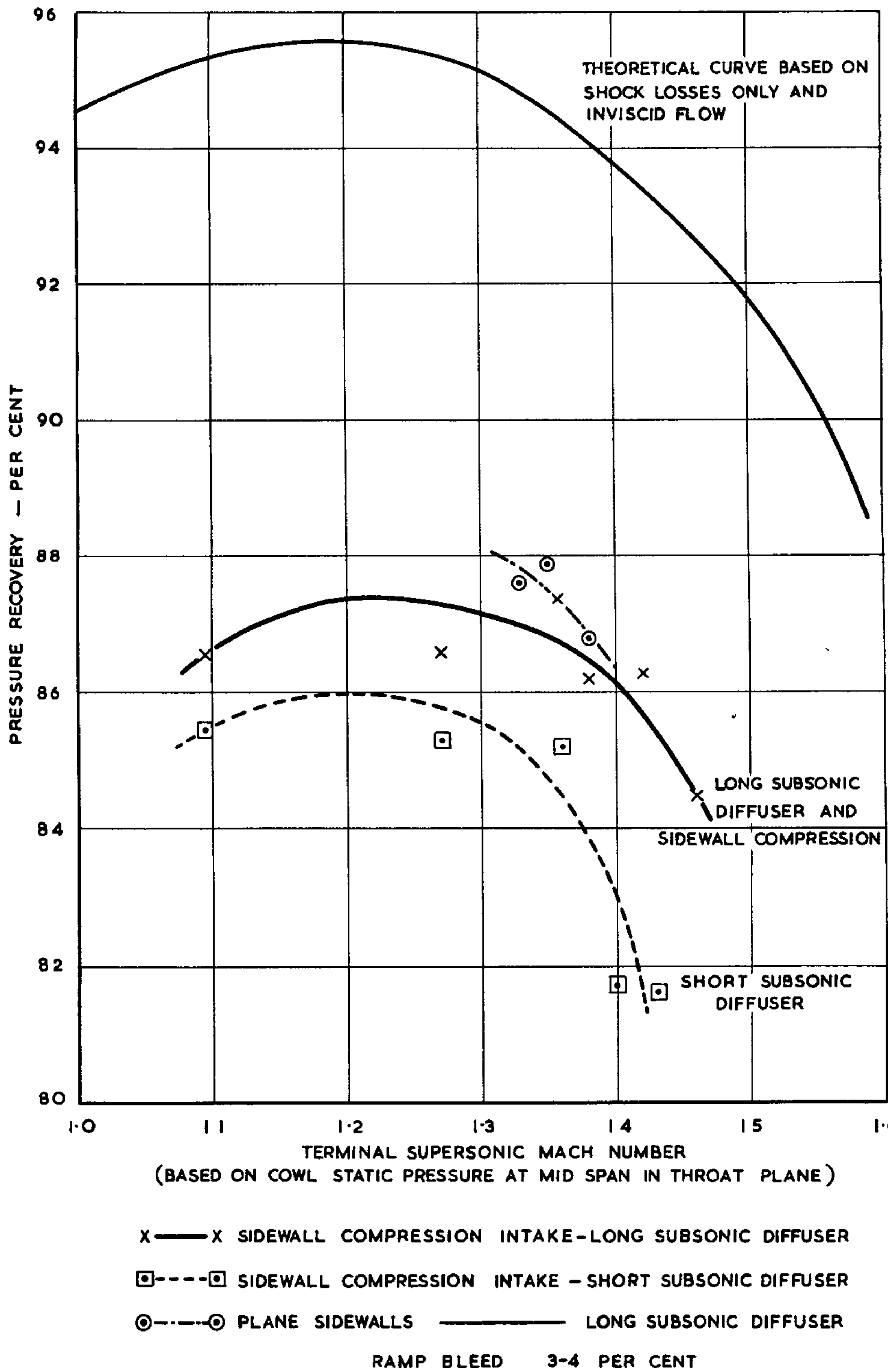
(a) COWL RETRACTION = 0 INTAKE CAPTURE HEIGHTS

(b) COWL RETRACTION = 0·06 INTAKE CAPTURE HEIGHTS

(c) COWL RETRACTION = 0·12 INTAKE CAPTURE HEIGHTS

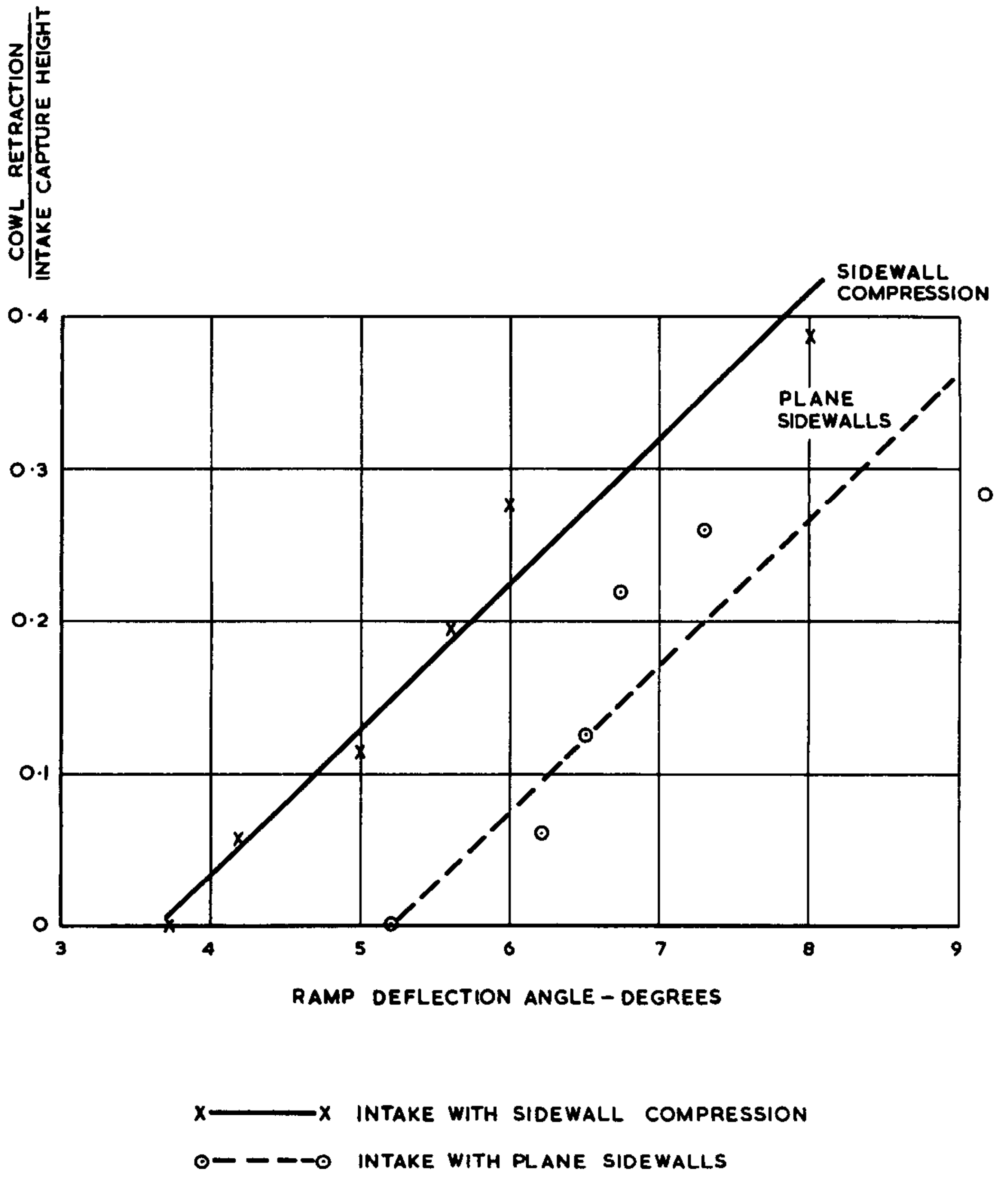
COWL STATIC PRESSURE DISTRIBUTIONS

FIG. 6



INTAKE PRESSURE RECOVERY AS A FUNCTION OF THE TERMINAL SUPERSONIC MACH NUMBER

FIG. 7.



COWL RETRACTIONS NECESSARY FOR SHOCK FOCUSSING

D 86669/1/129528 K4 5/67 CL

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