C.P. No. 939

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Tests with a Two-dimensional Intake having All-external Compression and a Design Mach Number of 2.2

By

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LONDON. HER MAJESTY'S STATIONERY OFFICE
1967

FOUR SHILLINGS NET

U.D.C. No. 533.697.2:620.1

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Tests with a two-dimensional intake having all-external compression and a design Mach number of 2.2

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SUMMARY

Results are reported of tests on a two-dimensional external compression intake having a design Mach number of 2.2. The tests were conducted at a Mach number of 2.23 and at a Reynolds number, based on free stream conditions and intake capture height, of approximately 1×10^6.

A stable critical flow could only be achieved when the intake was pitched slightly, relative to the free stream, in the direction tending to increase the deflection generated by the ramp. It is thought that the principal effect of applying the pitch was to move the ramp shocks forward from the cowl tip.

At 2° pitch a pressure recovery of 89.9 per cent was obtained with $6\frac{1}{2}$ per cent bleed; with only 2.4 per cent bleed the pressure recovery was 88.3 per cent.

*Replaces N.G.T.E. M.383 - A.R.C. 26125

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ILLUSTRATIONS

1.0 Introduction

This Memorandum describes tests with a two-dimensional external compression intake having a design Mach number of 2.2. The tests continue the experimental investigation of the external compression intake previously examined at a design Mach number of 2.0 (Reference 1).

The background to the tests is described in Appendix I.

2.0 Description of the model

The aerodynamic design is shown in Figure 1. The ramp consists of an initial wedge inclined at 8° to the free stream, followed by a further 8° turn and finally four angles, each of 1°. The total ramp turning is thus 20°, so arranged that at $M = 2.2$, and without allowing for boundary layer growth, the shocks focus on the cowl tip. The internal surface at the cowl tip is inclined initially at 15° to the free stream, so that the flow deflection at the tip is equal to 5°. The procedure adopted in the design of the cowl was to continue the internal surface along a straight line from the tip to the point at which a perpendicular from the surface intersects the foot of the strong solution shock emanating from the cowl tip. Subsequently a radius of 7.1 throat heights turns the cowl through 9°, so that the final cowl direction is inclined outwards at 6° relative to the free stream. The rather slow rate of turn and the final outward inclination derive from the employment in the present tests of components designed for earlier intakes.

The design intention was to position the terminal shock (assumed to be the strong solution shock radiating from the cowl tip) at the upstream edge of the bleed slot. Thus as in Reference 1, allowance for boundary layer effects was made by positioning the upstream edge of the bleed a short distance downstream of the shock position calculated on the assumption of inviscid flow. The bleed slot extends over an axial distance of approximately 0.4 throat heights. After passing into a plenum chamber the bleed enters two ducts serving as measuring lengths and containing pitot tubes and static tappings. A throttle at the exit from the measuring ducts controls the bleed mass flow. The downstream lip of the bleed slot had a sharp edge and an included angle of 5°. The profile of the subsonic diffuser tip was to some extent arbitrary in that it had been originally manufactured for another intake mode. In the position shown in Figure 1 the tip of the subsonic diffuser protrudes into the annulus lying between the cowl arc and the concentric "centrebody" arc. Thus from one point of view the tip might be regarded as providing a throat contraction through the introduction of a small ram scoop effect. In Reference 1 such a contraction provided a favourable effect on subcritical stability at the expense of a small reduction in pressure recovery. The subsonic diffuser design was that used in Reference 1, and is shown in Figure 2.

The intake sidewalls commence on the line joining the ramp and cowl tips. A chamfer angle of 16° in the free stream direction means that the shocks generated by the sidewalls are detached from their leading edges. However the arguments necessitating the adoption of large chamfer angles were advanced in Reference 1, where it was pointed out that experimental evidence indicates that the effect of the shock detachment is very small.

The intake capture height was $2\frac{1}{2}$ in. and the span $3\frac{1}{2}$ in. giving an aspect ratio of 1.4. The latter figure corresponds fairly closely with the aspect ratios currently proposed for supersonic transport installations.

A flap downstream of the subsonic diffuser exit was used to position the terminal shock at the intake throat. The throttle in the bleed ducts has already been mentioned.

A rake of 20 total head tubes, distributed on an equal area basis, was located at the exit plane of the subsonic diffuser. A number of static tappings were provided on the ramp surface, in the bleed plenum, on the sidewalls of the subsonic diffuser, and at the subsonic diffuser exit plane.

Windows in the plane of the throat permitted observation of the local flow by means of a shadowgraph system.

A total pressure of 40 in.Hg abs was used for the tests. The corresponding Reynolds number, based on free stream conditions and intake capture height, was approximately 1×10^6.

3.0 Results and discussion

3.1 Stability and pressure recovery

When the model was tested at zero incidence it was found impossible to stabilise the terminal shock at the cowl tip. As the throttle downstream of the subsonic diffuser was closed the intake ran straight from the supercritical condition to "buzz". There was no intermediate stable range. This situation could be corrected by applying a small amount of pitch to the model in such a direction as to increase the total ramp deflection. It was found that as little as $\frac{1}{2}^{\circ}$ of pitch sufficed to provide a stable sub-critical margin, whilst the stability was further improved with larger amounts of pitch. Figure 3 shows the experimental results.

With $\frac{1}{2}^{\circ}$ of pitch the theoretical Mach number upstream of the cowl shock (based on two-dimensional inviscid flow) is reduced only from 1.50 at zero incidence to 1.48. Moreover observation of the throat flow pattern revealed little change over this range of incidence. It is therefore thought that the explanation for the change in the stability characteristics of the intake with incidence lies in some other direction and is associated most probably with the positioning of the ramp shocks relative to the cowl tip. Unfortunately the cowl tip could not be observed during the tests, as it was concealed between the sideplates. However the test Mach number was, at 2.23, somewhat higher than the design figure. It is therefore suggested that at zero incidence one or more of the ramp shocks was impinging on the cowl surface, and that a small amount of pitch sufficed to move the ramp shocks forward from the cowl tip. Progressively larger amounts of pitch would move the shocks further forward from the cowl tip, so that as would be expected on the basis of the Ferri criterion[2] the stable sub-critical region was progressively increased. The marked increase between 1° and 2° in Figure 3 perhaps also reflects the effect, mentioned earlier, of the increased throat "contraction". (From a practical point of view these results confirm previous suggestions that on a full scale installation it may be necessary to arrange for spillage not only at the design Mach number, but also at the maximum overspeed Mach number, in order to obtain the necessary stable critical and sub-critical range. The drag penalty so entailed would require careful evaluation, and perhaps might be regarded as analogous to the much discussed "control penalty" associated with the mixed compression intake.)

The improvement of sub-critical stability with reduction of bleed shown in Figure 3 accords with the results presented in Reference 1. It was suggested there that the improvement might derive from the corresponding slight reduction of the rate of subsonic diffusion. An alternative suggested was that the additional contraction of the flow to the subsonic diffuser caused by a small bleed, as opposed to a large one, might lead to sonic conditions at some point downstream of the cowl shock and effectively insulate the supersonic compression system from buzz-inducing influences further downstream.

Figure 3 also shows the exchange of pressure recovery with bleed for different angles of pitch. The point indicating a pressure recovery of 84.3 per cent with 2.1 per cent bleed at 1° of pitch is an isolated departure from the general trend which shows that within the experimental range of bleed the rate of exchange is rather low. Broadly speaking, increasing the bleed from 2 per cent to 5 per cent raises the pressure recovery by only $1\frac{1}{2}$ per cent. The point just mentioned is also an exception to the general rule that with a given bleed the pressure recovery increases with the angle of pitch. The measured recoveries thus follow the theoretical shock recoveries, which are also marked on the figure. (It should be borne in mind that although the theoretical and measured pressure recoveries are increased by increasing the angle of pitch, the effective cowl angle is also raised.) The maximum pressure recovery at 2° pitch was 89.9 per cent, $6\frac{1}{2}$ per cent bleed being required to attain this figure. However the low rate of exchange of pressure recovery with bleed makes of more practical interest the recoveries of 89.5 per cent with 4.1 per cent bleed and 88.3 per cent with 2.4 per cent bleed. The difference between the measured recovery of 89.9 per cent and the corresponding theoretical shock recovery, assuming inviscid flow, is only 2.8 per cent. In practice viscous effects on the ramp surface and also on the sidewalls increase the theoretical shock recovery by an amount which, according to the arguments advanced in Reference 1, is difficult to specify precisely. The nett effect in the present tests is probably to increase the difference between the shock recovery and measured pressure recovery to approximately 4 per cent of the free stream total pressure.

3.2 Diffuser exit distributions

Some total pressure distributions at the subsonic diffuser exit are shown in Figure 4, together with the values of $\frac{P_{tot_{max}} - P_{tot_{mean}}}{P_{tot_{mean}}}$ and $\frac{V_{max}}{V_{mean}}$. As would perhaps be expected, the distributions are rather worse than those obtained earlier with an external compression intake operating at a free stream Mach number of 2.0. For example $\frac{V_{max}}{V_{mean}}$ is slightly over 1.3 compared with 1.2 in the earlier work.

3.3 Mainly concerning the cowl shock

The throat flow patterns differed considerably from those shown in Reference 1 in which the strong solution shock covered the full throat height. In the present tests, independently of the bleed, the cowl shock commenced at the cowl tip at an angle approximating to a strong solution. The shock strength then very rapidly weakened until halfway to the ramp, when the shock angle corresponded with the weak solution. The latter then continued to the ramp surface. As would be expected, downstream of that portion of the cowl shock corresponding with the weak solution, a weak normal shock completed the transition to subsonic flow. Reference 1 suggested that the type of throat flow pattern just described entailed little or no penalty - either on pressure recovery or exit distributions - compared with the uniform strong shock solution across the full throat height. This view is strengthened by the present results, which show a minimum difference of only 2.8 per cent between the theoretical shock recovery and the measured pressure recovery.

The cowl contour used in the earlier work incorporated a turn of 14° at a radius of 4.2 throat heights, whereas the present cowl has 9° of turn and a radius of 7.1 throat heights. One factor influencing the form of cowl shock might therefore be the rate and the amount of turn on the cowl. In Reference 1 an increase in the bleed weakened the cowl shock from the simple strong solution to the curved type of shock obtained in the present tests. An increased bleed might be regarded in the present context as equivalent to a change in the contour of the subsonic diffuser, so that a more rapid rate of turn on the "centrebody" might also be expected to influence the form of cowl shock. This rate of turn is not, of course, independent of the rate of turn on the cowl. The two must be matched in order to avoid choking at the throat. It might therefore be that the optimum intake at the design Mach number, from the points of view of low external drag and high internal performance, would be achieved with a curved cowl shock. The strong solution across a half or two thirds of the throat height would be generated by a rapidly turning cowl. Nearer the centrebody the correspondingly rapid rate of turn required in order to avoid choking would lead to a weakening of the cowl shock, and to the local requirement for a normal shock in order to complete the transition to subsonic flow.

Summarising, the present results considered with the earlier work suggest that the form of cowl shock is dependent on the internal cowl contour, the contour of the diffuser downstream of the bleed slot, and the quantity of bleed, all of which presumably influence the pressure downstream of the shock.

4.0 Conclusions

A two-dimensional all-external compression intake has been tested at a free stream Mach number of 2.23 and a Reynolds number of approximately 1×10^6. The design Mach number of the intake was 2.2.

It was necessary to apply to the intake a small amount of pitch (in the direction tending to increase the initial ramp angle) - in order to obtain a stable critical flow. It is thought that the principal effect of the incidence was to move the oblique shocks generated by the ramp surface forward from the cowl tip. Such an explanation would confirm that spillage over the cowl, with the associated drag, is necessary in order to obtain stable critical and sub-critical flows.

At 2° pitch a pressure recovery of 89.9 per cent was obtained with $6\frac{1}{2}$ per cent bleed; with only 2.4 per cent bleed the pressure recovery was 88.3 per cent.

A strong solution shock extending across the full throat height, as in Reference 1, was not obtained during the present tests. This result is principally ascribed to the enforced adoption of a rather more "flat" cowl contour than previously used. However present evidence is that the changed shock structure detracts from neither the pressure recovery nor the diffuser exit distributions.

REFERENCES

No.	Author(s)	Title, etc.
1	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. No. 937
2	A. Ferri L. Nucci	The origin of aerodynamic instability of supersonic inlets at subcritical conditions NACA RM L50K30 January 1951
3	J. Leynaert J. M. Brasseur	Work at O.N.E.R.A. Problems d'Aerodynamique interne posés par l'avion de transport supersonique à Mach 2 Paper presented at European Aeronautical Congress at Venice September 1962

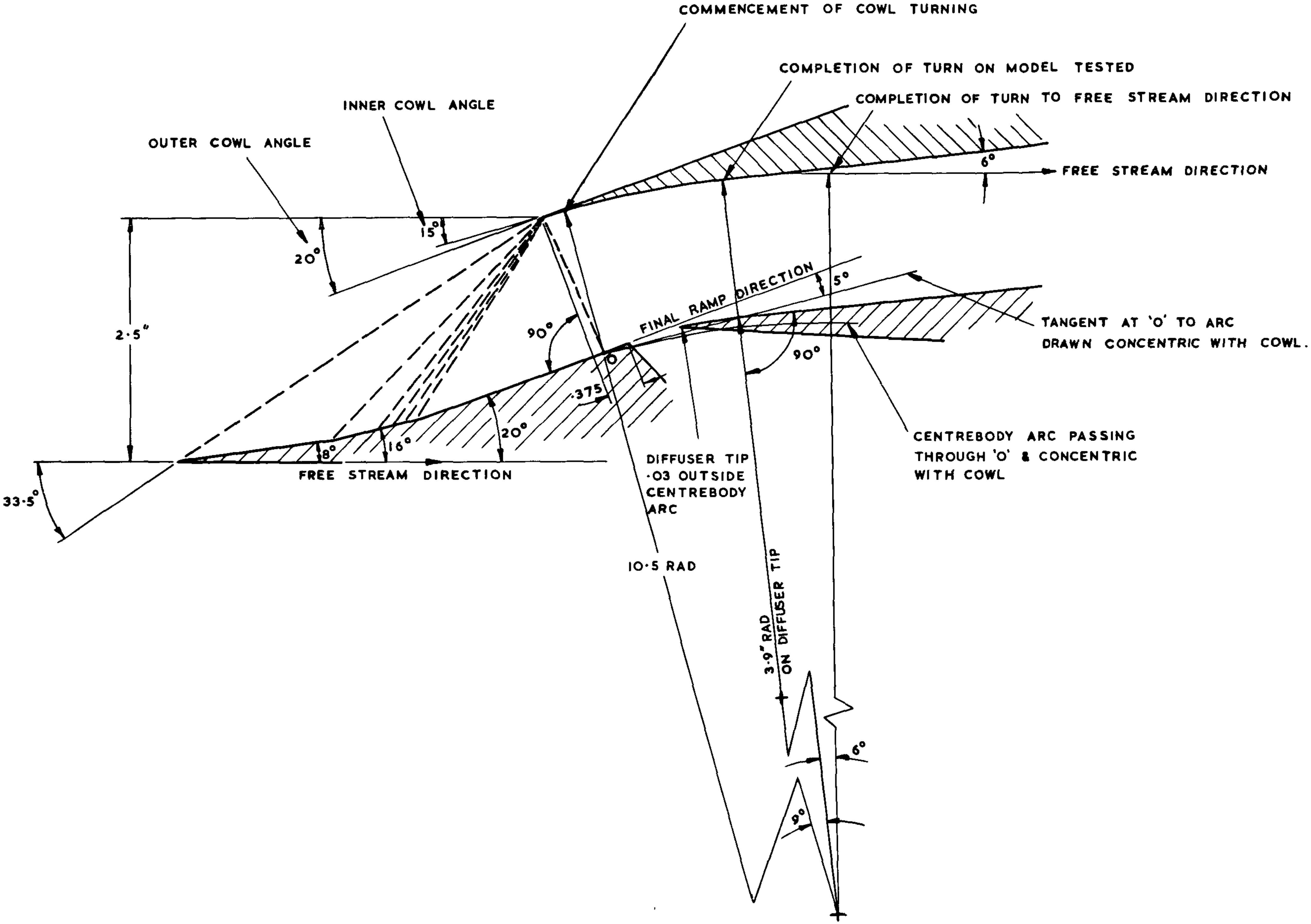
APPENDIX I

Background to the tests

References 1 and 3 described a type of external compression intake in which the internal angle of the cowl was less than the maximum ramp deflection. The capture flow in such an intake is deflected at the cowl tip, and the transition to subsonic flow is effected through an oblique shock rather than the normal shock characteristic of the conventional external compression design. The earlier paper[1] suggested that the introduction of flow deflection at the cowl tip could postpone until higher flight Mach numbers the point at which the intake featuring part internal compression would be preferred to the all-external compression design. The theoretical performance of the two types of intake at design Mach numbers of 2.0 and 2.2 were briefly compared. It appeared that at M = 2.0 there was little to choose between the two types, but at M = 2.2 the theoretical differences were widened.

At the flight Mach numbers under review, high theoretical shock recoveries i.e., 95 per cent or more, entail supersonic diffusion down to Mach numbers of about 1.4 or less. The corresponding turning from a free stream Mach number of 2.2 amounts to some 25°, so that even with flow deflection at the cowl tip, the cowl angle of an external compression intake becomes very high. For example the detachment angle at M = 1.38 is 9°. Thus the 25° of turning that are necessary to achieve this Mach number from a free stream Mach number of 2.2 necessitate a cowl angle of at least 16° in order to attach the shock at the cowl tip. A better compromise between the internal performance and external drag would probably be achieved with a smaller amount of ramp turning. With only 20° of turning, 12½° of deflection at the cowl tip are required theoretically in order to produce detachment. (Were it practicable to run at this condition the theoretical shock recovery would be 94½ per cent and the internal cowl angle 7½°.) In practice smaller deflections at the cowl tip are necessary in order to avoid detachment, and therefore the initial cowl angle has to be greater than the theoretical minimum. It follows that the theoretical shock recovery is reduced. Reverting to the intake with 20° of ramp turning operating at M = 2.2, 10° of cowl deflection reduce the theoretical shock recovery, based on the strong solution shock, to 92.4 per cent and increase the cowl angle to 10°. With a deflection of 5° these figures become 91.7 per cent and 15°, whilst with zero deflection (and in consequence a normal terminal shock) they equal 91.2 per cent and 20°.

A deflection of 5° was selected for the intake used in the tests described in this Memorandum.



M=2·2 EXTERNAL COMPRESSION INTAKE: 15° COWL ANGLE.

(SCALE: FULL SIZE)

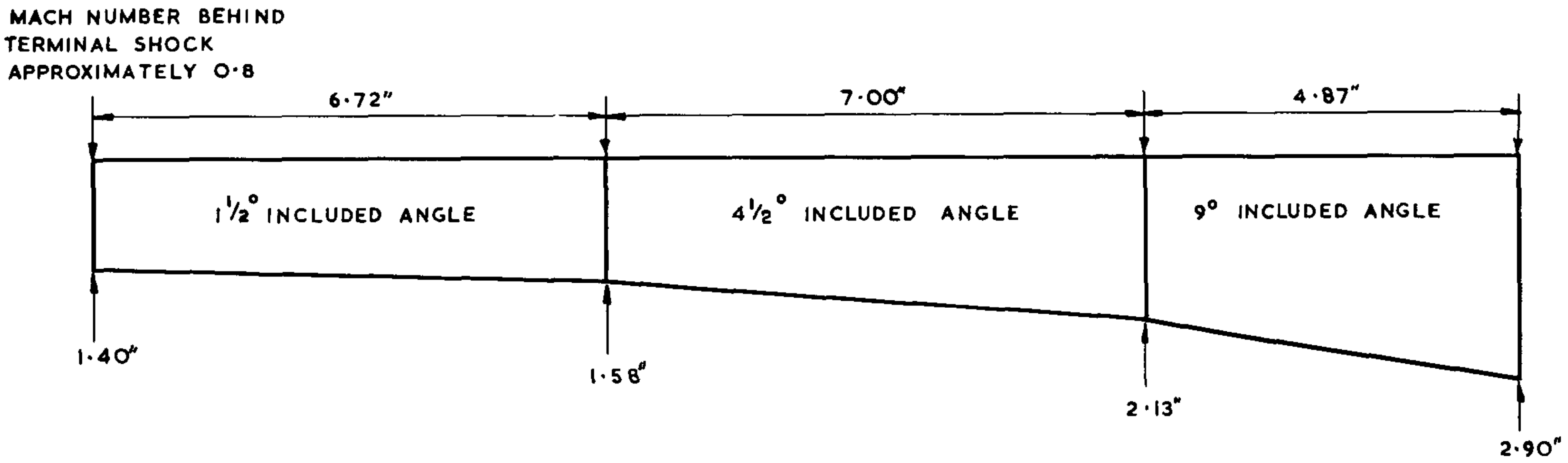
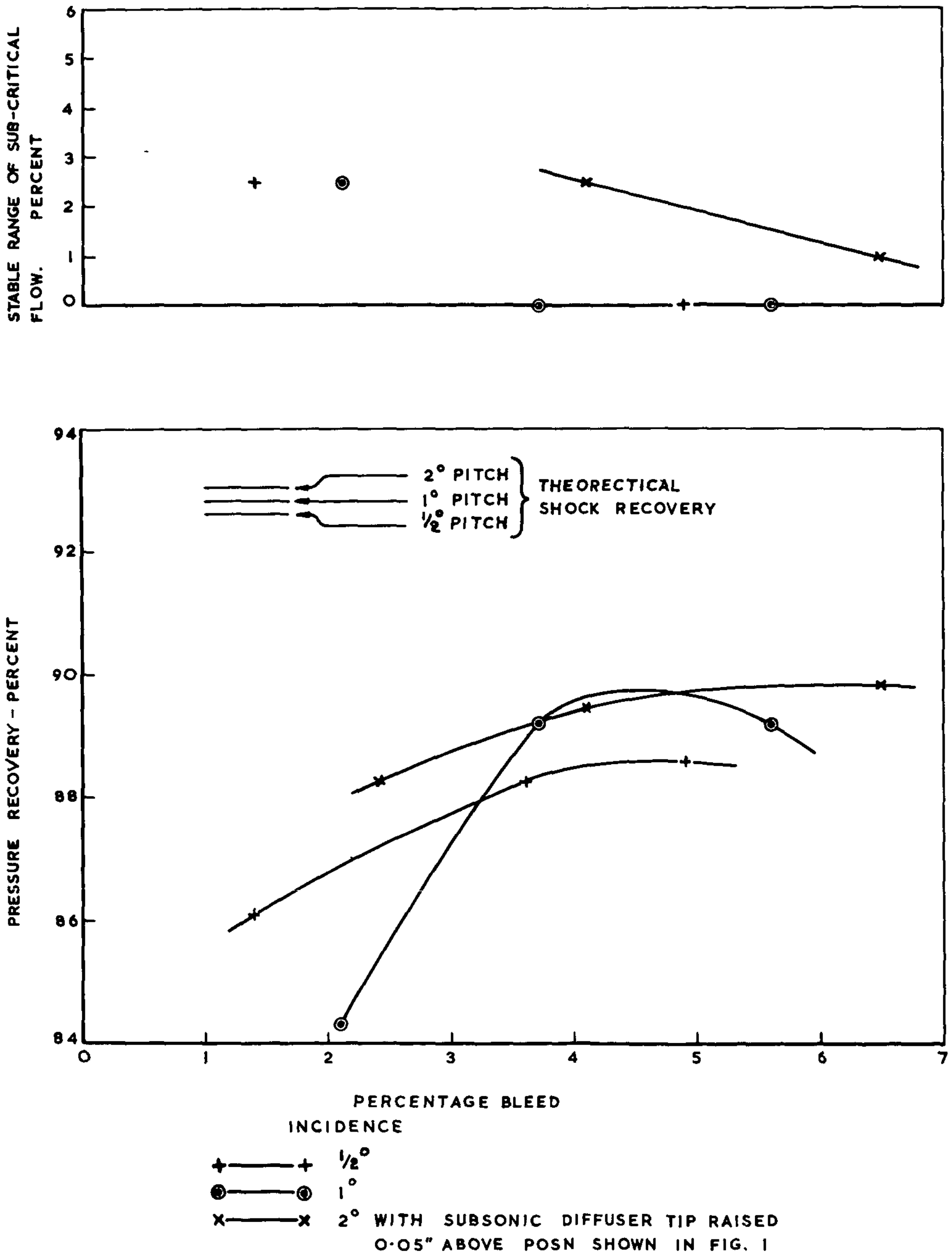


FIG. 2

SUBSONIC DIFFUSER.



PRESSURE RECOVERIES AND STABILITY REGIONS.

A.R.C. CP. No. 939 533.697.2:620.1

April 1964
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DETACHABLE ABSTRACT CARDS

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C.P. No. 939

S.O. Code No. 23-9017-39