R. & M. No. 3204

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Summary.—The effect of internal contraction, cowl and subsonic diffuser shape on the pressure recovery of a $\theta_c = 25$ deg conical-centrebody intake designed for a Mach number of 2·46 has been studied experimentally at $M = 2 \cdot 48$. Substantial gains in pressure recovery have been recorded with increase of initial angle of the cowl undersurface and the internal contraction ratio. Small gains were also recorded by decreasing the initial rate of subsonic diffusion and correspondingly increasing the rate at lower duct velocities. Calculations have been made of the increased drag at full mass flow due to excessive internal contraction at Mach numbers below the design value.

An empirical correlation of pressure recovery at full mass flow with contraction ratio and initial undersurface angle of the cowl yields results which should aid in the prediction of pressure recovery for conical-centrebody intakes.

1. *Introduction.*—It has been shown by Ferri (Ref. 1) that the pressure recovery of conical-centrebody intakes is materially affected by the internal contraction of the duct, the cone angle and the initial internal angle of the cowl. However, the pressure-recovery values obtained appear to exceed the values of all other experimenters by amounts varying up to some 10 per cent. Independent checks on identical designs both by the Royal Aircraft Establishment and by the National Advisory Committee for Aeronautics show that these values cannot be repeated.

A limited experimental investigation has been undertaken at the R.A.E. to evaluate the effects of varying the internal contraction, the initial rate of subsonic diffusion and the initial cowl internal angle on pressure recovery for a $\theta_c = 25$ deg design at a free-stream Mach number of 2·48. The effect of the internal contraction on the drag at full mass flow at Mach numbers at and below design has also been calculated.

2. *Range of Investigation.*—It has been shown in Ref. 2 that the duct area distribution can have an appreciable effect on the subsonic diffusion losses. In particular, if the action of the shock on the external boundary layer has resulted in separation, the incorporation of a constant area or slowly diverging initial portion, has a beneficial effect. This effect can easily be studied

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with the two-dimensional side intakes of Ref. 2 the variation in geometry being limited to varying the top wall of the duct. In the case of conical-centrebody intakes, however, the duct area distribution is determined by the shape of both the cowl and the centrebody and thus, in general, the effect of the shape and position of the ' corner '* cannot be eliminated.

The effect of the ' corner ' will be to decrease the pressure recovery if it is located ahead of the rearmost position of the second shock as an expansion is introduced in front of the shock which accentuates the shock/boundary-layer interaction and results in increased losses. The ' corner ' must necessarily be located in such a position if the initial internal angle of the cowl is small and the duct does not contract to any appreciable extent.

The effect of internal contraction can be viewed from two aspects. Theoretically it should be possible to establish an efficient multi-shock system internally which will raise the shock compression efficiency just at the critical point. A sudden decrease is then obtained directly spillage commences and the shock system is reduced to the familiar two-shock pattern.

Alternatively internal contraction can be instrumental in securing higher pressure recoveries by :

(*a*) Suppressing the boundary-layer breakaway downstream of the second shock by imposing a favourable pressure gradient on the resultant subsonic flow.

(*b*) Avoiding the effect of the ' corner ' by locating this region some distance downstream of the duct entry. The amount of internal contraction is then dictated by the cowl internal shape.

As can be seen from the pressure-recovery/mass-flow curves (Figs. 5b to 8b) there is no sudden increase in pressure recovery at the critical point and thus we are not considering the effect of an internal multi-shock system.

If we assume a two-shock system (conical shock followed by a normal shock) the residual losses can be calculated by the method of Ref. 2 if we have :

(*a*) no internal contraction

(*b*) no ' corner ' effect

(*c*) a straight subsonic diffuser.

Conditions (*a*) and (*b*) can be satisfied for one of our configurations and the method has been applied in this instance (*see* Section 5.2).

A systematic investigation of the effects of internal contraction, the ' corner ' and of a curved subsonic diffuser (in conjunction with separated flow), is beyond the scope of this Report. Such an investigation is planned using two-dimensional wedge-centrebody intakes. In the meantime this largely data Report is presented as there does not seem to be any systematic data of this kind for conical-centrebody intakes. The tests have been based on a cone semi-angle of 25 deg and a θ_l of 37·7 deg (*i.e.*, θ_w at $M_\infty = 2\cdot46$).

The external drag aspect of this investigation is of lesser importance as the drag at full mass flow is obviously somewhat arbitrary. The pressure-recovery considerations only fix the initial internal angle of the cowl and a minimum value for r_{en}/r_f and thus a variety of cowl external shapes and projected areas are possible. At below design Mach number the drag at full mass flow will rise in a readily predictable manner as pre-entry drag appears (due to the cone shock moving forward of the cowl lip) and cowl drag alters correspondingly until a Mach number is reached at which the internal contraction becomes excessive. Below this Mach number the flow is choked at the minimum-area section of the intake and hence the mass flow is restricted below that dictated by conical-flow considerations, the second shock is detached and the drag

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* The corner (Fig. 1) is defined as the region in which the slope changes (usually fairly rapidly) from the cone value to zero or some small positive or negative value which thereafter remains sensibly constant in the initial diverging part of the duct.

increases. Unpublished tests at R.A.E. have shown that the drag in this condition can be calculated in the same manner as for a conical-centrebody intake under normal spillage conditions. Thus the drag of the various configurations at below design Mach number has been calculated to illustrate the penalty incurred by adopting internal contraction to improve the pressure recovery at the design Mach number.

3. *Models.*—3.1. *Internal Contraction and Initial Internal Cowl Angle.*—A number of centrebodies were designed to give a range of contraction ratios (up to and exceeding the maximum permissible, which is 0·86 at the model design Mach number of 2·48) for the four cowls ST.10, SD.10, SD.13 and SD.2 which have initial internal angles of 1·5, 3·4, 11·3 and 14·85 deg respectively. The cowls and centrebodies (numbered 25°—1 to 12) are shown in Figs. 2 and 3a.

3.2. *Area Distribution Downstream of Minimum Section.*—A number of the centrebodies used in the investigation of the effect of internal contraction were redesigned to alter the initial rate of subsonic diffusion. Thus the models have kept the same length, the same overall diffuser area ratio and the same centrebody shape up to the minimum-area section as the equivalent designs in Section 3.1 and are designated with same number with suffix A appended.

The co-ordinates of the forward portions of these conical centrebodies are given in Fig. 3b. These bodies screw on to the webbed centrebodies shown to complete the subsonic diffusion down to the annular area defined by the outer cowl and sting diameters.

4. *Apparatus and Procedure.*—The rig for measuring the pressure recovery consists of three racks of seven pitot tubes each and is shown in Fig. 4. The method of measurement has been described in Ref. 3.

5. *Results.*—5.1. *Effect of Internal Contraction.*—The effect of internal contraction on pressure recovery is shown in Figs. 5 to 8. The variation in internal contraction has been obtained by combining a number of centrebodies with cowls ST.10, SD.10, SD.13 and SD.2. The favourable effect of the contracting duct on the boundary-layer breakaway and the effect of the gradual elimination of the corner is reflected in the increase in pressure recovery as the contraction ratio increases. The initial rates of subsonic diffusion are illustrated by the A/A_t vs. x graphs for the various cowl and centrebody combinations. In general the rates are very similar and from the continuity of the P_f/P_∞ vs. A_t/A_i curves it is apparent that even when departures from the general trend do occur (SD.10—25°/11, Fig. 6) the effect is small.

It is interesting to note that the gains in pressure recovery at the higher contraction ratios are not so large for the cowls with the larger initial undersurface angles (SD.13 and SD.2). Presumably the longer throat lengths that are occasioned by these geometries result in higher skin-friction losses and so result in the observed dropping off in pressure recovery with internal contraction ratio (Figs. 7b and 8b).

5.2. *Effect of Area Distribution in the Subsonic Diffuser.*—The favourable effect of having a long constant-area portion at the beginning of the subsonic diffuser on flow instability has been demonstrated. The favourable effect on pressure recovery has not been made so obvious. If the cone surface Mach number is such that there is no separation due to shock/boundary-layer interaction the pressure recovery is decreased due to higher skin-friction losses resulting from higher mean velocities in the duct. With separation, however, the constant or slowly diverging area at the beginning of the duct has a favourable effect in reducing the losses due to mixing.

In this case the duct length has been kept constant and the results (Figs. 9 to 11) show the direct effect of decreasing the rate of diffusion in the first part of the duct and increasing it farther down. Presumably the losses will reach a minimum value and increase again if this process is taken too far, *i.e.*, if the diffusion towards the end of the duct is made too rapid.

In Fig. 11b a comparison between measured and calculated values for pressure recovery (using the method of Ref. 2) is shown. In this case the internal contraction is negligible and the 'corner' is positioned so far inside the cowl that it should have no effect on the shock/boundary-layer interaction on the cone surface. Thus only the effect of the curvature of the subsonic diffuser is not accounted for when applying the method of Ref. 2.

The agreement for centrebody 7 is quite close but the favourable effect of changing the area distribution to that given by 7A is not well predicted. It should be remembered that the boundary layer in this case is laminar (the experiments of Ref. 2 were all performed with a turbulent boundary layer), and the diffuser area ratio (2·01) is larger than in any of the experiments of Ref. 3 (1·5).

5.3. *Effect of Cowl Shape.*—As the initial angle of the cowl undersurface is increased a more favourable shape for the centrebody can (for a given contraction ratio) be employed. This together with the effect of the cowl shape itself is shown in Fig. 12. This pressure-recovery increase has of course to be weighed against the accompanying increase in cowl drag. However, as we have seen (Section 3.1) the adoption of a smaller contraction ratio to obtain a particular pressure recovery means that the drag at low Mach number may be less. This is illustrated in Figs. 13 to 16 which show the calculated drag of the intakes at Mach numbers below the design Mach number of 2·48. The drags have been calculated using the method given in Appendix II of Ref. 3. The results of some unpublished tests show that this method gives results which agree quite well with experimental values if the position of the detached second shock is known accurately. This is best obtained by means of Schlieren photographs but in this case has been calculated and so the results are liable to be in error by some 10 to 20 per cent.

In Figs. 17 and 18 a more realistic evaluation of the drag penalty at below design Mach number is shown. Values of internal contraction ratio have been chosen for cowls SD.2, SD.13, SD.10 and ST.10 such that pressure recoveries of 0·72, 0·70, 0·68 and 0·66 can be obtained at $M_\infty = 2\cdot48$. The drags of these configurations at full mass flow have been evaluated over the Mach number range 1·6 to 2·48. It can be seen that for a given level of pressure recovery at $M_\infty = 2\cdot48$, in general, the low-angle cowls that have low drag at this Mach number retain their characteristics throughout the Mach number range, *i.e.*, despite the increased internal contraction ratio necessary to attain the desired pressure-recovery level and hence the larger increases of drag with reduction of Mach number, the initial advantage over the higher cowl-drag configurations is never completely lost.

5.4. *Pressure Recovery of Conical-Centrebody Intakes—a General Analysis of Collected Results.*—A large number of experimental results for the pressure recovery of conical centrebody-intakes at supersonic speeds now exist. These indicate that a wide variation of pressure recovery (particularly at Mach numbers in excess of 2·0) (Fig. 19) can exist for different designs which nominally have the same features as regards external supersonic compression (*i.e.*, for a given cone and lip position angle). As is well known the shock compression efficiency is reflected in the overall contraction ratio, *i.e.*, A_∞/A_i (without internal contraction) or A_∞/A_t (with internal contraction). Now as we have seen in practice internal contraction does not improve the shock pressure recovery at full mass flow by inducing a more efficient oblique shock system inside the intake. Nevertheless the near-linear variation of pressure recovery with internal contraction leads us to suppose that an empirical correlation of the pressure recovery with overall contraction A_∞/A_t could lead to useful results. Similarly, as we have already noted, the effect of the corner when it is positioned in or in front of the entry plane is to increase the centrebody-surface Mach number and hence decrease the compression efficiency. This again is reflected in a smaller overall contraction ratio due to A_i being enlarged. Finally, as we have seen in this present investigation pressure recovery appears to be affected by the cowl undersurface angle and thus it is reasonable to suppose that an empirical correlation of the pressure recovery will be obtained if we plot $(P_f/P_\infty)_{\text{F.M.F.}} \cos \eta_i$ vs. contraction ratio $(A_\infty/A_t)_{\text{F.M.F.}}$. This has been done for a large number of experimental results for cone angles of 22·5, 25 and 30 deg for Mach numbers which give $M_c > 1{\cdot}3$. For cone-surface Mach numbers below $1{\cdot}3$ there is of course no cone-surface boundary-layer breakaway and the pressure-recovery results do not appear to be influenced by cowl undersurface shape and thus the cos η_i factor has been omitted.

The results show (Figs. 20 to 28) a scatter of $\pm 0{\cdot}02$ (in general) and hence should materially assist in the prediction of pressure recovery for all such conical centrebody designs. However, the limitations of this crude method of correlation should be clearly understood. The analysis of losses (other than shock losses) for these conical-centrebody intakes must obviously follow the same pattern as outlined in Ref. 2 for normal-shock side intakes. Thus the component parts are :

(a) *External skin friction*.—This is negligible for all normal conical centrebody-intakes.

(b) *Internal skin friction*.—This is a fairly important component (the main component when there is no boundary-layer breakaway on the cone surface) and is affected by area distribution in the subsonic diffuser (Ref. 4) and by the total perimeter/cross-sectional area (P/A) ratio of the duct. We may also credit the effect of any wakes and subsequent mixing losses due to the termination of the centrebody before the pressure-recovery measuring station to internal skin friction. Thus in the present analysis we have only used results obtained with duct geometries which are similar to those illustrated in Fig. 4. The results of N.A.C.A. TIB/3488 show lower pressure recoveries than generally obtained for similar designs due to having much larger values of P/A and to terminating the centrebody before the measuring station, and have therefore been omitted. The variations due to duct area variations are not, of course, covered by this correlation.

(c) *Mixing losses due to Cone-Surface Boundary-Layer Breakaway*.—This becomes the major component as cone-surface Mach number increases above $1{\cdot}3$ and is obviously affected by this, by position ratio (*i.e.*, surface area in front of duct entry plane/duct entry area, S/A_i), by the area distribution and by the rapidity of flow turning at the beginning of the duct. The cone-surface Mach number is a function of the supersonic compression ratio A_∞/A_i and hence its effect is partly taken into account by the method of plotting (only partly, because it is obviously possible, with internal contraction, to have the same contraction ratio A_∞/A_t with different cone angles and hence different cone-surface Mach numbers). It is assumed that the changes in position ratio for the lip position and cone angles considered are so small as not to materially affect these losses. Thus the correlation endeavours to describe the subsonic diffuser area variations and the conditions of flow turning by the use of the two parameters A_t/A_i and the initial inclination of the cowl undersurface. As we have seen in this present Report (Figs. 9 to 11) decreasing the initial rate of diffusion can result in increases in pressure recovery of $0{\cdot}02$ to $0{\cdot}03$. Obviously this effect will become more important as internal contraction ratio decreases and is illustrated in Figs. 24 and 26. Unfortunately not enough data exist to make any systematic empirical correction. Mean values of $d(A/A_i)/d(x/r_{en})$ have been quoted at an arbitrary distance x/r_{en} of $1{\cdot}0$ from the throat to illustrate the order of the effect. Thus we see that the subsonic diffuser area variation downstream of the throat can have a quite large effect particularly if the amount of internal contraction is small. Further systematic tests are necessary to finally elucidate this point.

To sum up, when applying these graphs to any particular conical-centrebody design it should be remembered :

(1) They only apply when the second shock is attached (at the cowl lip) hence they cannot be used if the internal contraction ratio is above the maximum allowable.

(2) Although area distribution and cowl undersurface angle effects only become appreciable at cone-surface Mach numbers in excess of $1{\cdot}3$, this transition is obviously not instantaneous at $M_c = 1{\cdot}3$.

(3) For $M_c > 1 \cdot 3$ a rough estimate of the effect of area distribution can be made by increasing the recommended pressure-recovery values by $0 \cdot 03$ for no internal contraction and by $0 \cdot 01$ for maximum internal contraction to account for a long constant- or nearly constant-area portion downstream of the minimum-area section.

(4) The $\cos \eta_i$ factor should only be strictly applied up to $\eta_i = 15$ to 20 deg and care should be taken to see that it gives values which are sensible (*i.e.*, that are below the shock pressure recovery, as given on the graph) when applied to the maximum allowable contraction-ratio case. Experimental results indicate that the shock pressure-recovery values can be very closely approached which probably indicates the assumption that the second shock is normal to the cone flow is erroneous.

(5) The results do not apply when the cone shock falls appreciably within the cowl lip.

6. *Conclusions.*—For a $\theta_c = 25$ deg, $M_{w1} = 2 \cdot 46$ conical-centrebody intake at a free-stream Mach number of $2 \cdot 48$:

(1) Pressure recovery increases (approximately linearly) with increase in duct internal contraction ratio.

(2) For a given value of internal contraction ratio, pressure recovery increases (approximately linearly) with increase in initial internal angle of the cowl.

(3) The effect of changing the subsonic diffuser area variation from an approximately linear distribution to one which diffuses more slowly where the flow velocity is high and more quickly where the velocity is low, is to increase the overall pressure recovery by $0 \cdot 02$ to $0 \cdot 03$.

(4) A calculation of drag variation (at full mass flow) with Mach number and internal contraction ratio shows that notwithstanding the greater contraction ratio required by small angle (low drag) cowls to attain a certain pressure-recovery level at $M = 2 \cdot 48$, their drags at lower Mach numbers are, in general, the lowest obtained.

(5) An empirical correlation of pressure recovery with contraction ratio and initial angle of the cowl undersurface yields results which should aid in the prediction of pressure recovery at full mass flow for most conical-centrebody intake designs.

LIST OF SYMBOLS

A	Cross-sectional area (sq in.)
$C_{D_{\mathrm{ext}_0}}$	External drag coefficient at full mass flow
L	Overall length from duct entry to measuring section (in.)
M	Mach number
P	Total pressure
r	Radius (in.)
S	Surface area (sq in.)
x	Axial length (in.)
θ	Angle to horizontal of a line passing through the cone vortex
η	Angle to horizontal of cowl undersurface
$(\ )_c$	At the cone surface
$(\ )_f$	At the measuring section
$(\ )_i$	At the duct inlet
$(\ )_l$	At the cowl lip
$(\ )_t$	At the duct minimum-area section
$(\ )_w$	At the cone shock wave
$(\ )_\infty$	In the free stream
$(\ )_{en}$	At the duct entry
$(\ )_{\mathrm{F.M.F.}}$	At full mass flow
$(\ )_{\max}$	Maximum value

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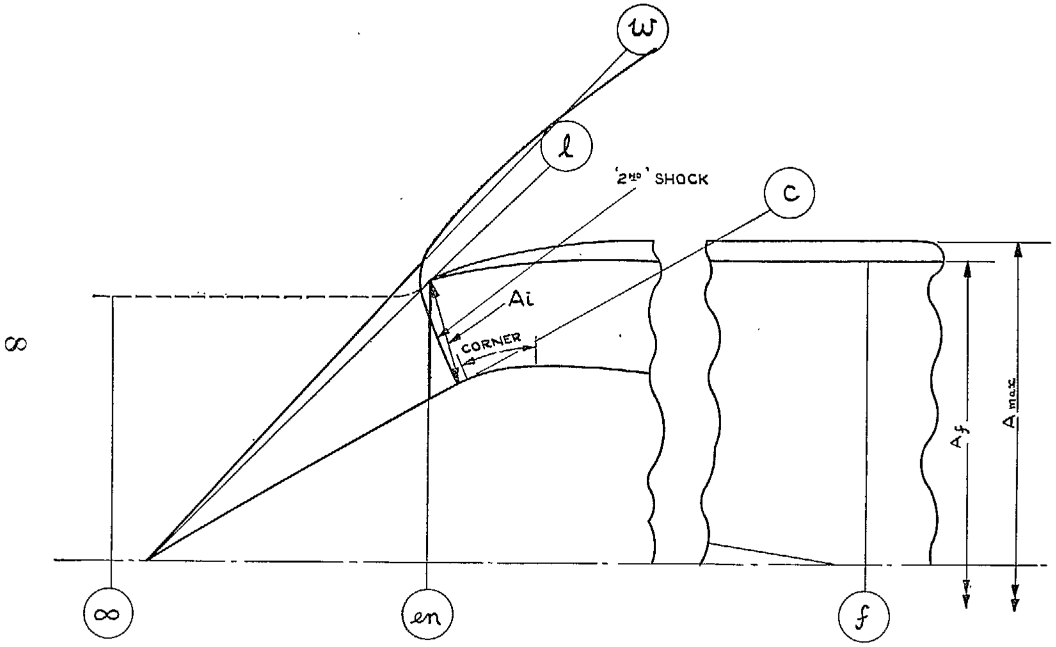
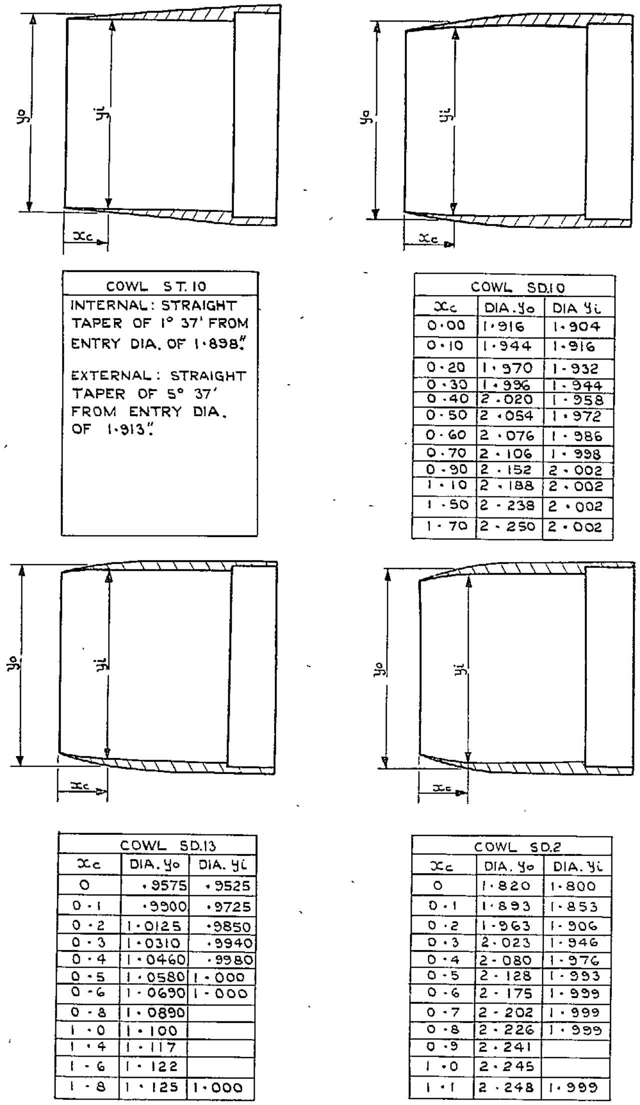


FIG. 1. Suffix notation.



COWL ST. 10
INTERNAL: STRAIGHT TAPER OF 1° 37' FROM ENTRY DIA. OF 1·898".
EXTERNAL: STRAIGHT TAPER OF 5° 37' FROM ENTRY DIA. OF 1·913".

COWL SD.10

x_c	DIA. y_o	DIA y_i
0·00	1·916	1·904
0·10	1·944	1·916
0·20	1·970	1·932
0·30	1·996	1·944
0·40	2·020	1·958
0·50	2·054	1·972
0·60	2·076	1·986
0·70	2·106	1·998
0·90	2·152	2·002
1·10	2·188	2·002
1·50	2·238	2·002
1·70	2·250	2·002

COWL SD.13

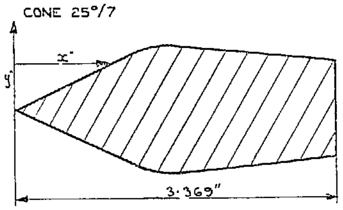
x_c	DIA. y_o	DIA. y_i
0	·9575	·9525
0·1	·9900	·9725
0·2	1·0125	·9850
0·3	1·0310	·9940
0·4	1·0460	·9980
0·5	1·0580	1·000
0·6	1·0690	1·000
0·8	1·0890	
1·0	1·100	
1·4	1·117	
1·6	1·122	
1·8	1·125	1·000

COWL SD.2

x_c	DIA. y_o	DIA. y_i
0	1·820	1·800
0·1	1·893	1·853
0·2	1·963	1·906
0·3	2·023	1·946
0·4	2·080	1·976
0·5	2·128	1·993
0·6	2·175	1·999
0·7	2·202	1·999
0·8	2·226	1·999
0·9	2·241	
1·0	2·245	
1·1	2·248	1·999

FIG. 2. Cowl dimensions.

CONE 25°/7



x	y	x	y
0	0	1·60	0·680
25° TAPER TO		1·65	0·678
1·00	0·466	1·70	0·676
1·20	0·560	1·75	0·672
1·30	0·607	STRAIGHT TAPER	
1·40	0·650	3·369	0·506
1·45	0·664		
1·50	0·673		
1·55	0·678		

CONE 25°/3

x	y	x	y
0	0	1·55	0·628
25° TAPER TO		1·60	0·627
1·00	0·466	1·65	0·624
1·10	0·513	STRAIGHT	
1·20	0·557	TAPER TO	
1·30	0·597	3·369	0·506
1·40	0·618		
1·45	0·624		
1·50	0·627		

CONE 25°/4

x	y	x	y
0	0	1·55	0·657
25° TAPER TO		1·60	0·660
1·00	0·466	1·65	0·662
1·10	0·514	1·70	0·662
1·20	0·558	1·75	0·660
1·30	0·599	1·80	0·658
1·40	0·633	1·85	0·654
1·45	0·646	STRAIGHT TAPER	
1·50	0·653	3·369	0·506

CONE 25°/6

x	y	x	y
0	0	1·55	0·637
25° TAPER TO		1·60	0·635
1·00	0·466	STRAIGHT	
1·20	0·555	TAPER TO	
1·30	0·595	3·369	0·506
1·35	0·617		
1·40	0·630		
1·45	0·637		
1·50	0·640		

CONE 25°/9

x	y	x	y
0	0	1·55	0·645
25° TAPER TO		1·60	0·646
1·00	0·466	1·65	0·645
1·20	0·560	1·70	0·641
1·30	0·607	1·75	0·638
1·35	0·627	1·80	0·635
1·40	0·637	1·90	0·631
1·45	0·640	STRAIGHT TAPER	
1·50	0·642	3·369	0·508

CONE 25°/10

x	y	x	y
0	0	1·65	0·710
25° TAPER TO		1·70	0·709
1·00	0·466	1·75	0·706
1·20	0·559	1·80	0·702
1·30	0·605	1·90	0·692
1·40	0·650	STRAIGHT	
1·50	0·691	TAPER TO	
1·55	0·703	3·369	0·512
1·60	0·709		

CONE 25°/11

x	y	x	y
0	0	1·60	0·662
25° TAPER TO		1·65	0·658
1·00	0·466	1·70	0·656
1·20	0·559	1·75	0·652
1·30	0·605	1·80	0·648
1·40	0·650	STRAIGHT	
1·45	0·660	TAPER TO	
1·50	0·660	3·369	0·509
1·55	0·661		

CONE 25°/12

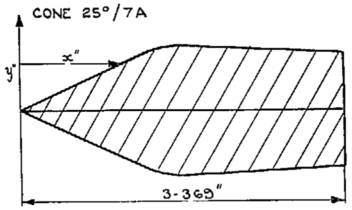
x	y	x	y
0	0	1·70	0·717
25° TAPER TO		1·75	0·712
1·00	0·466	1·80	0·708
1·20	0·559	1·90	0·697
1·30	0·605	2·00	0·685
1·40	0·649	2·25	0·654
1·50	0·699	2·50	0·623
1·60	0·719	3·00	0·561
1·65	0·718	3·360	0·514

CONE 25°/14

x	y	x	y
0	0	1·80	0·754
25° TAPER TO		1·85	0·749
1·40	0·651	1·90	0·744
1·50	0·698	STRAIGHT	
1·55	0·720	TAPER TO	
1·60	0·7379	3·369	0·6100
1·65	0·752		
1·70	0·758		
1·70	0·7585		

FIG. 3a. Centrebody dimensions.

CONE 25°/7A



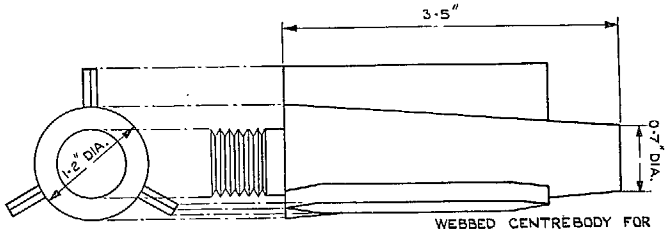
x	y	x	y
0	0	1·60	0·680
25° TAPER TO		1·70	0·680
1·00	0·466	1·180	0·679
1·20	0·560	1·190	0·678
1·30	0·607	2·00	0·676
1·40	0·650	2·50	0·658
1·45	0·664	3·00	0·632
1·50	0·673	3·369	0·606
1·55	0·678		

CONE 25°/10A

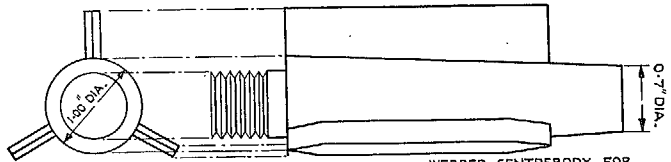
x	y	x	y
0	0	1·65	0·710
25° TAPER TO		1·70	0·711
1·00	0·466	1·80	0·711
1·20	0·560	1·90	0·710
1·30	0·607	2·00	0·709
1·40	0·650	2·50	0·688
1·50	0·691	3·00	0·652
1·55	0·703	3·369	0·613
1·60	0·709		

CONE 25°/11A

x	y	x	y
0	0	1·70	0·660
25° TAPER TO		1·80	0·660
1·00	0·466	1·90	0·659
1·20	0·560	2·00	0·657
1·30	0·607	2·50	0·643
1·40	0·650	3·00	0·624
1·45	0·658	3·369	0·606
1·50	0·660		
1·60	0·660		



WEBBED CENTREBODY FOR
'A' CONICAL BODIES & 25°/14



WEBBED CENTREBODY FOR
ALL OTHER CONICAL BODIES.

FIG. 3b. Centrebody dimensions.

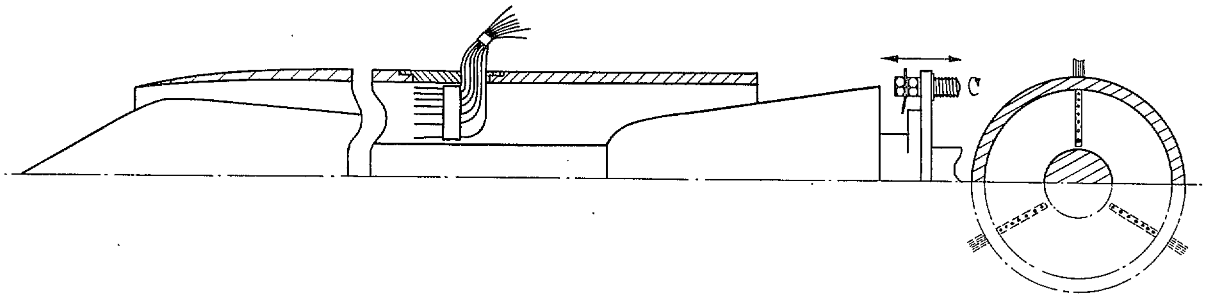


FIG. 4. Pressure-recovery measuring rig.

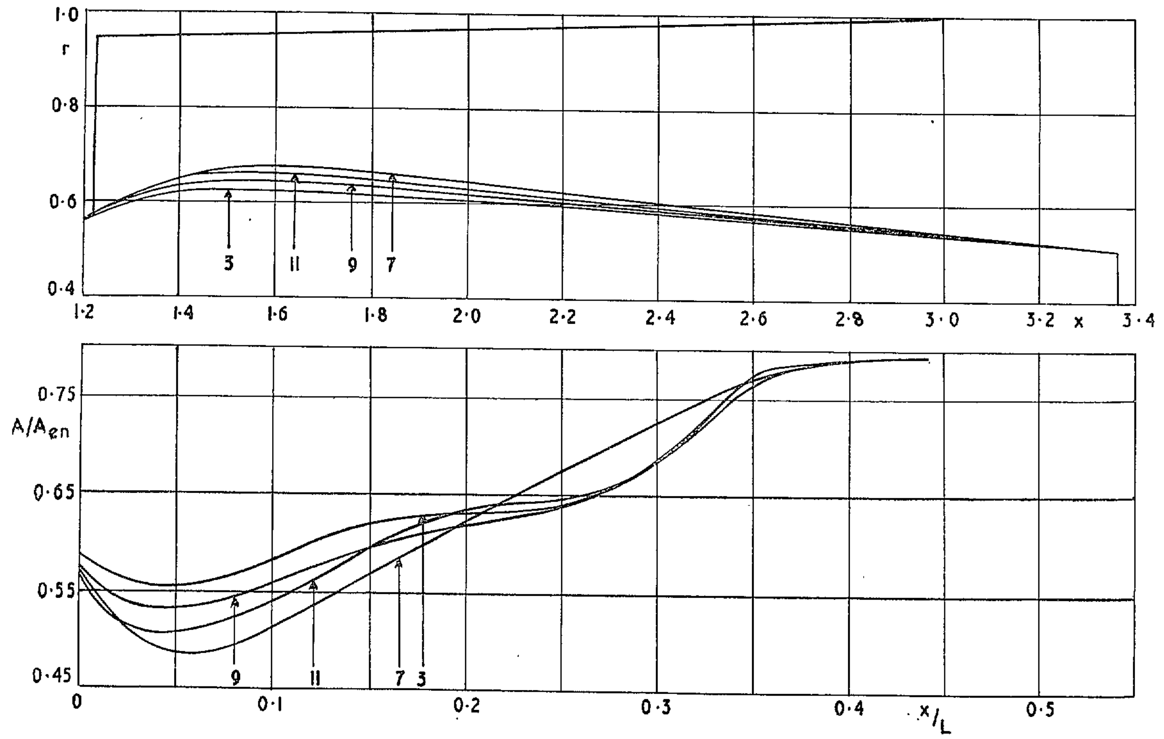


FIG. 5a. Contours of centrebodies 3, 7, 9, 11 and duct area distributions with cowl ST.10.

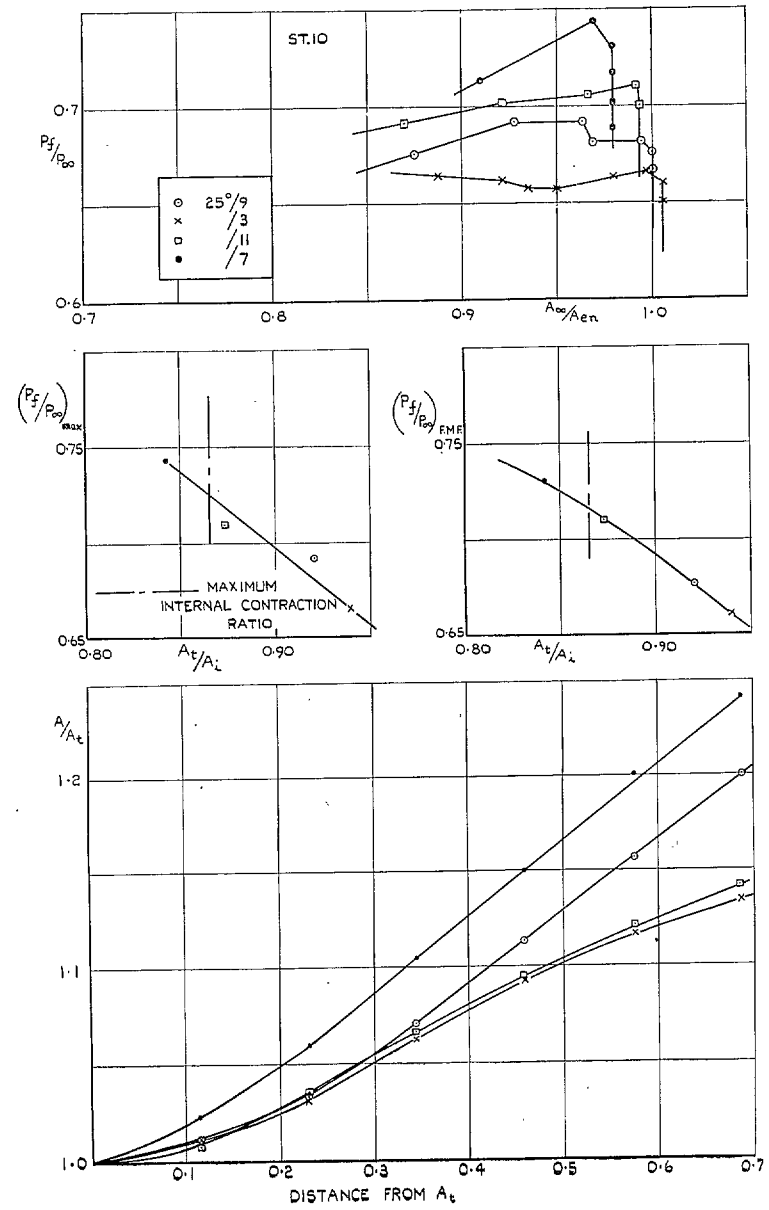


FIG. 5b. Variation of pressure recovery with internal contraction (centrebodies 3, 7, 9 and 11, cowl ST.10).

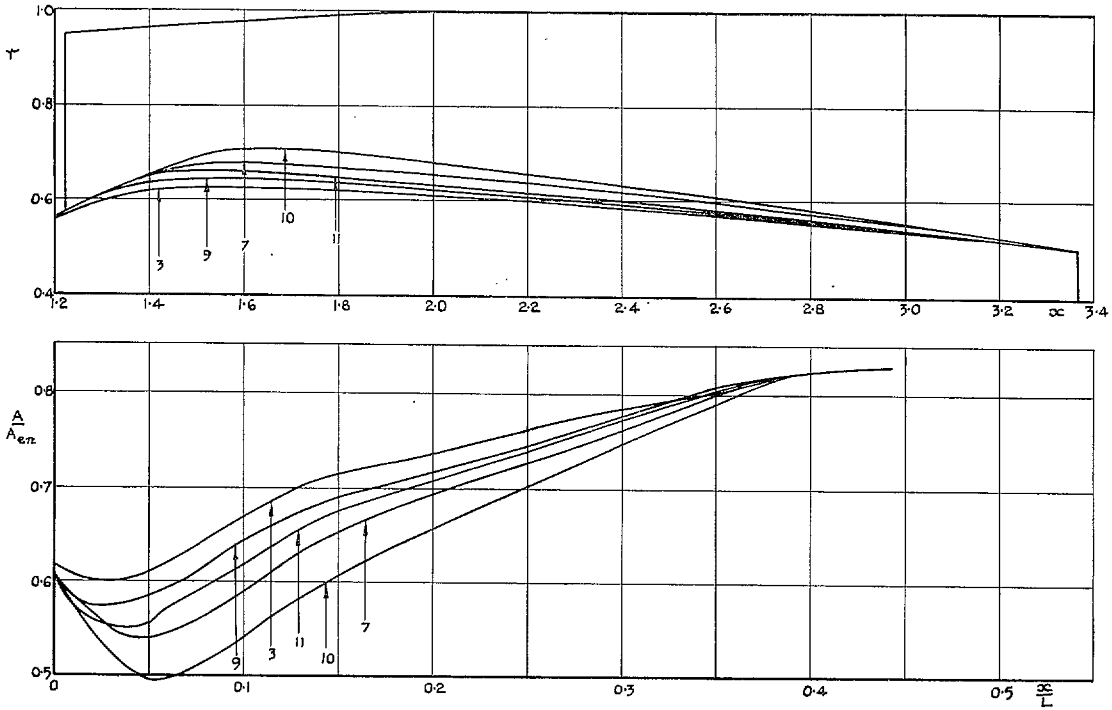


FIG. 6a. Contours of centrebodies 3, 7, 9, 10, 11 and duct area distributions with cowl SD.10.

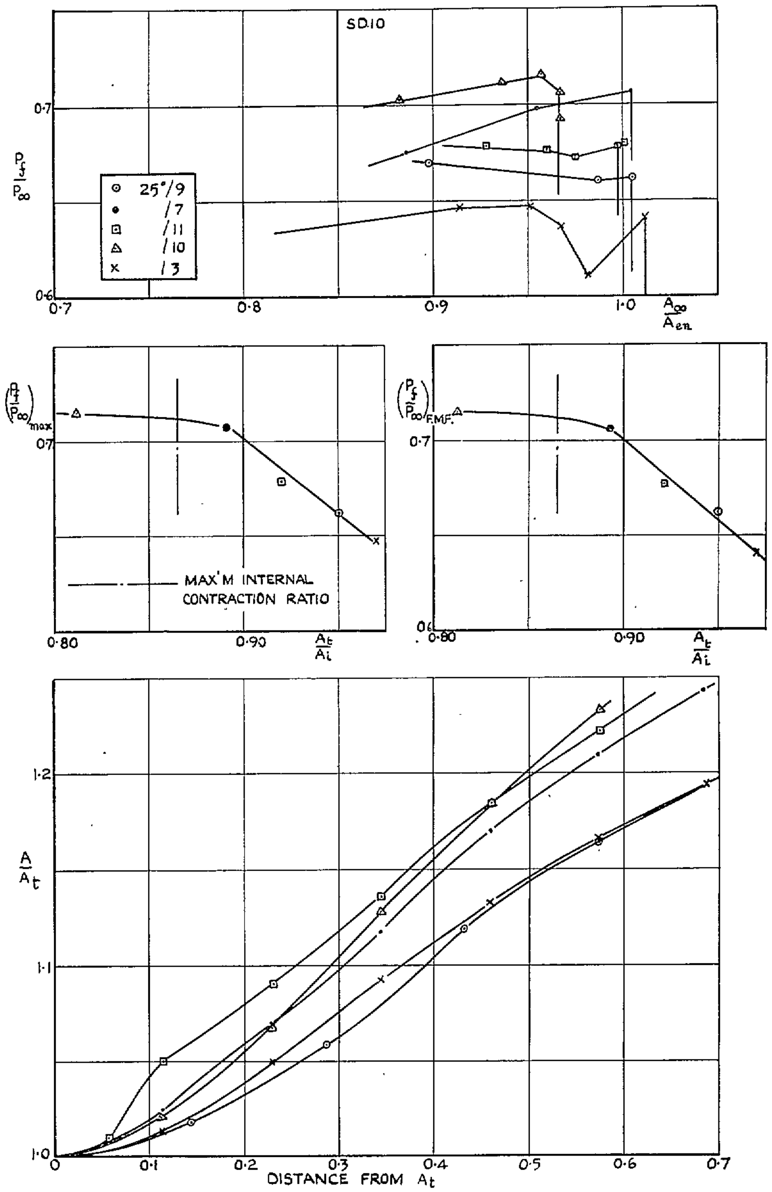


FIG. 6b. Variation of pressure recovery with internal contraction (centrebodies 3, 7, 9, 10 and 11, cowl SD.10).

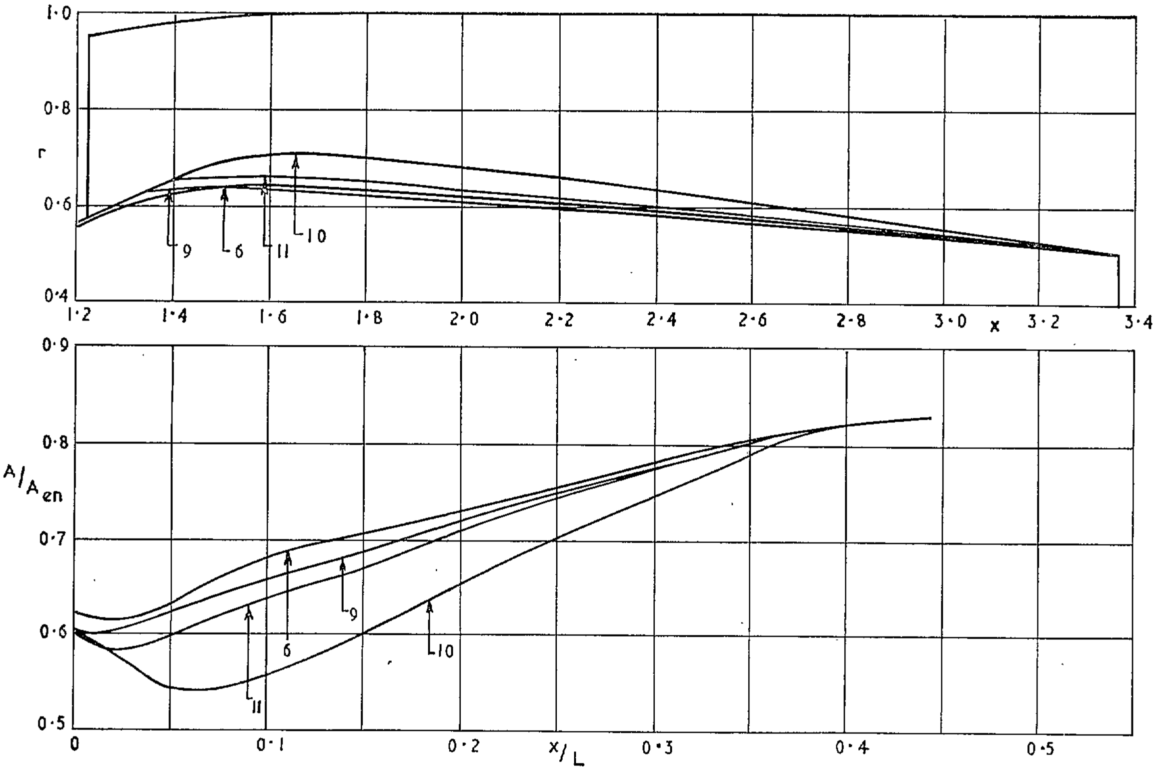


FIG. 7a. Contours of centrebodies 6, 9, 10, 11, 12 and duct area distributions with cowl SD.13.

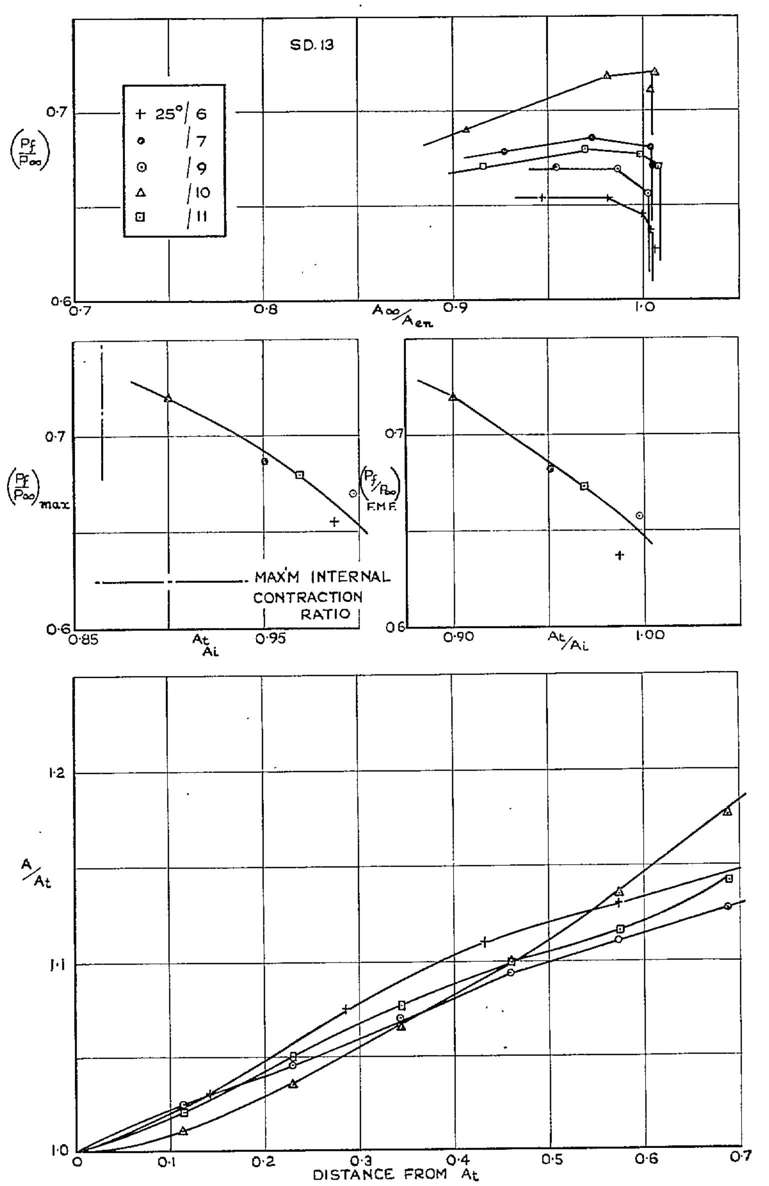


FIG. 7b. Variation of pressure recovery with internal contraction (centrebodies 6, 7, 9, 10 and 11, cowl SD.13).

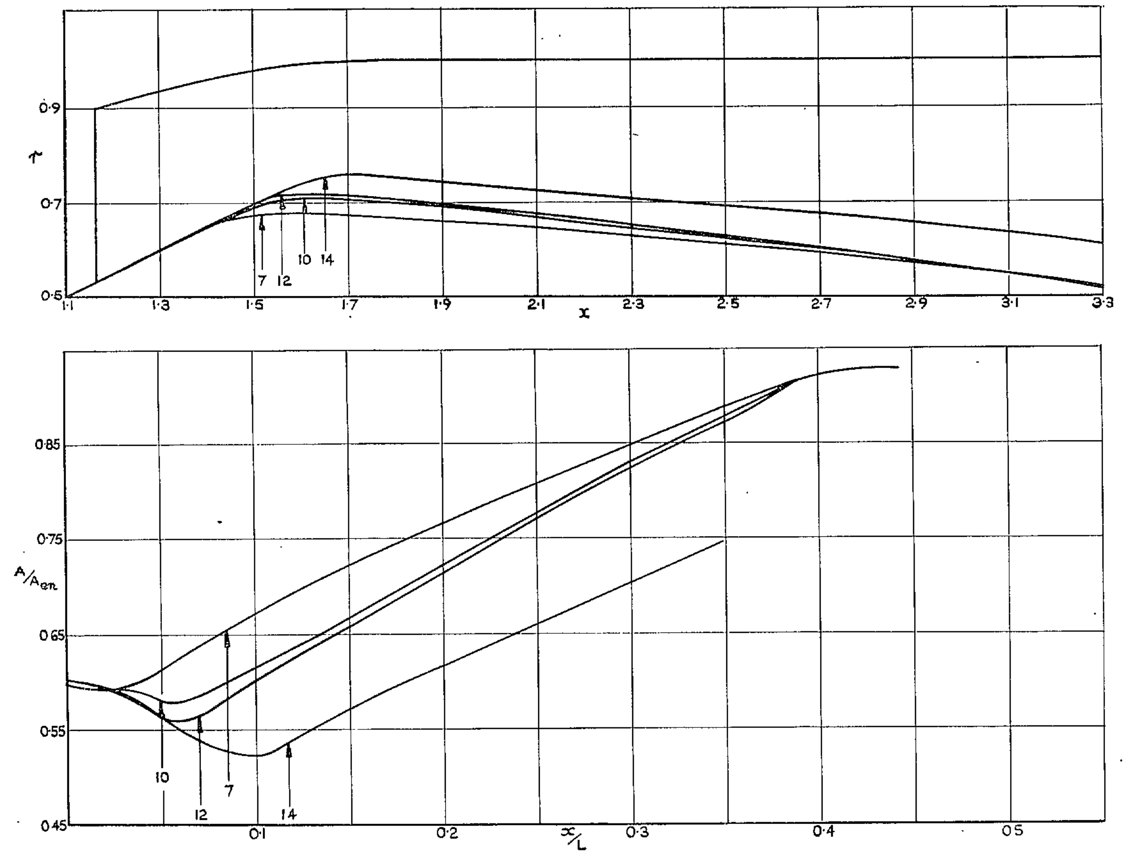


FIG. 8a. Contours of centrebodies 7, 10, 12, 14, and duct area distributions with cowl SD.2.

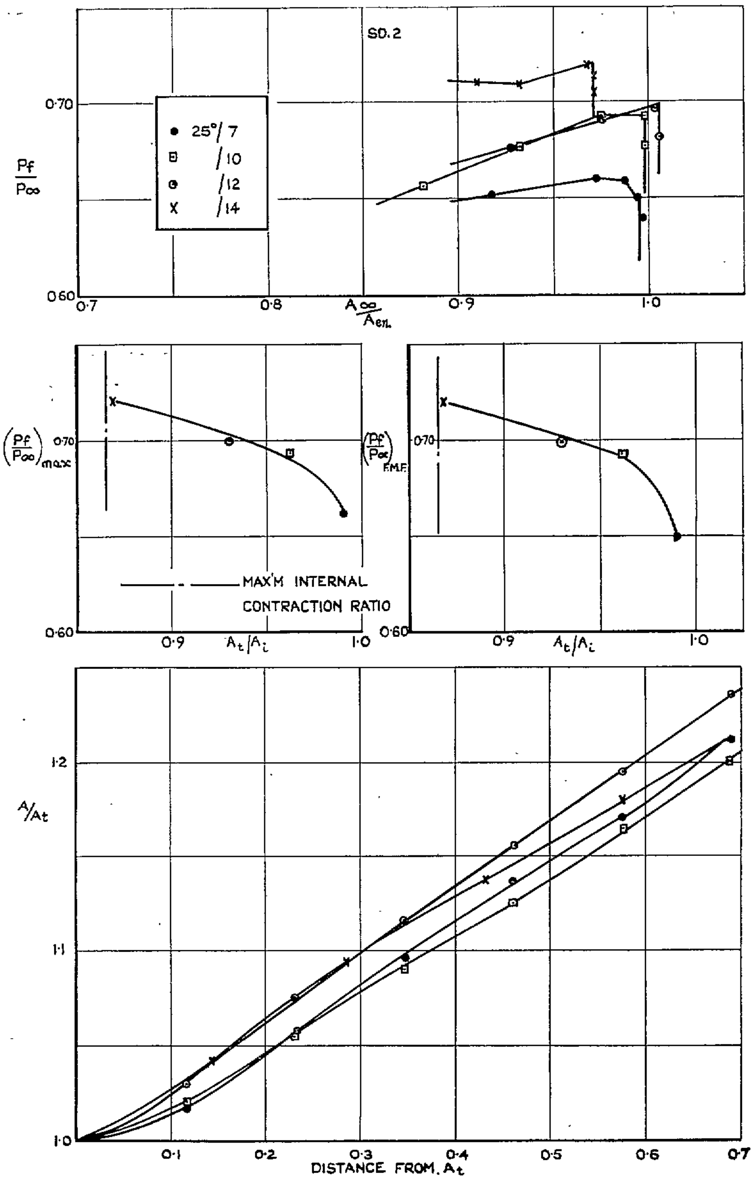


FIG. 8b. Variation of pressure recovery with internal contraction (centrebodies 7, 10, 12, 14, cowl SD.2).

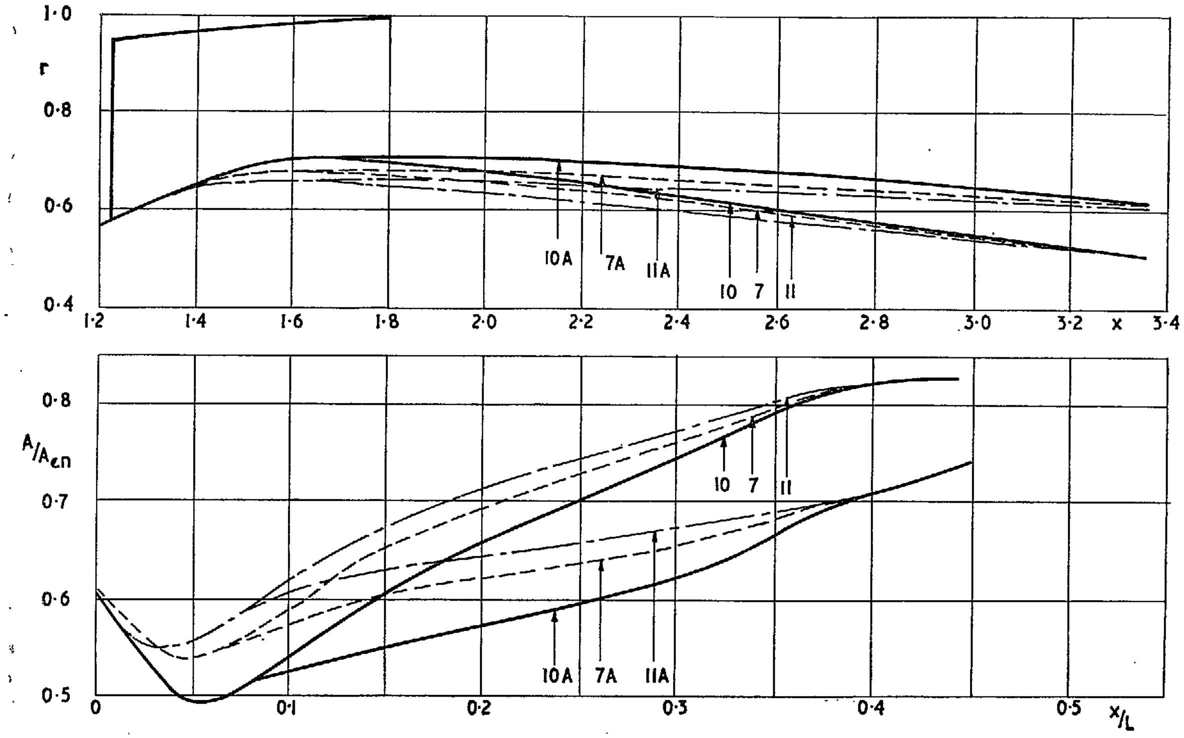


FIG. 9a. Contours of centrebodies 7, 7a, 10, 10a, 11, 11a and duct area distributions with cowl SD.10.

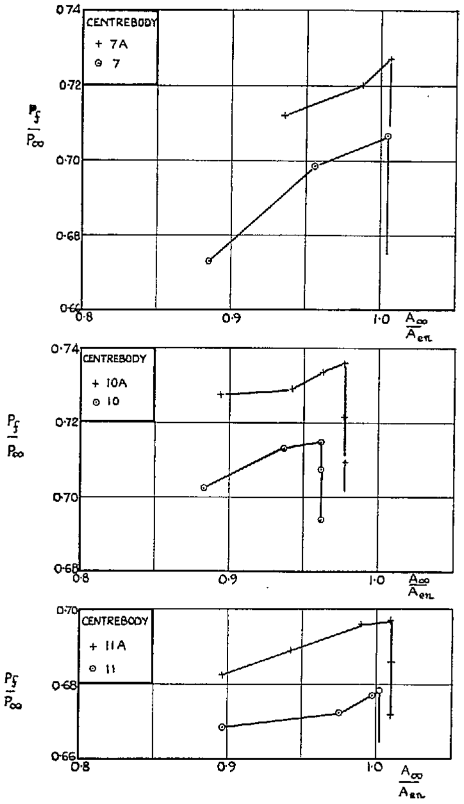


FIG. 9b. Effect on pressure recovery of slowly diverging subsonic diffuser (SD.10 cowl).

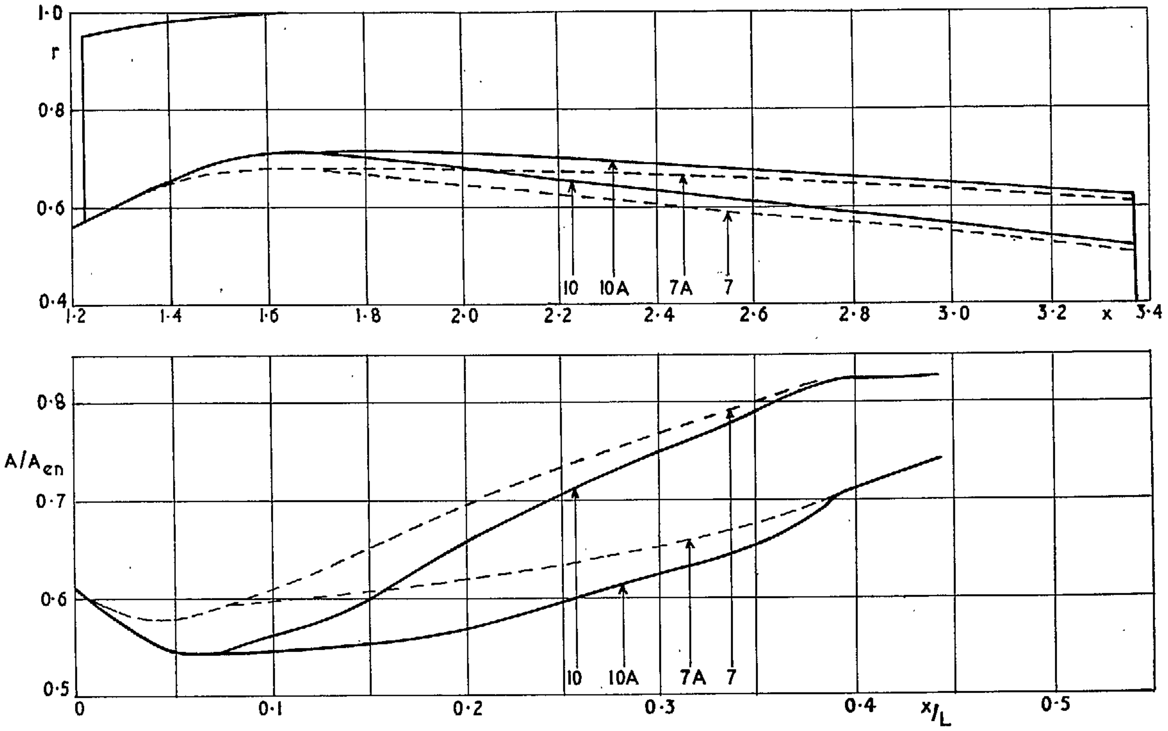


FIG. 10a. Contours of centrebodies 7, 7a, 10, 10a and duct area distributions with cowl SD.13.

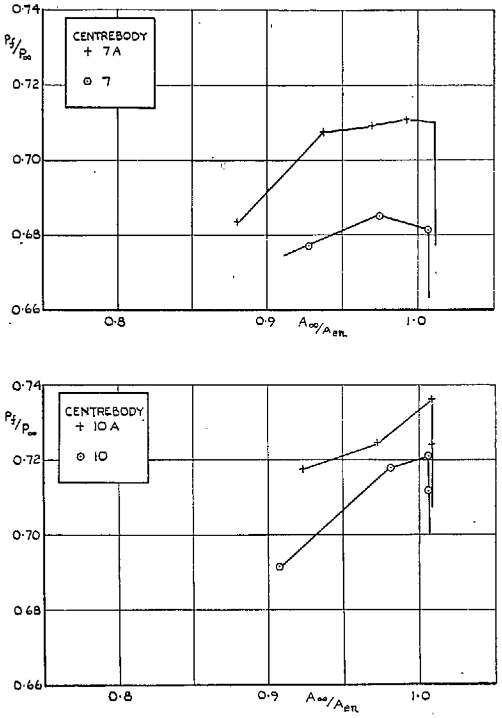


FIG. 10b. Effect on pressure recovery of slowly diverging subsonic diffuser (SD.13 cowl).

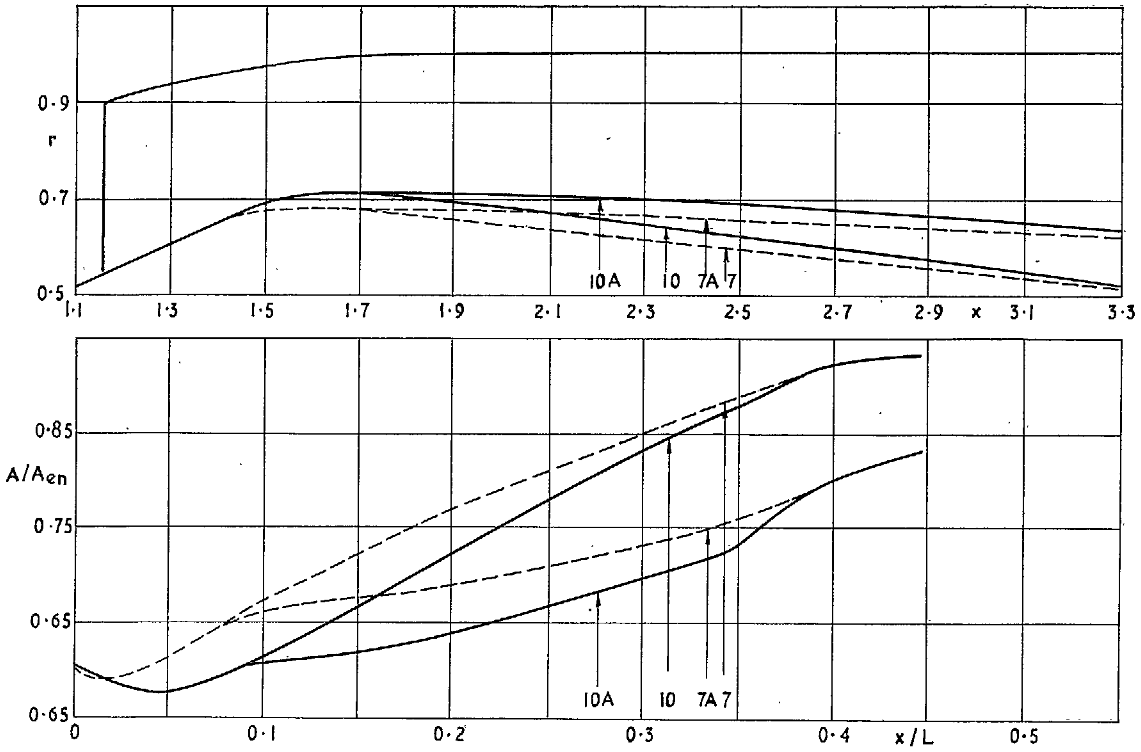


FIG. 11a. Contours of centrebodies 7, 7a, 10, 10a and duct area distributions with cowl SD.2.

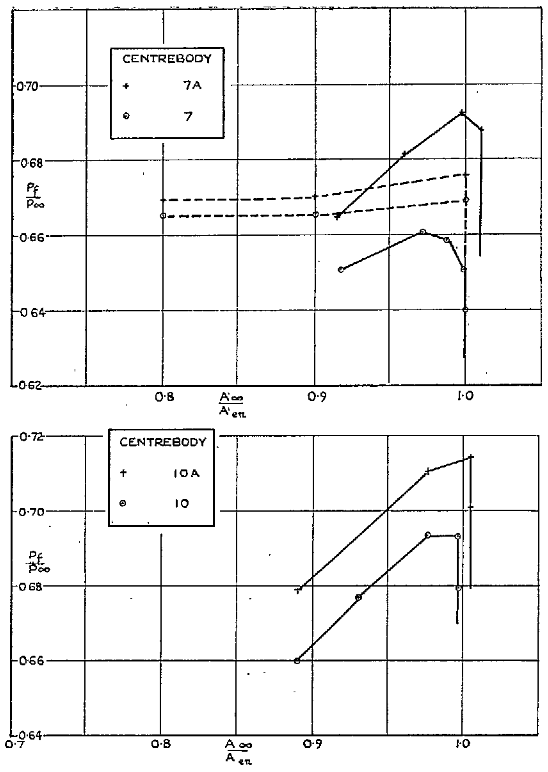


FIG. 11b. Effect on pressure recovery of slowly diverging subsonic diffuser (SD.2 cowl).

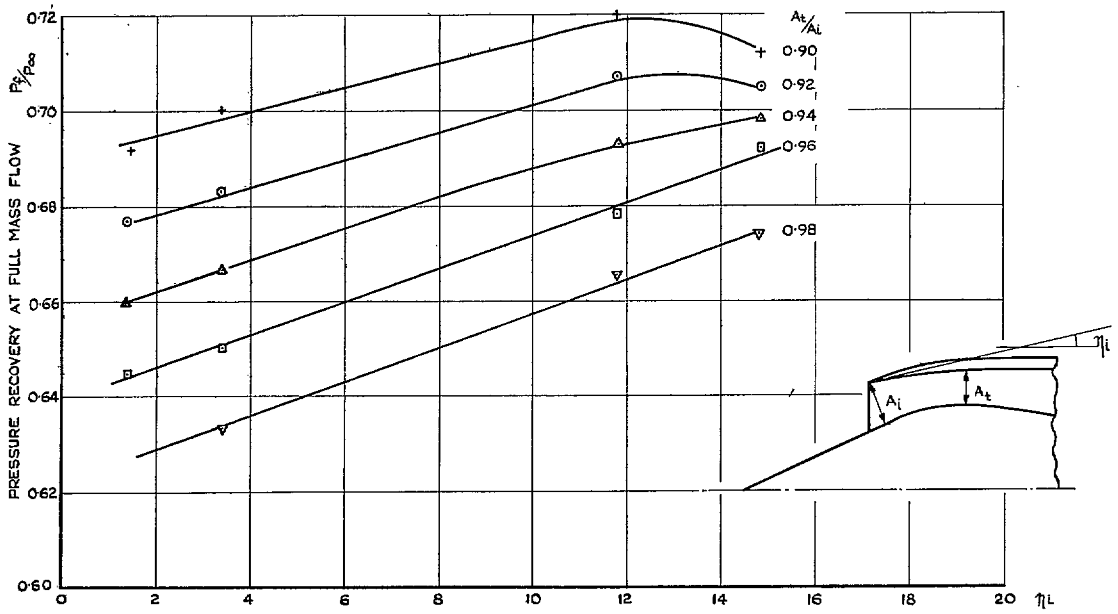


FIG. 12. Variation of pressure recovery (at full mass flow) with initial internal cowl angle for a range of internal contraction ratios.

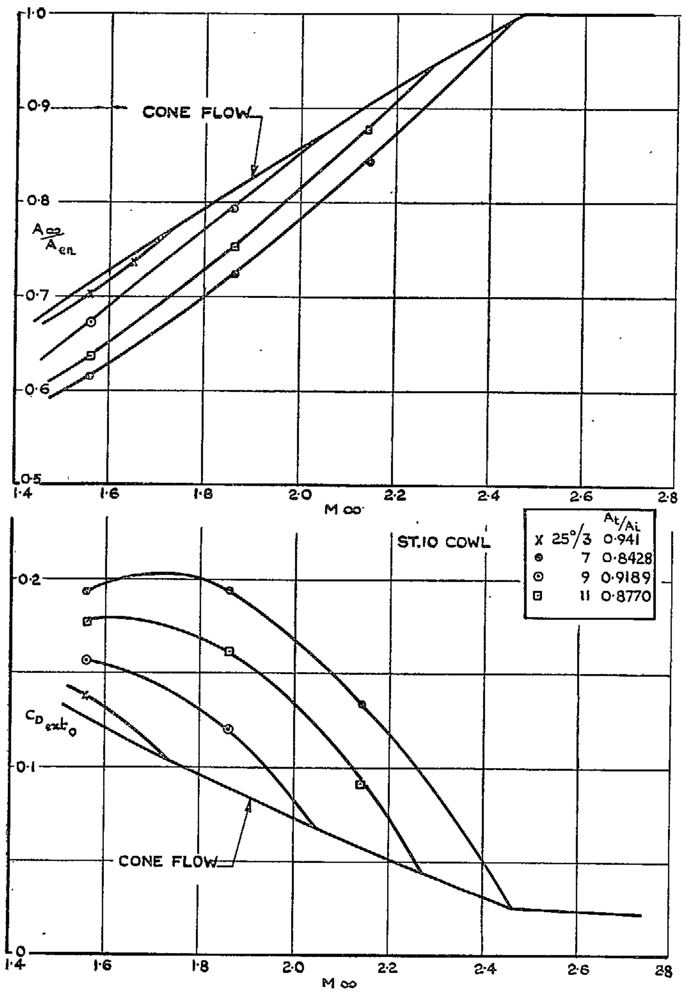


FIG. 13. Variation of drag (at full mass flow) with Mach number (ST.10 cowl, centrebodies 3, 7, 9 and 11).

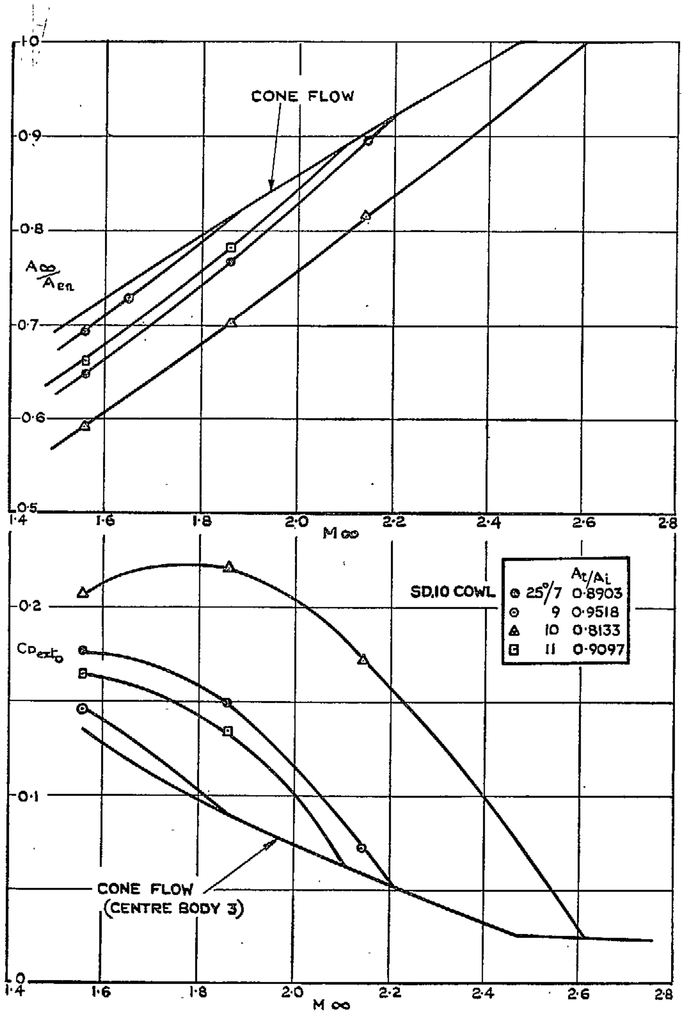


FIG. 14. Variation of drag (at full mass flow) with Mach number (SD.10 cowl, centrebodies 7, 9, 10 and 11).

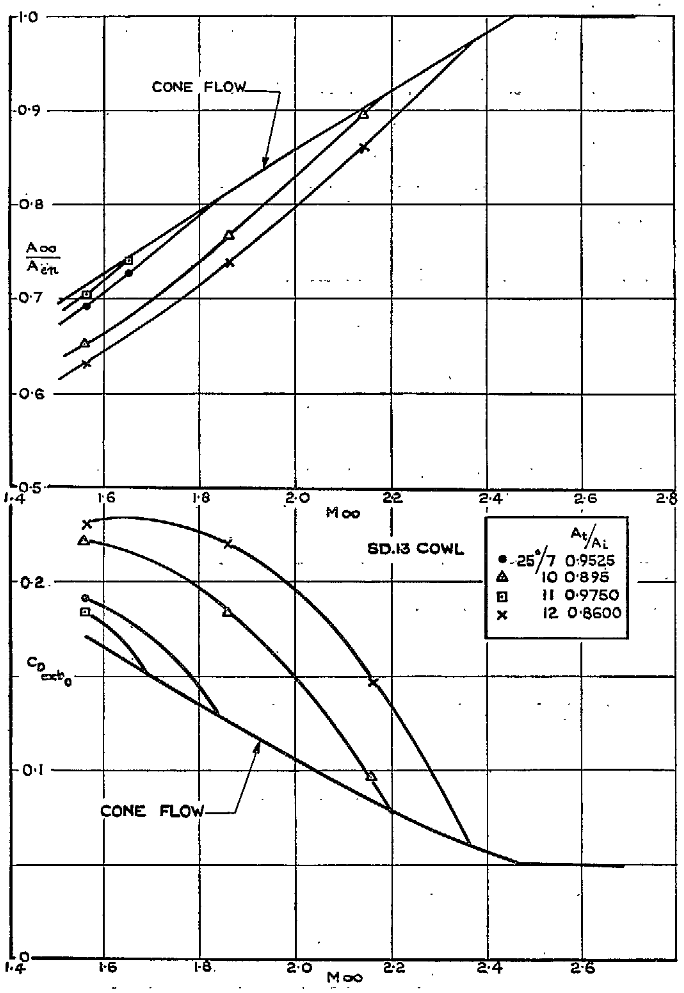


FIG. 15. Variation of drag (at full mass flow) with Mach number (SD.13 cowl, centrebodies 7, 10, 11 and 12).

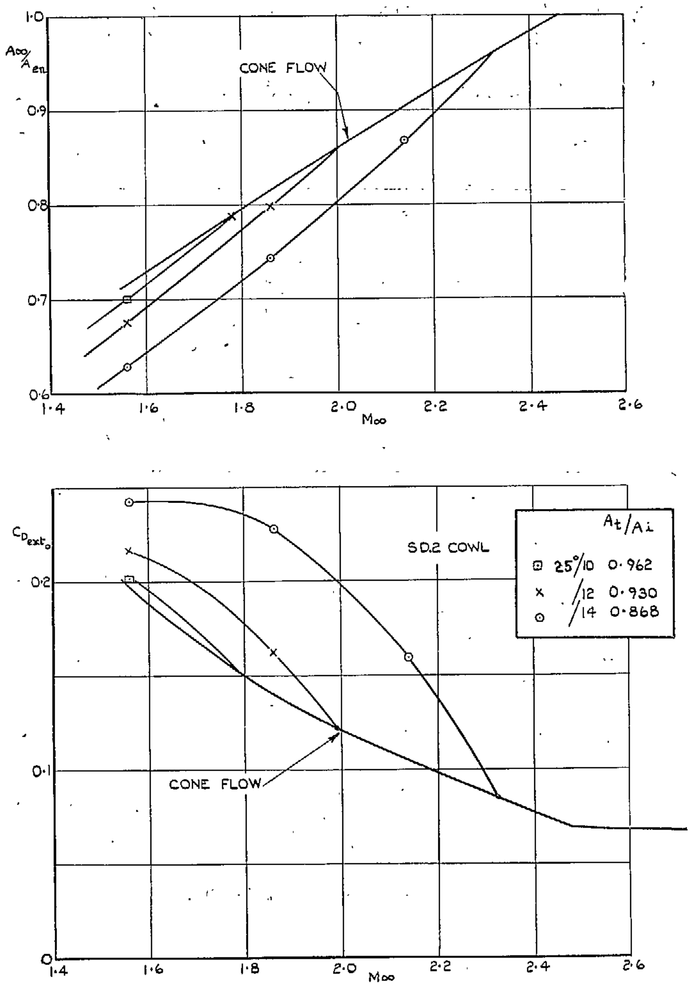


FIG. 16. Variation of drag (at full mass flow) with Mach number (SD.2 cowl, centrebodies 7, 10, 12 and 14).

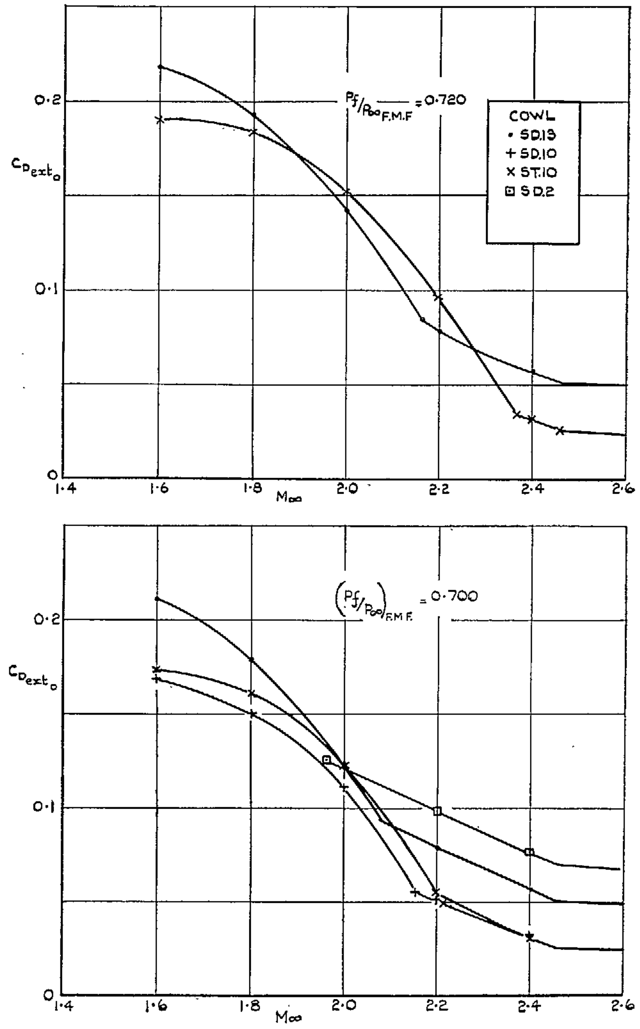


FIG. 17. Variation of drag (at full mass flow) for pressure recoveries of 0·72 and 0·70 at $M_\infty = 2{\cdot}48$.

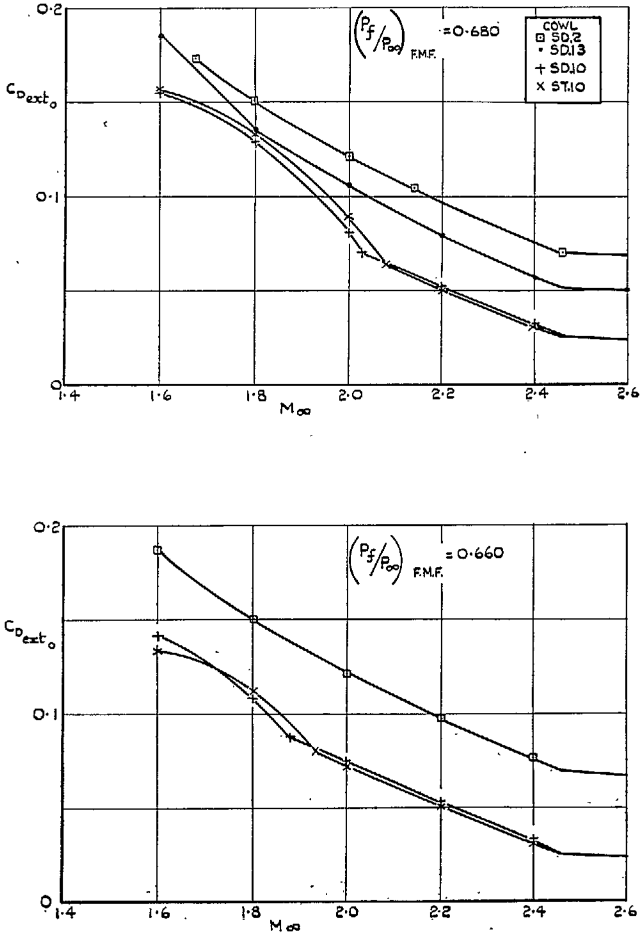


FIG. 18. Variation of drag (at full mass flow) for pressure recoveries of 0·68 and 0·66 at $M_\infty = 2{\cdot}48$.

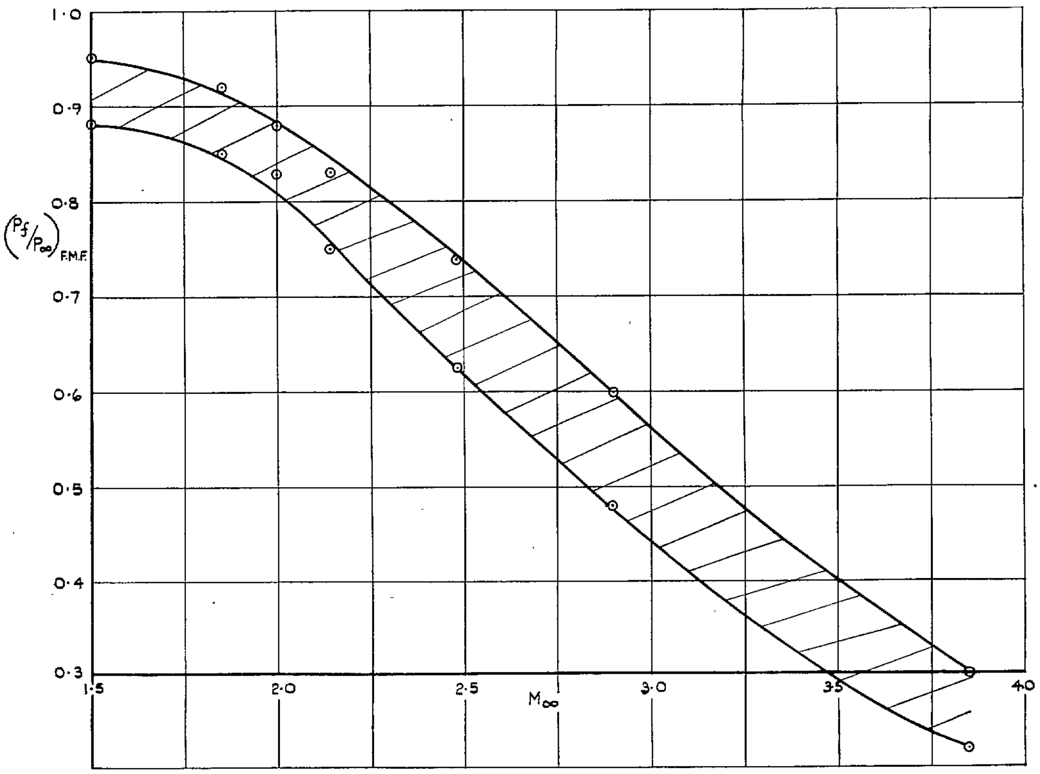


FIG. 19. Pressure recovery (at full mass flow) vs. Mach number—range of published values.

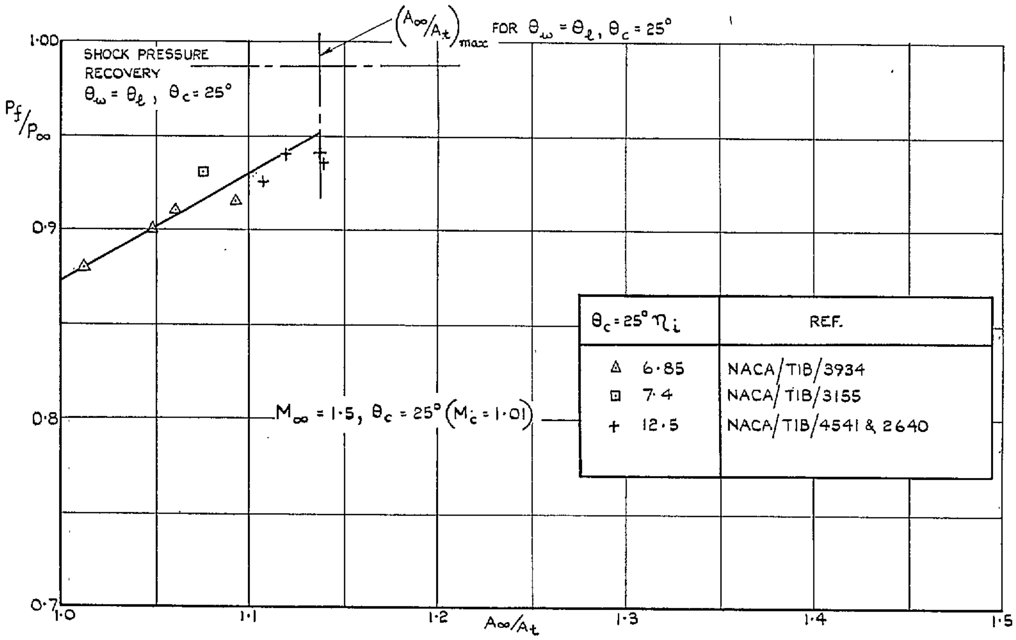


FIG. 20. Pressure recovery/contraction ratio correlation, $M_\infty = 1·50$.

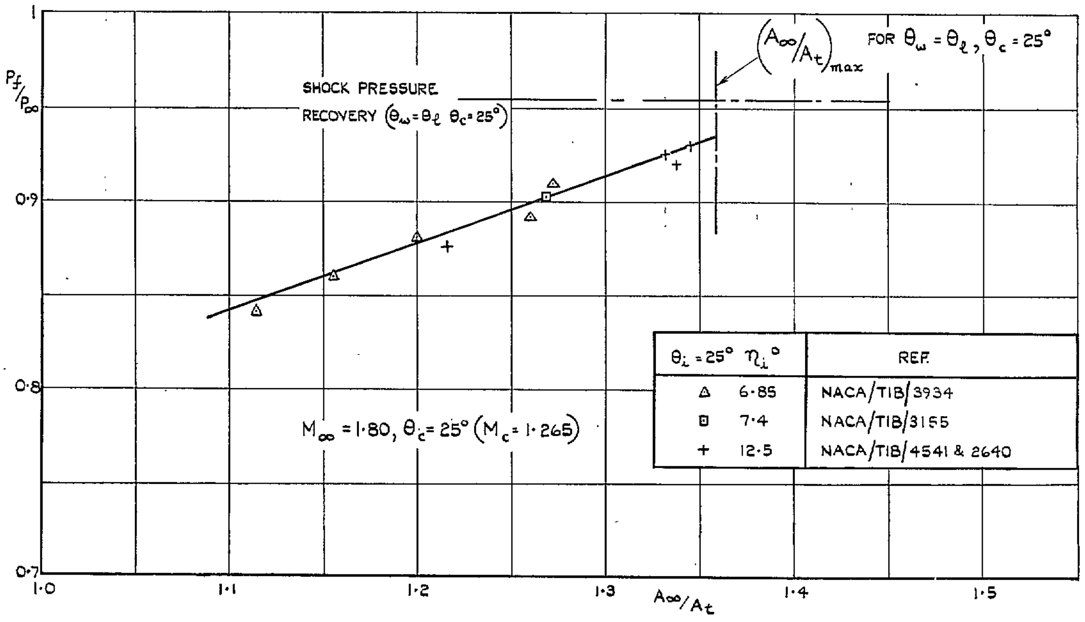


FIG. 21. Pressure recovery/contraction ratio correlation, $M_\infty = 1·80$.

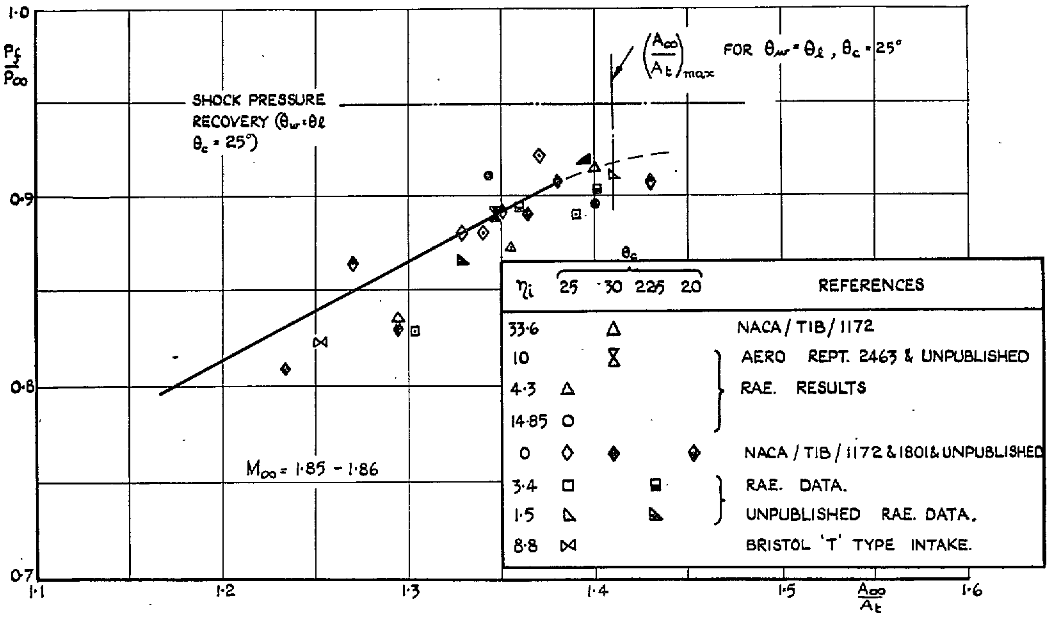


FIG. 22. Pressure recovery/contraction ratio correlation, $M_\infty = 1·85–1·86$.

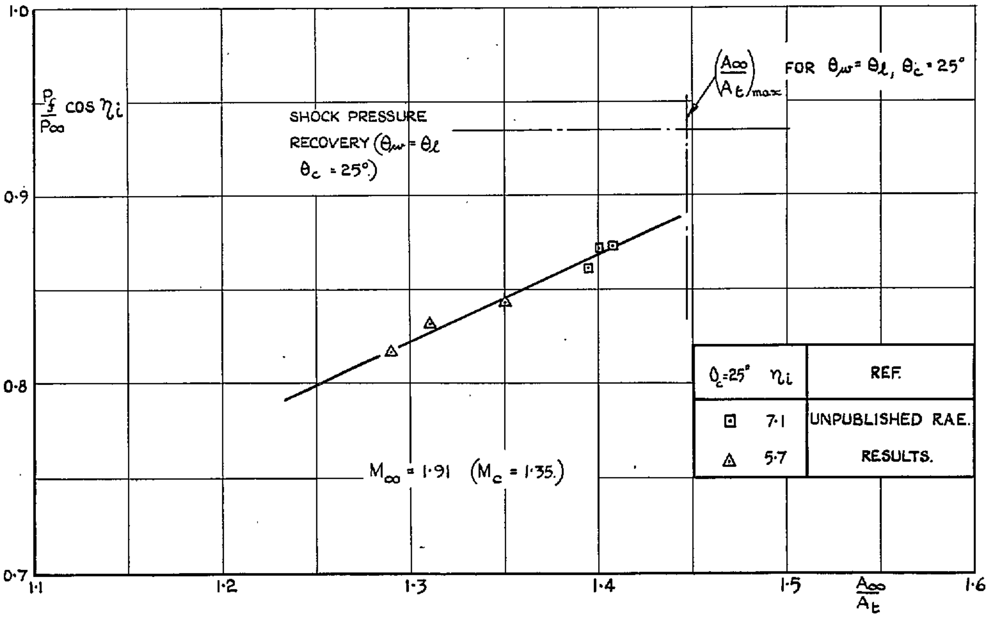


FIG. 23. Pressure recovery/contraction ratio correlation, $M_\infty = 1·91$.

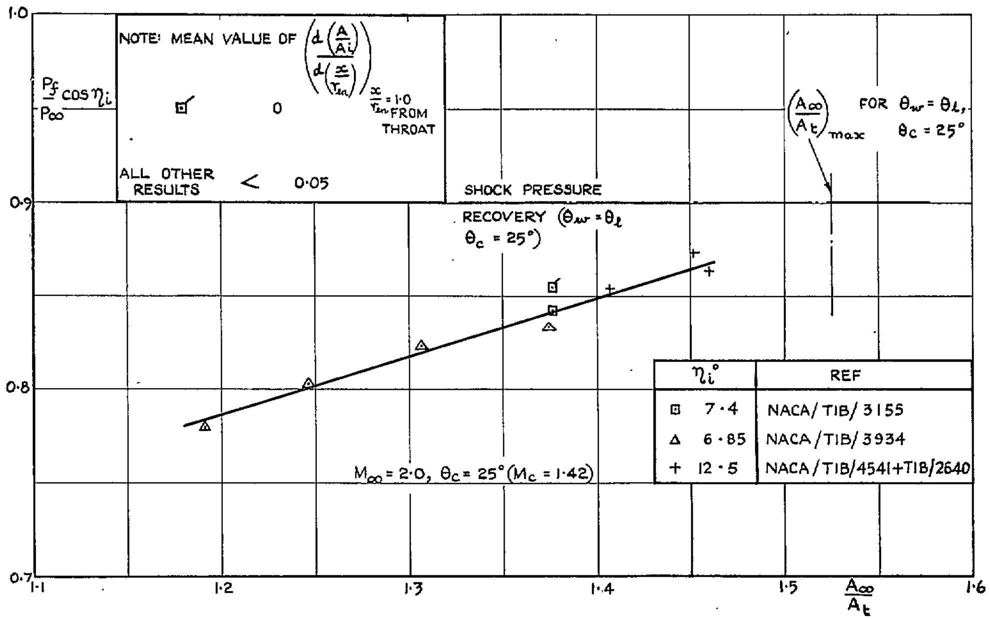


FIG. 24. Pressure recovery/contraction ratio correlation, $M_\infty = 2·0$.

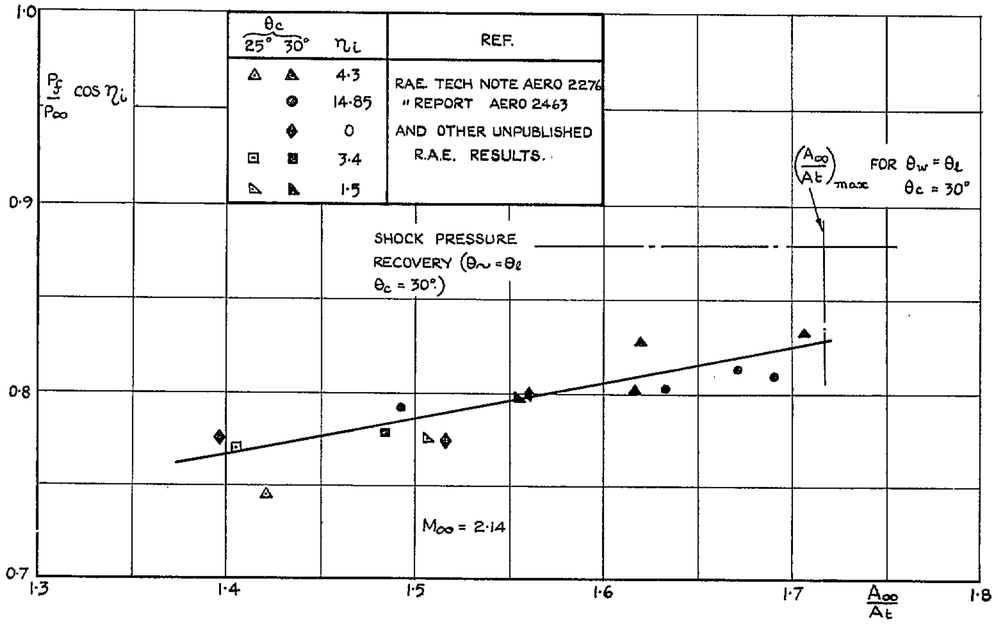


FIG. 25. Pressure recovery/contraction ratio correlation, $M_\infty = 2·14$.

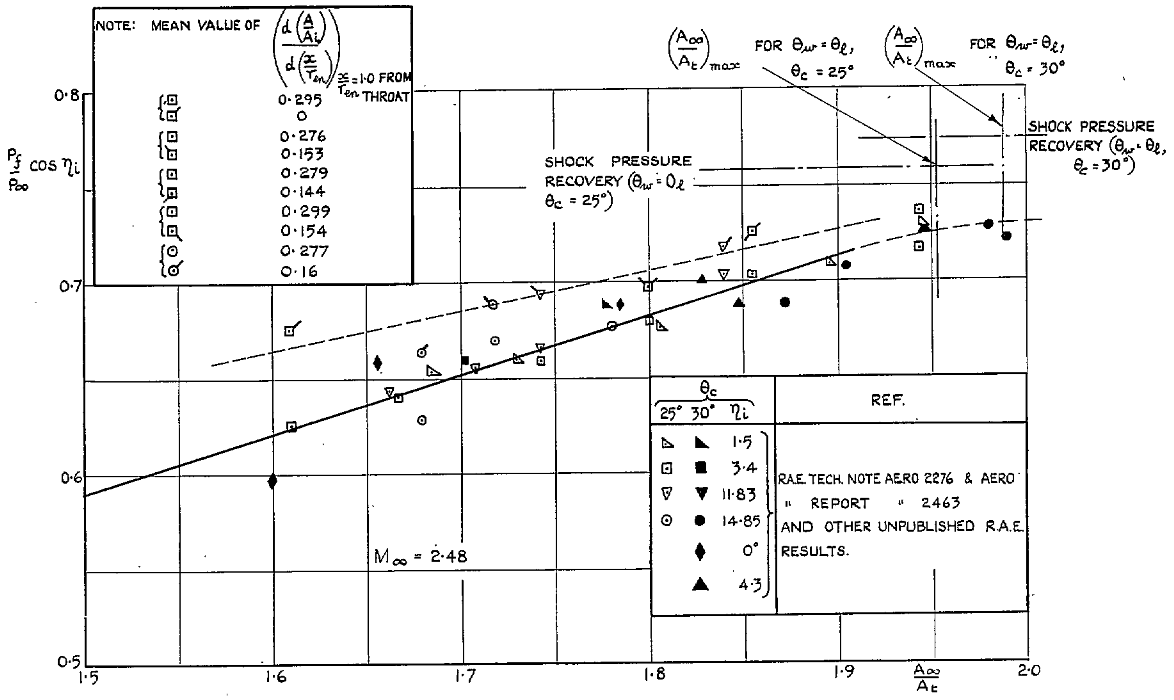


FIG. 26. Pressure recovery/contraction ratio correlation, $M_\infty = 2{\cdot}48$.

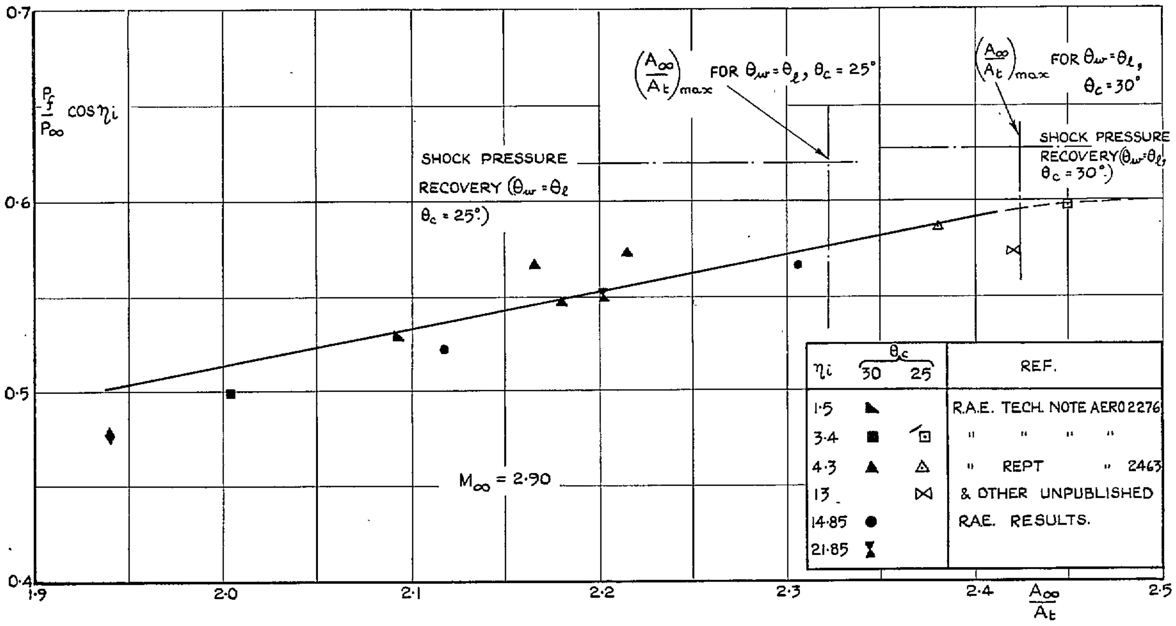


FIG. 27. Pressure recovery/contraction ratio correlation, $M_\infty = 2{\cdot}90$.

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THE EFFECT OF INTERNAL CONTRACTION, INITIAL RATE OF SUBSONIC DIFFUSION, AND COWL AND CENTREBODY SHAPE ON THE PRESSURE RECOVERY OF A CONICAL-CENTREBODY INTAKE AT SUPERSONIC SPEEDS

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