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Summary.—In twin air-intake systems (*i.e.*, a pair of intakes discharging into a common duct or chamber) in which the losses are affected by external boundary layers, asymmetry of flow between the two ducts occurs below a certain critical value of the flow coefficient (entry velocity ÷ free-stream velocity). The effects of this asymmetry on intake efficiency, and more particularly on flow distribution at the compressor, may be important. If, as seems possible, the flow oscillates between the two sides, this may give rise to vibration of the aircraft.

Wind-tunnel model tests have been made on a pair of wing-root leading-edge intakes and on various arrangements of body-side submerged intakes. In all cases a region of flow asymmetry was observed. The appropriate flow coefficients are outside the main working range of the intakes, but are such as might be encountered in a dive, or on suddenly throttling back in level flight.

The main factors determining the extent of the asymmetry are analysed briefly. A theory of intake loss is adapted to provide a method of predicting the critical flow coefficient.

1. *Introduction*.—In low-speed model tests of twin air-intake systems, as for example a pair of swept-wing root intakes or a pair of body-side intakes, leading into a common duct or chamber, it has been observed that as the total flow through the system is reduced (at constant tunnel speed), a critical point is reached below which unequal flows develop in the two intakes. In one intake the flow begins to increase again, in the other it falls rapidly to zero and even becomes negative. The difference in flow on the two sides reaches a maximum, then decreases as the total flow is reduced still further, but asymmetry usually persists down to zero net flow, *i.e.*, with the exit blocked there is a considerable inflow at one entry and a corresponding outflow at the other.

This phenomenon has been described by Martin and Holzhauser[1], who show that it is associated with that part of the flow range in which the static pressure (and total head) in the individual intake decreases with a decrease of flow. If a small disturbance from the steady state of equal flows in the two ducts occurs, the static pressure in the mixing section (particularly if this is a plenum chamber) tends to an average value, and under the above condition it can be shown that this averaging process is in a direction which tends to increase the magnitude of the disturbance. Thus the initial steady state is an unstable one, and the flows in the two ducts diverge until a stable state is reached, in which the static pressures on the two sides are again equal but one flow has increased above the critical value and the other has decreased accordingly. The mean total head corresponding to this new state of equilibrium is generally lower than that corresponding to the initial unstable state. The net result, as it affects the engine, is that as the flow is decreased through the critical value the intake efficiency falls suddenly and, probably a more important effect, the velocity distribution suffers a marked deterioration. In addition, if the flow oscillates

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between the two intakes, as may reasonably be expected in unsteady flight conditions near the critical value, this may set up vibration in the aircraft.

Unsymmetrical flow of the kind described may be expected to occur, in some degree, with any twin-intake system in which the losses are affected by external boundary layers. The word external here refers to any surface ahead of the effective entry which is wetted by air going into the duct. This may be the side of a body, part of the wing surface, etc. In the special case of a swept leading-edge intake, which has been studied recently, it refers to the partly enclosed surfaces ahead of first completely closed section normal to the axis of the duct. Loss from external boundary layers, known as the approach loss, automatically implies the existence of a region in which the intake pressure decreases with decreasing flow, and thus in a twin system opens up the possibility of flow asymmetry.

According to the argument, the critical flow is that corresponding to the peak of the static pressure characteristic of the individual intake forming one of a pair. The total-head characteristic will generally reach a maximum at a somewhat higher flow coefficient (entry velocity ÷ free-stream speed). If the twin system is designed to operate near the total-head peak in top-speed level flight, which is usual, then it is possible in say a dive, or on suddenly throttling back in level flight, for the flow coefficient to fall below the critical. This will result in unequal and possibly oscillatory flow in the two intakes.

Model tests have been made of (*a*) a pair of wing-root leading-edge intakes and (*b*) an arrangement of body-side submerged intakes, to determine the extent of the region of unsymmetrical flow, and to investigate some of the factors affecting the critical value. In a general discussion (section 4) a theory of intake loss is applied to show the effect of other factors and to provide a method of predicting the critical.

2. *Details of Model and Tests.*—The tests were made in the No. 1, 11½-ft. Low-Speed Wind Tunnel of the Royal Aircraft Establishment during September and December, 1950. The model was a 1/5 scale representation of a typical swept-wing fighter having a single engine housed in the body, fed by the pair of intakes. An axial-flow engine was assumed, so there was no sudden change of area at the junction of the two intakes. The common duct led along the body to an exit at the rear.

The general arrangements of the two forms of intake are shown in Figs. 1 and 2. The wing-root intakes (Fig. 1) were roughly triangular in section, with a sweepback of 30 deg on the entry plane. A forward-facing bypass was provided at the inboard end to remove the fuselage boundary layer. Tests were made both with and without bypass, the latter case being simulated by building a fairing on the side of the body so as to cover the entry to the bypass.

The body-side intakes (Fig. 2) were of N.A.C.A. submerged type with divergent approach ramps. In this case the model had been used previously to investigate the general loss characteristics of submerged intakes, and because of this the intakes were different on the two sides. The principal distinction was that one entry was located 22 per cent of the root chord forward of the wing leading edge, while the other was at the leading edge. They are termed here the 'forward' and 'rear' intakes respectively. It was considered that while the differences might be sufficient to determine the direction in which flow asymmetry developed, they would not obscure the main effects.

Two modifications, each of which reduced the intake efficiency, were tried in order to determine the reactions of the critical flow coefficient. The first consisted in removing the side walls of the ramp, leaving a flat platform ahead of the entry; the second in placing an obstacle across this platform in the form of a transverse ridge of wood, in height roughly half the mean height of the entry.

Total head and static pressure were measured in the separate ducts a short distance upstream of the mixing section, and again in the common duct near the exit. With the side intakes, additional static-pressure measurements were made at the mixing section itself. These showed only small differences from the readings farther upstream in the separate ducts. The total flow through the exit was controlled by means of a series of nozzles.

The tests were made at a single small incidence in each case ($C_L = 0$ in the first experiment and 0·08 in the second).

3. *Results.*—Results for the wing-root intakes are shown in Figs. 3 to 5 and those for the side intakes in Figs. 6 to 8. It is convenient to plot in terms of a flow coefficient V_i/V_0*, rather than the inverse V_0/V_i (used in the study of intake loss and termed the entry velocity ratio). The first diagrams in each group give the basic static and total pressure characteristics of the single intakes. To obtain these, the mean pressures are plotted against flow coefficient as measured in the individual ducts. The remaining diagrams show the flow asymmetry effect for the twin systems. Flow in each duct is plotted against the mean flow as measured near the common exit. Down to the critical flow coefficient, the values for the two ducts lie close to the mean line. Below the critical they diverge rapidly as already described. The mean static pressure is plotted on these diagrams, and in the case of wing-root intakes (symmetrical) the mean total head also. This is an average value over the area of the mixing section. Below the critical, owing to the uneven distribution, an energy mean (total head weighted with respect to velocity) would be appreciably higher. The plain average total head is preferred because its lower value reflects the bad distribution which in practice the compressor would have to face.

The main features of the results are as follows:

(i) Asymmetry of flow over the lower part of the range is observed in all cases. The best example is in Fig. 8a, where the critical flow coefficient is closely determined. The value (0·37) corresponds to the peak of the static-pressure characteristic of the rear intake of the unsymmetrical pair (Fig. 7), which is the one with the greater approach loss, *i.e.*, the higher flow coefficient for peak static pressure. Below this value the flow in the forward intake begins to increase again, while that in the rear intake (this now being on the unstable part of the characteristic) decreases rapidly and becomes zero at $V_i/V_0 = 0 \cdot 29$, which may be called the reversal point. The mean static pressure falls rapidly below the critical flow coefficient, then recovers below the reversal point. It may be shown that this recovery results from the nature of the pressure characteristic of the individual intake with reversed flow.

(ii) Values of critical flow coefficient and flow coefficient for reversal for the various arrangements, taken from Figs. 4 and 5, and 8a to 8f, are given in the table below. This also shows the flow coefficients for maximum static pressure of the single intakes.

TABLE 1

Arrangement	Values of V_i/V_0			
	Critical	Reversal	Maximum C_p	
Wing-root intakes (symmetrical)				
(*a*) With bypass	0·34	0·28	0·36	
(*b*) Without bypass	0·32	0·29	0·35	
Body-side intakes (unsymmetrical)			A†	B
(*a*) Both intakes with ramps	0·37	0·29	—	0·37
(*b*) Both intakes without ramps	0·42	0·36	0·37	0·41
(*c*) †A with ramp, B without	0·44	0·35	—	0·41
(*d*) A without ramp, B with	0·45	0·33	0·37	0·37
(*e*) As (*d*) with 2½ deg yaw (B forward *i.e.*, into wind)	0·45	0·37	0·37	0·37
(*f*) Both intakes without ramps, with obstacles	0·43	0·12	—	0·41

† A denotes forward intake, B denotes rear intake.

* V_i = mean entry velocity, V_0 = free-stream velocity.

Generally there is good agreement between the critical flow coefficient and the value for maximum C_p in the individual intake (using the higher value where the two sides differ). The main exceptions to this are given by tests (*d*) and (*e*) in the second group, for which the critical value is higher than might be expected. Figs. 8d and 8e show that in these cases there is at flow coefficients in the stable range an inequality between the flows on the two sides (owing to the unsymmetrical intakes) which may tend to advance the critical.

(iii) The reversal point is at a flow coefficient about $0 \cdot 06$ lower, on the average, than the peak C_p position. This may be used as a simple indication of when the asymmetry has become severe. If the reversal point is at $V_i/V_0 = 0 \cdot 3$, say, then a rough idea of the distribution at the compressor may be obtained by assuming that at this point the flow is zero in one duct and uniformly $0 \cdot 6 V_0$ in the other.

(iv) The wing-root intakes have a low critical value, which makes it unlikely that the effect would be encountered to an appreciable extent in practice. Eliminating the bypass does not produce the rise in critical which would have been expected. This appears to be because the bypass is not working efficiently at such low flow coefficients. The result is discussed further in terms of intake loss coefficient in the general discussion which follows later in the report.

(v) An interesting point is that the mean total head does not invariably fall with the static pressure on passing through the critical flow, since it is possible for the gain in one duct (that in which the flow increases) to offset the loss in the other. This happens in the case of the wing-root intakes without bypass (Fig. 5).

(vi) In the second group of results, increasing the approach loss of the intake by removing the ramp walls results in an increase of critical flow value. Conversely it can be shown (*see* general discussion) that increasing the internal duct loss has the opposite effect. Both effects are present in the final case – test (*f*) – where the obstacles effectively increase the duct loss by blocking off part of the entry. The net result is that there is only a small change in critical value.

(vii) It was found in the tests that the asymmetry always occurred in a definite direction at a fixed flow coefficient, and there was no tendency for the flow to oscillate. With the side intake arrangement the forward intake generally gained flow below the critical at the expense of the rear intake. This is consistent with the former having a more favourable pressure characteristic. By removing ramp walls from the forward intake only – test (*d*) – the pressure peaks of the individual intakes were made to occur at the same velocity ratio. The result (Fig. 8d) was that the asymmetry at first developed in the opposite direction (*i.e.*, in favour of the rear intake) but at $V_i/V_0 = 0 \cdot 22$ it reversed and then continued in the more usual sense. When the model was given $2\frac{1}{2}$ deg yaw (rear intake into wind) – test (e), Fig. 8e – an asymmetry in favour of the rear intake was obtained down to zero net flow. This suggests that if the intake characteristics are sufficiently closely alike, slight fluctuations in net flow coefficient, degree of yaw, etc., might cause the flow to oscillate. There was however no evidence of actual oscillation in the tests of the wing-root intakes, which were nominally identical.

4. *General Discussion.*—The tests confirm that unsymmetrical flow occurs in twin intake systems at low values of the flow coefficient, if the intake characteristic is such that decreasing the flow decreases the pressure recovery. The critical flow coefficient is approximately that which would give maximum static pressure in the individual intake taken by itself. In the case of direct (*i.e.*, fully ducted) intakes, this is essentially a lower value than that for maximum total head, which is the nominal design point for top level speed. It follows that flow asymmetry will not usually develop under what are normally accepted as the main flight conditions (ground running, climb, cruise, top level speed), but may occur under more transient conditions, as in a dive or on suddenly throttling back in level flight.

With a plenum chamber installation the static pressure and total head in the plenum chamber are virtually equal, so the critical flow coefficient coincides with maximum total head. The region of flow asymmetry is therefore more liable to cut into the main working range of the intake.

An approximate theory of intake loss, developed in Ref. 2, shows that the total-head loss coefficient of an individual intake varies as the cube of the entry velocity ratio V_0/V_i (the inverse of the flow coefficient). The result may be written in the form

$$\frac{\Delta H}{q_i} = a\left(\frac{V_0}{V_i}\right)^3 + b, \quad \ldots \quad (1)$$

where ΔH is the loss of total head from free stream to measuring point and q_i is the mean entry dynamic head $\frac{1}{2}\rho V_i^2$. It follows that

$$\frac{\Delta H}{q_0} = a\frac{V_0}{V_i} + b\left(\frac{V_i}{V_0}\right)^2;$$

and hence if A_i, A_c are the areas of the duct at entry and at mixing section, the static pressure at the latter position is given approximately by

$$C_p = \frac{H}{q_0} - \left(\frac{A_i}{A_c}\right)^2\left(\frac{V_i}{V_0}\right)^2 = 1 - a\frac{V_0}{V_i} - c\left(\frac{V_i}{V_0}\right)^2, \quad \ldots \quad (2)$$

where $c = b + (A_i/A_c)^2$.

From equation (2), it is seen that C_p is a maximum when

$$\left(\frac{V_0}{V_i}\right)^3 = \frac{2c}{a}. \quad \ldots \quad (3)$$

In general the coefficient b, which represents primarily the internal duct loss, is of the order of 0·1, while for direct inlets $(A_i/A_c)^2$ is of the order of 1. To a first approximation therefore, b may be neglected in the expression for c. So the critical flow may be written as

$$\left(\frac{V_0}{V_i}\right)_{\text{crit}}^3 = \frac{2}{a}\left(\frac{A_i}{A_c}\right)^2$$

or

$$\left(\frac{V_i}{V_0}\right)_{\text{crit}}^3 = \frac{a}{2}\left(\frac{A_c}{A_i}\right)^2. \quad \ldots \quad (4)$$

For the case of a plenum chamber installation, if it is assumed that the whole of the duct dynamic head is lost on discharging into the plenum chamber, then the pressure in the chamber is the same as that at the end of the duct, so the result (4) still applies provided that A_c is taken as the area of the duct just before the plenum chamber.

The coefficient a is given by the slope of the curve of total-head loss coefficient against $(V_0/V_i)^3$. In terms of the theory of Ref. 2,

$$a = k\frac{S}{A_i}C_f, \quad \ldots \quad (5)$$

where S is the surface area ahead of entry wetted by the duct flow

(defined for $V_0/V_i = 1{\cdot}0$)

A_i is the entry area

k is a retardation factor, generally about 0·7

C_f is the effective friction coefficient of the intake.

S/A_i is known as the position ratio. Its value is zero for a nose entry or an unswept leading-edge entry away from the body and generally speaking the value increases as an intake moves back along the body, or as the entry sweepback is increased.

Thus from equation (4) we see that the two primary factors affecting the critical flow value are the position ratio of the entry and the amount of diffusion in the duct. An increase of either of these quantities increases the value of V_i/V_0 below which flow asymmetry occurs. An increase in the internal duct loss has the opposite effect, as may be seen by re-including the term b in the analysis.

If flow separations develop, which is not unusual at low values of V_i/V_0, an analysis in terms of friction coefficient is clearly not valid. Nevertheless, it is often found that the loss coefficient is still linear with $(V_0/V_i)^3$. In these circumstances equation (4) may still be applied, but the slope a will no longer be given by equation (5).

In Figs. 9 and 10 loss coefficients for the wing-root and body-side intakes respectively are plotted against $(V_0/V_i)^3$. From the slopes of the lines and the diffusion ratio A_c/A_i values of critical flow coefficient have been estimated according to equation (4). These are compared with the measured values in the following table.

TABLE 2

Arrangement	Critical V_i/V_0	
	Estimated	Measured
Wing-root intakes		
(*a*) with bypass	0·20	0·34
(*b*) without bypass	0·34	0·32
Body-side intakes		
(*a*) both intakes with ramp.. ..	0·33	0·37
(*b*) both intakes without ramp ..	0·41	0·42
(*c*) A with ramp, B without ..	0·41	0·44
(*d*) A without ramp, B with ..	0·37	0·45

In most cases the agreement is satisfactory. This merely reflects the fact that the formula (4) gives the position of maximum C_p of the intake reasonably well. The case of the wing-root intakes with bypass is an exception. Here the loss curve (Fig. 9) shows that the action of the bypass, satisfactory in the main flight range, breaks down when $(V_0/V_i)^3$ is about 20 (*i.e.*, $V_i/V_0 = 0 \cdot 37$) resulting in maximum C_p being obtained near this point (Fig. 3). This explains the disagreement and also shows that if the bypass efficiency were maintained, the region of asymmetry would be confined to mean flow coefficients below about 0·2, *i.e.*, the effect would be negligibly small.

It will be noticed that in Fig. 10 the straight line characteristics as drawn ignore in each case a number of experimental points at the low end of the range. The actual loss curves curl off in this region owing to the onset of additional losses originating inside the lip of the submerged intake, caused by the flow 'dipping in' at an angle from the free stream. This is quite separate from the boundary-layer problem which affects the present issue, and is a form of the well-known 'static' loss, which in the case of a submerged intake extends further than usual into the flight range.

5. *Concluding Remarks.*—The tests have shown that asymmetry of flow occurs in typical twin-intake systems under conditions which may be encountered in a dive, or at lower speeds on reducing the engine airflow. Intake loss theory provides a simple formula for estimating the critical flow value of a given arrangement. The chief factors affecting the critical value have been demonstrated in the analysis.

LIST OF SYMBOLS

V_0	Free-stream velocity
V_i	Mean entry velocity
V_i/V_0	Flow coefficient
V_0/V_i	Entry velocity ratio
q_0	Free-stream dynamic head
q_i	Mean entry dynamic head
H	Mean total head at measuring section
ΔH	Loss of total head up to measuring section
C_p	Static-pressure coefficient at measuring section (mean static — atmospheric)/q_0
A_i	Duct area at entry
A_c	Duct area at measuring section
S/A_i	Position ratio of entry
k	Retardation factor
C_f	Effective friction coefficient of intake

REFERENCES

No.	*Author*	*Title, etc.*
1	N. J. Martin and C. A. Holyhauser	Analysis of factors influencing the stability characteristics of symmetrical twin-intake air-induction systems. N.A.C.A. Tech. Note 2049. March, 1950.
2	J. Seddon	Air intakes for aircraft gas turbines. *J.R.Ae.S.* October, 1952.

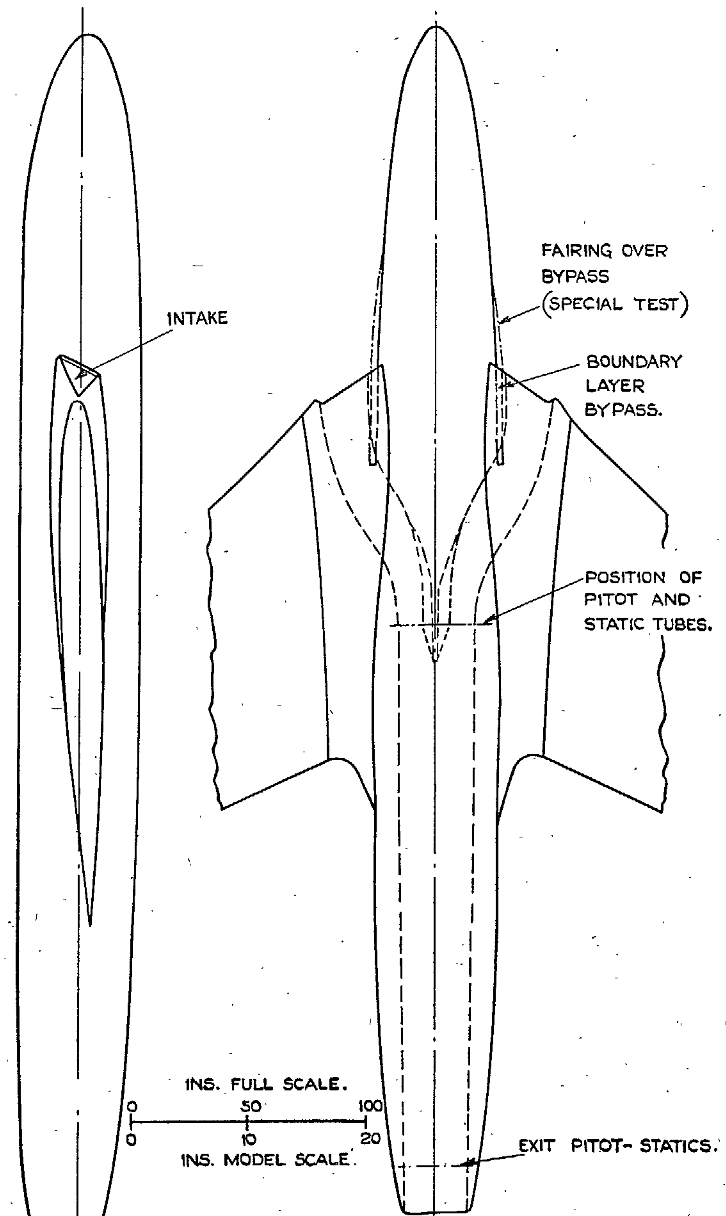

FIG. 1. General arrangement of model with wing-root intakes.

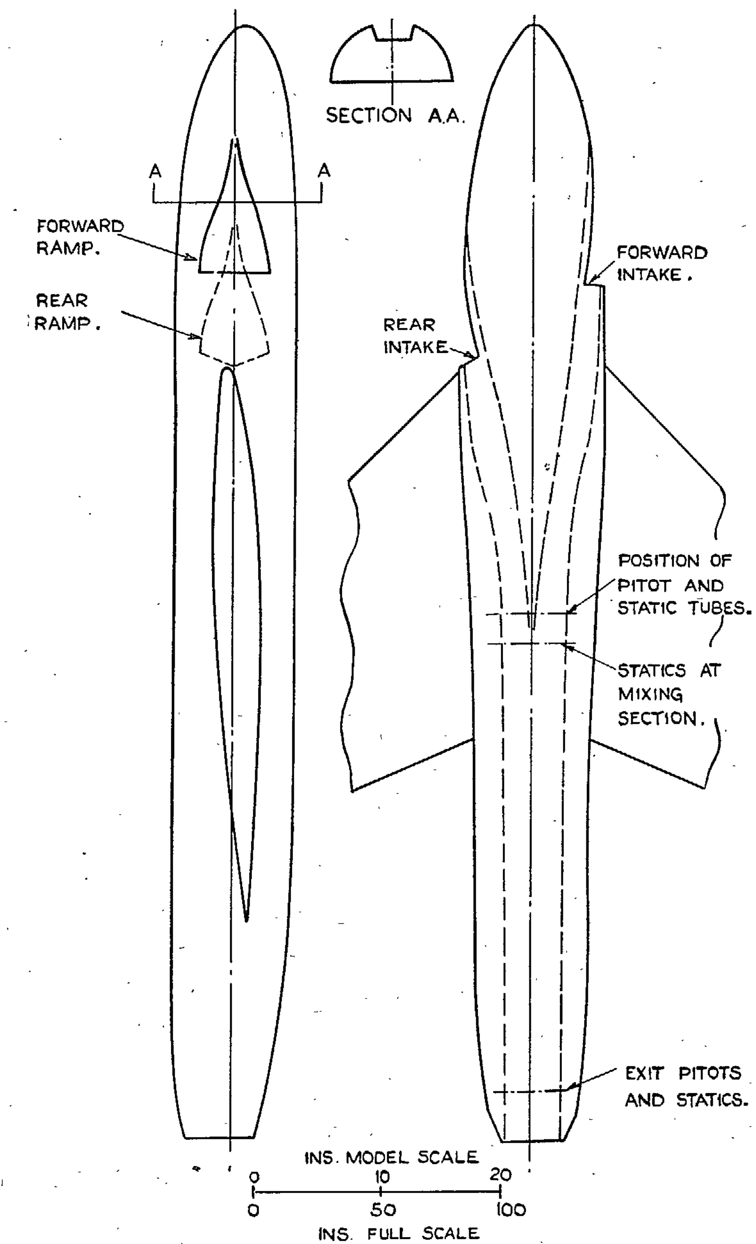

FIG. 2. General arrangement of model with body submerged intakes.

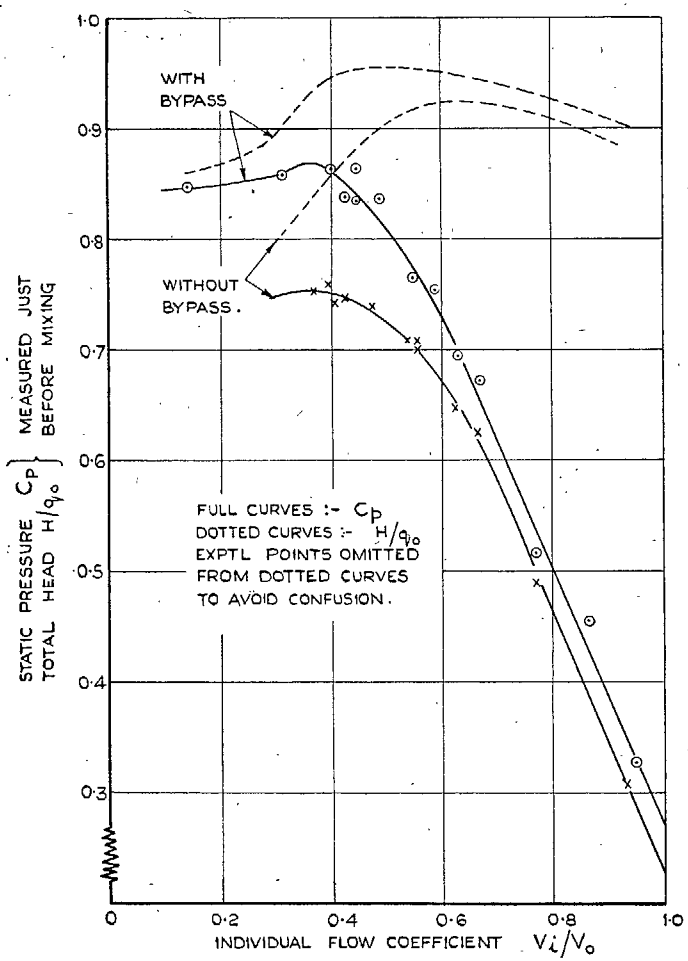

FIG. 3. Wing-root intakes (symmetrical). Pressure characteristics of individual intake.

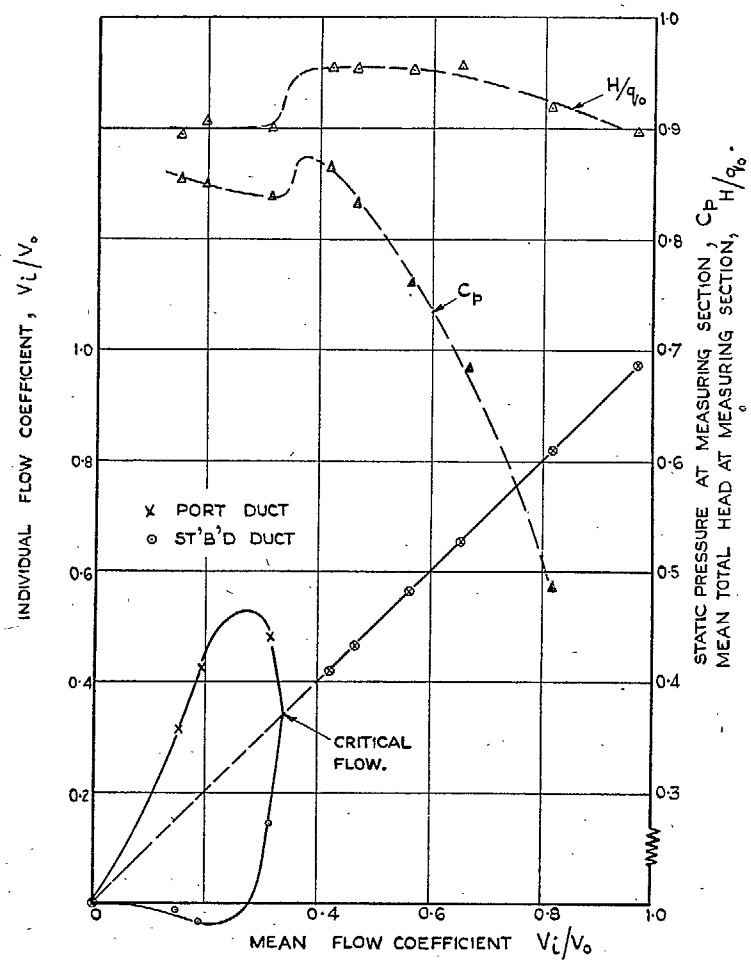

FIG. 4. Wing-root intakes (symmetrical). Flow and pressure characteristics of twin intakes with bypass.

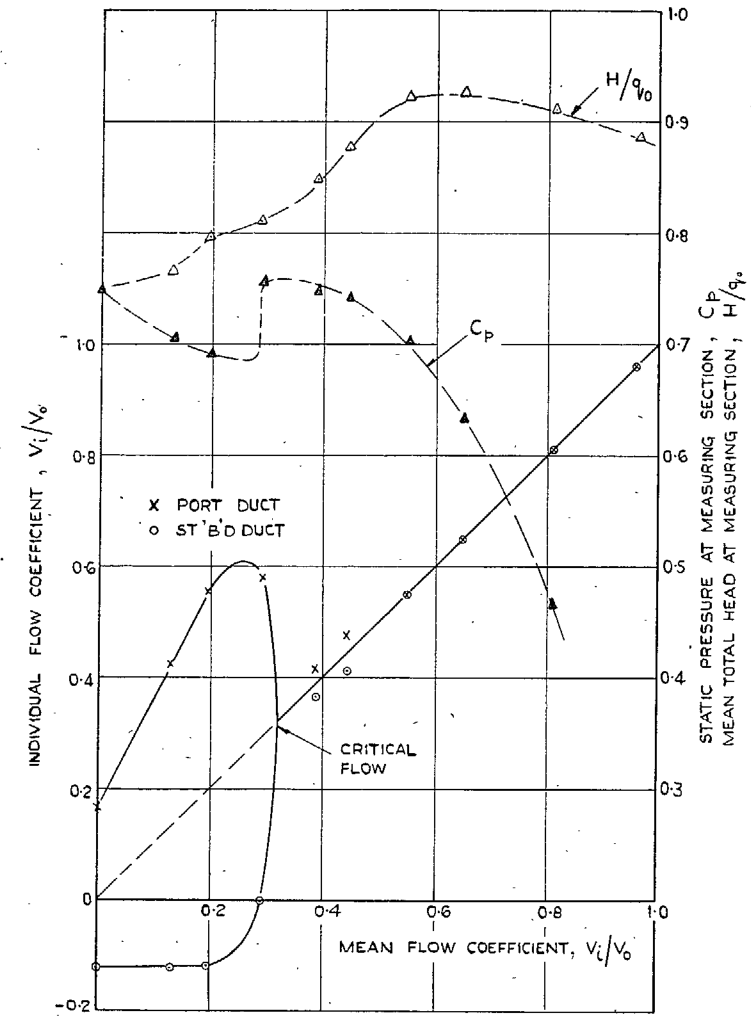

FIG. 5. Wing-root intakes (symmetrical). Flow and pressure characteristics of twin intakes without bypass.

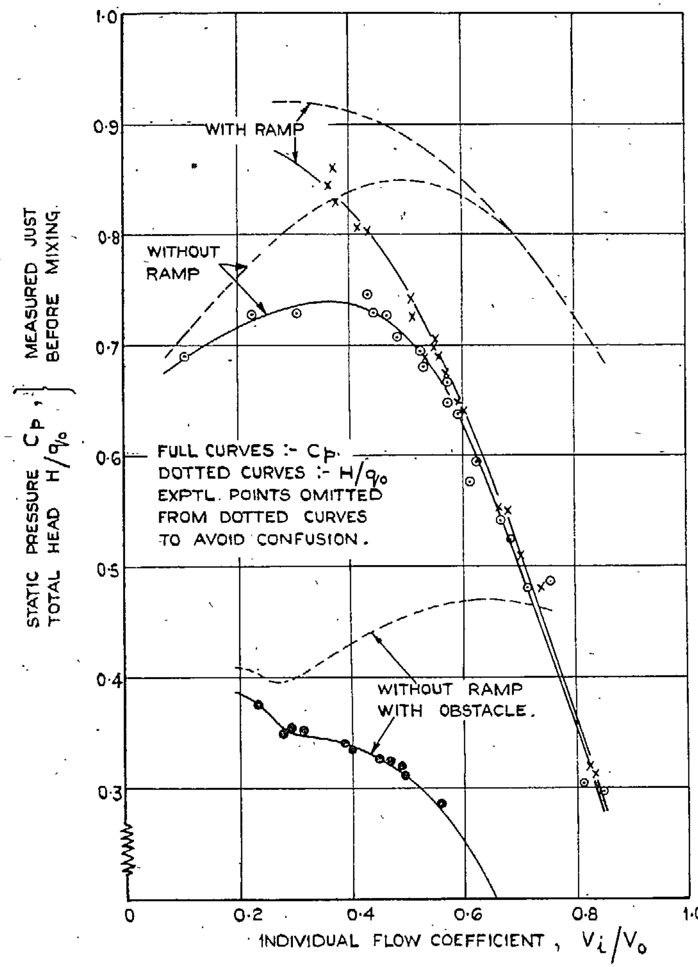

FIG. 6. Body submerged intakes (unsymmetrical). Pressure characteristics of forward intake alone.

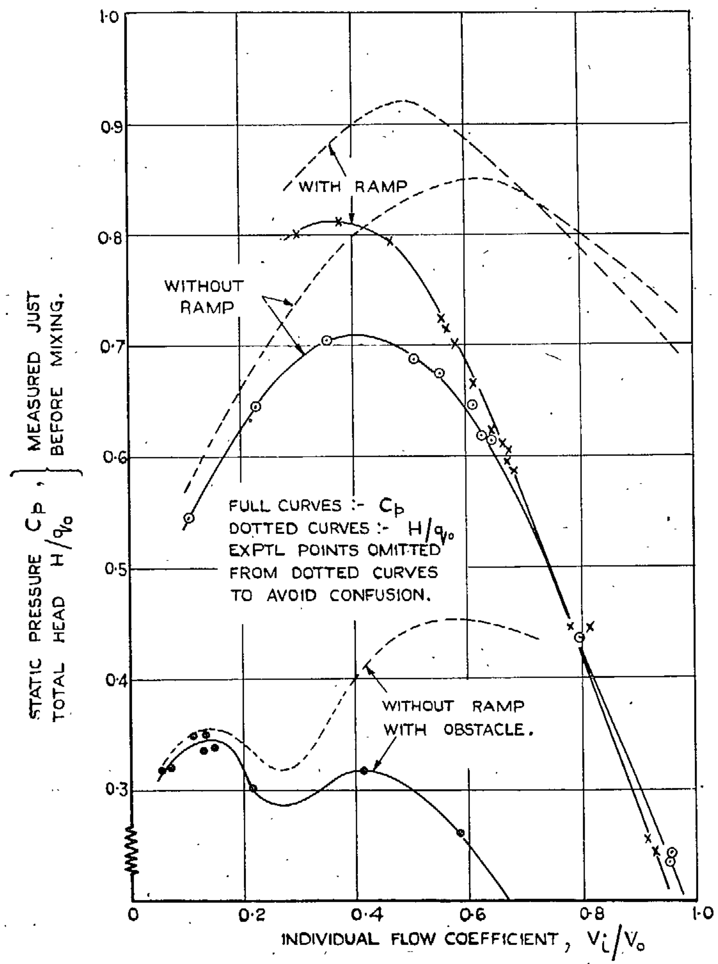

FIG. 7. Body submerged intakes (unsymmetrical). Pressure characteristics of rear intake alone.

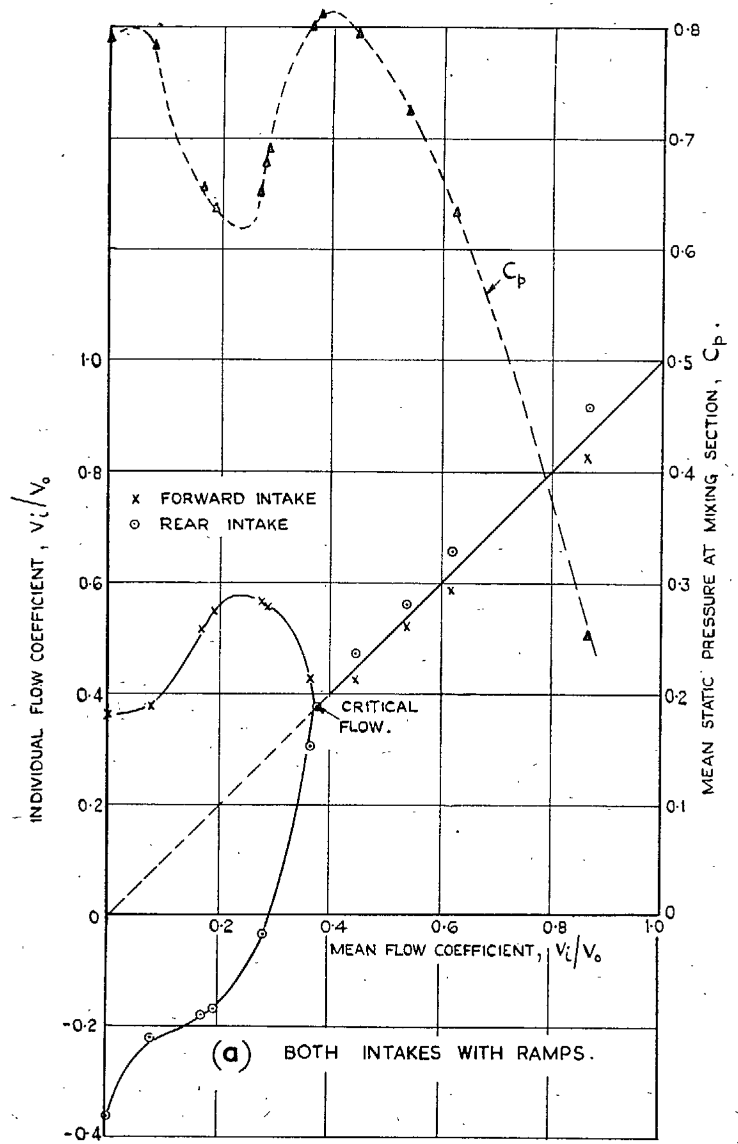

FIG. 8a. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

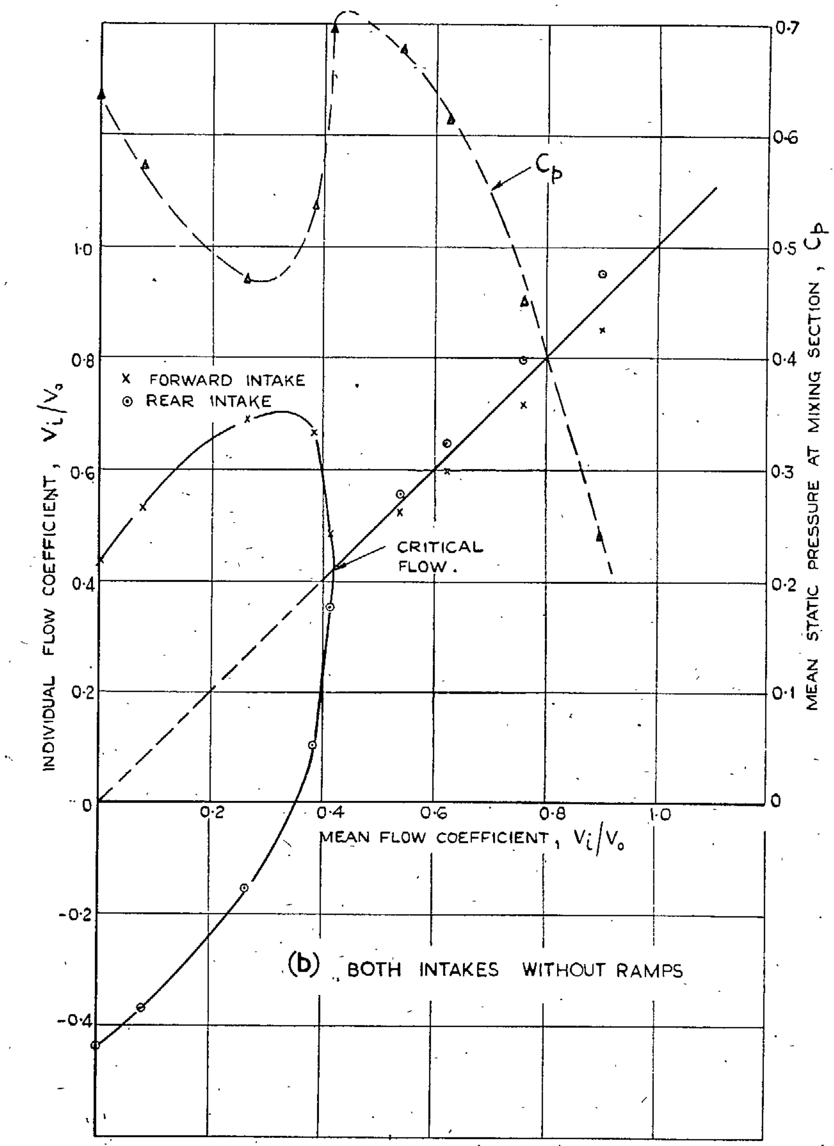

FIG. 8b. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

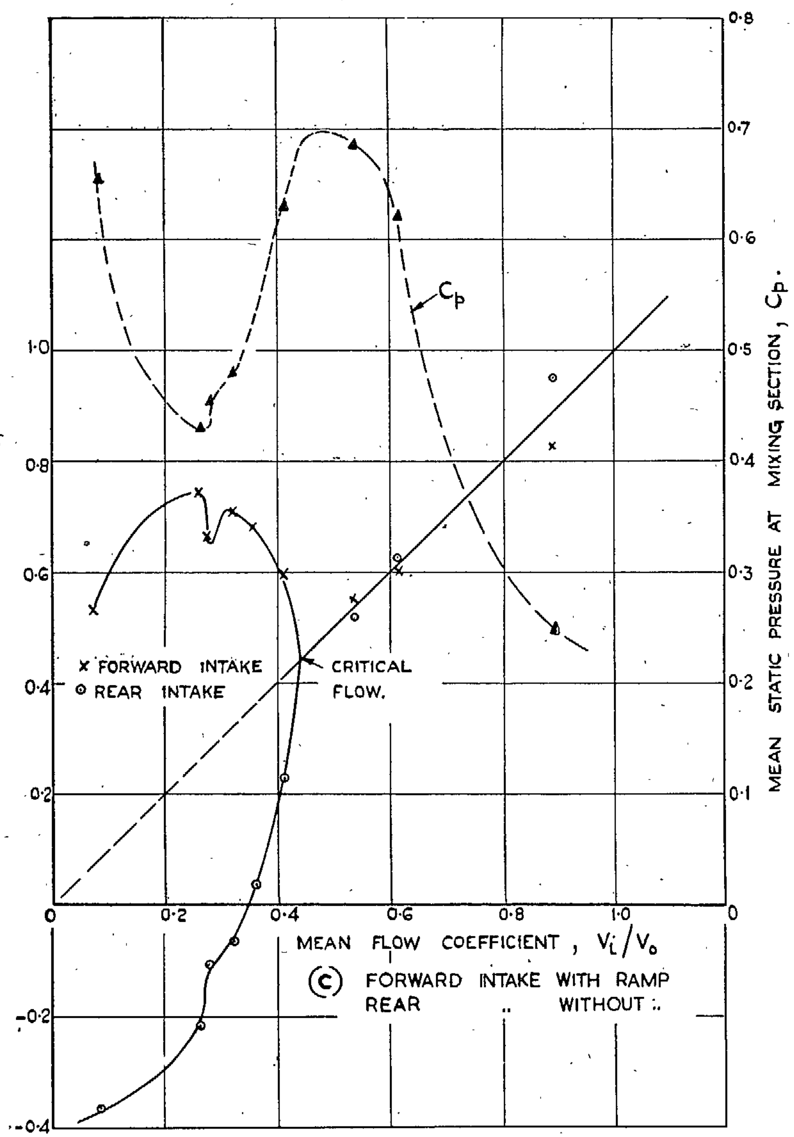

FIG. 8c. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

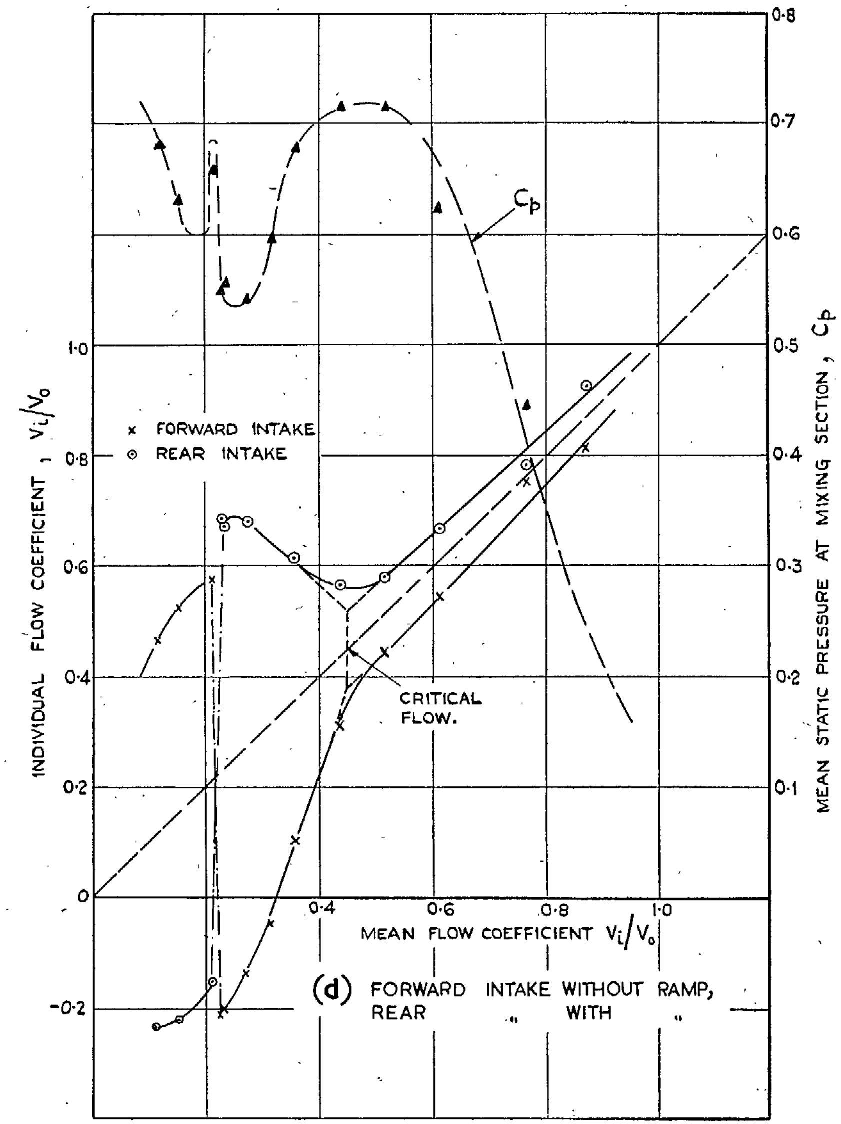

FIG. 8d. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

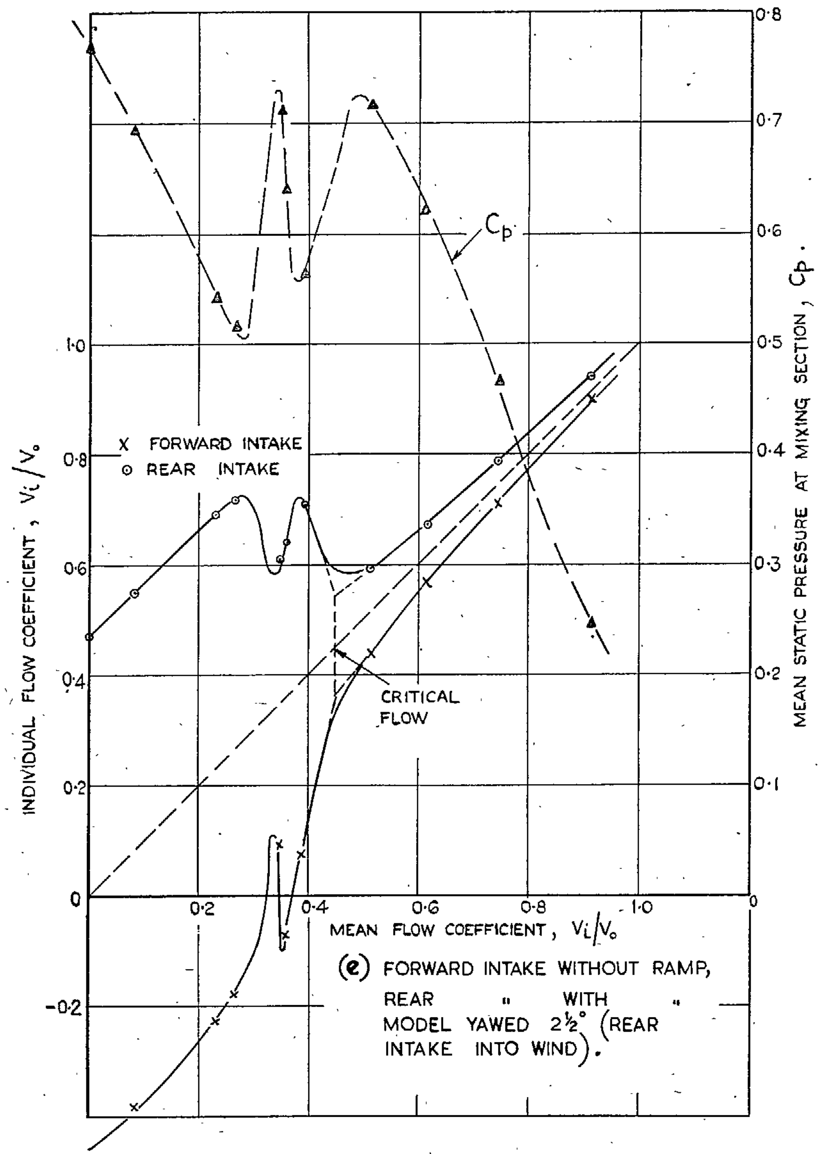

Fig. 8e. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

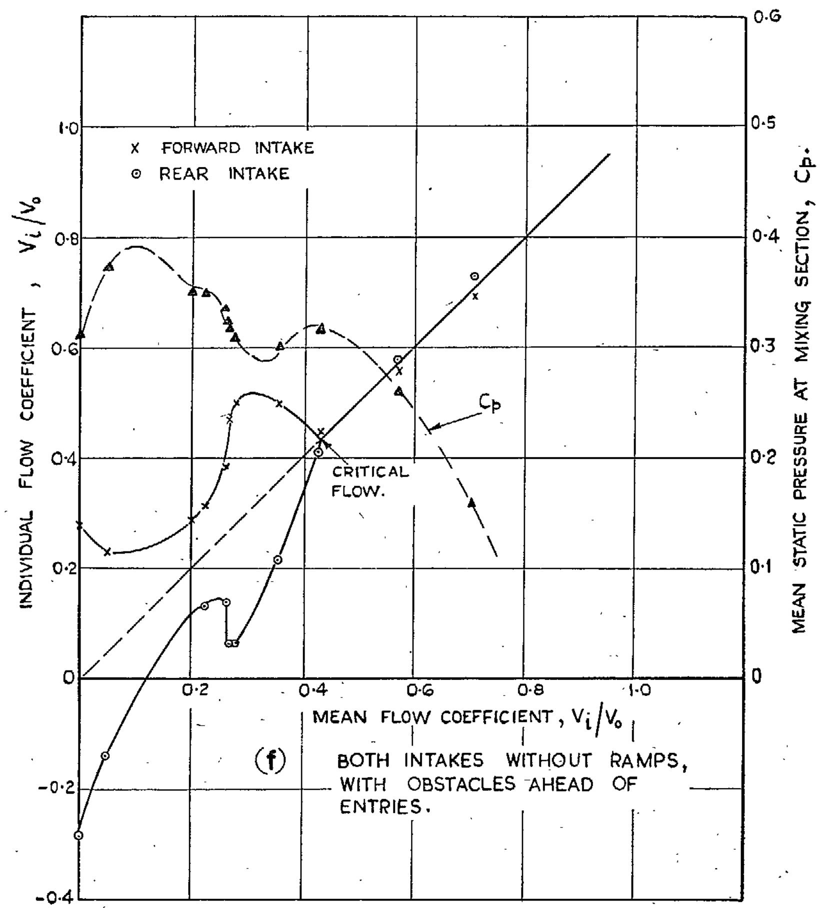

Fig. 8f. Body submerged intakes (unsymmetrical). Flow and pressure characteristics of double intake system.

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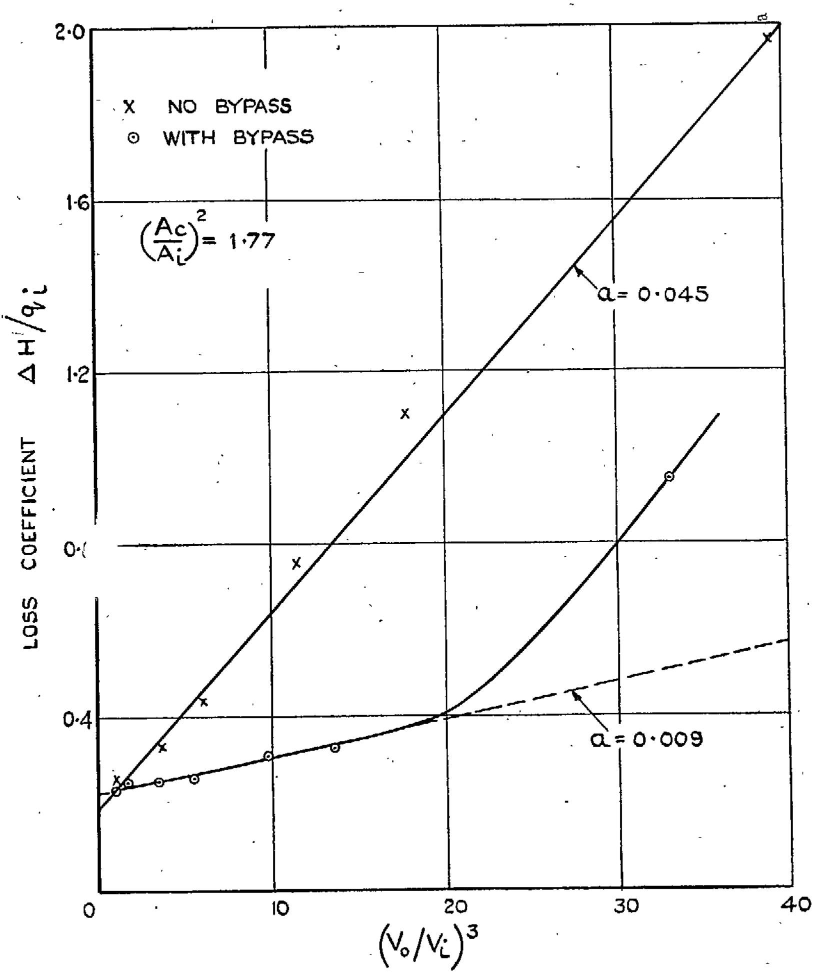

FIG. 9. Wing-root intakes (symmetrical). Loss characteristics used for estimating critical flow (section 4).

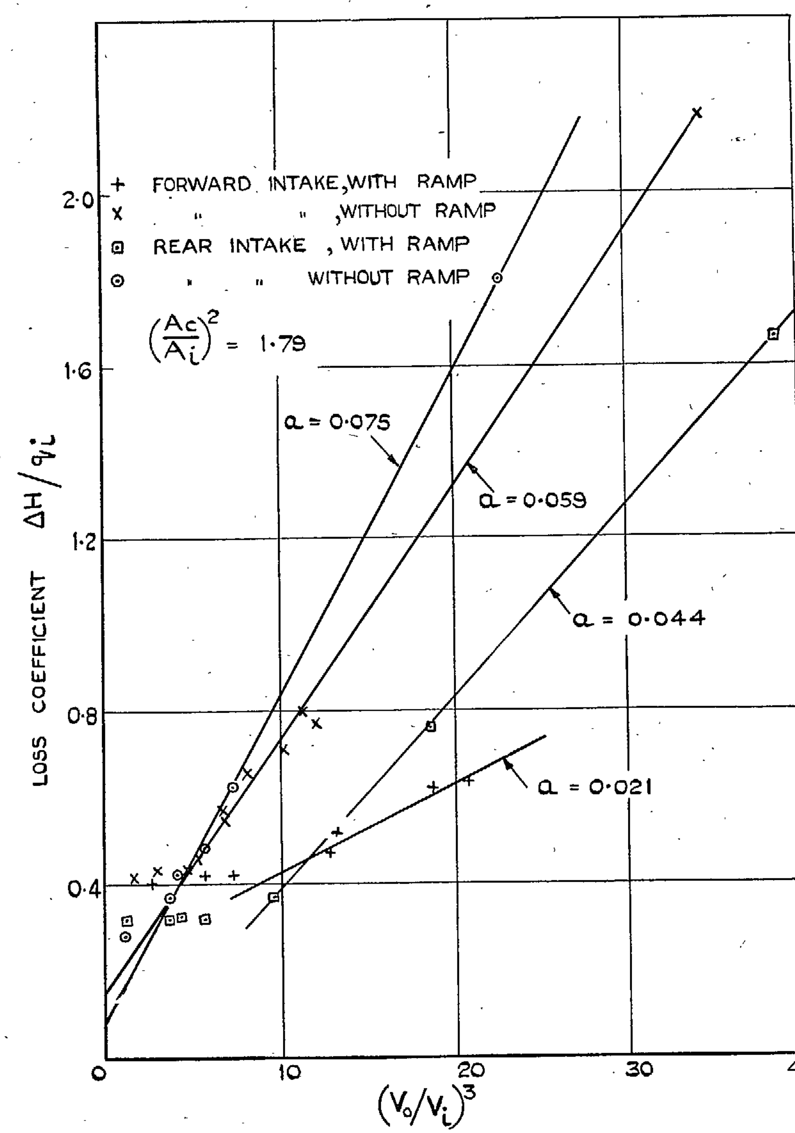

FIG. 10. Body submerged intakes (unsymmetrical). Loss characteristics used for estimating critical flow (section 4).

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