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Tank Tests on the Effect of Slipstream on the Water Performance of a Large Four Engined Flying Boat (Shetland I)

By

S. Raymond, B.Sc. (Tech.)

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Tank Tests on the Effect of Slipstream on the Water Performance of a Large Four-Engine Flying Boat
(Southco 1)

by

S. Raymond, B.Sc. (Tecn.)

SUMMARY

Tank tests have been made to examine the dependence of the porpoising stability measured when the model is manually severely disturbed in pitch on the correct representation of air flow over the hull, wings and tailplane.

It is shown that the porpoising stability measured when the model is manually severely disturbed in pitch can be (1) much too optimistic when there is bad interference with the air flow over the hull, (2) improved considerably by the presence of slipstream. The severe model disturbance used is a fairly rapid applied nose down displacement in pitch of $7^\circ$. The porpoising stability measured with no initial disturbance shows little dependence on the local air flow conditions but with an initial disturbance of $3^\circ$ an intermediate condition of stability is obtained. This intermediate stability range gives the best agreement with flight tests made under four operational conditions.

Porpoising stability has been measured in the past without slipstream with the models attached at the C.G. to a large fitting which can interfere considerably with the air flow over the hull. For tests with slipstream represented the model is suspended by the vang tarp. With the first rig there is good stability above 40 knots, with the second rig no stability, using a $7^\circ$ disturbance.

The addition of slipstream to the model with vang tip suspension restores a narrow stability range for take off.

The free to trim attitudes with elevator control are also shown to depend on the form of suspension, but there is little effect of slipstream. The effect of adding slipstream is of the same order as can be calculated, although more substantially, from changes of pitching moment. The best agreement with flight tests is obtained with the vang tip suspension, but model attitudes are still higher just above the hump speed.

The rate of change of attitude with elevator angle, measured in the absence of slipstream as an additional with flight test results.

The nature of the spray is radically altered by the presence of slipstream, the resulting flow qualitatively agreeing much better with flight tests. In particular interference between the propellers and bow spray at low speeds is only found model wake in the presence of slipstream.
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Introduction

Tests were required to examine the full scale correlation of tank tests on porpoising stability, trim and spray on a large, four engined flying boat as effected by (1) slipstream, (2) degree of initial disturbance, (3) method of towing the model. These tests form part of a research programme to investigate the difference between model and full scale results.

Earlier tests have been made to determine the effect of slipstream on the stability, trim and spray of a twin engined flying boat (Lembeck), and in particular to develop the technique of representing slipstream on dynamic models. The complete representation of slipstream was found to have the expected marked effect on trim, but little on spray or porpoising stability. Some increase in stability was found for the unstable Lembeck hull form but in general it was clear that the effect of slipstream was small when the hull form was either very stable or very unstable. It was not possible to make a comparison with full scale.

The usefulness of model scale results must depend on (1) correct representation of full scale conditions, and (2) a knowledge of scale effect. The correct representation of the former is now thought to require the following items to be correct:-

1. load on water
2. applied pitching moments
3. aerodynamic tail and wing damping
4. slope of lift curve and stalling incidence

The major scale effect is probably on interference between the afterbody of a hull and the wake from the forebody. This interference appears to be a primary cause of instability, high drag and change of trim at high speeds. It normally begins at a critical angle between the afterbody keel and the wake, and it is this angle which is probably subject to aerodynamic and scale differences. The degree and form of disturbance, in pitch used to examine porpoising stability is therefore as important as the correct representation of other full scale conditions.

Thus report describes further tests made with slipstream and disturbance in the towing tank at the R.A.E., and correlates the results with the available full scale evidence.

Range of Investigation

Tests on the water porpoising stability, trim and spray characteristics in take off and landing were made at two all up weights, 120,000 lb, and 130,000 lb, on a powered dynamic model of the Shetland. A G.A. of the Shetland T is given in Fig. 1, and the hull lines in Fig. 2. The tests on the take off condition were made first with slipstream on, and secondly without slipstream but using relieving loads of the correct magnitude as measured in the tank. The tests in the landing conditions were made at 130,000 lb A.U.W. Zero flap was used in all conditions.

The results were examined with respect to

1. effect of slipstream on stability, trim and spray characteristics of the model at both weights,
2. effect of disturbance on the stability of the model at both weights.
3. Effect of the method of suspension of the model on stability and trim.

4. Effect of 1, 2, and 3 on comparison with full scale results.

Full scale results were obtained from flight tests made at M.A.S.E. on a 1/2.75 scale Shetland hull fitted to the Saro 37, both with its original tailplane and with the Shetland tailplane. These tests included water stability and trim during take-off, landing and steady runs, flight tests of the effect of fins on take-off performance and some photographs of the spray conditions.

Aerodynamic model data was given by wind tunnel tests made on the Saro 37 and Shetland, including tests of the effect of slipstream and ground.

Tank tests have also been made previously on a 1/19th scale model Shetland, using the centre suspension, but without slipstream.

3 Experimental Methods

3.1 Representation of Slipstream

For the present tests, the hull of the 1/19th scale model made for previous stability tests was used. A new wing was constructed incorporating compressed air driven impulse turbines and propellers. A photograph of the complete model is shown in Fig. 3 and details of the mounting of the turbines in Fig. 4. The nozzles were not made to represent the actual contours, installation, but represents a streamline form. This was to avoid the possibility of poor air flow over model radial engine cowlings at the low Reynolds numbers met with in tank testing.

Four bladed fixed pitch propellers were used to represent the four bladed constant speed propellers fitted to the full scale flying boat, but they are not quite to correct size or solidity. The dimensions of the propellers, model and full scale, are included in Table I.

Details of the turbines and method of suspension of the model from the carriage have been fully described in an earlier report, but the turbines now used differ from the earlier version in that they have a single instead of a double reduction gearing between the turbine and the propeller shaft. This gives the later version a more efficient power-weight ratio.

3.2 Measurement of wing lift and thrust

Wing lift and propeller thrust measurements were made with the model suspended just clear of the water. The former was measured with and without the hull, over an incidence range of 0° to 20°, at a carriage speed of 30 ft/sec, and the latter was measured at speeds of 0, 10, 20, 30 and 40 ft/sec, over a range of air pressures applied to the turbines.

3.3 Measurements of percussion stability

During each steady speed run the model was given successively a 3 degs. and a 7 degs. nose down disturbance if it was initially stable without any disturbance. The boat was considered to be unstable if the resultant unsteady oscillation exceeded 2 degress in amplitude. When instability occurred, the amplitude and limits of the resultant, steady motion were noted.
3.4. Observation of spray

For observation of the effect of the propellers on bow spray, a wooden lattice guard was fitted to the carriage along the starboard rail, and a remote controlled camera was rigged to the end of this as shown in Fig.5. The camera was about 3 feet from the starboard outer propeller and at an angle of approximately 60 degs. to the axis of symmetry of the model. The bow spray characteristics, i.e. those of the blister emanating from the region of the main step, were recorded by a camera mounted aft of the model at an angle of approximately 40 degs. to the axis of symmetry.

4. Results

4.1. Lift and Thrust

The lift characteristics of the 1/19th scale model as measured in the tank are given in Fig.6, together with R.A.E. wind tunnel measurements of the Shetland and Saunders-Roe wind tunnel measurements on the Saro 37. The Saro 37 was the one on the 1/2.75 scale model. The slopes of all three curves for the slipstream case are identical, the most serious differences being in $C_L$ max and the stalling angle. Under the non-turbulent air flow conditions of the tank, and at the low Reynolds Numbers concerned, the stalling angle of the tank model is depressed by 2.5 degs., and its $C_L$ max by 0.26, when compared with the R.A.E. and tunnel tests. The stalling angle and $C_L$ max for the 1/19th scale Shetland compare well with the results from the Saro tunnel, but they also operate at low Reynolds Numbers, at which the results may be subject to considerable scale effect.

<table>
<thead>
<tr>
<th>Model</th>
<th>Reynolds Number</th>
<th>$C_L$ max</th>
<th>Stalling Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.A.E. Wind Tunnel</td>
<td>$0.75 \times 10^6$</td>
<td>1.35</td>
<td>18°</td>
</tr>
<tr>
<td>Saro Wind Tunnel</td>
<td>$0.2 \times 10^6$</td>
<td>1.05</td>
<td>15.2°</td>
</tr>
<tr>
<td>R.A.E. Tank</td>
<td>$0.18 \times 10^6$</td>
<td>1.05</td>
<td>15.5°</td>
</tr>
</tbody>
</table>

The addition of slipstream to the 1/19th scale model postpones the stall almost 3 degs., and alters the slope considerably. The increments in lift due to the slipstream were also calculated by the method of Ref.6 and are compared with the measured tank results in Fig.7. If the calculated increment in $C_L$ due to slipstream is added to the $C_L$-a curve obtained from the R.A.E. wind tunnel, the resulting curve is in good agreement with that obtained in the tank for the slipstream case. Addition of these theoretical increments to the tank curve, however, shows large discrepancies at higher angles because of the stalling of the wing.

The Saro 37 wing, and the 1/19th scale Shetland wing give curves in fair agreement, so that it has been assumed that the effect of slipstream is the same on both. It has also been assumed, in the absence of full scale data, that the lift characteristics of the 1/19th scale wing with slipstream are representative of full scale.

The lift characteristics of the wing without slipstream will not be representative of the full scale wing but in view of the absence of full scale data no attempt was made to improve them.
The propeller thrust was correctly represented to study the effect of thrust moment on trim, but the \( T_2 \) at any one speed was a little higher than for either the Skelton full scale propellers or the Sore 37 propellers, and the slipstream velocity was accordingly too high. Full scale thrusts were estimated by the method of Ref. 7. The variation of thrust coefficient with speed, model and full scale as given in Fig. 5, and from these curves it can be seen that the greatest discrepancy occurs below the hump speed (40 knots). At the higher speeds the differences are small, and over the effective range of speeds - 40 knots to 90 knots - the agreement is well within the accuracy of the thrust estimation.

4.2 Trim

Model and full scale trim have been compared on the basis of elevator effectiveness \( (\alpha/\alpha_d) \), and free to trim attitudes with elevator neutral. The observed results are plotted in Figs. 5 and 10, and free to trim attitudes are reproduced in Fig 11. The effect of the slipstream is to trim the boat down by comparison with the trims obtained using relieving loads, this being due to thrust moment, and change in aerodynamic pitching moment produced by the slipstream. In Appendix I it is shown that these measured changes in trim are of the same order as those obtained by calculation. This change in trim is greater than 1 deg at speeds between 40 knots and 60 knots for both weights tested. Results obtained in a 1/15th scale model Skelton supported at its r.g. by an attachment in the hull showed the same high attitudes without slipstream above the hump speed.

If the free to trim attitudes of the present tests, with and without slipstream, are compared with the I.A.E.I. results, it will be seen that, model scale, the boat does not trim down so quickly as full scale above the hump speed. This tendency to stick increases both with increase in weight and removal of slipstream.

Comparison of elevator effectiveness model and full scale is given in Fig. 12. Curves giving model heel datum attitudes against elevator setting, are drawn for three speeds, and points obtained during the I.A.E.I. tests are superimposed. At both weights, whilst individual trim of the tank model with slipstream are generally high, the slopes of the curves, i.e. elevator effectiveness, agree closely with those of the flying model over the take-off range. Comparison of the curves for the 1/15th scale Skelton models show that there is a large increase in elevator effectiveness due to slipstream. The two sets of curves obtained in tests without slipstream agree fairly well except at 45 knots at the lower weight.

4.3 Porpoising Stability

The observed results are given in Figs. 5 and 10. In order to study the effects of disturbance, slipstream and method of suspension of the model on the stability of the model, the limits have been taken from Figs. 5 and 10 and redrawn in Figs. 13 and 14.

For a disturbance of 7 degs., the model is unstable at all speeds above 50 knots when the slipstream lift increment is simulated by relieving loads of the measured magnitude. The addition of slipstream introduced a narrow, stable band, up to a speed of 30 knots, and this band becomes narrower as all up weight increases. For zero disturbance, there is a large stability range which is unaffected by the presence of slipstream. The 1/15th scale centre-towed model has a wide stable band up.
to 60 knots for 7 days, disturbances, which shows signs of widening with increase in all up weight. It was not possible to reach no-disturbance limits with the model used in this way, and its upper limit of stability for a severe disturbance is higher than the limit for no-disturbance, when the model is drag-tip tared.

Neither the 7 days disturbance nor the no-disturbance limits on the drag-tip tared model agree with those obtained at H.A.E.L. on the 1/2.75 scale model. With a disturbance of 3 dogs, an intermediate set of limits was found, lying closer to those disturbance limits. At 120,000 lb all up weight, with slippstream on, these 3 dogs disturbance limits lie almost exactly on the stability limits obtained by H.A.E.L. The agreement of these two sets of limits is not so good at 150,000 lb all up weight. The effect of slippstream on the model is to widen the stable band between these limits slightly, especially at the critical speed of 60 knots.

A landing case, i.e. no relieving load, was done at 150,000 lb all up weight, and the free to trim attitudes with elevator neutral, and the stability limits are given in Fig.16. An estimate of the full scale trim limits - corrected to model, e.g. position and zero slip - are superimposed. As for the case of the model of the stable band, model and full scale, are in good agreement, but the model limits are high by approximately the same amount as the free to trim.

The instability of the full model, with slippstream, at speeds in the region of 30 knots full scale, takes the form of a bounce with little change in trim. Such bounce propelling is also observed on the flying model in this speed region. Without slippstream, violent pitching occurs on the model.

4.4 Spray

The results are given in Figs.17 to 24, with the values of the three operational parameters relevant to spray formation,

\[ C_\Delta = \frac{b}{\rho g} \]  = beam loading

\[ C_v = \frac{\nu}{\sqrt{gb}} \]  = coefficient of velocity

\[ \alpha = \text{attitude of keel driver} \]

where \[ \Delta = \text{load on the water} \]
\[ \rho = \text{density of water \((t4 \text{ lb/ft}^3)\)} \]
\[ b = \text{beam} \]
\[ \nu = \text{velocity} \]
\[ g = \text{acceleration due to gravity} \]

Curves of \( C_\Delta \) against \( C_v \) for varying values of \( \alpha \) are given in Fig.16.
The effect of the slipstream on bow spray at a $C_y$ of 1.7 is very
clearly shown in Figs. 17 and 18. With the motors on, the blower is
sucked up into the propeller disc, whilst with them off there is no
indication of such an effect. A comparison of 1/19th scale model and
1/2.75 scale model bow spray is given in Figs. 23. Full scale, spray
tends the propeller disc over the $C_y$ range 1.5 - 2.0. As $C_y$
increases, the blower leaves the chine at points increasingly far
out so that it is not drawn into the disc. The suction field created by
the slipstream, however, causes the blower to be drawn upwards and
breaks it into spray which then hits the after under surface of the
wing.

A study of the model photographs of main spray, Figs. 19 - 22,
reveals that the boat is darkest at a $C_y$ of 2.6. The breaking up
of the chine blower by the slipstream is clearly seen, and also the
tendency for the slipstream to swing the blower into the body. At a
$C_y$ of 3.2, this latter effect becomes much more marked and the step
blower hits the tunnel plane well inboard of the tips. The slipstream
also tends to clear the wing trailing edge of spray. Comparisons of
the main spray model and full scale are given in Figs. 23 and 24 and
show qualitatively good agreement.

The effect of increase in full up weight is to make the spray
heavier, both with and without slipstream. The spray rises higher
round the after body and extends further along the trailing edge of
the wing towards the tips.

Discussion

It has been shown that the 1/19th scale model Shetland with wing
tip suspension is dependent on the slipstream for its stability with
7 degs. disturbance. This confirms the suggestion that slipstream can
be important when the stability is intermediate between good and bad.
The explanation probably lies in the effect of the slipstream on (a) the
ventilation of the afterbody, (b) the onset of the stall and improvement
in lift curve slope, and (c) wing and tailplane damping.

The increase in air stream velocity gives better ventilation and also modifies the water flow. In his report on air interference effects, Gott shows that for a given speed, there is a tendency for the water 
drag curve to "peak" in a localised region about a certain attitude. He deduces from this that there may be smaller localised increases in afterbody suction in the immediate neighbourhood of particular attitudes. According to this, the location of the stability limit depends upon the amplitude of the initial disturbance; i.e. it must be sufficiently large to carry the boat past the critical angle at which those suction forces occur. The nature of the resultant undamped oscillation is independent of the magnitude of the initial disturbance, provided that it is large enough to bring the boat into the region: where these destabilising interference forces are operative. Thus at a particular trim at a particular speed there is a limiting initial disturbance required to start upper 
limit porpoising, and the stability can be specified as corresponding to a certain disturbance. It should be noted here that the stability limits are based on the undisturbed attitude and not the mean attitude of the resultant oscillation.

For no-disturbance instability, we are primarily concerned with
the water forces on the hull, and whether the boat has such an upper
limit or not depends on whether it has sufficient elevator power to
trim it to the critical attitude at which it occurs. Where such a limit
has been found for the slipstream off case, it agrees well with the same
limit slipstream on.
The stability limits with disturbance are a function of the aerodynamic, as well as the wetter, forces, because of the alteration in wing lift and aerodynamic pitching moment caused by the disturbance. These aerodynamic forces are modified by the addition of slipstream, and whilst it is possible to allow, by calculating loads, for such an effect as stalling of the wing which occurs when slipstream is not present, it is impossible to represent correctly the change in wing lift and aerodynamic pitching moments following a disturbance by any method other than the addition of slipstream. The increase in the damping factors of wing and tailplane due to slipstream is important in view of the critical nature of disturbance, i.e., the extra damping may be sufficient to damp out the destabilising interference forces to a higher attitude.

Full scale disturbances under normal operational conditions seldom exceed 3 degs. if the all up weight is greater than 50,000 lb, and tank stability limits based on this degree of disturbance have been shown to link up well with the stability limits obtained full scale.

The previous tests on a 1/18th scale Shetland do not give limits which link up with the present tests. These tests were made with the model taken from the attachment in the hull and the towg connection was very large by comparison with the size of the model. Its effect on the air flow round the towg root probably worsened the stalling characteristics of the wing. The relieving loads used to represent slipstream lift increments in these tests were calculated, and hence made no allowance for the severe stalling of the wing without slipstream.

The attitude results show that when due allowance has been made for the effect of slipstream and thrust moment on trim, model scale attitudes are still higher than those found on the flying model, for speeds just higher than the hump. This is presumably a scale effect.

The scale parameter governing spray characteristics is the surface tension number - \( \gamma / \rho N^2 \)

where
- \( \gamma \) = surface tension coefficient of water
- \( \rho \) = density (slugs/ft\(^3\))
- \( N \) = beam of boat
- \( V \) = velocity of boat.

Since tank tests are made at the correct Froude number, the surface tension number full scale is \( N^2 \) times the surface tension number model scale, where \( N \) is the ratio of corresponding lengths on the models. The spray full scale may, therefore, be very different in form from that on the model, and in fact full scale blisters break into spray which behaves in a very different manner to the solid blisters obtained on the model. The present tests indicate that the slipstream from the model propellers tends to break up the blisters and when broken up the spray behaves in a manner similar to full scale. This improvement in the correlation of model and full scale spray results is highly desirable in view of the large scale differences mentioned above.

b Conclusions

The results of the present tests on a 1/18th scale model Shetland show that the addition of slipstream greatly improves the correlation
of porpoising stability, free to trim attitudes, elevator effectiveness and spray characteristics with full scale.

6.1 The slipstream improves the lift characteristics of the wing, so that during oscillations the correct load on water obtains. The increase in wing and tailplane damping caused by the increased air flow over them alters the nature of the instability.

6.2 It is shown that the width of the stable region depends on the magnitude of the initial disturbance, and the present tests indicate that a disturbance of 3 degs. gives limits of the same order as those obtained full scale. This disturbance is rarely exceeded in normal operations on a full scale flying boat of over 30,000 lb all up weight.

6.3 A comparison of the present results, without slipstream, with those of similar tests made on a 1/19th scale centre-towed model shows that, in changing from centre suspension to wing tip suspension, the model loses all its 7 degs. disturbance stability.

6.4 The thrust moment and change in aerodynamic pitching moment due to slipstream have a large effect on the trim, and whilst estimations of this change in trim of the correct order are possible, it is simpler and more accurate to represent the correct conditions. When the effects of thrust moment and slipstream have been allowed for, the model attitudes, free to trim, are still higher than those obtained on the flying model and this is presumably due to scale effect.

6.5 The elevator effectiveness \((\text{deg} / \text{deg})\) of the model is greatly increased by slipstream and is shown to agree well with the full scale value.

6.6 Slipstream radically alters the nature of the model spray by breaking up the blister, and gives spray characteristics which are in qualitative agreement with those observed at M.A.E. At low values of \(C_{\alpha}\) (1.5 - 2.0) the characteristics shown into the propeller disc and this interference of the slipstream with the spray is confirmed by M.A.E.
List of Symbols, Coefficients

b  beam, ft
\( \omega \)  density of water (64 lb/ft\(^3\))
\( \rho \)  density of water, slugs/ft\(^3\)
\( D \)  total water drag
\( \Delta \)  displacement, i.e. all up weight minus wing lift and thrust component, lb
\( g \)  acceleration due to gravity, ft/sec\(^2\)
\( V \)  forward velocity, ft/sec
\( \alpha \)  angle of the keel down to the horizontal, degs.
\( \eta \)  elevator angle to tailplane, degs.
\( \gamma \)  surface tension of water, lb/ft

\[ C_v = \frac{V}{\sqrt{2b}} = \text{coefficient of velocity} = \text{Froude Number} \]

\[ C_\Delta = \frac{\Delta}{\omega b^3} = \text{beam loading} \]

\[ C_{\Delta o} = \frac{\Delta V^2}{\omega b^3} = \text{static beam loading} \]

\[ \frac{\gamma}{\rho b V^2} = \text{surface tension number} \]

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APPENDIX I

Calculation of the change in water trim of a model due to slipstream

Tunnel tests have been made on the Shetland Model with slipstream and ground. Aerodynamic pitching moment coefficients are given as functions of thrust coefficient and wing incidence for constant elevator angle. The trim of the boat with slipstream off is known, and also the $T_c$ when the propellers are on. From the tunnel curves, the pitching moments with slipstream and without slipstream ($T_c = 0$) can be found, and hence the change in pitching moment due to slipstream and thrust moment. From the hydrodynamic pitching moment curves the change in trim of the boat associated with such a change of aerodynamic moment can be found. The results are given below, and the calculated change of trim is compared with the actual trim change measured in the tank.

<table>
<thead>
<tr>
<th>Speed, knots full scale</th>
<th>$\alpha$ degree</th>
<th>$T_c$</th>
<th>$C_m$ slipstream on</th>
<th>$C_m$ slipstream off</th>
<th>$\Delta C_m$ due to slipstream</th>
<th>$\frac{\alpha}{\beta} V S^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>10.7$^\circ$</td>
<td>2.5</td>
<td>-0.59</td>
<td>-0.10</td>
<td>-0.49</td>
<td>3.17 x 10^5</td>
</tr>
<tr>
<td>55</td>
<td>9.8$^\circ$</td>
<td>1.5</td>
<td>-0.15</td>
<td>-0.02</td>
<td>-0.13</td>
<td>4.75 x 10^5</td>
</tr>
<tr>
<td>65</td>
<td>8.3$^\circ$</td>
<td>1.0</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.06</td>
<td>6.6 x 10^5</td>
</tr>
<tr>
<td>75</td>
<td>6.8$^\circ$</td>
<td>0.7</td>
<td>-0.02</td>
<td>-0.04</td>
<td>-0.01</td>
<td>8.75 x 10^5</td>
</tr>
<tr>
<td>85</td>
<td>5.4$^\circ$</td>
<td>0.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed, knots full scale</th>
<th>45</th>
<th>55</th>
<th>65</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \alpha$ due to slipstream</td>
<td>-155,000</td>
<td>-62,000</td>
<td>-40,000</td>
<td>-9,000</td>
</tr>
<tr>
<td>Estimated $\Delta \alpha$ due to slipstream and thrust moment</td>
<td>-1.4$^\circ$</td>
<td>-2.0$^\circ$</td>
<td>-1.7$^\circ$</td>
<td>-0.5$^\circ$</td>
</tr>
<tr>
<td>Measured $\Delta \beta$ due to slipstream and thrust moment</td>
<td>-1.4$^\circ$</td>
<td>-2.0$^\circ$</td>
<td>-1.9$^\circ$</td>
<td>-1.1$^\circ$</td>
</tr>
</tbody>
</table>

In view of the approximations made in estimating the change in moment, namely, that $C_m$ does not change over the change in attitude, and that air-water interference does not alter the hydrodynamic pitching moment, the estimated trim change can only be expected to be of the right order. The agreement obtained for this model is quite good.
## Table I

### Model Data on Shetland

<table>
<thead>
<tr>
<th>Item</th>
<th>Full Scale Shetland</th>
<th>1/12 scale Shetland</th>
<th>1/2,15 scale Shetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>Göttingen</td>
<td>Göttingen</td>
<td>-</td>
</tr>
<tr>
<td>Gross Area</td>
<td>2936 sq. ft</td>
<td>7.3 sq. ft</td>
<td>340 sq. ft</td>
</tr>
<tr>
<td>Span</td>
<td>1.083 ft</td>
<td>0.99 ft</td>
<td>-</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>8.51</td>
<td>8.61</td>
<td>-</td>
</tr>
<tr>
<td>Washout</td>
<td>none</td>
<td>none</td>
<td>-</td>
</tr>
<tr>
<td>Dihedral</td>
<td>4° 50' on wing</td>
<td>4° 50' on wing</td>
<td>-</td>
</tr>
<tr>
<td>Sweep back on chord</td>
<td>10° 2°</td>
<td>10° 2°</td>
<td>-</td>
</tr>
<tr>
<td>Wing setting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root chord</td>
<td>6° 38' to hull</td>
<td>6° 38' to hull</td>
<td>Aerodynamic chord 6° 41'</td>
</tr>
<tr>
<td>Aerofoil dat.</td>
<td>5° 30' to hull</td>
<td>5° 30' to hull</td>
<td>to Shetland</td>
</tr>
<tr>
<td>Hull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>R.A.F.30</td>
<td>R.A.F.30</td>
<td>R.A.F.30</td>
</tr>
<tr>
<td>Gross Area</td>
<td>114 sq. ft</td>
<td>1.14 sq. ft</td>
<td>53.85 sq. ft</td>
</tr>
<tr>
<td>Span</td>
<td>42.5 ft</td>
<td>2.52 ft</td>
<td>15.4 ft</td>
</tr>
<tr>
<td>Elevator area</td>
<td>13 sq. ft</td>
<td>0.39 sq. ft</td>
<td>16.25 sq. ft</td>
</tr>
<tr>
<td>Dihedral</td>
<td>6° on tail plane</td>
<td>none</td>
<td>6° on tail plane</td>
</tr>
<tr>
<td>Top chord above hull datum</td>
<td>20.35'</td>
<td>1.07'</td>
<td>-</td>
</tr>
<tr>
<td>Tail plane setting</td>
<td>4° 38' to hull</td>
<td>4° 38' to hull</td>
<td>2° 0° to hull</td>
</tr>
<tr>
<td>Hull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam</td>
<td>12.5'</td>
<td>0.96'</td>
<td>4.52'</td>
</tr>
<tr>
<td>Forebody - beam ratio</td>
<td>3.3</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Afterbody - beam ratio</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Step included angle in plan</td>
<td>136°</td>
<td>136°</td>
<td>136°</td>
</tr>
<tr>
<td>Unfair ed step length</td>
<td>9° of beam</td>
<td>9° of beam</td>
<td>9° of beam</td>
</tr>
<tr>
<td>After keel angle to forebody keel</td>
<td>7° 35'</td>
<td>7° 35'</td>
<td>7° 35'</td>
</tr>
<tr>
<td>Keel angle to hull datum</td>
<td>2° 35'</td>
<td>2° 35'</td>
<td>2° 35'</td>
</tr>
<tr>
<td>C.G. position during test, distance forward of main step</td>
<td>3.14 ins</td>
<td>normal 12.01&quot;</td>
<td>forward 2° 0.35&quot;</td>
</tr>
<tr>
<td>Height above hull datum</td>
<td>-</td>
<td>0.84</td>
<td>-</td>
</tr>
<tr>
<td>All up weights</td>
<td>120,600 lb</td>
<td>17.50 lb</td>
<td>5,700 lb</td>
</tr>
<tr>
<td>during tests</td>
<td>120,600 lb</td>
<td>18.34 lb</td>
<td>6,200 lb</td>
</tr>
<tr>
<td>Static bear.</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Loadings</td>
<td>1.04</td>
<td>1.04</td>
<td>1.04</td>
</tr>
<tr>
<td>Item</td>
<td>Full scale</td>
<td>1/19 scale</td>
<td>1/2.75 scale</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
<td>------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Engines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Centaurus VII</td>
<td>-</td>
<td>Pobjoy</td>
</tr>
<tr>
<td></td>
<td>(M gear only)</td>
<td></td>
<td>Niagara III</td>
</tr>
<tr>
<td>T.G. rating</td>
<td>2400 H.P./2700</td>
<td>-</td>
<td>85 HP/3135 RPM</td>
</tr>
<tr>
<td></td>
<td>KB/S, L/4+7½ lb</td>
<td></td>
<td>S.L./zero boost</td>
</tr>
<tr>
<td>Propellers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>De Havilland L-blade</td>
<td>Wooden 4-blade fixed pitch</td>
<td>Wooden 2-blade fixed pitch</td>
</tr>
<tr>
<td>Diameter</td>
<td>15.75 ft</td>
<td>0.797 ft</td>
<td>6.5 ft</td>
</tr>
<tr>
<td>Solidity</td>
<td>0.114</td>
<td>0.139</td>
<td>0.07</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>0.40</td>
<td>-</td>
<td>0.468</td>
</tr>
</tbody>
</table>
- SHETLAND -
HULL LINES.

SCALE 1/30, 1/90
FIG. 3. MODEL

FIG. 4. DETAIL OF AIR TURBINE AND PROPELLER INSTALLATION

SHETLAND
FIG. 5. VIEWS SHOWING MODEL MOUNTED IN FRONT OF CARRIAGE

SHETLAND
FIG 6.

- Δ SARO WIND TUNNEL TESTS ON A SHETLAND MODEL WITH SLIPSTREAM - TC=0.070
- ○ TANK TESTS ON A SHETLAND MODEL WITH SLIPSTREAM - TC=0.70
- • R.A.E WIND TUNNEL TESTS ON A SHETLAND MODEL - NO SLIPSTREAM.
- △ TANK TESTS ON A SHETLAND MODEL - NO SLIPSTREAM.
- ■ SARO WIND TUNNEL TESTS ON A SARO 37 MODEL - NO SLIPSTREAM

SHETLAND - WING LIFT CURVES.
FLAPS AT 0°

SHETLAND.
FIG. 7.

**SHETLAND MEASURED & CALCULATED LIFT INCREMENTS DUE TO SLIPSTREAM.**

**SHETLAND.**
CHANGE OF THRUST COEFFICIENT WITH SPEED ON SHETLAND AND SARO 37.

SHETLAND.
FIG. 9

PORPOISING STABILITY OF SHETLAND WITH AND WITHOUT SLIPSTREAM.
Porpoising stability of Shetland with and without slipstream
FIG II.

ATTITUDE OF KEEL DATUM, DEG.

SHETLAND—FREE TO TRIM ATTITUDES,
MODEL AND FULL SCALE.
SHETLAND - TRIM CURVES
1. Effect of disturbance on stability limits:
- \( \alpha \) vs. Keel
- 0° Dist
- 3° Dist
- 7° Dist

2. Effect of rig on stability limits:
- Wing Tip Suspension
- 7° Dist. Wing Tip Suspension
- Keel

3. Effect of slipstream on stability limits:
- Slipstream on and off
- 3° Dist.

4. Comparison of limits:
- \( \alpha \) vs. Keel
- 7° Dist. Wing Tip Suspension
- 3° Dist. Wing Tip Suspension
- Slipstream on and off
- \( \alpha \) vs. Knots, Full Scale

Fig. 13.
1 EFFECT OF DISTURBANCE ON STABILITY LIMITS
\( \frac{1}{9} \) SCALE SHETLAND WITH SLIPSTREAM

2 EFFECT OF SUSPENSION ON STABILITY LIMITS
\( \frac{1}{9} \) SCALE SHETLAND WITHOUT SLIPSTREAM

3 EFFECT OF SLIPSTREAM ON STABILITY LIMITS
\( \frac{1}{9} \) SCALE SHETLAND SLIPSTREAM ON AND OFF

4 COMPARISON OF LIMITS
\( \frac{1}{9} \) SCALE WITH SLIPSTREAM
\( \frac{1}{275} \) SCALE TAKE-OFF CASE
FIG 15.

ATTITUDES FREE TO TRIM (ELEVATORS NEUTRAL)

1 2/75 SCALE LANDING CASE

LANDING KNOTS, FULL SCALE 130,000 LB. AVW

ROUGH ESTIMATE FOR 2/75 SCALE LANDING CASE WITH NO FLAP

STABILITY LIMITS

SHETLAND
Fig. 16.

Curves of $C_\alpha$ against $C_v$ during take-off. Shetland.

120,000 lb A.U.W
No Flaps

130,000 lb A.U.W
No Flaps

Angle of keel datum.
FIG. 17. EFFECT OF SLIPSTREAM ON CHINE BLISTER
120,000 lb. A.U.W.

SHETLAND
FIG. 18. EFFECT OF SLIPSTREAM ON CHINE BLISTER.
130,000 lb. A.U.W.
SHETLAND
FIG. 19. EFFECT OF SLIPSTREAM ON MAIN BLISTER
120,000 lb. A.U.W.

SHETLAND
FIG. 20.

EFFECT OF SLIPSTREAM ON MAIN BLISTER
120,000 lb. A.U.W.

SHETLAND
FIG. 21. EFFECT OF SLIPSTREAM ON MAIN BLISTER
130,000 lb. A.U.W.
SHETLAND
FIG. 22. EFFECT OF SLIPSTREAM ON MAIN BLISTER
130,000 lb. A.U.W.

SHETLAND
FIG. 23. COMPARISON OF SPRAY ON TANK MODEL AND FLYING MODEL. SLIPSTREAM ON 130,000 lb. A.U.W.

SHETLAND
FIG. 24. COMPARISON OF SPRAY ON TANK MODEL AND FLYING MODEL. SLIPSTREAM ON 130,000 lb. A.U.W. SHETLAND