R. & M. No. 2719
(6834)
A.R.C. Technical Report



MINISTRY OF SUPPLY

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# A Method for Determining the Water Stability of a Seaplane in Take-off and Landing

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H. G. White, B.Sc., and A. G. Smith, B.Sc., A.R.C.S., D.I.C.



LONDON : HIS MAJESTY'S STATIONERY OFFICE
1952
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# A Method for Determining the Water Stability of a Seaplane in Take-off and Landing

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Communicated by the Principal Director of Scientific Research (Air),
Ministry of Supply

*Reports and Memoranda No.* 2719*

*May,* 1943

*Summary.*—A direct method of determining the water stability in take-off and landing of full-scale seaplanes is described. The customary method of measuring full-scale stability is by steady runs over a range of speed and attitudes. This is tedious ; it does not give the true take-off stability and does not give the landing stability. The steady-run stability is assumed to correspond very closely to the take-off stability but was originally used to obtain full-scale conditions comparable with model scale. This report gives a method of analysis of take-off records of attitude against speed, and results obtained by this method are compared with the steady-run results.

Results on the Scion fitted with a $\frac{1}{2}$ scale Sunderland hull and Saro with a $\frac{1}{2\cdot75}$ scale Shetland hull are used to establish the method, but it has also been checked against the available date on the full-scale Seal and Sunderland I.

The take-off stability limits show remarkable agreement with the corresponding steady run limits (to within $\frac{1}{2}$ deg) of the Scion and Saro. Evidence on the Seal and Sunderland is insufficient for a definite conclusion in these cases, but there is no disagreement between the results obtained. The method is accurate and quick to use, but takes no account of of the amplitude of porpoising so that a few steady runs would still be necessary to establish this where required. By use of this method the investigation of the stability characteristics of a seaplane under different conditions of weight, c.g. and flap angle can proceed quickly on the evidence of about eight take-off records at each condition, these records covering the full attitude range. The method may also be applied to find landing stability from landing records.

1. *Introduction.*—A direct method of determining the water stability of full-scale seaplanes in take-off and landing was required which would be quick and accurate. It has been customary in recent years to investigate the water stability of seaplanes by means of steady runs. This method gives good results but it takes a long time in practice, since a large number of runs have to be made each of which requires the attainment of steady speed. It was originally adopted in order to reproduce as closely as possible the conditions of model tests (which are made at steady speeds) so that evidence might be afforded on the validity of model tests and scale effect. Model tests assume that there is no acceleration effect on stability although there might be on amplitude, so that such results will apply to take-off and landing conditions. Full-scale steady runs require the use of engine and are therefore subject to slipstream and thrust effects which are a little less than those present during a take-off run, particularly in the region of the hump speed. They have in fact been assumed to represent take-off conditions. Steady-run tests without engine cannot be made full scale so that no full-scale landing stability limits have so far been obtained.

A direct method of obtaining limits from take-off and landing attitude records would therefore give considerably more quantitative information on full-scale stability and check the validity of both model and full-scale steady run tests. Since the difference between full-scale steady runs and take off conditions is slight, a comparison of take-off and steady-run limits has been made as the best test possible of the method of determining take-off limits.

* M.A.E.E. Report H/Res/163—received 28th June, 1943

2. *Range of Investigation.*—Take-off records of attitude against water speed have been analysed to give the stability limits which have been compared with the results of steady-run tests. The records for the Scion with the half-scale Sunderland hull[1] and the Saro 37 with the $1/2{\cdot}75$ scale Shetland hull[2] have been chosen to illustrate the method as they are the most complete results available. The method has also been checked against the full scale Seal[3], and Sunderland[4], for which a limited amount of information was available.

3. *Analysis of Take-off and Landing Records.*—In a take-off, attitude and acceleration are recorded against time by a two-axis accelerometer and gyro pitch recorder. The longitudinal acceleration, corrected for attitude, is integrated and the result added to the initial water speed to give the water speed at any time. From the resulting curve of attitude against water speed the stability can be determined. (Water speed rather than air speed is the determining factor for water stability.)

For the purposes of this analysis, instability in take-off is defined by undamped porpoising. Porpoising regardless of amplitude is used because the actual amplitude has little significance in accelerated motion when the region of instability may be passed quickly. A mean curve is drawn through the record of attitude against speed and the record examined at chosen intervals of water speed. If the attitude curve is steady or any oscillation is damped, a stable point is plotted at the mean attitude; if a divergent or steady oscillation is present, an unstable point is plotted at the mean attitude. When there is any variation in the stability over the chosen intervals of water speed, additional points are plotted at intermediate speeds in order to obtain a greater density of points on the borderline between stable and unstable conditions, *i.e.*, on the limit of stability. A single oscillation is not taken to indicate instability since the first change in attitude may be due to a disturbance such as elevator movement or waves and which, when there is no instability, damps out. A second peak of greater or equal amplitude is necessary to prove instability. Stable and unstable points are plotted by this method over as wide a range of speed and attitude as possible and stability limits drawn. Where possible, records of elevator angle against water speed are also examined so that any apparent porpoising due to elevator movements may be detected. The take-offs should be made with fixed stick positions, as far as possible, to eliminate angular displacements due to elevator movement, but in doubtful regions a known displacement will help to establish stability characteristics. Similarly a train of waves may cause apparent instability but examination of the period of oscillation from the attitude time record will easily detect such cases, especially at high speeds. The take-offs should also be made in calm conditions with the wind speed generally less than 5 kt to avoid wind effects and big wave disturbances.

These stability limits are based on all unstable points regardless of amplitude and will therefore be defined for future use as the minimum stability limits, because they define a minimum stable range. They differ from the steady-run limits based as unstable oscillations of over 2 deg amplitude only, which will be defined as the '2 deg stability limits'[7]. They are comparable with minimum steady-run stability limits. It is impossible to specify a limiting amplitude for accelerated runs since insufficient time is allowed at any one speed for the maximum amplitude to build up.

4.1. *Scion (c.g. Normal) Take-off Stability.*—Scion (c.g. normal) take-offs are shown in Fig. 1. The stability points derived from these take-offs are shown in Fig. 2 and the corresponding steady-run results in Fig. 3. Figs. 2 and 3 show that there is very good agreement both between the distribution of stable and unstable points and in the shape and position of the limits for the take-offs and steady runs. There are local differences of up to 1 deg between the limits, but examination of the individual points suggests that these differences are mainly due to difference in interpolation in drawing the limits. Comparison of the points available shows no evidence of real difference between the limits. The limitation of 2 deg amplitude which defines the standard limits apparently makes little difference to the comparison in this case.

4.2. *Scion (c.g. Forward) Take-off Stability.*—Take-offs for the Scion, c.g. forward, are shown in Fig. 4, derived stability points in Fig. 5, and steady-run results in Fig. 6. The high attitude take-offs with stick back terminate at about 35 kt and so the upper limit does not cover the whole speed range. The take-off and steady-run limits are in fair agreement but there is an indication of more instability in the take-off case. There is practically no stable range from 20 to 30 kt in take-off, whereas there is a 2 deg range for the 'steady-run 2-deg limits' and 1 deg for the 'steady-run minimum limits'. Hence it appears that when the stability is small, the limitation of 2 deg amplitude can be important when drawing limits.

4.3. *Shetland Take-off Stability : c.g. Normal, 0 deg Flap, 120,000 lb.*—Shetland take-offs for a weight of 120,000 lb are shown in Fig. 7, the corresponding stability limits in Fig. 8, and the steady-run limits in Fig. 9. The comparison of the stability points for the take-offs and steady runs is again very good but the minimum stability limits as drawn differ by up to 1 deg in places. In the region of the hump speed and at low attitudes at high speed there is indication of more instability in take-offs than in steady runs. All the high attitude porpoising at the hump in take-off is very mild. This agrees with the steady-run results and such points would be unimportant in practice, as they are within the 2 deg steady-run limits. The bounce porpoise was only encountered once in these take-offs and it is within the steady-run bouncing porpoise[2] limit. No other cases within this limit were encountered.

4.4. *Shetland Take-off Stability : c.g. Normal,* 0 deg *Flap,* 130,000 *lb.*—Take-offs for the Shetland at 130,000 lb are shown in Fig. 10, derived stability points in Fig. 11, and the corresponding steady-run limits in Fig. 12. Both the points and minimum stability limits give exceptionally good agreement over the range of speeds and attitudes for which comparison is possible. Only one bounce porpoise was experienced in take-off and this is just on the edge of the corresponding steady-run bounce porpoise limit. The high-attitude, low-speed porpoising is mild in both take-offs and steady runs.

4.5. *Application of Method to Take-off Results for the Seal and Sunderland.*—Take-offs for the Seal[3] are given in Fig. 13, the derived stability points in Fig. 14, and steady-run Stability points in Fig. 15. The steady-run results have been taken from Ref. 3 and replotted in accordance with the present definition of porpoising as any undamped pitching oscillation. Stability limits have been interpolated from the take-off points and are also superimposed on the steady run points for comparison. On the basis of the definition of porpoising for minimum limits as any undamped oscillation in pitch, no stable range exists for the Seal in steady-run tests. However, there are insufficient take-off or steady-run data to establish reliable limits, and for the range available there is no disagreement. Some porpoising occurs within the limits drawn for both take-off and steady runs but qualitative agreement is good.

Sunderland[4] results are given for a weight of 43,000 lb, 0 deg flap and no fairing. Five take-off records are shown in Figs. 16, and the take-off and steady-run points in Fig. 17. A few more steady points are shown than in Ref. 4. The stability points for take-offs and steady runs show no disagreement where comparison is possible, but there is insufficient data for a complete comparison. The evidence is too slight for upper limits to be drawn but there does seem to be a common lower limit above 40 kt.

The data for the Seal and Sunderland are insufficient to draw reliable stability limits by the method proposed, but what is available shows no disagreement between take-off and steady-run minimum stability.

5. *Discussion.*—Since the stability points derived from take-offs give no indication of the amplitude of porpoising, the limits drawn for the take-offs are minimum stability limits and have been compared with the corresponding minimum limits for steady runs. The difference between these limits is never more than 1 deg and is generally less. The distribution of the points is always in excellent agreement and the small difference in limits would often appear to be due

to the personal equation in drawing these limits. The general comparison however, does suggest that slightly more instability occurs on take-off at the hump speed and near the take-off speed at low attitudes.

Since the take-off records are continuous it is possible to investigate stability at all speeds and to draw limits with greater precision than in steady runs where it is very difficult at times to obtain sufficient evidence in regions where the pilot has difficulty in maintaining a steady speed. For example, in the region of the hump speed, and near take-off speed.

The comparison of the take-offs and steady runs for the Seal and Sunderland is inconclusive because of the paucity of data available, but shows no evidence of disagreement between the two limits. Take-offs must be made over the complete range of attitudes in order to establish take-off stability limits by this method.

This method of analysis should provide a rapid determination of the minimum stability limits since it only requires about eight take-offs at steady stick positions to cover the complete attitude range. These measurements can be combined with acceleration and elevator efficiency measurements. It will, however, be necessary to supplement the take-offs with a range of steady runs around the limits indicated by the take-offs, so that the 2 deg amplitude limits can be drawn when required.

It should be emphasised here that this proposed method of determining stability from take-off records of attitude and speed should give the true stability for the take-off condition. There is no real reason other than the small differences in operating conditions, why steady run and take-off limits should disagree. The comparison with steady-run limits has been made because it is the only check possible of the validity of the method. Assuming the validity to be established in this way the method can be applied to landing records, but the limits will be expected to be quite different from the full-scale steady-run limits because of the different conditions.

6. *Conclusions.*—The method of establishing stability limits from seaplane take-off and landing records takes no account of the amplitude of porpoising but otherwise should give a very good indication of the water stability of the aircraft. There is fair agreement between the results obtained from take-off and steady-run tests, which means, on the one hand, that steady runs, and therefore, tank tests, give a good approximation to take-off conditions, and, on the other, that the steady runs form a reasonable check on the accuracy of the proposed method. A few steady runs will still be required to establish the 2 deg amplitude limits when required.

7. *Further Development.*—It is proposed to apply this method to the determination of stability on landings.

Further evidence will be collected in order to determine the value of this method of stability measurement.

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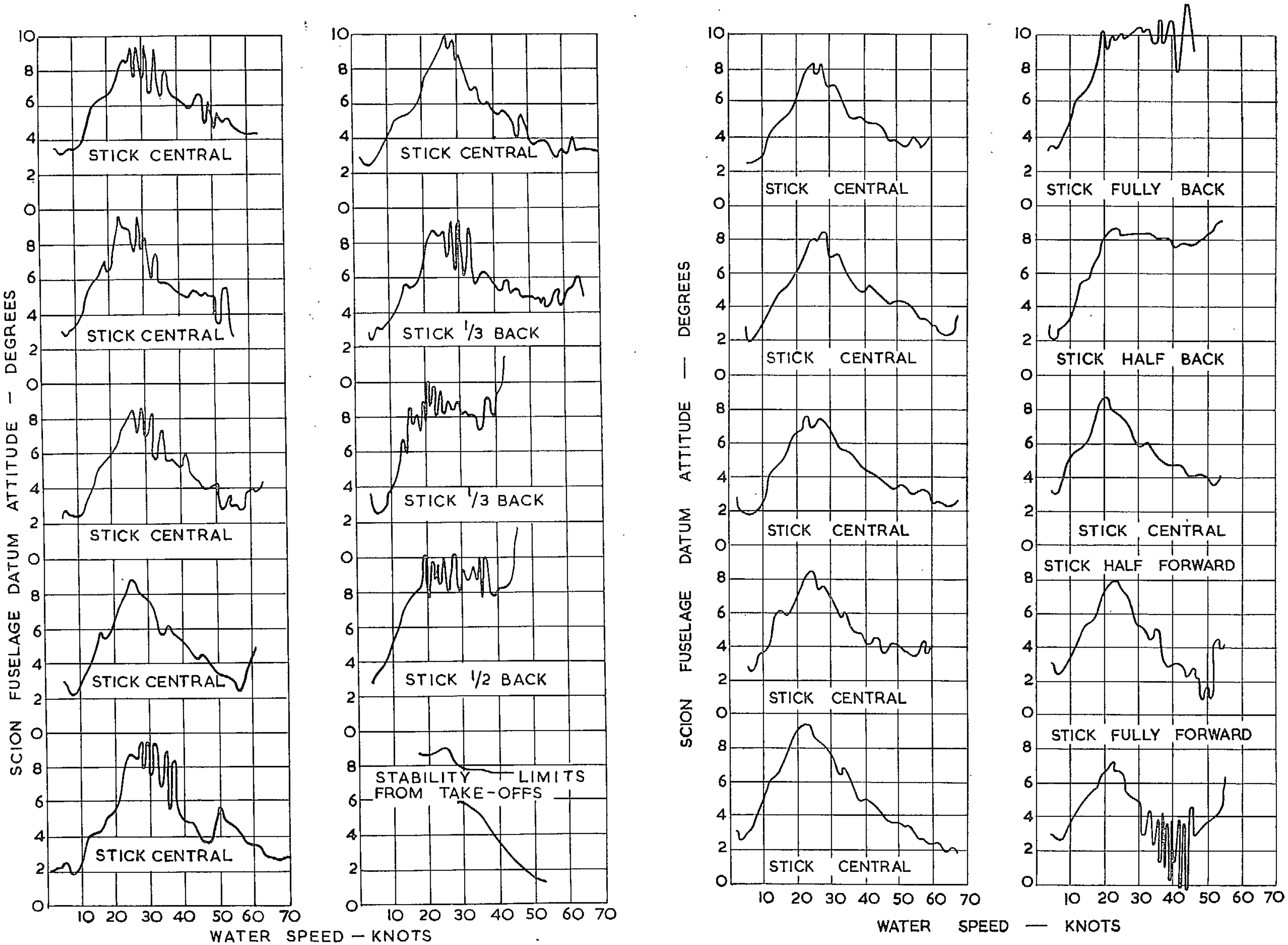



FIG. 1. Scion : C.G. normal. Take-offs. Wt. 5,900 lb.

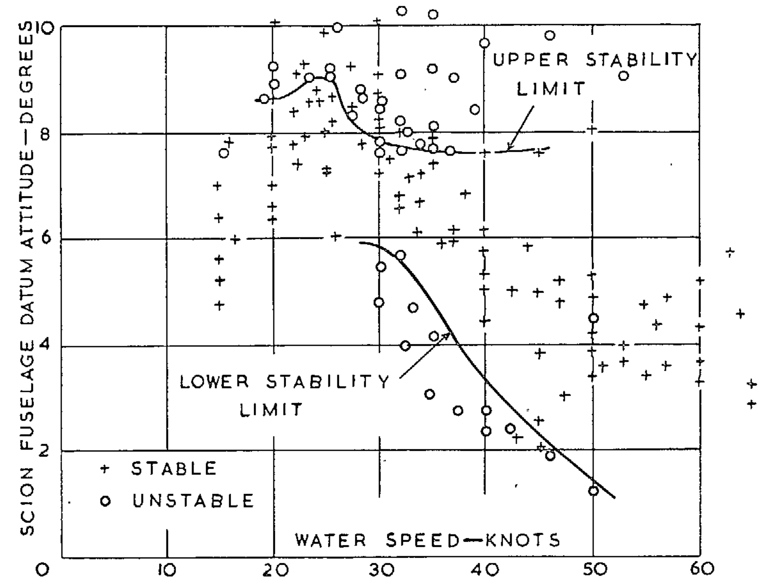



FIG. 2. Scion: C.G. normal. Stability in take-off. Wt. 5,900 lb.

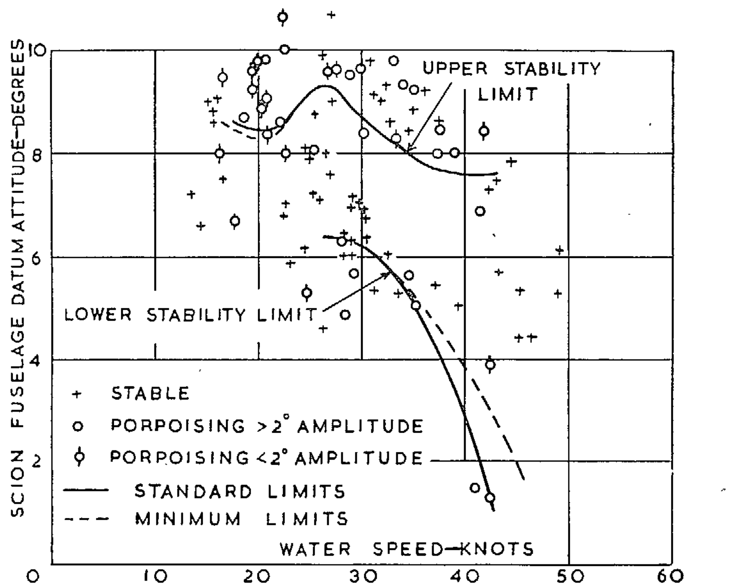



FIG. 3. Scion: C.G. normal. Stability in steady runs. Wt. 5,900 lb.

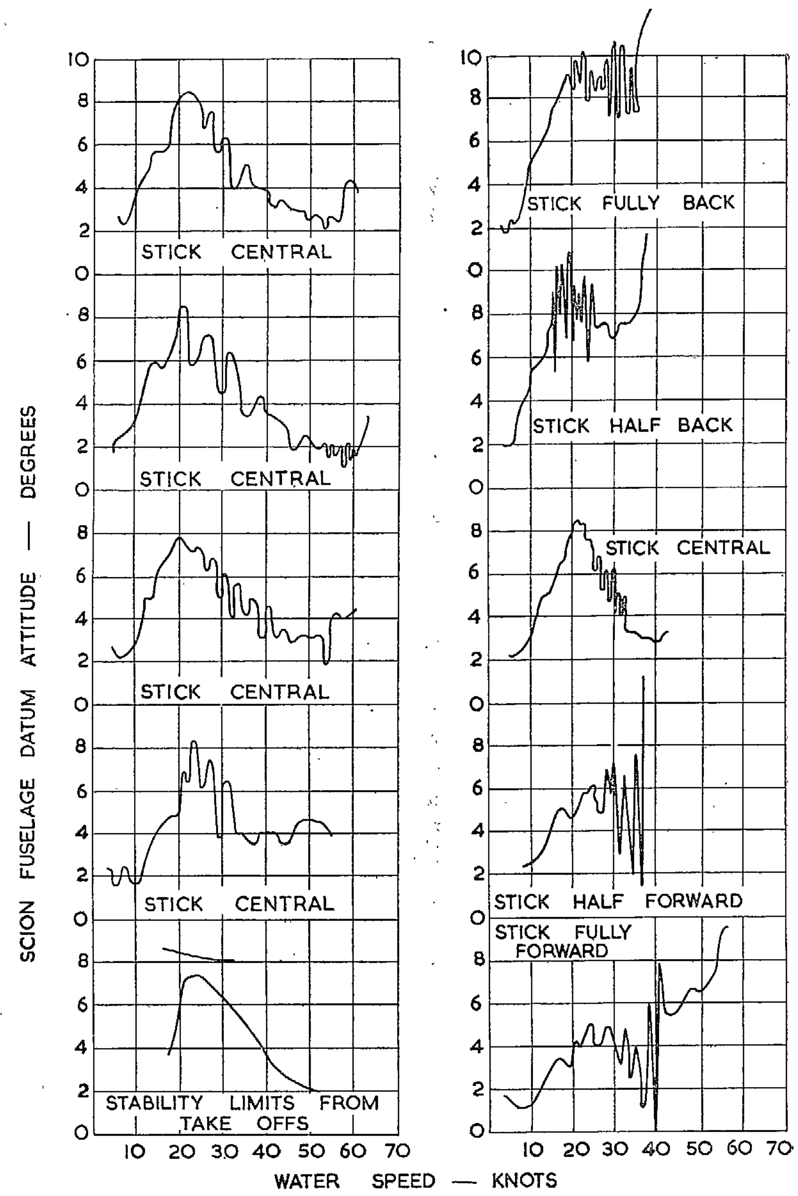



FIG. 4. Scion: Take-offs. C.G. forward. Wt. 5,900 lb.

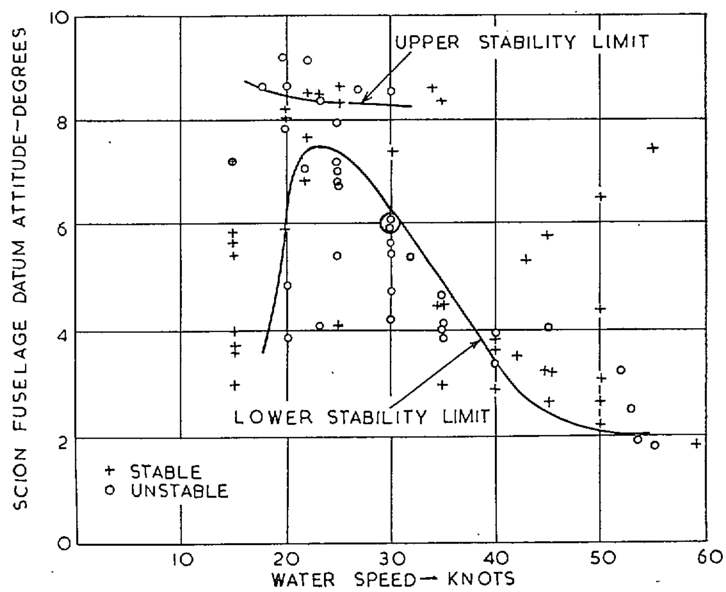



FIG. 5. Scion: C.G. forward. Stability in take-off. Wt. 5,900 lb.

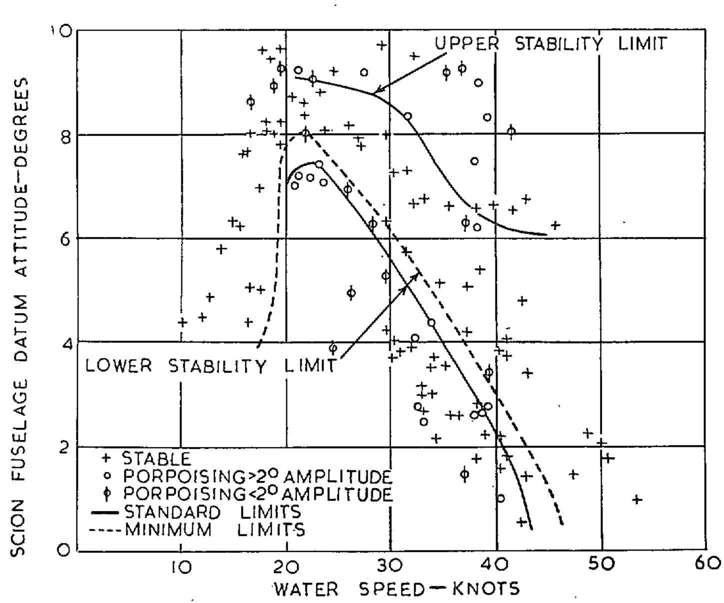



FIG. 6. Scion: C.G. forward. Stability in steady runs. Wt. 5,900 lb.

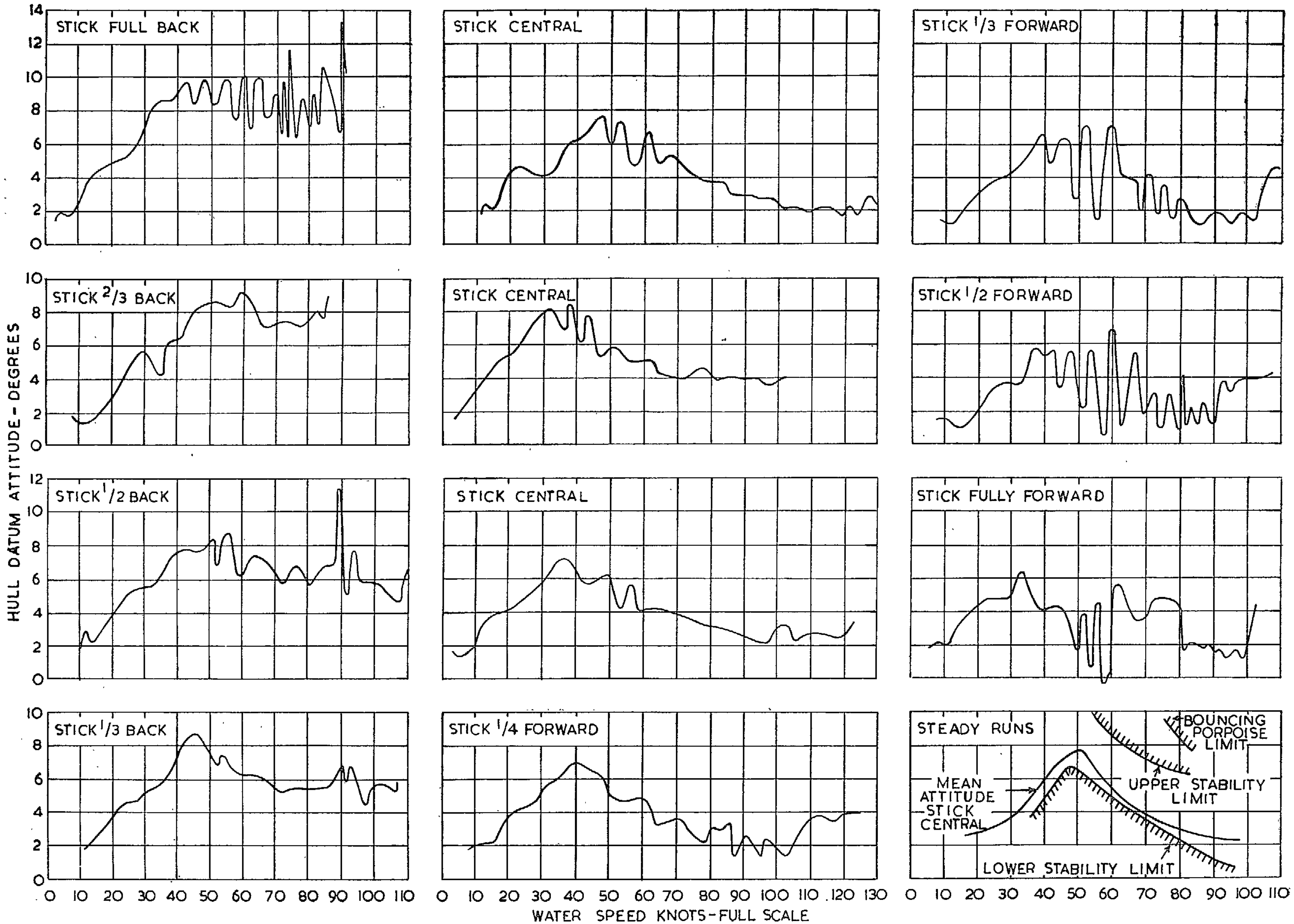



FIG. 7. Shetland: Take-offs. C.G. normal. 120,000 lb. 0 deg flaps.

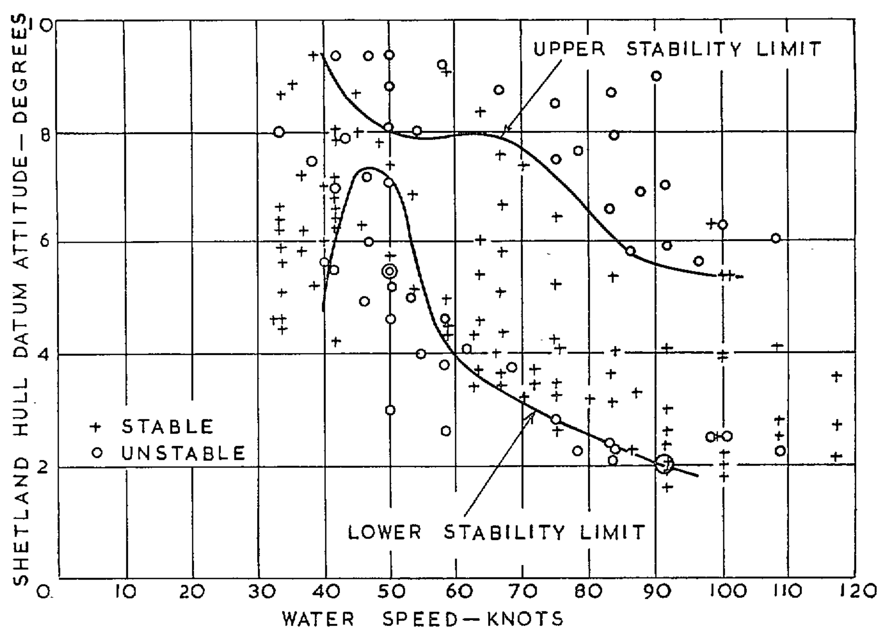



FIG. 8. Shetland: Stability in take-off. C.G. normal. 120,000 lb. 0 deg flaps.

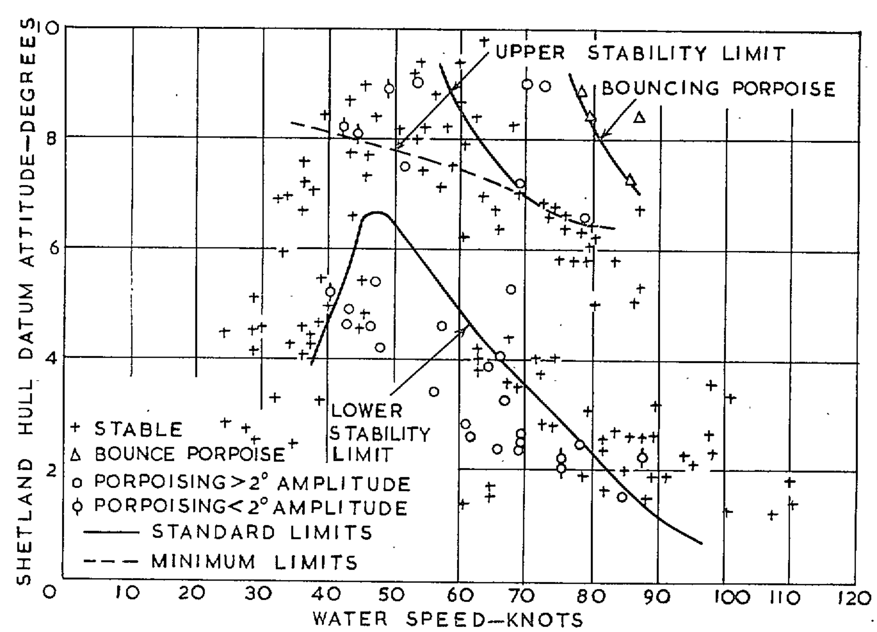



FIG. 9. Shetland: Stability in steady runs. C.G. normal. 120,000 lb. 0 deg flaps.

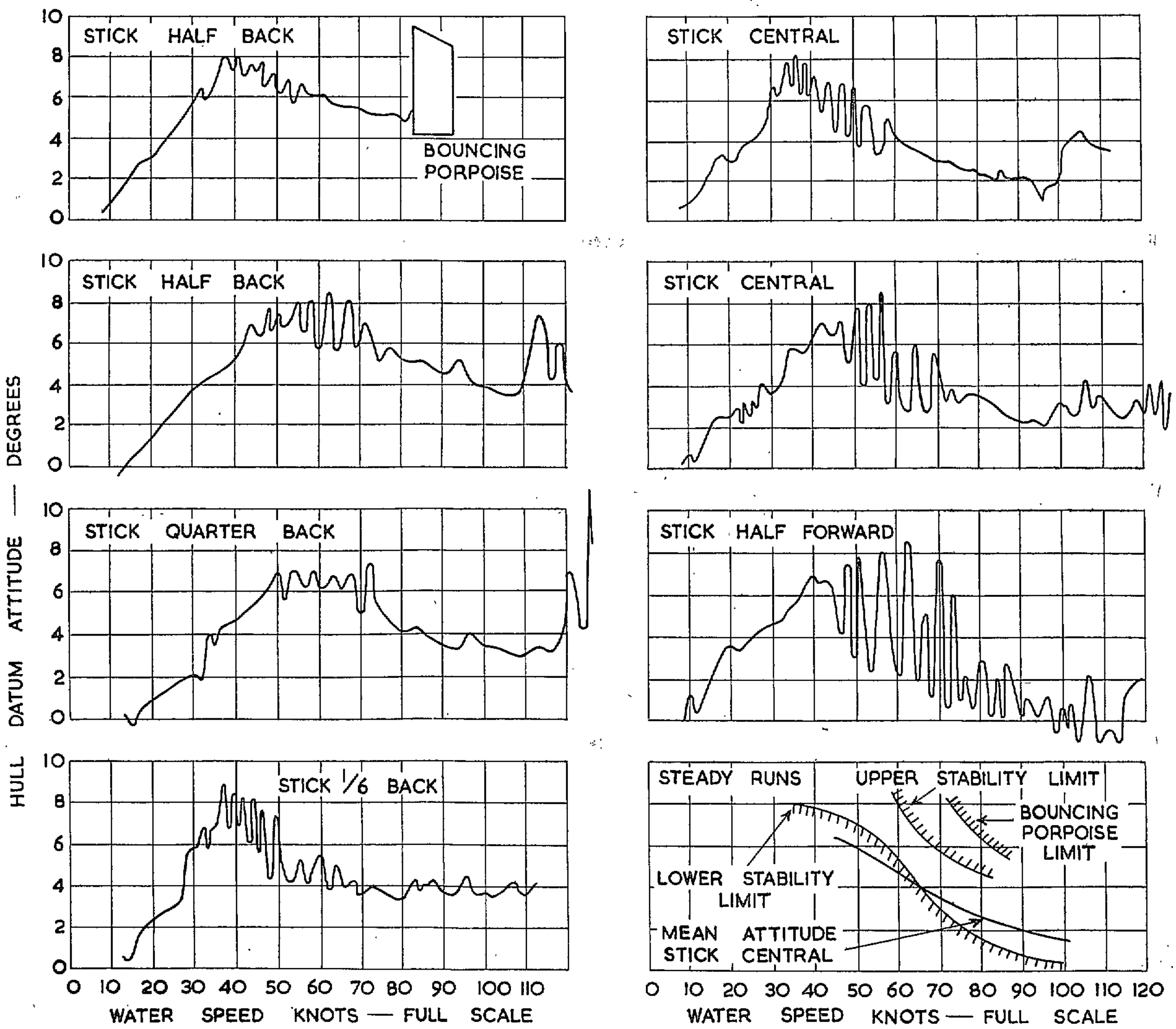



FIG. 10. Shetland: Take-offs. C.G. normal. 130,000 lb, 0 deg flaps.

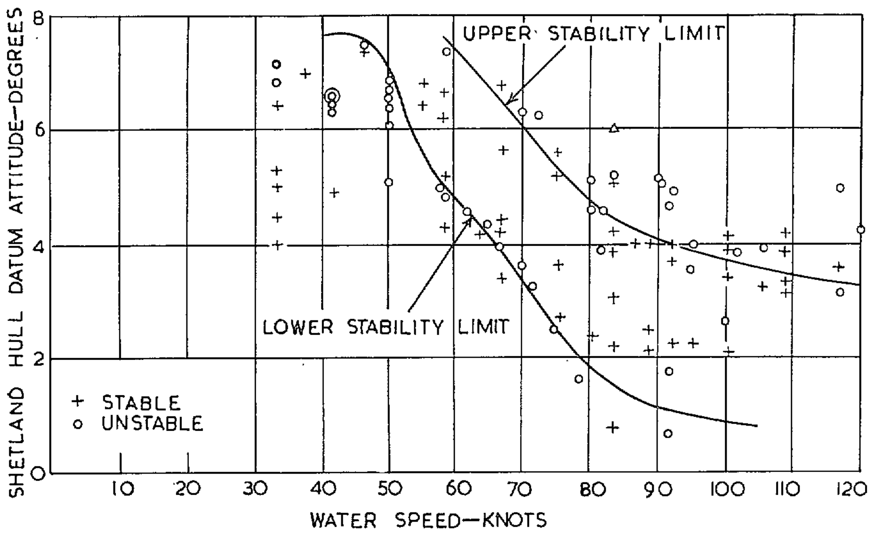



FIG. 11. Shetland: Stability in take-off. C.G. normal. 130,000 lb. 0 deg flap.

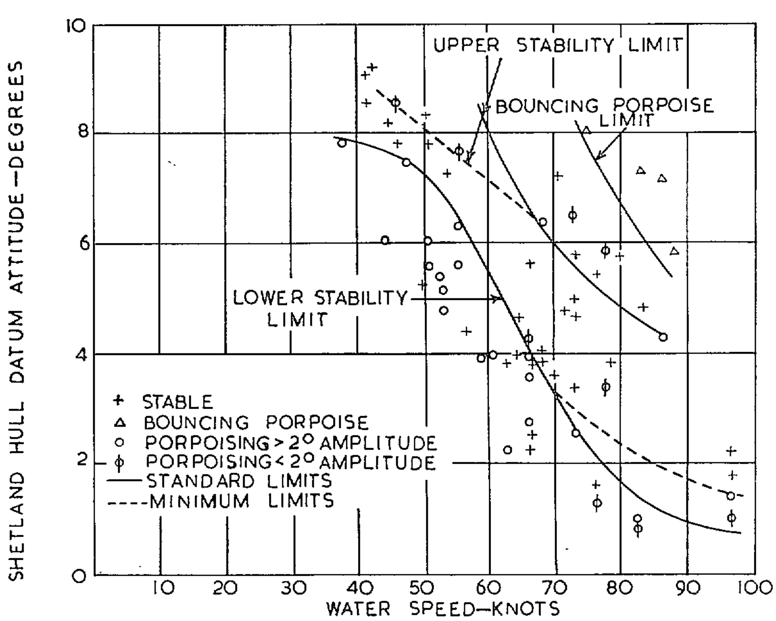



FIG. 12. Shetland: Stability in steady runs. C.G. normal. 130,000 lb. 0 deg flap.

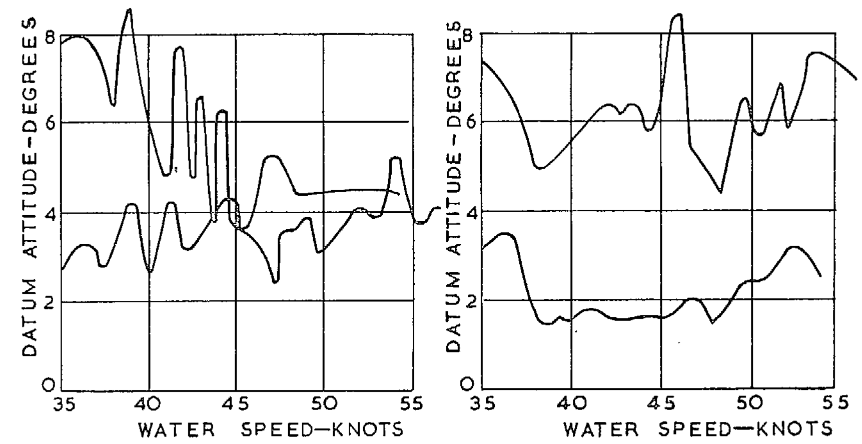



FIG. 13. Take-offs

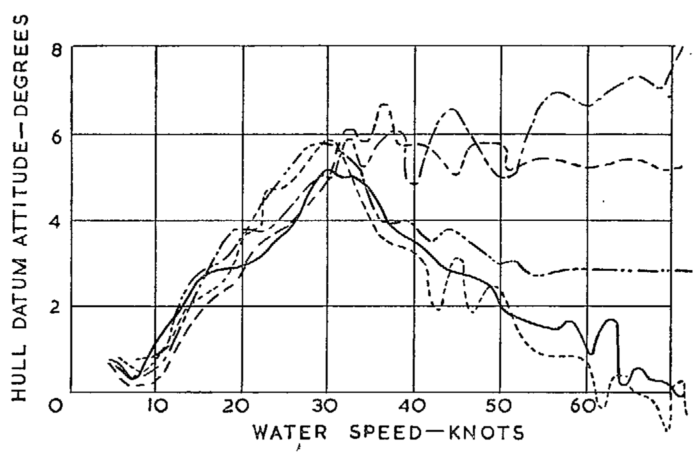



FIG. 16. Take-offs

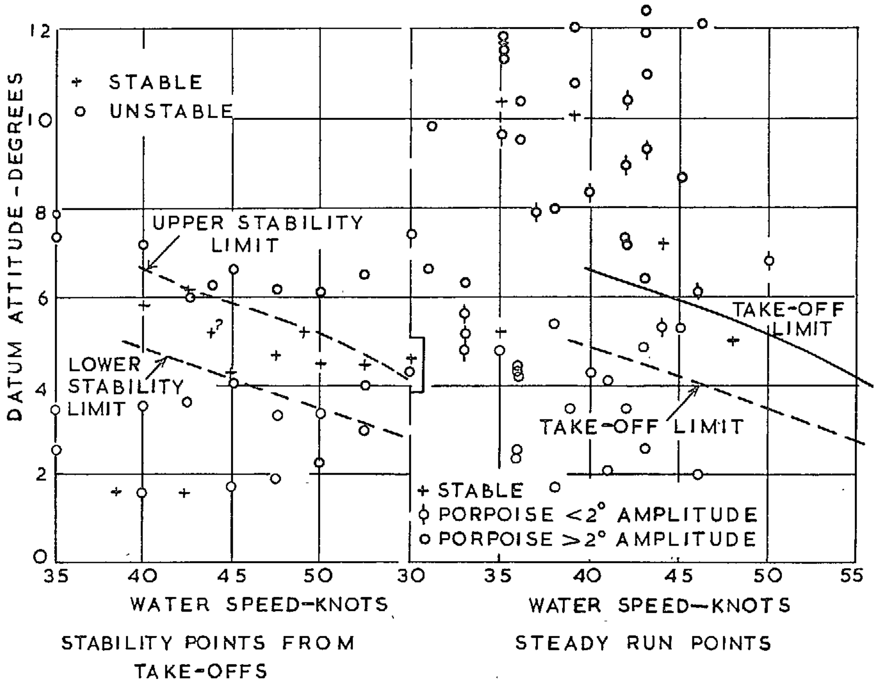
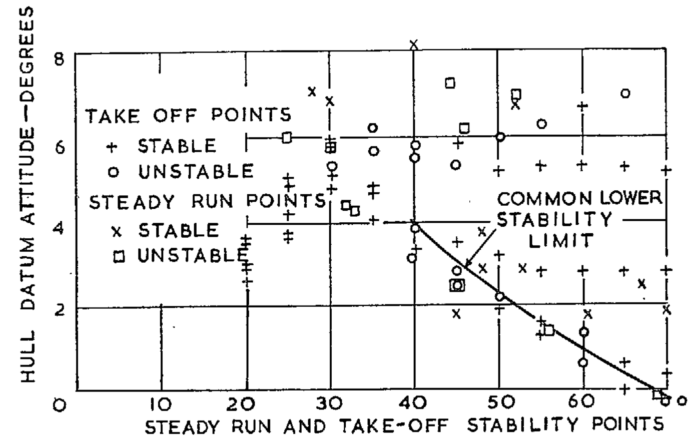



FIG. 14

FIG. 15

Seal : Stability in take-off and steady runs.




FIF. 17. Sunderland I : Stability in take-off and steady runs at 43,000 lb. 0 deg. flap. C.G. normal.

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