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An Investigation into the Effect of Forced and Natural Afterbody Ventilation on the Hydrodynamic Characteristics of a Small Flying Boat (Saro 37) with a 1:20 Fairing over the Main Step

By

J. A. HAMILTON, B.Sc.

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J. A. HAMILTON, B.Sc.
COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
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Summary.—Introduction.—In continuation of the tests reported in R. & M. 2463, an investigation was made into the hydrodynamic qualities of a small flying boat (Saro 37) with a 1 : 20 double curvature fairing over the main step. As before, the aircraft was equipped with means for forced and natural ventilation of the afterbody. Apart from the 1 : 20 fairing, the Saro 37 hull is a 1 : 2·75 scale model of a larger flying boat (Shetland), of 120,000 lb all-up-weight.

Ventilation Apparatus.—Forced ventilation was supplied by an auxiliary power unit driving a centrifugal air compressor. The fairing was ventilated by three sets of ventilating ducts—one set immediately behind the main step, an intermediate set at 30 per cent beam aft of the step, and an aft set at 90 per cent beam aft of the step, *i.e.*, at the inflexion line of the 1 : 20 fairing. Only the forward ducts were force ventilated in the present tests.

Range of Investigation.—The tests were made at two weights: 5,900 lb ($C_{\Delta_0} = 1{\cdot}00$) and 6,200 lb ($C_{\Delta_0} = 1{\cdot}05$). At 5,900 lb the hydrodynamic characteristics were investigated in taxy runs and take-offs over a range of fixed elevator positions, and in landings over a range of touch-down attitudes. These tests were made with the ducts naturally ventilated. At 6,200 lb the tests were confined to taxy runs with and without forced ventilation.

Conclusions.—

(i) At 5,900 all-up weight the 1 : 20 hull has a fair stability range in take-off (>3 deg) but the landing stability is bad. The hull appears to be very sensitive to disturbance in heave.

(ii) At 6,200 lb all-up weight the take-off skipping limit without forced ventilation is raised by 1 deg, and is 2 deg above the corresponding limit for a 1 : 15 fairing on the same hull and at the same weight. The 1 : 15 fairing had less ventilating duct area than the 1 : 20.

(iii) The addition of forced ventilation to the 1 : 20 fairing at 6,200 lb all-up weight produces no apparent amelioration of the take-off stability characteristics, but does lower the free-to-trim curve.

(iv) The addition of forced ventilation at 6,200 lb all-up weight increases the mean planing acceleration by 0·015*g*.

(v) Even with forced ventilation the planing resistance of the 1 : 20 hull is much greater than that of the 1 : 15 hull.

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1. *Introduction.*—An earlier report, R. & M. 2463, has described the hydrodynamic qualities of a small flying boat (Saro 37) with a 1 : 15 fairing fitted over the main step. In that report it was concluded that the forebody-afterbody angular discontinuity was at a critical value (13 deg) and that a smaller value of this angle would cause considerable deterioration in hydrodynamic stability and resistance. To investigate this problem a 1 : 20 double curvature fairing was constructed over the Saro 37 step, reducing the forebody-afterbody angle to 7·5 deg. This fairing could be ventilated in a manner similar to the ventilation system tested on the 1 : 15 fairing.

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2. *Description of Fairing and Ventilation System.*—The 1 : 20 fairing and its attendant ventilation system are illustrated in Figs. 1 to 4. As with the 1 : 15 fairing there was no cove at the step and during the test programme considerable care was taken to keep the forebody-afterbody junction as smooth as possible.

A ventilation system based on that of the 1 : 15 fairing, was adopted. In addition to the two sets of forward ducts utilised on the 1 : 15 fairing however, a set of larger ducts was constructed at the inflexion point of the double curvature fairing (Figs. 3 and 4). These aftmost ducts were designed specifically for natural ventilation since the earlier tests had shown how efficient was this form of ventilation. Forced ventilation could still be applied to the forward ducts by means of the Kestrel-Rotol blower unit described in R. & M. 2463.

3. *Range of Investigation.*—The tests were made at two weights, *viz.*, 5,900 lb and 6,200 lb and may be described conveniently under these headings.

3.1. *Tests at* 5,900 *lb.*—This weight was achieved by removing the Kestrel-Rotol blower unit and therefore the corresponding tests were made with forward, intermediate and aft ducts all naturally ventilated from the hull interior. In this condition the stability was investigated by a series of taxy runs, take-offs and landings. The taxy and take-off stability was measured over a range of fixed elevator positions, and at a constant flap angle of 15 deg. Landings were made at 30 deg flap angle employing the technique described in R. & M. 2463. Most of the stability points were obtained for zero pitch disturbance—apart from any motion due to the water surface. Those points for which a nose-down disturbance was given by the pilot are indicated on the appropriate stability diagram (Fig. 5).

3.2. *Tests at* 6,200 *lb.*—Owing to structural deterioration—revealed after the tests at 5,900 lb—and the increase in all-up-weight caused by the re-installation of the Kestrel-Rotol blower unit, the tests at 6,200 lb were confined to taxy runs on the water (Flap angle 15 deg).

To investigate the effect of forced ventilation, the blower unit was connected to the forward set of ventilating ducts and taxy runs made with and without the unit in operation. The intermediate and aft ducts remained open to the hull interior as for the tests at 5,900 lb. Because of the danger of inadvertent take-off no external pitching disturbance was applied at this weight.

3.3. *Instrumentation.*—Measurements appropriate to the tests were recorded by a Royal Aircraft Establishment two-axes accelerometer and gyro pitch indicator and an automatic observer, synchronised by a common timing clock. The automatic observer contained the following instruments :—

A.S.I. recording aircraft speed.

A.S.I. recording air speed in the aft ducts.

A.S.I. recording air speed in the intermediate ducts.

A.S.I. recording air speed in the forward ducts or discharge from the blower unit.

Desynn indicator recording elevator angle.

Stop watch.

The air flow through the ducts was measured by a pitot-static system similar to that described in R. & M. 2463.

3.4. *C.G. Position.*—The centre of gravity for all tests was at 19·0 in. forward of the main step point (C.G. limits 15·3 in. to 24·0 in. forward of the main step point. All distances parallel to hull datum line).

3.5. *Weather Conditions.*—All tests were confined to days when the wind velocity was less than 10 m.p.h. and to sheltered water.

4. *Results.*—4.1. *Stability and Trim During Taxi Runs and Take-offs.*—The stability and trim curves obtained from steady speed runs, accelerated runs and take-offs are illustrated in

Figs. 5 to 12 under the collective title of take-off stability and trim. For the stability plots the following notation has been employed :—

⊙ Normal porpoising instability, either upper or lower limit.

⊡ Skipping instability (*cf.*, R. & M. 2463 for a definition of skipping).

⊞ Borderline skipping instability. To indicate the region where a slight pitching disturbance or increase in speed would cause skipping.

⊕ Porpoising of total amplitude less than 2 deg or to indicate a point where the stability is dubious.

\+ Stable. The subscripts in Fig. 5 refer to the degree of applied nose down disturbance for which the point is valid.

At 5,900 lb the 1 : 20 fairing with natural ventilation gives a usable take-off stability range of more than 3 deg, the lower limit being fixed by directional rather than longitudinal instability. The stable points near the skipping limit were confirmed with 4 deg nose down disturbance. Near the hump there is slight evidence of an upper stability limit but the elevator has insufficient power at this weight to reach the attitudes necessary to confirm this instability.

At 6,200 lb (Fig. 6) the lower limit is raised by 1½ deg at the hump and because of the higher attitudes attainable at this weight, the presence of a porpoising upper limit is confirmed. The skipping limit is raised 1 deg above that for 5,900 lb but this limit is valid for zero disturbance only, and was less thoroughly investigated because of the ban on take-off at 6,200 lb. The addition of forced ventilation to the forward ducts has produced no apparent amelioration of the stability characteristics. (Fig. 7).

Configuration *B* of the 1 : 15 fairing is most nearly similar to the ventilation system on the 1 : 20 fairing, and in Fig. 8 the stability limits from the two fairings are compared. The 1 : 15 fairing has a better lower limit stability at the hump—1 deg lower than the 1 : 20—but the 1 : 20 skipping limit is 2 deg higher and occurs at higher speed than that of the 1 : 15.

Individual trim curves are illustrated in Figs. 9 to 11 and compared with the 1 : 15 fairing in Fig. 12. The increased planing trim caused by the 1 : 20 fairing is at once obvious. The addition of forced ventilation has reduced the difference slightly.

4.2. *Landing Stability.*—The method of analysing landing performance has been described in R. & M. 2463, and for convenience the notation is repeated here.

\+ Stable landing. The aircraft touches down at fixed elevator position and is subsequently free from any violent motion in pitch or heave.

⊞ Borderline landing. The aircraft exhibits considerable movement in heave and/or pitch but does not leave the water.

⊡ Skip landing. Immediately on touch-down the attitude increases rapidly and the aircraft is thrown into the air. If in the subsequent touch-down another skip occurs this is also plotted as an unstable point.

In Fig. 13 the touch-down stability points have been plotted. Unstable landings occurred over the whole range of available landing attitudes and hence no stability limit has been drawn. The stable points which seem to be scattered at random among skipping points, were obtained by ‘ flying ’ the aircraft on to the water under power and with very little rate of descent.

4.3. *Hydrodynamic Resistance.*—A feature of the tests on the 1 : 20 fairing was the effect of forced ventilation on planing resistance. This is best illustrated by Fig. 14 which compares the full throttle planing accelerations for the 1 : 20 fairing with and without forced ventilation and those of the 1 : 15 fairing with forced ventilation.

Two points are noteworthy :—

(i) The 1 : 20 hull with forced ventilation has only slightly more than half the acceleration of the 1 : 15 hull at 6,200 lb.

(ii) The addition of forced ventilation increases the acceleration of the 1 : 20 hull by about 0·015*g*. at a weight of 6,200 lb.

4.4. *Air Flow.*—During tests with forced ventilation the air flow from the compressor was maintained at 83 lb/min which is equivalent to 1,050 cu ft/min at the mean delivery temperature and pressure (85 deg C and 18·7 lb/sq in.).

The air flow through all three sets of ducts was measured and the results for the forward and intermediate sets are plotted in Figs. 15 to 18. Fig. 15 deserves special comment since it shows that the forward ducts provide no effective ventilation when the aircraft is planing above the free to trim attitude. Unfortunately the measuring apparatus of the large aft ducts was insensitive to all but large air flows and the air flow through these ducts fluctuated so violently that the construction of a speed-flow curve was not possible. However, the order of air flow induced through the aft ducts may be gauged from the plots of individual landings shown in Figs. 19 and 20.

5. *Discussion.*—5.1. *Take-off Stability and Trim.*—At 5,900 lb all-up-weight, the stability limits for the 1 : 20 fairing follow the pattern obtained for more conventional fairings. The validity of the stable points at take-off for 4 deg pitching disturbance should discount their being applicable to calm conditions only. When skipping does occur, however, it is vicious and likely to prove hazardous with an inexperienced pilot or with a less easily controlled aircraft.

Evidence on the effect of weight on upper stability limits is confusing, probably because there are two conflicting actions at work. The improved afterbody-wake clearance resulting from the increased draft reduces the afterbody suctions and tends to raise the skipping limit but to counteract this effect, the increased draft also results in a loss of chine ventilation. Since most of the ventilation for the 1 : 20 fairing is provided from the hull interior and not from the chines, the former effect should predominate and the skipping limit should be raised with increase in weight. This contention is confirmed by the results (Figs. 5 to 8).

But there is a dangerous motion with the 1 : 20 fairing at 6,200 lb which is not clearly emphasised in the stability diagram in its present form. At, and immediately after the hump where the increase in weight has raised the lower limit well above the free-to-trim curve, lower limit porpoising may be sufficiently violent to trim the aircraft into the porpoising upper limit. The motion which ensues may lift the aircraft out of the water even at this low speed (25 to 30 kt) and because of the large porpoising amplitude there is a real danger of ' nosing in.' This characteristic was most marked in the present tests owing to the small acceleration of the naturally ventilated fairing through the danger region. As in the tests on the 1 : 15 fairing, forced ventilation produced no apparent amelioration of the take-off stability. This is hardly surprising when one compares the 3,000 cu ft/min supplied by the naturally ventilated aft ducts with the 1,000 cu ft/min supplied by the compressor.

The improved skipping limit of the 1 : 20 hull compared with that of the 1 : 15 hull may be attributed to the better ventilating system of the former. When the blower was in operation the total air flow to the 1 : 15 fairing was approximately 1,400 cu ft/min at take-off, while for the 1 : 20 fairing with natural ventilation alone, the total air flow was almost 4,000 cu ft/min. Admittedly the limits for the 1 : 20 fairing at 6,200 lb are open to criticism since they were determined for the zero disturbance condition, but the improvement is marked even at 5,900 lb where the limit is valid for a 4 deg disturbance.

The trim curves (Figs. 9 to 12) warrant no particular comment.

5.2. *Landing Stability.*—During landing tests at 5,900 lb it was discovered that the tendency to skip was very sensitive to the rate of descent at touch-down. The stable landings scattered apparently at random among unstable points in Fig. 13 were all achieved by adopting a flat engine-assisted approach and touching down with very little vertical velocity. This sensitivity to rate of descent, which can be interpreted as a sensitivity to disturbance in heave, may account in some measure for the difference between the stable range in take-off and that in landing, for the 1: 20 hull. Take-off and taxy-run tests are normally made in calm water, and though a disturbance in pitch may be applied by the pilot there is little likelihood of a disturbance in heave occurring.

If this theory is true, then it gives rise to a point of considerable importance. In towing tank test work a seaplane hull is usually tested in the taxy-run condition and pitching disturbance only, applied. For a long fairing of the present Saro 37 type, this technique would not uncover the inherent dangerous landing characteristics of the hull. Before expressing any dogmatic opinion, however, more quantitative data on this disturbance sensitivity is required. It may well be that only very highly faired hulls have this particular characteristic and that for conventional hulls the landing stability can be deduced with sufficient accuracy from the take-off performance.

5.3. *Hydrodynamic Resistance.*—The increased resistance of the 1 : 20 fairing over its 1 : 15 counterpart (Fig. 14) may be attributed to two effects :—

(i) Increased afterbody wetting brought about by the reduced afterbody clearance of the 1 : 20 fairing.

(ii) Less efficient separation of the flow at the step because of the reduced forebody-afterbody angular discontinuity.

Of these two, the latter appears to have more effect, for the following reasons :—

(i) Increased afterbody wetting is usually associated with the phenomenon called ' afterbody sticking ' (*cf.* R. & M. 2463). No afterbody sticking was encountered with the 1 : 20 fairing.

(ii) During planing, the air flow through the forward set of ducts was negligible unless the running attitude were lower than the free-to-trim attitude, indicating that the forward duct exits were still being wetted in this condition.

(iii) The ejection of air through the forward ducts, by helping the separation process, produced a considerable reduction in planing resistance. (Fig. 14).

For any highly faired hull, therefore, ventilation has to serve two functions. Forced ventilation is required immediately aft of the step to induce a separation there, and additional ventilation, forced and/or natural must be provided further aft to ensure an adequate supply of air to the regions of minimum pressure on the afterbody. The need for forced ventilation immediately behind the step is dictated by the forebody-afterbody angular discontinuity. With the 1 : 15 fairing, having a forebody-afterbody angle of 13 deg, the planing resistance was not appreciably improved by forced ventilation.

6. *Conclusions.*—6.1. *Stability.*—

(i) At 5,900 lb all-up weight ($C_{\Delta 0} = 1{\cdot}0$) the Saro 37 with a 1 : 20 double curvature step fairing has a fair stability range in take-off but the landing stability is bad. The hull appears to be very sensitive to disturbance in heave.

(ii) At 6,200 lb all-up weight ($C_{\Delta 0} = 1{\cdot}05$) the take-off skipping limit is raised by 1 deg, and is 2 deg above the corresponding limit for a 1 : 15 fairing on the same hull and at at the same weight, the 1 : 15 fairing having less ventilation area than the 1 : 20.

(iii) The addition of forced ventilation to the 1 : 20 hull at 6,200 lb all-up weight produces no apparent amelioration of the stability characteristics in take-off (effect on landing could not be examined), but does lower the free to trim curve.

6.2. *Resistance.*—

(i) At 6,200 lb all-up weight the addition of forced ventilation to the 1 : 20 fairing raises the mean planing acceleration by $0{\cdot}015g$.

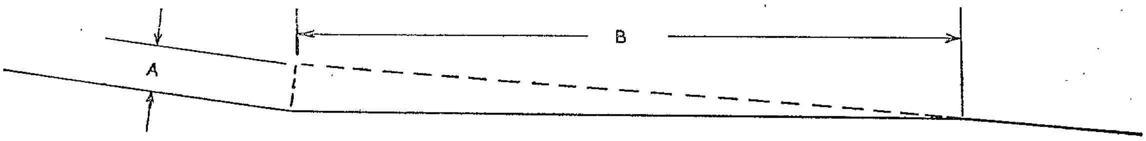
(ii) Even with forced ventilation however, the planing resistance of the hull with the 1 : 20 fairing is much greater than that of the hull with the 1 : 15 fairing.

List of Symbols

α_k	Attitude of forebody keel to horizontal.
η	Elevator angle.
C_v	$\dfrac{V}{\sqrt{gb}}$ (Froude number).

Definitions

Heel-to-Heel line.	Straight line joining the forebody keel at the main step to the aft step.
Heel-to-Heel angle	Angle between forebody keel and heel-to-heel line.
Afterbody Angular Break.	Angle between the tangent to the step fairing at the forebody keel and the forebody keel line.
Fairing Ratio.	is defined as A : B where A and B are as in the sketch :—



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No.	*Author*	*Title, etc.*
1	J. A. Hamilton	An investigation into the effect of forced and natural afterbody ventilation on the hydrodynamic characteristics of a small flying boat (Saro 37) with a 1 : 15 fairing over the main step. R. & M. No. 2463. December, 1946.

TABLE 1

Aircraft Data

Hull	
Beam	4·52 ft
*Forebody length	16·39 ft
*Afterbody length	14·96 ft
Unfaired step depth	4·8 in.
Angle of forebody keel to hull datum	1° 32′
Angle of deadrise at step	25°
After keel angle to forebody keel	7° 38′
Heel-to-heel angle	9° 9′
Keel angle to wing no-lift angle	—6° 9′
Wings	
Gross area	340 sq ft
Span	50 ft
Aspect ratio	7·35
Tailplane	
Total area	53·9 sq ft
Span	16·54 ft
Elevator area	18·25 sq ft
Elevator movement	25° Up 20° Down

* Measured from front perpendicular to the keel at the step line.

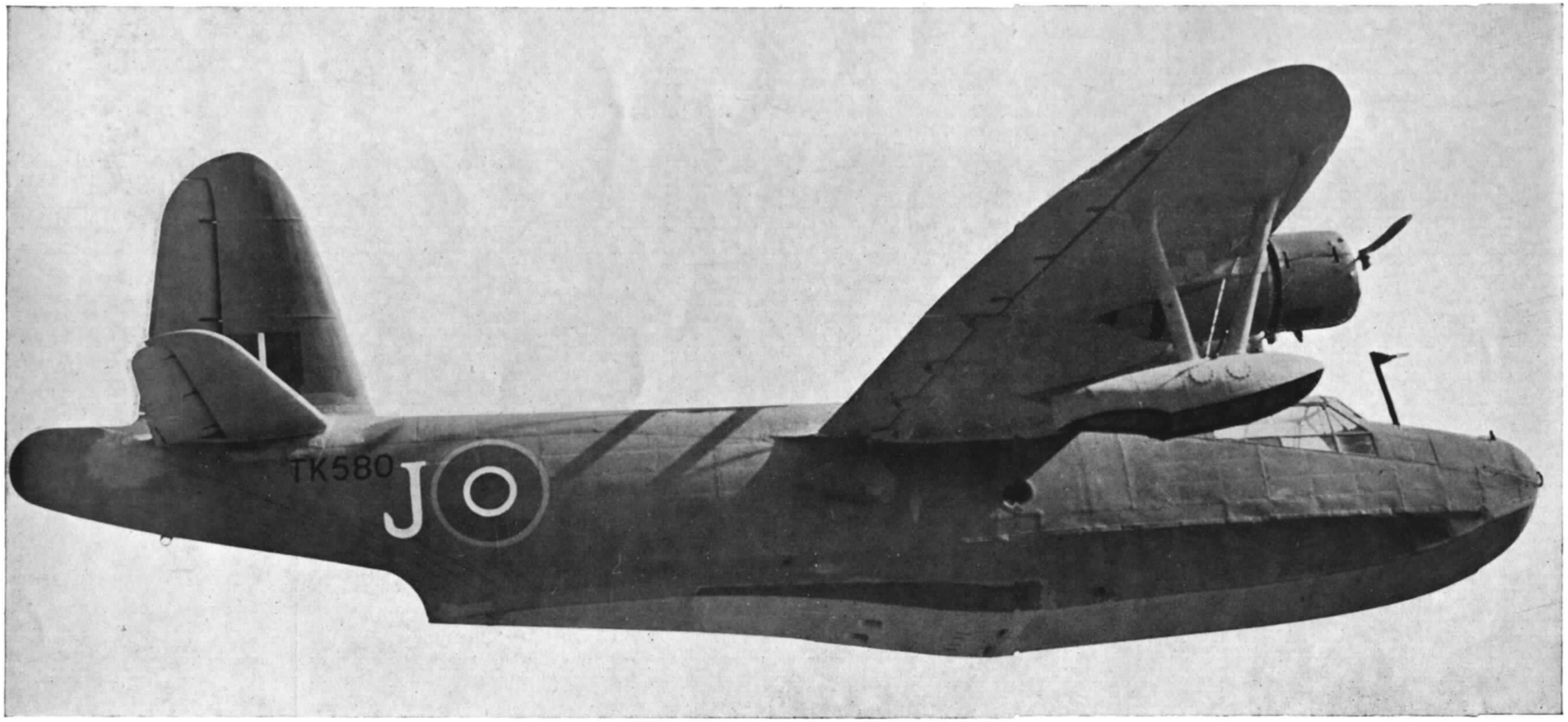
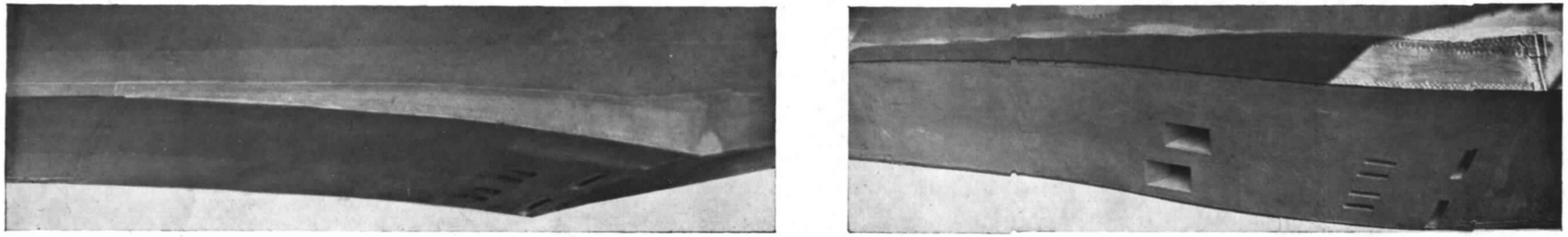


FIG. 1. Saro 37. 1 : 20 double curvature fairing fitted



1 : 15

1 : 20

FIG. 2. Comparison between 1 : 15 and 1 : 20 fairings showing ventilation exits.

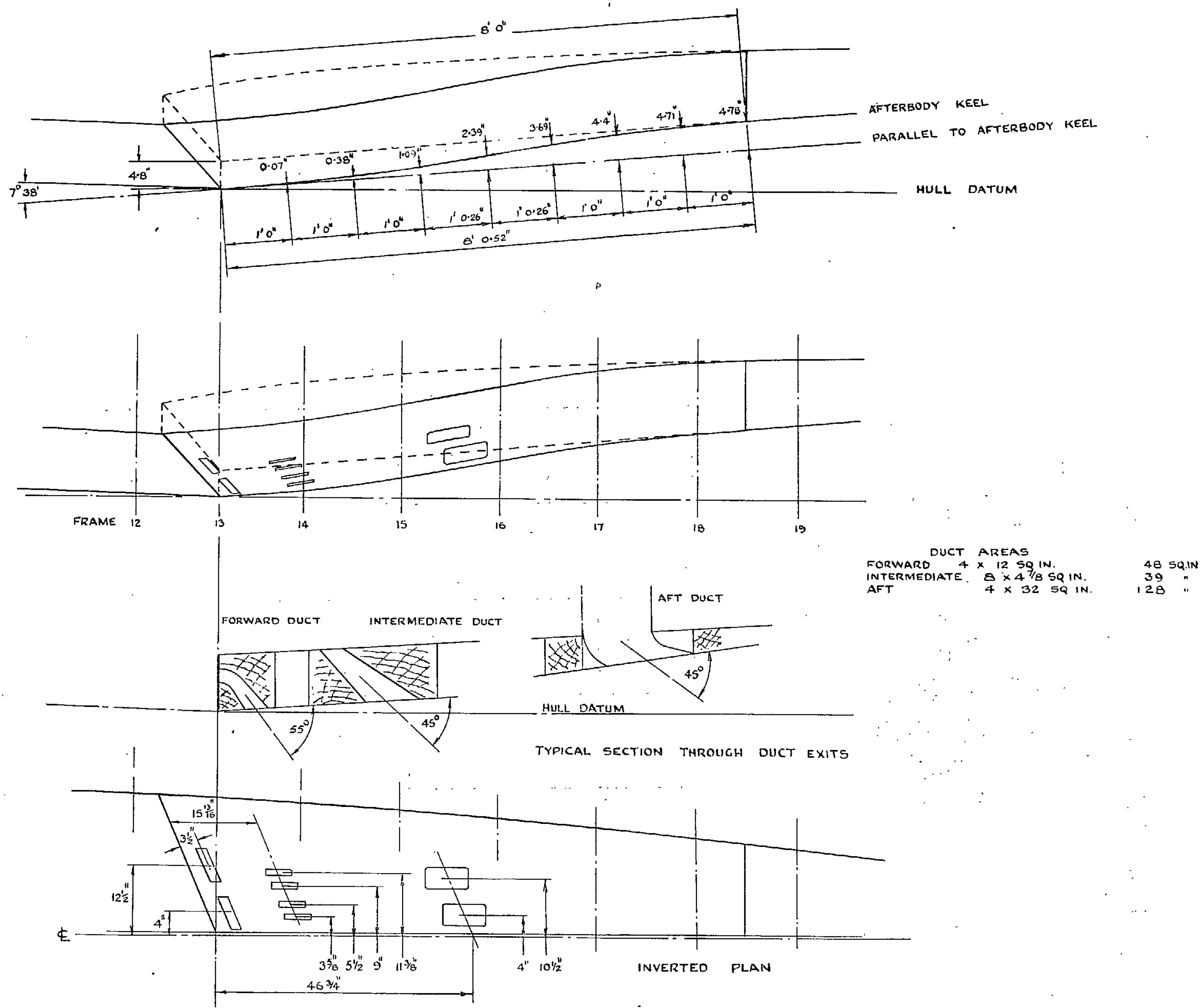


FIG. 3. Dimensions of 1 : 20 fairing and ventilation exits

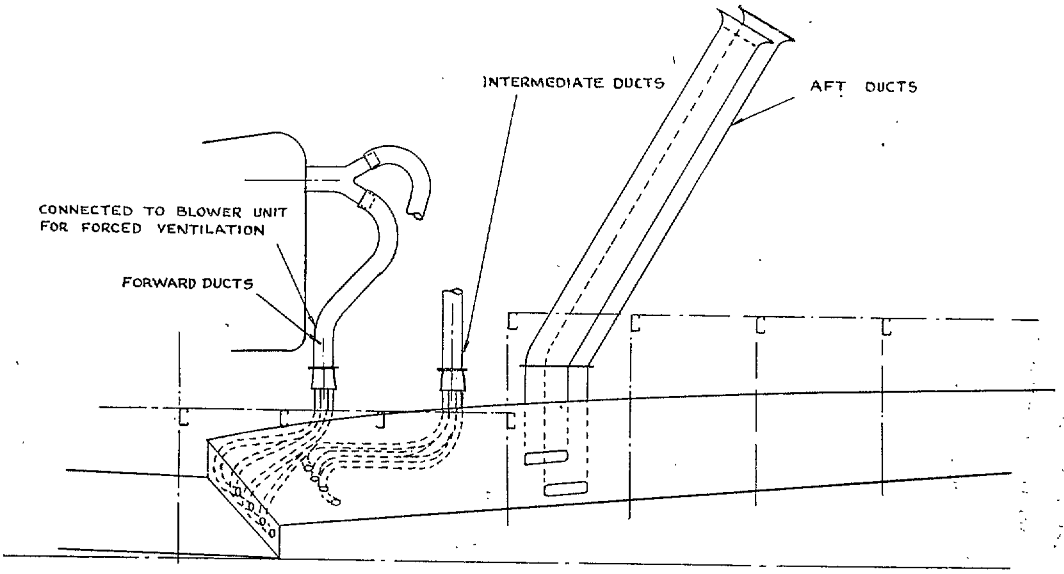


FIG. 4. Ventilation system 1 : 20 fairing

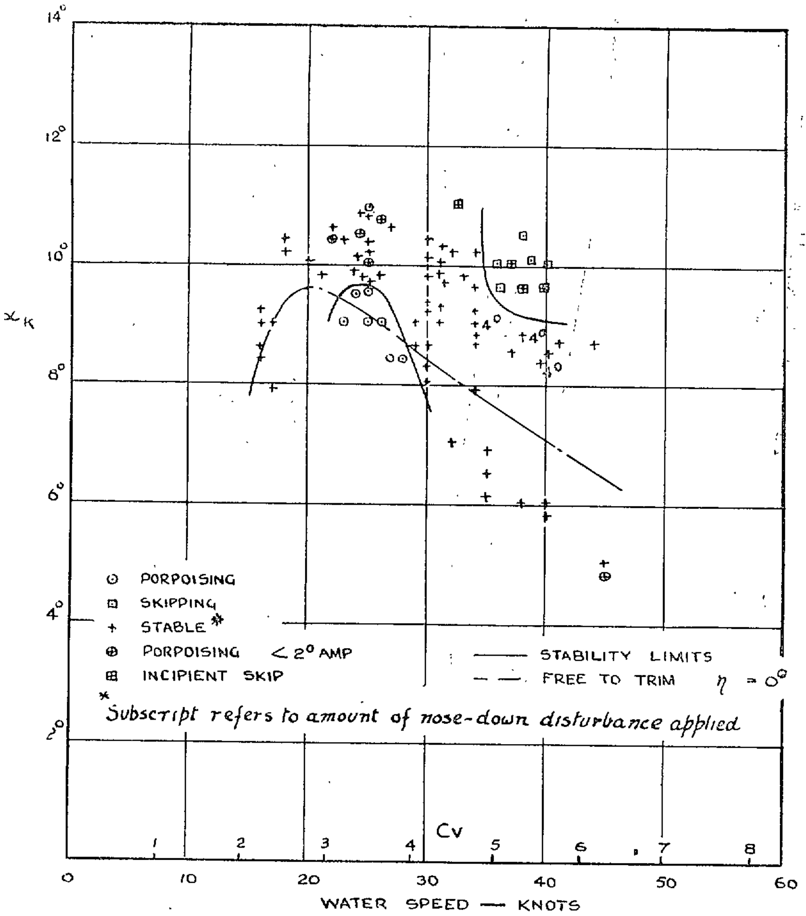


FIG. 5. Take-off stability. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

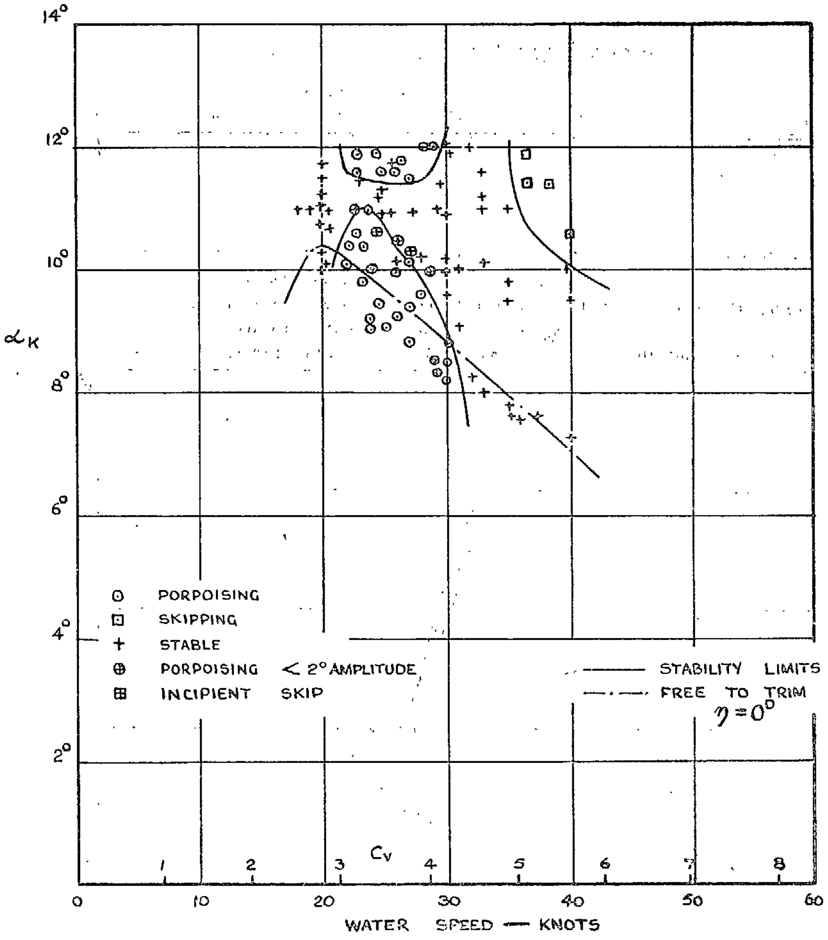


FIG. 6. Take-off stability. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural ventilation

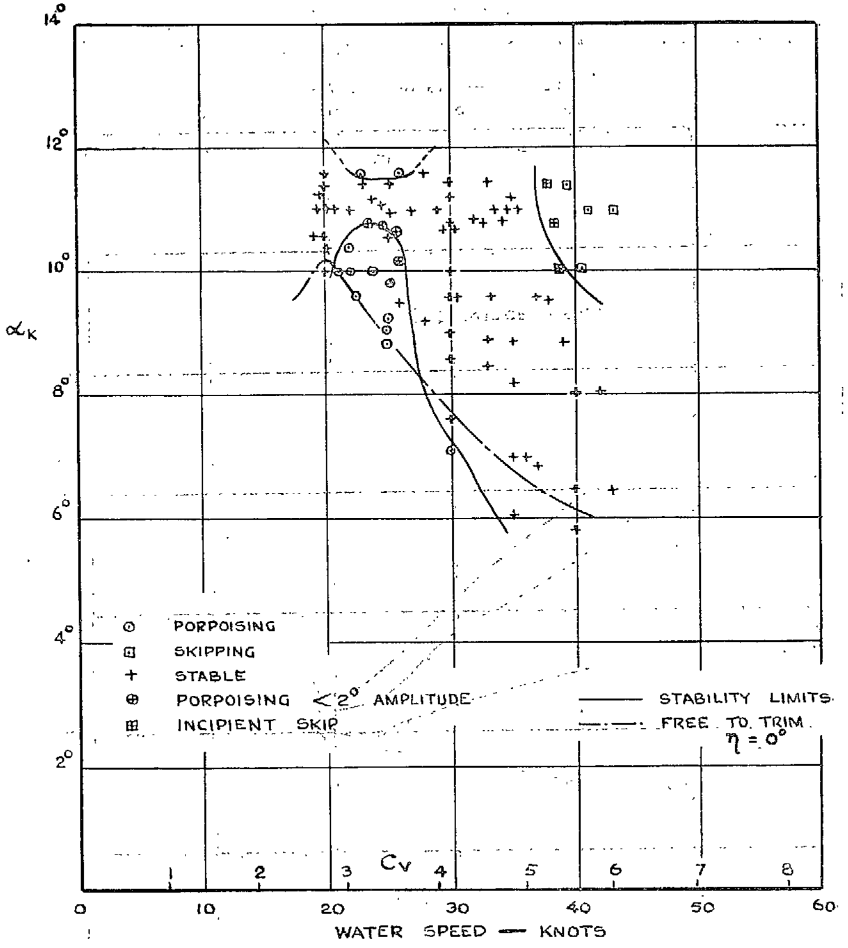


FIG. 7. Take-off stability. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural and forced ventilation

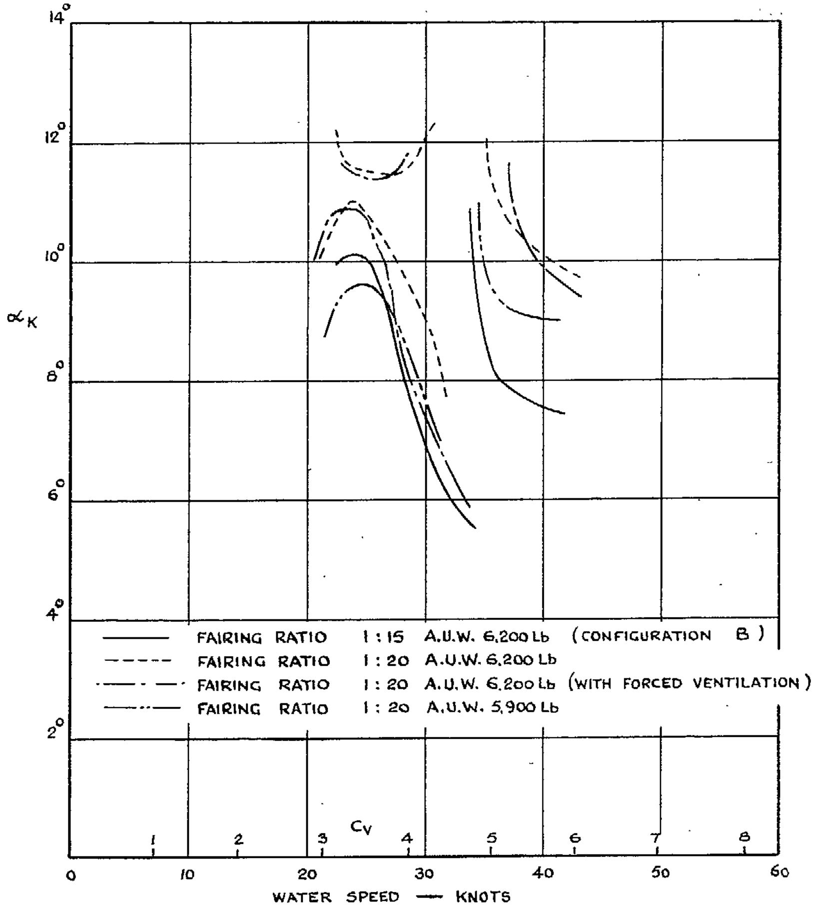


FIG. 8. Comparison of stability limits.

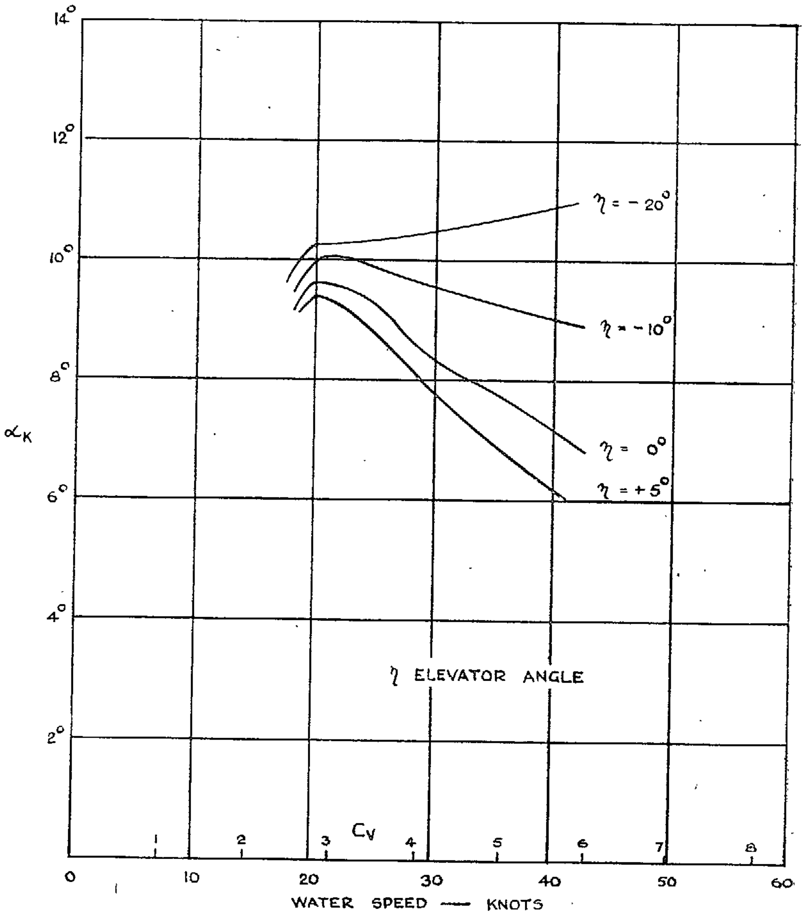


FIG. 9. Trim curves. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

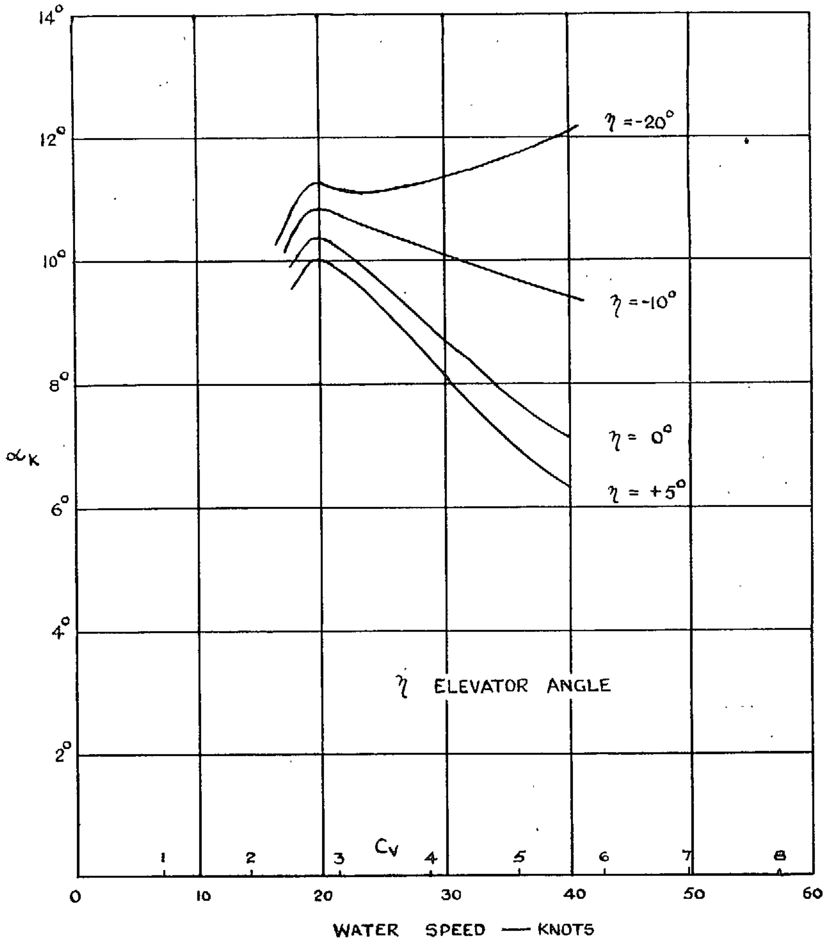


FIG. 10. Trim curves. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural ventilation

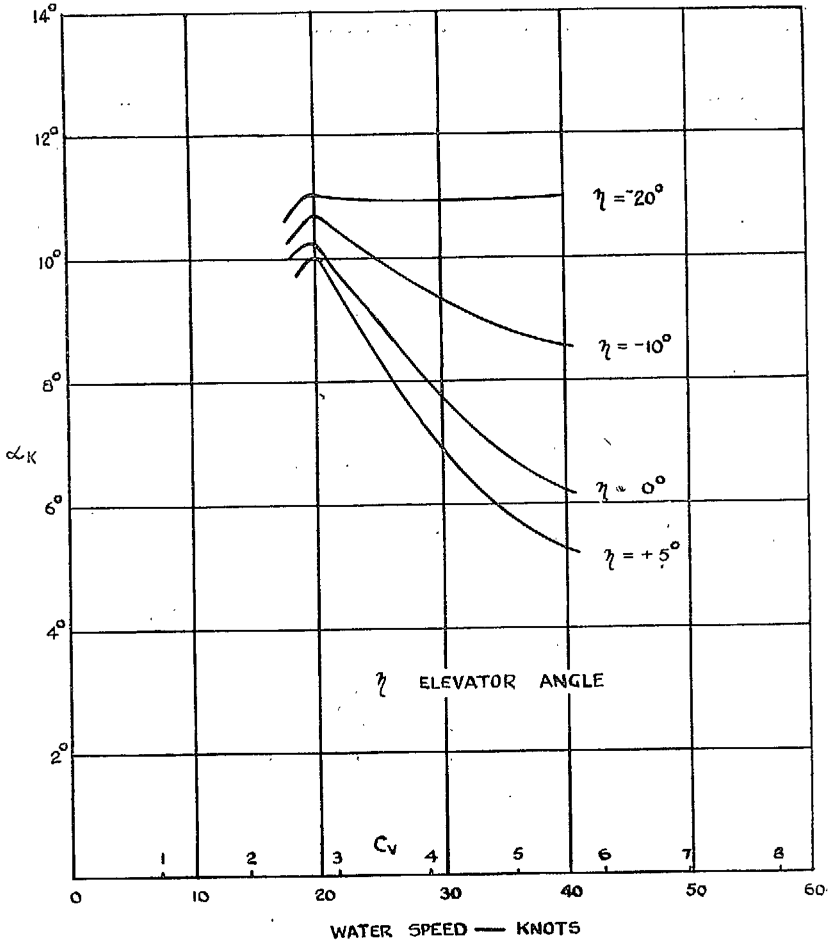


FIG. 11. Trim curves. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural and forced ventilation

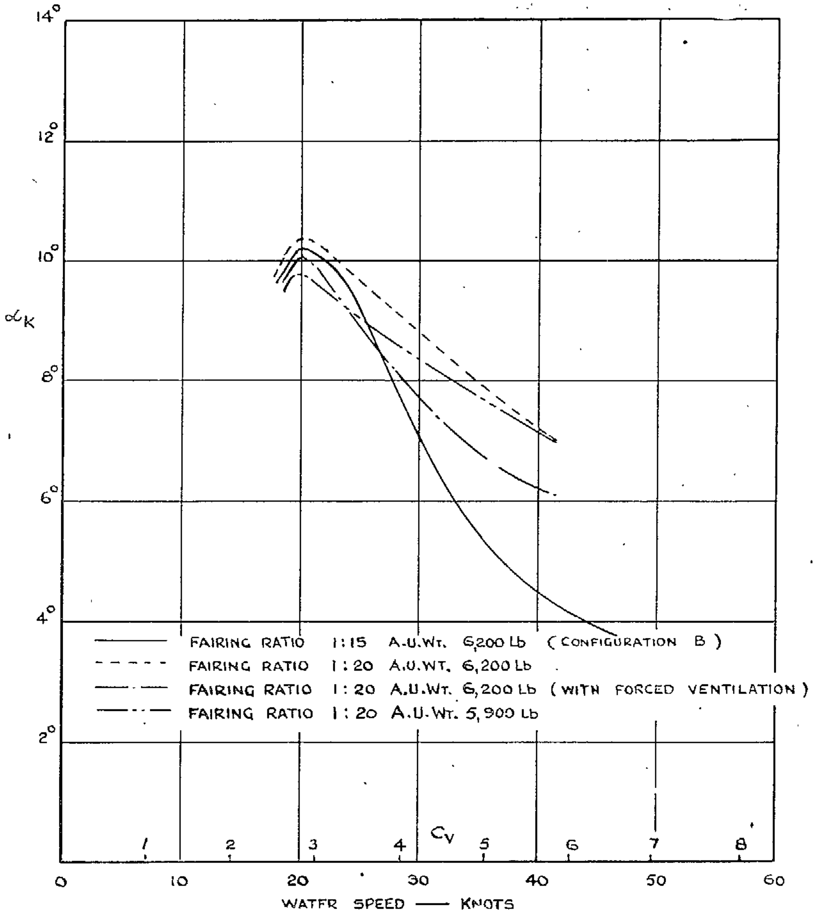


FIG. 12. Comparison of free to trim curves

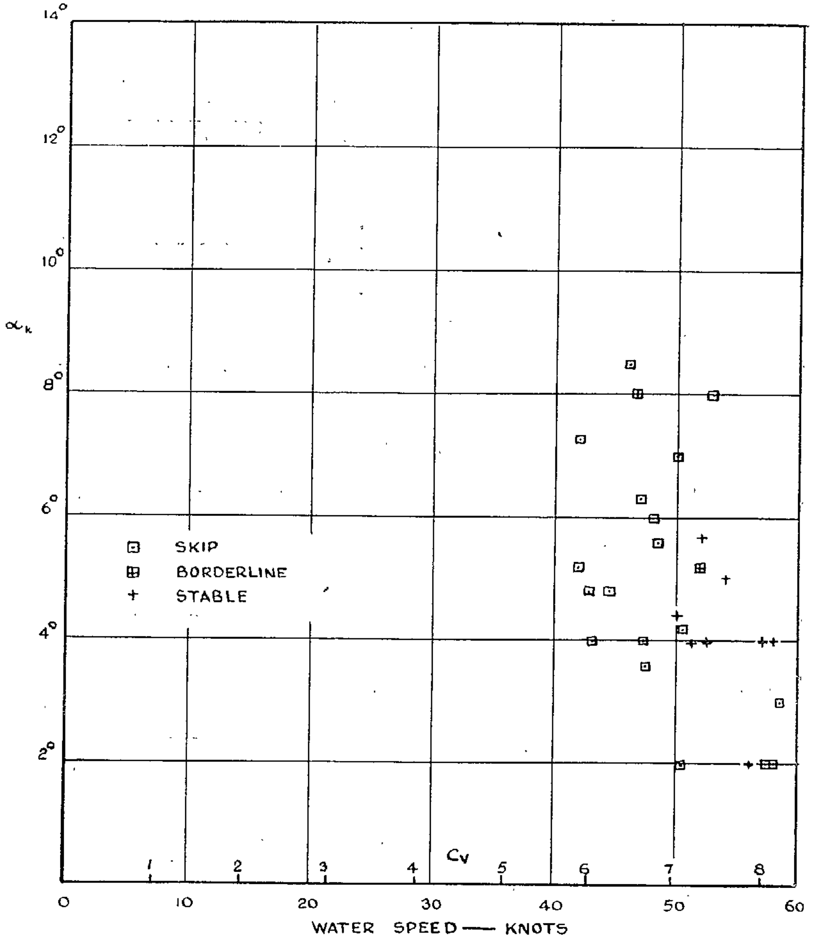


FIG. 13. Landing stability. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

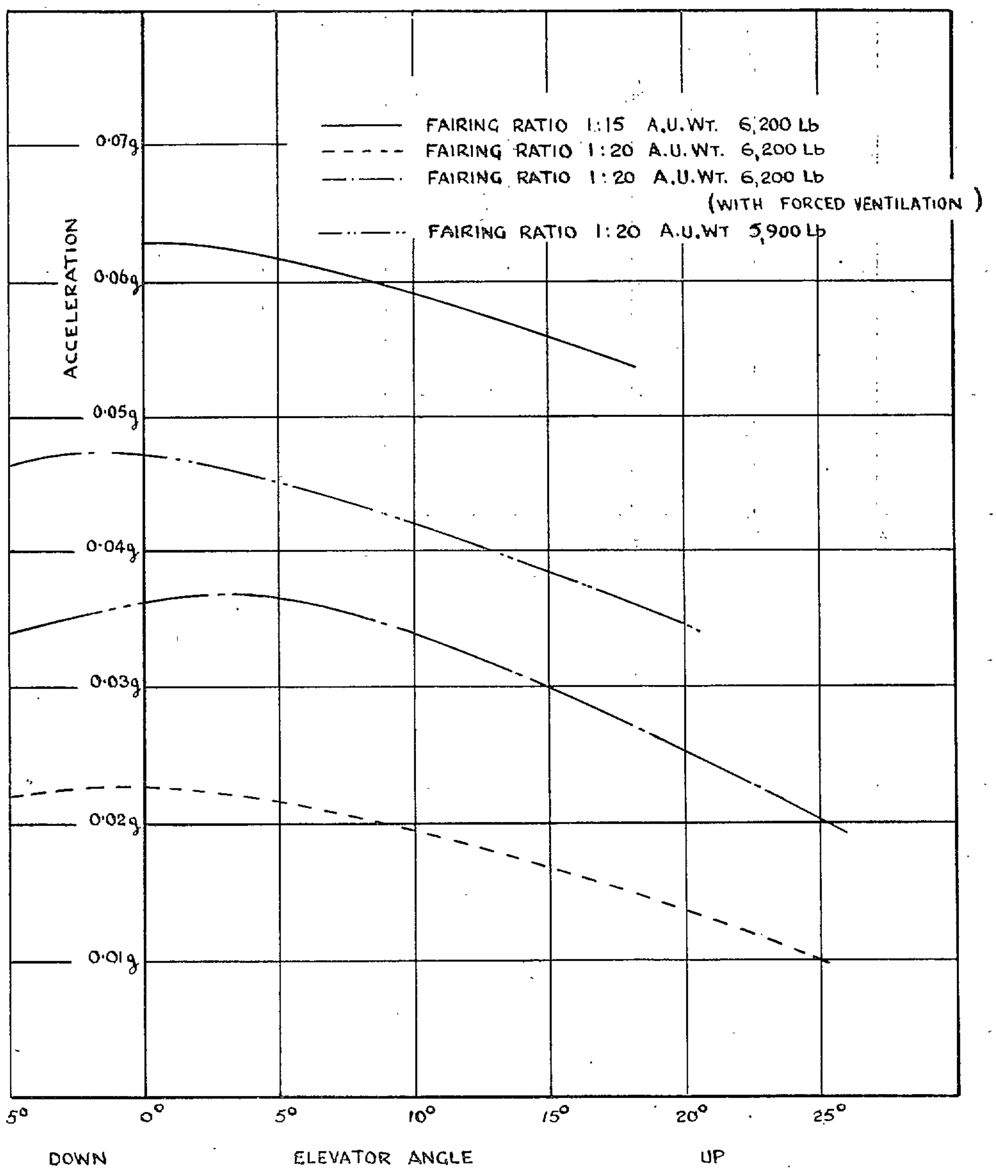


FIG. 14. Effect of fairing and ventilation on the mean longitudinal acceleration during planing

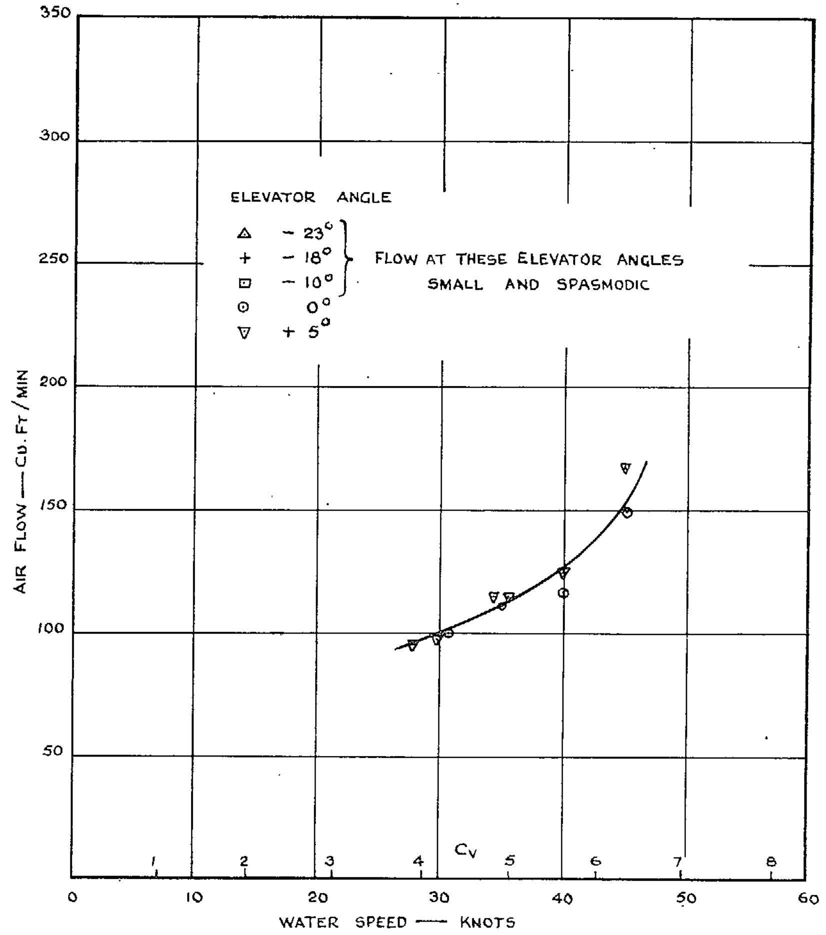


FIG. 15. Air flow through forward ducts. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

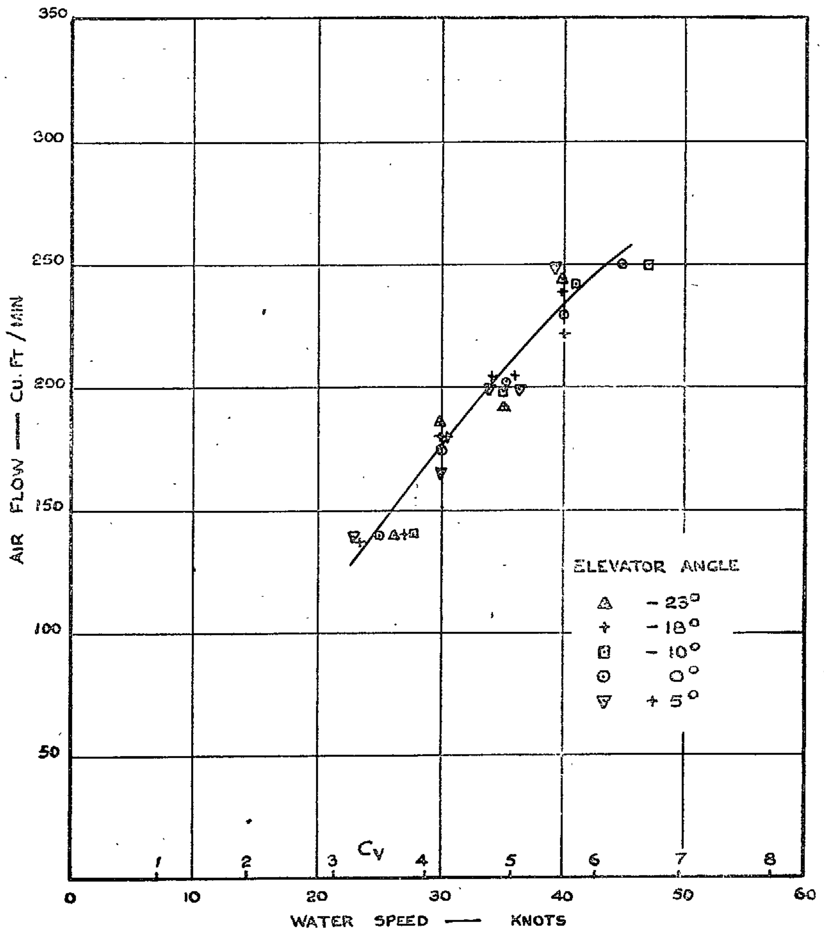


FIG. 16. Air flow through intermediate ducts. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

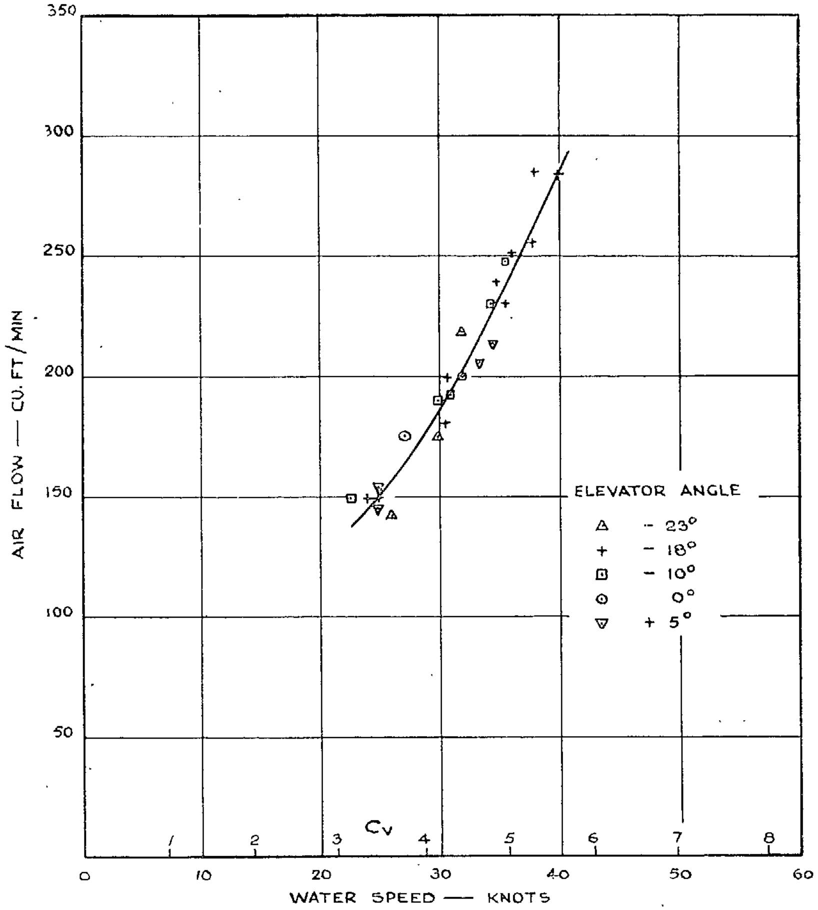


FIG. 17. Air flow through intermediate ducts. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural ventilation

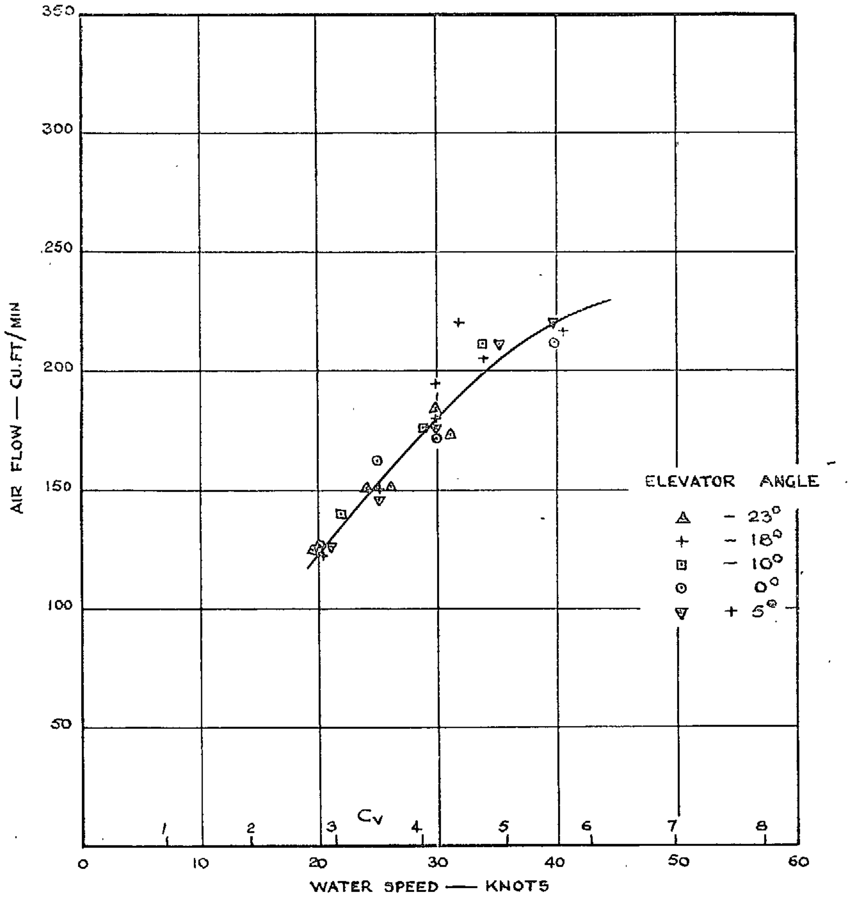


FIG. 18. Air flow through intermediate ducts. Fairing ratio 1 : 20. All-up weight 6,200 lb. Natural and forced (forward ducts only) ventilation

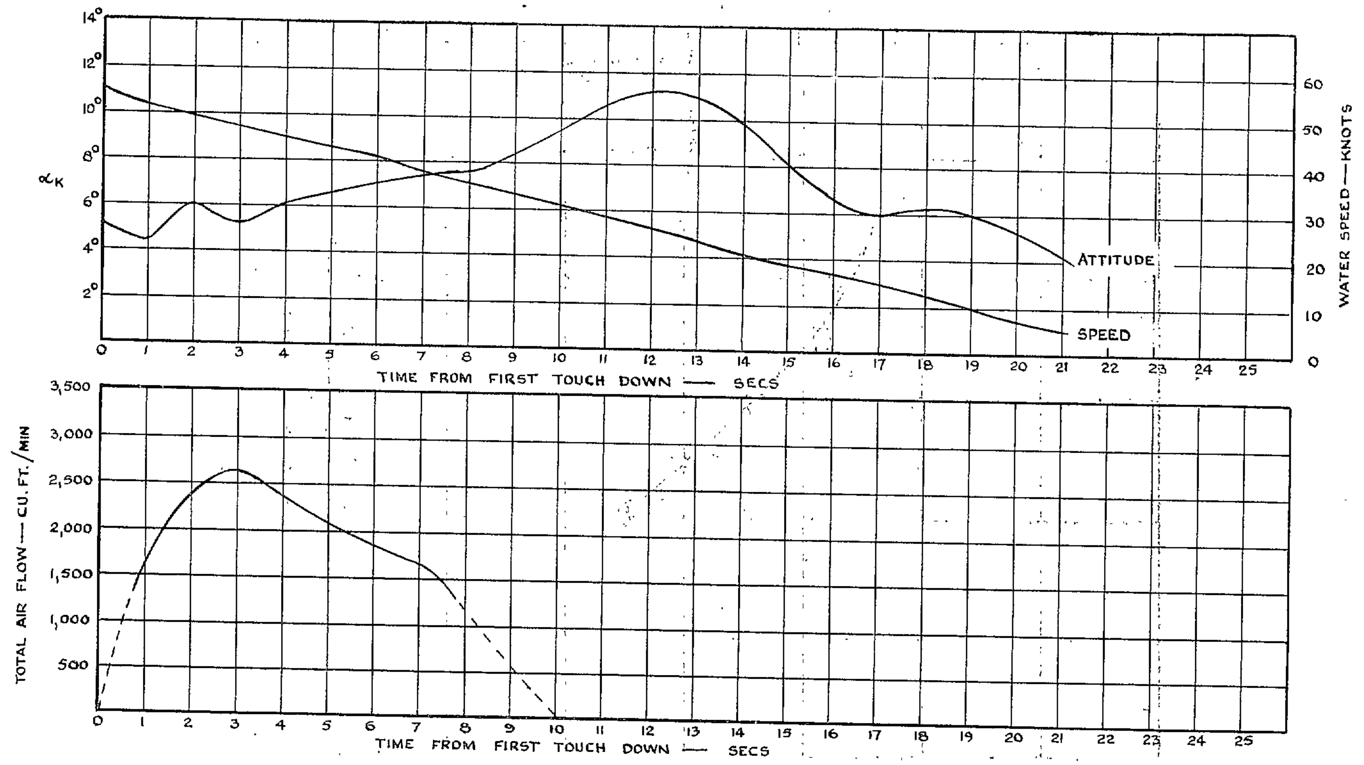


FIG. 19. Stable landing showing air flow through aft ducts. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

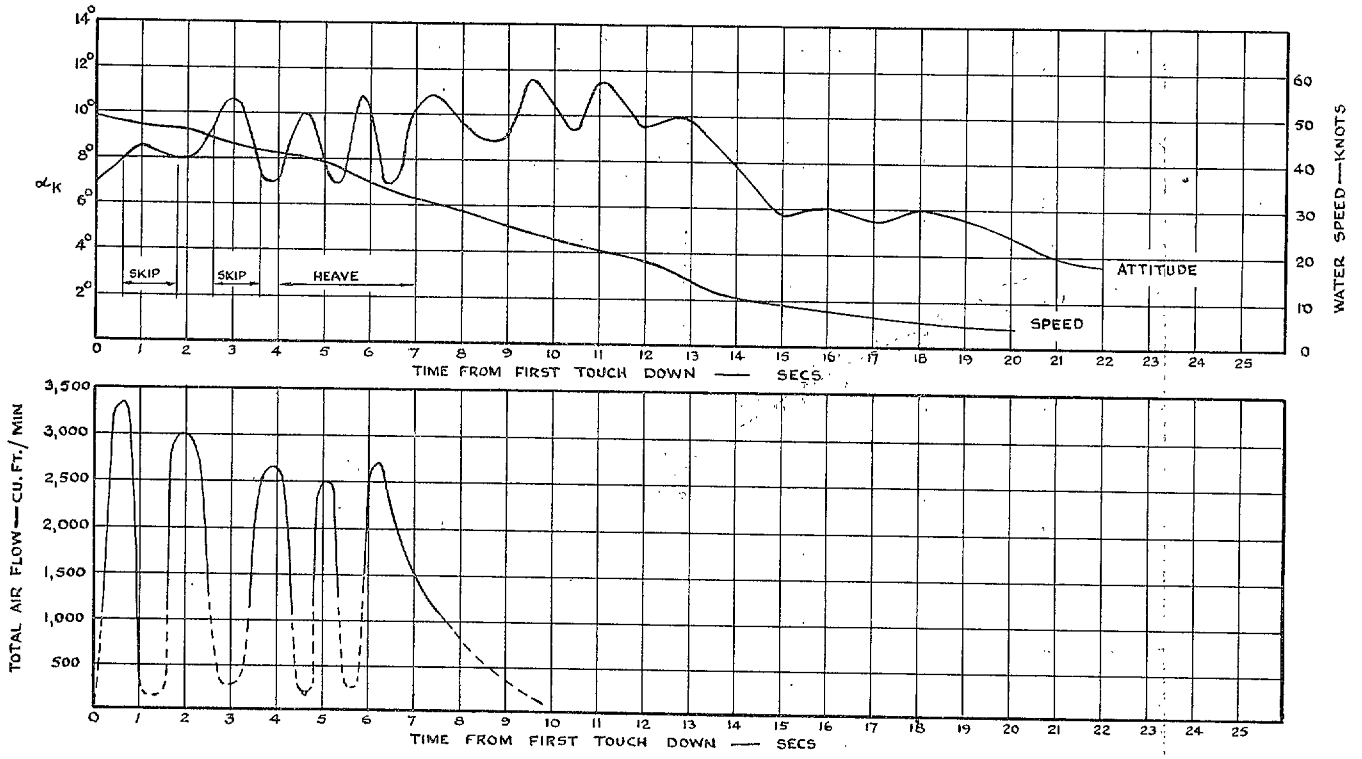


FIG. 20. Unstable landing showing air flow through aft ducts. Fairing ratio 1 : 20. All-up weight 5,900 lb. Natural ventilation

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