C.P. No. 6
(8741)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
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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.)

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1950

Price 2s. 6d. net.

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

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SUMMARY

Tank tests have been made to examine the dependence of the porpoising stability, trim and spray of a four engined flying boat 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 initially 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 quickly applied nose down displacement in pitch of 7°. The porpoising stability measured with no initial disturbance shows little dependence on the local air flow conditions but with an initial disturbance of 3° an intermediate condition of stability is obtained. This intermediate stability range gives the best agreement with flight tests made under fair 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 wing tips. With the first rig there is good stability above 40 knots, with the second rig no stability, using a 7° disturbance.

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

The free to trim attitudes with elevator central 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 laboriously, from changes of pitching moment. The best agreement with flight tests is obtained with the wing 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 presence of slipstream is in good agreement with flight test results.

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

LIST OF CONTENTS

1 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[1] to investigate the difference between model and full scale results[2].

Earlier tests have been made to determine the effect of slipstream on the stability, trim and spray of a twin engined flying boat (Lerwick[3]), 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 Lerwick 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[3,4]. 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.

This 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[5].

2 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 I 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.E.E. on a 1/2.75 scale Shetland hull fitted to the Saro 37, both with its original tailplane and with the Shetland tailplane[5]. These tests included water stability and trim during take-off, landing and steady runs, flight tests of the effect of flaps 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 nacelles were not made to represent the actual Centaurus 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 the method of suspension of the model from the carriage have been fully described in an earlier report[3], 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 slipstream, over an incidence range of 2° to 20°, at a carriage speed of 30 f.p.s., and the latter was measured at speeds of 0, 10, 20, 30 and 40 f.p.s., over a range of air pressures supplied to the turbines

3.3 Measurements of porpoising 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 undamped oscillation exceeded 2 degs. 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 girder 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 main 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 wing is the one on the 1/2.75 scale model. The slopes of all three curves for the slipstream off 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 0.28, when compared with the R.A.E. wind 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 this also operates at low Reynolds Numbers, at which the results may be subject to considerable scale effect.

Model	Reynolds Number	$C_{L_{max}}$	Stalling Angle
R.A.E. Wind Tunnel	0.75×10^6	1.33	18°
Saro Wind Tunnel	0.12×10^6	1.06	15.2°
R.A.E. Tank	0.18×10^6	1.05	15.5°

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 have also been 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 $C_L - \alpha$ 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 on 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_c at any one speed was a little higher than for either the Shetland full scale propellers or the Saro 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 is given in Fig.8, 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 trims have been compared on the basis of elevator effectiveness $({}^{d\alpha}/d\eta)$, and free to trim attitudes with elevator neutral. The observed results are plotted in Figs.9 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 80 knots for both weights tested. Results obtained on a 1/19th scale model Shetland supported at its c.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 M.A.E.E. 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 all up weight and removal of slipstream.

Comparison of elevator effectiveness model and full scale is given in Fig.12. Curves giving model keel datum attitudes against elevator setting, are drawn for three speeds; and points obtained during the M.A.E.E. tests are superimposed. At both weights, whilst individual trims 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 1/19th scale Shetland 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 63 knots at the lower weight.

4.3 Porpoising stability

The observed results are given in Figs.9 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.9 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 80 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 1/19th scale centre-towed model has a wide stable band up to 80 knots for 7 degs. disturbances, which shows signs of widening with increase in all up weight. It was not possible to reach no-disturbance limits with the model towed 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 wing-tip towed.

Neither the 7 degs. disturbance nor the no-disturbance limits on the wing-tip towed model agree with those obtained at M.A.E.E. on the 1/2.75 scale model. With a disturbance of 3 degs., an intermediate set of limits was found, lying closer to the zero disturbance limits. At 120,000 lb all up weight, with slipstream on, these 3 degs. disturbance limits lie almost exactly on the stability limits obtained by M.A.E.E. The agreement of these two sets of limits is not so good at 130,000 lb all up weight. The effect of slipstream 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 130,000 lb all up weight, and the free to trim attitudes with elevator neutral, and the stability limits are given in Fig.15. An estimate of the full scale trim and limits - corrected to model c.g. position and zero flap - are superimposed. As for the take-off case, the widths of the stable bands, 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 tank model, with slipstream, at speeds in the region of 80 knots full scale, takes the form of a bounce with little change in trim. Such bounce porpoising is also observed on the flying model in this speed region. Without slipstream, 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,

namely $C_{\Delta} = \dfrac{\Delta}{wb^3}$ = beam loading

$C_V = \dfrac{V}{\sqrt{gb}}$ = coefficient of velocity

α = attitude of keel datum

where

Δ = load on the water

w = density of water (64 lb/ft^3)

b = beam

V = velocity

g = acceleration due to gravity.

Curves of C_{Δ} against C_V for varying values of α are given in Fig.16.

The effect of the slipstream on bow spray at a C_V of 1.7 is very clearly shown in Figs.17 and 18. With the motors on, the blister 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 Fig.23. Full scale, spray enters the propeller disc over the C_V range 1.5 - 2.0. As C_V increases, the blister leaves the chine at points increasingly far aft so that it is not drawn into the disc. The suction field created by the slipstream, however, causes the blister 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 dirtiest at a C_V of 2.6. The breaking up of the chine blister by the slipstream is clearly seen, and also the tendency for the slipstream to swing the blister into the body. At a C_V of 3.5, this latter effect becomes much more marked and the step blister hits the tailplane 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 all 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.

5 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[2] 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 tail plane damping.

The increase in air stream velocity gives better ventilation and also modifies the water flow. In his report on air interference effects[4], 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 similar 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 these 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 one 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 water, 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 relieving 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 30,000 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 1/19th scale Shetland do not give limits which link up with the present tests. These tests were made with the model towed from the attachment in the hull and the towing connection was very large by comparison with the size of the model. Its effect on the air flow round the wing 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 - $\gamma/\rho b V^2$

where

γ = surface tension coefficient of water

ρ = density (slugs/ft^3)

b = 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.

6 Conclusions

The results of the present tests on a 1/19th 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 $(d\alpha/d\eta)$ 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.E. At low values of C_v (1.5 - 2.0) the chine blister is drawn into the propeller disc and this interference of the slipstream with the spray is confirmed by M.A.E.E.

List of Symbols, Coefficients

b	beam, ft
ω	density of water ($64\ lb/ft^3$)
ρ	density of water, $slugs/ft^3$
R	total water drag
Δ	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
α	attitude of the keel datum to the horizontal, degs.
η	elevator angle to tailplane, degs.
γ	surface tension of water, lb/ft
$C_V = \frac{V}{\sqrt{gb}}$	= coefficient of velocity = Froude Number
$C_\Delta = \frac{\Delta}{\omega b^3}$	= beam loading
$C_{\Delta_0} = \frac{A.U.W.}{\omega b^3}$	= static beam loading
$\frac{\gamma}{\rho\ bV^2}$	= surface tension number

List of Tables

List of Figures

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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 Tc when the propellers are on. From the tunnel curves, the pitching moments with slipstream and without slipstream (Tc = o) 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.

Speed, knots full scale	α^o Keel Slip-stream off	T_c	C_m slip-stream on	C_m slip-stream off	ΔC_m due to slip-stream	$\frac{1}{2}\rho V^2 S \bar{c}$
45	10.7°	2.8	-0.59	-0.10	-0.49	3.17×10^5
55	9.8°	1.5	-0.15	-0.02	-0.13	4.75×10^5
65	8.3°	1.0	-0.08	-0.02	-0.06	6.6×10^5
75	6.8°	0.7	-0.02	-0.01	-0.01	8.75×10^5
85	5.4°	0.6	0	0	0	-

Speed, knots full scale	45	55	65	75
ΔM due to slipstream	-155,000	-62,000	-40,000	-9,000
Estimated $\Delta\alpha$ due to slipstream and thrust moment	-1.4°	-2.0°	-1.7°	-0.5°
Measured $\Delta\alpha$ due to slipstream and thrust moment	-1.4°	-2.0°	-1.9°	-1.1°

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

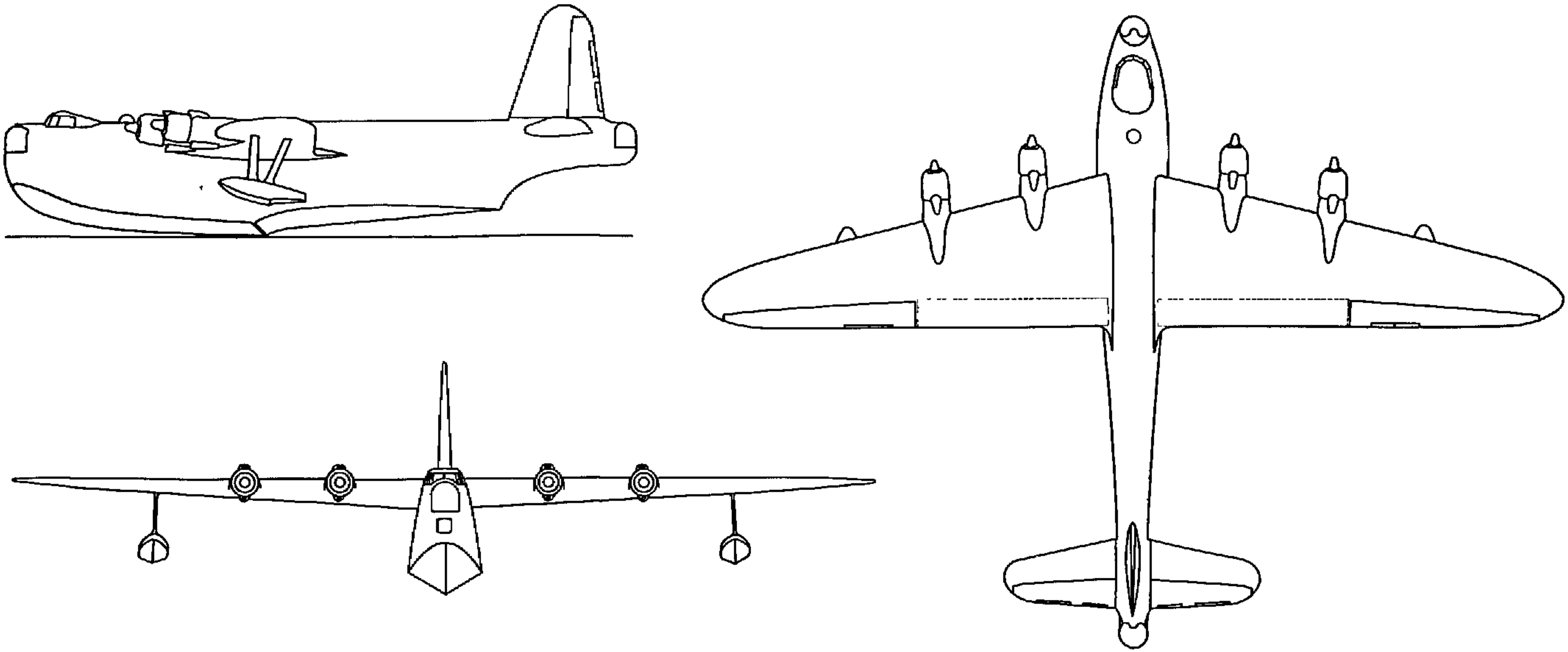
Item	Full Scale Shetland	1/19 scale Shetland	1/2.75 scale Shetland
Wing			
Section	Göttingen 436 (mod)	Göttingen 436 (mod)	-
Gross Area	2636 sq.ft	7.3 sq.ft	340 sq.ft
Span	150.33 ft	8.08 ft	50 ft
a.m.c.	18.95 ft	0.99 ft	-
Aspect ratio	8.61	8.61	7.35
Washout	none	none	2° from 15.5' from ℄ to tip
Dihedral	4° 30' on wing datum	4° 30' on wing datum	none
Sweep back on ½ chord	10° 24'	10° 24'	-
Wing setting			
Root chord	6° 38' to hull dat.	6° 38' to hull dat.	Aerodynamic chord 6° 11' to Shetland hull datum
Aerofoil dat.	5° 30' to hull dat.	5° 30' to hull dat.	
Tailplane			
Section	R.A.F.30	R.A.F.30	R.A.F.30
Gross Area	410 sq.ft	1.14 sq.ft	53.85 sq.ft
Span	45.5 ft	2.52 ft	16.54 ft
Elevator area	139 sq.ft	0.39 sq.ft	18.25 sq.ft
Dihedral	6° on tail plane datum	none	6° on tailplane datum
Tip chord above hull datum	20.33'	1.07'	-
Tail plane setting	4° 38' to hull dat.	4° 38' to hull dat	2° 0' to hull datum
Hull			
Beam	12.5'	0.66'	4.52'
Forebody - beam ratio	3.5	3.5	3.5
Afterbody - beam ratio	3.3	3.3	3.3
Step included angle in plan	136°	136°	136°
Unfaired step depth	9% of beam	9% of beam	9% of beam
After keel angle to forebody keel	7° 35'	7° 35'	7° 35'
Keel angle to hull datum	2° 35'	2° 38'	1° 32'
C.G. position during test, distance forward of main step	-	3.14 ins	normal 1'8.11" forward 2'0.35" aft 1'3.67"
Height above hull datum	-	0.84	-
All up weights during tests	120,000 lb 130,000 lb	17.50 lb 18.94 lb	5,700 lb 6,250 lb
Static beam loadings	0.96 1.04	0.96 1.04	0.96 1.05

TABLE I (Continued)

Item	Full scale Shetland	1/19 scale Shetland	1/2.75 scale Shetland
Engines			
Type	Centaurus VII (M gear only)	-	Pobjoy Niagara III
T.O. rating	2400 H.P./2700 RPM/S.L/+7$\frac{3}{4}$ lb	-	85 HP/3135 RPM S.L./zero boost
Propellers			
Type	De Havilland 4-blade Hydromatic	Wooden 4-blade fixed pitch	Wooden 2-blade fixed pitch
Diameter	15.75 ft	0.797 ft	6.5 ft
Solidity	0.114	0.139	0.07
Gear ratio	0.40	-	0.468

Wt.2078.CP6.K3. Printed in Great Britain.

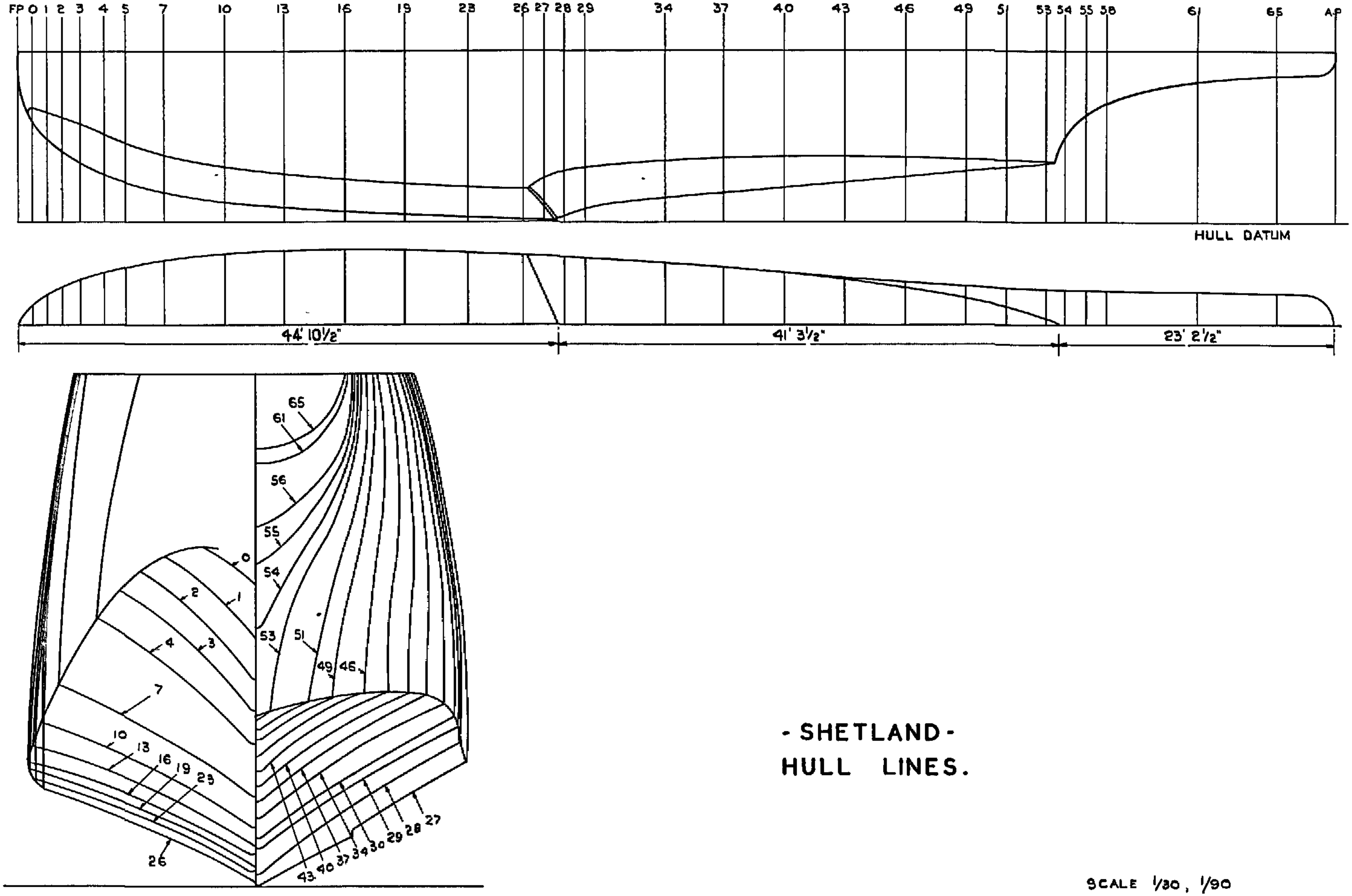
FIG I



GENERAL ARRANGEMENT

SHETLAND I

FIG. 2.



- SHETLAND -
HULL LINES.

SCALE 1/30, 1/90

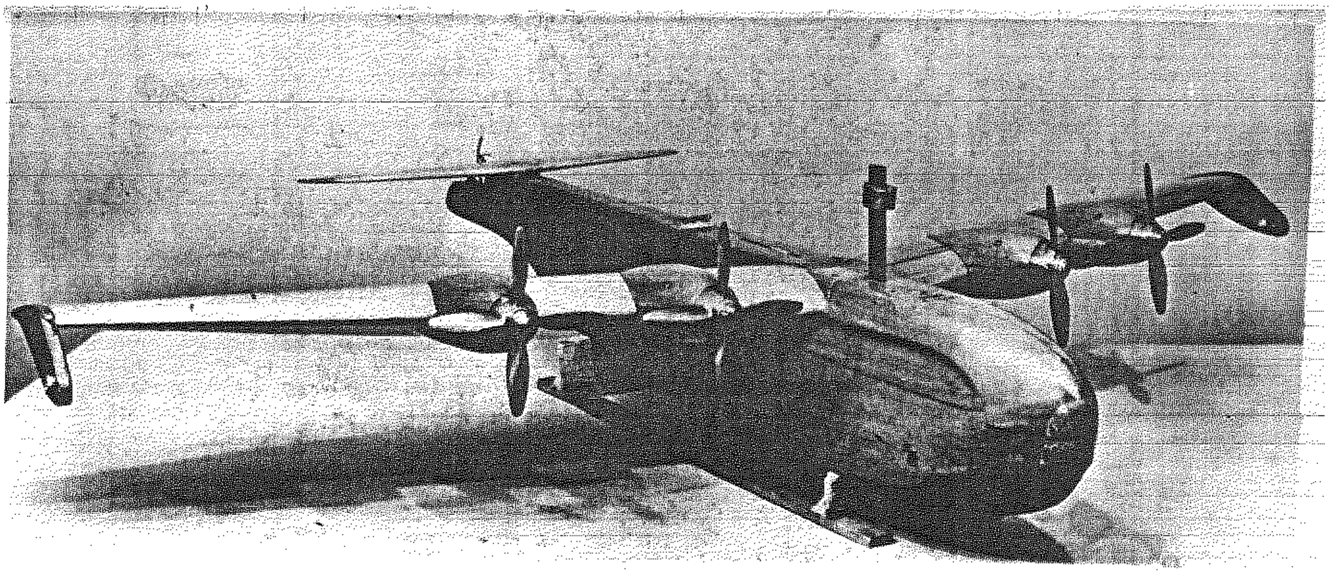


FIG.3. MODEL

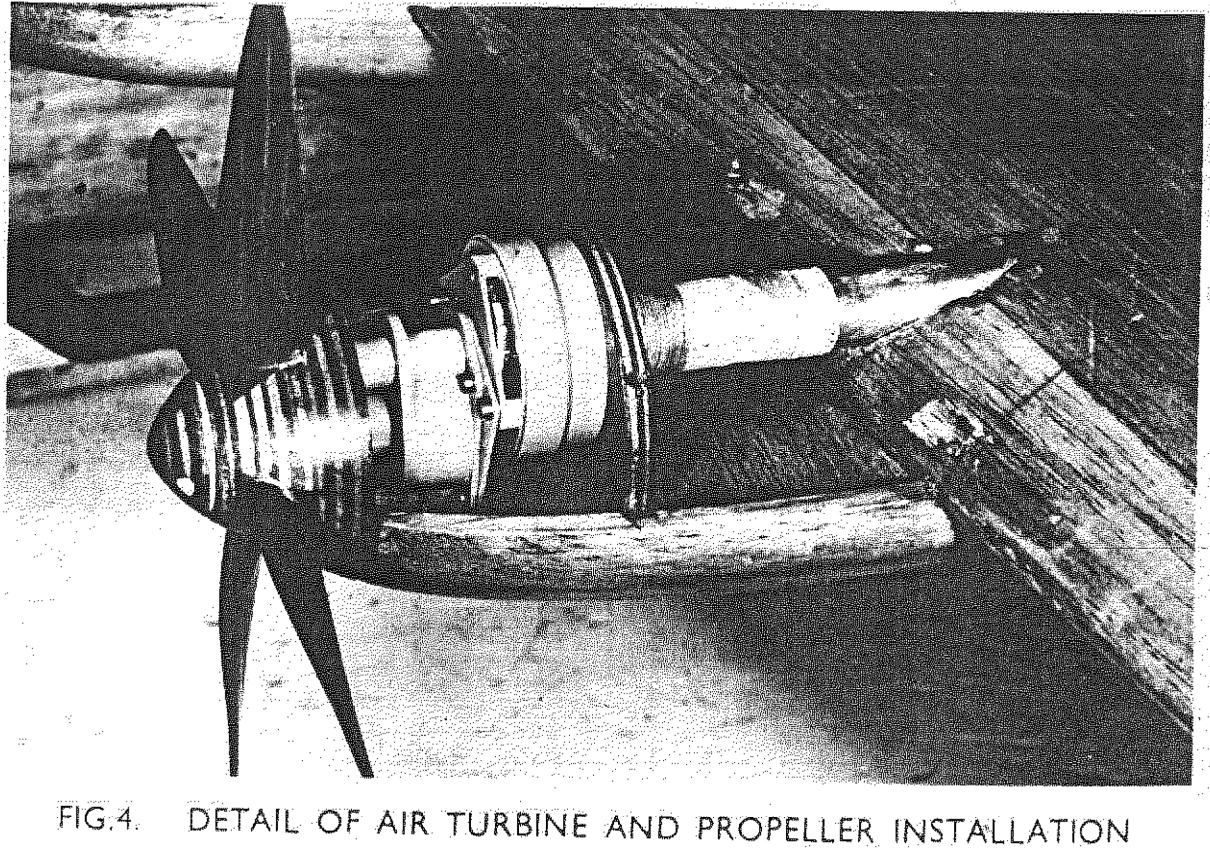


FIG.4. DETAIL OF AIR TURBINE AND PROPELLER INSTALLATION

SHETLAND

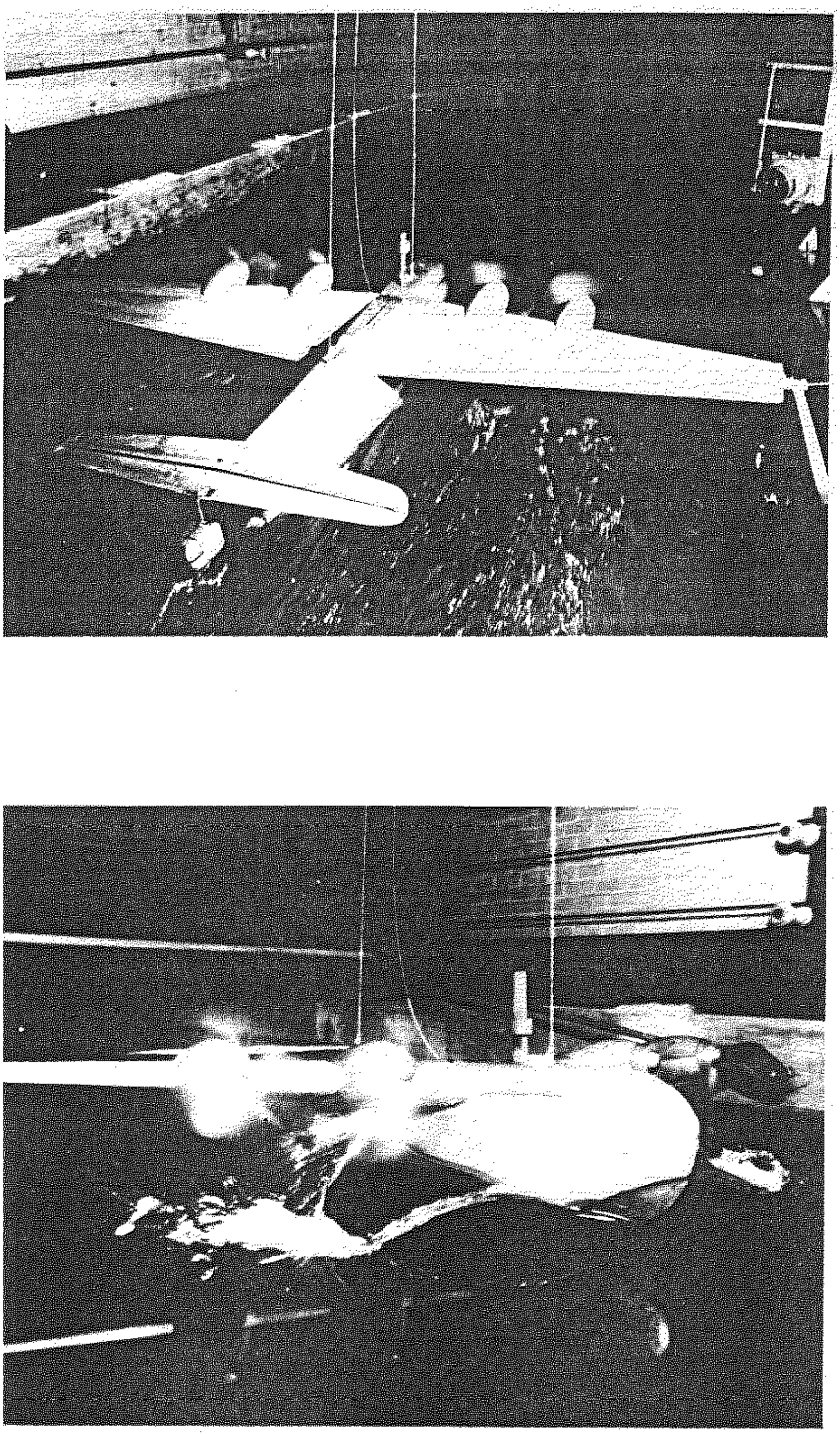
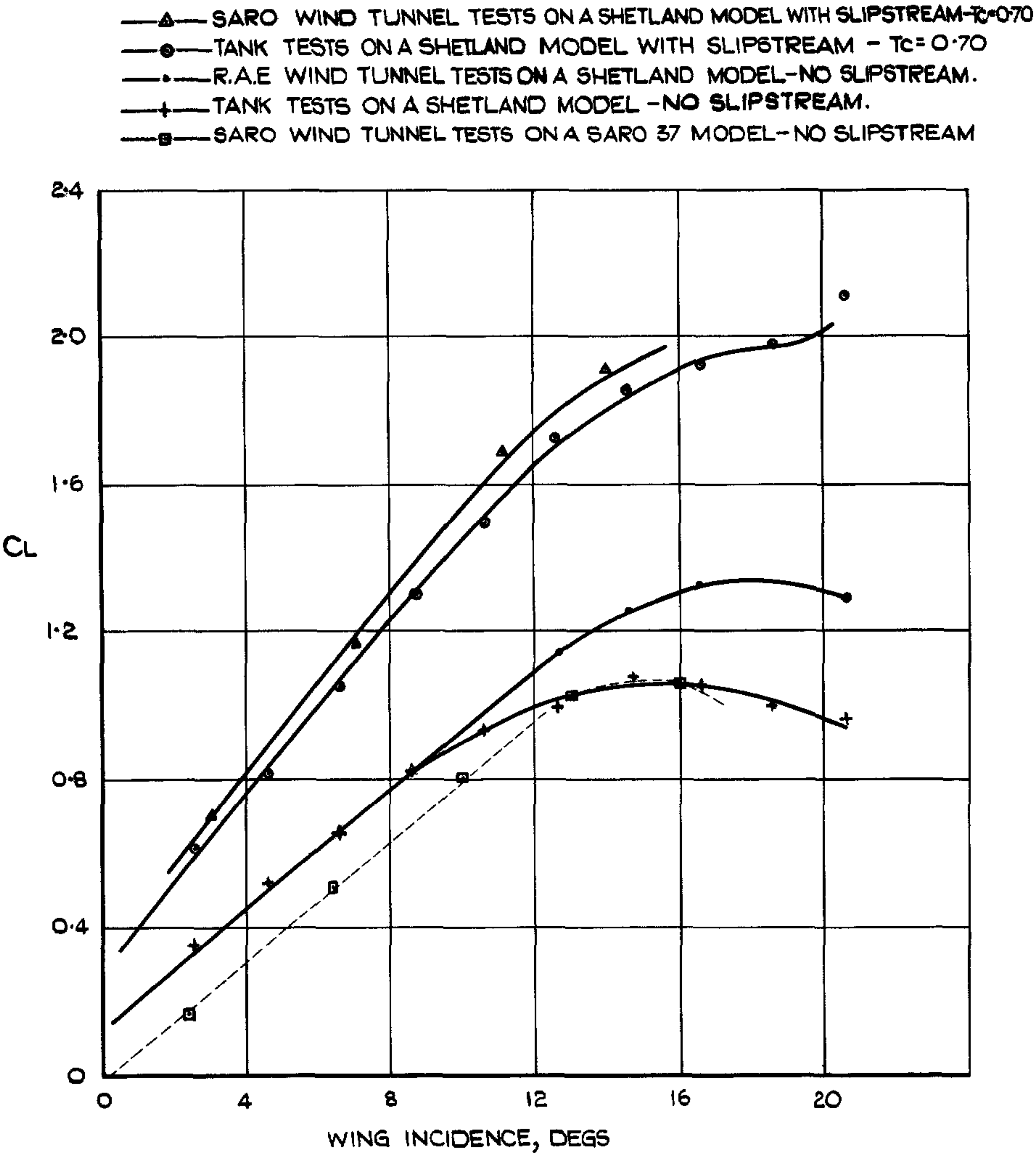


FIG.5. VIEWS SHOWING MODEL MOUNTED IN FRONT OF CARRIAGE

SHETLAND

FIG 6.

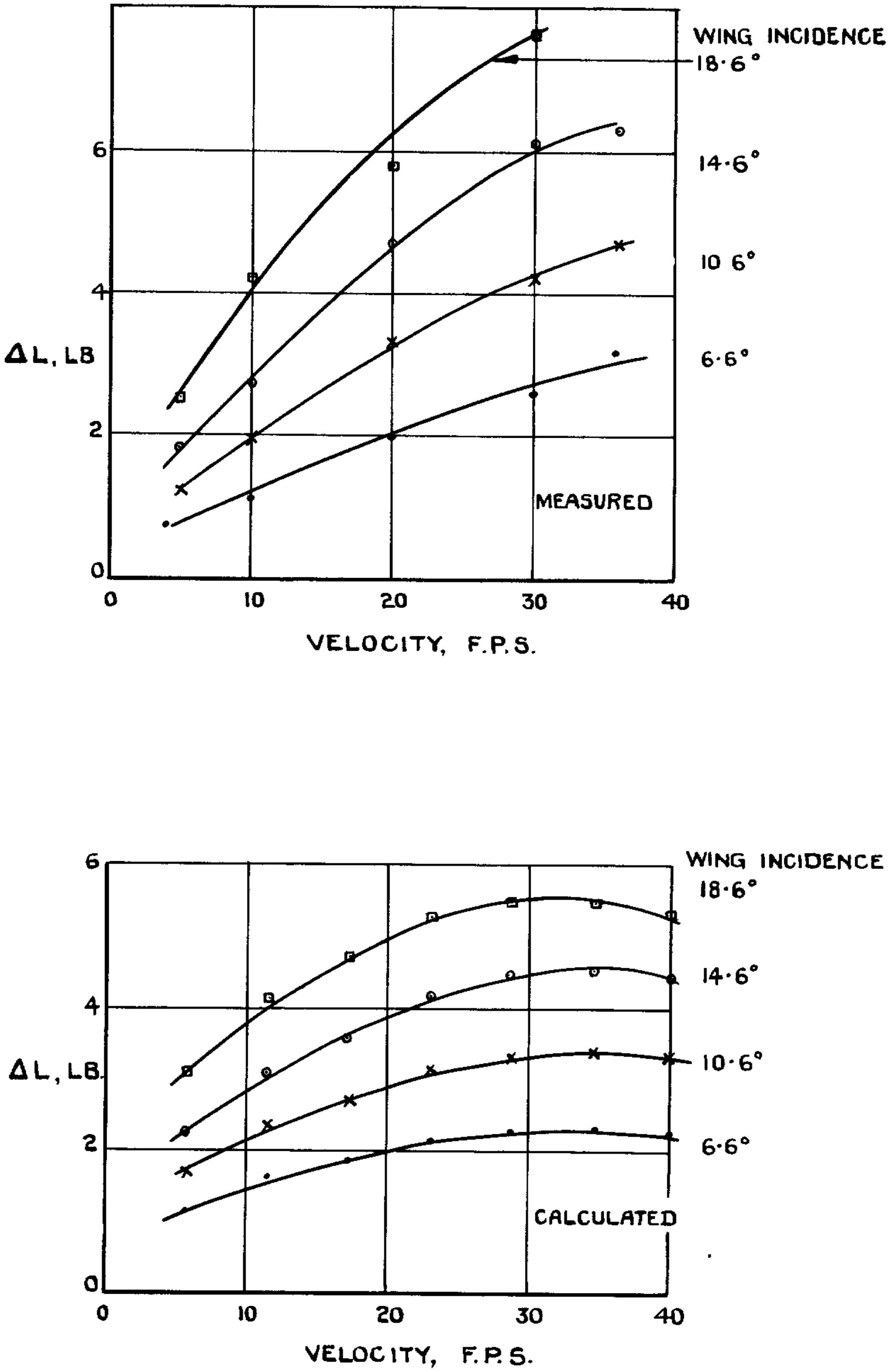


SHETLAND – WING LIFT CURVES.

FLAPS AT 0°

SHETLAND.

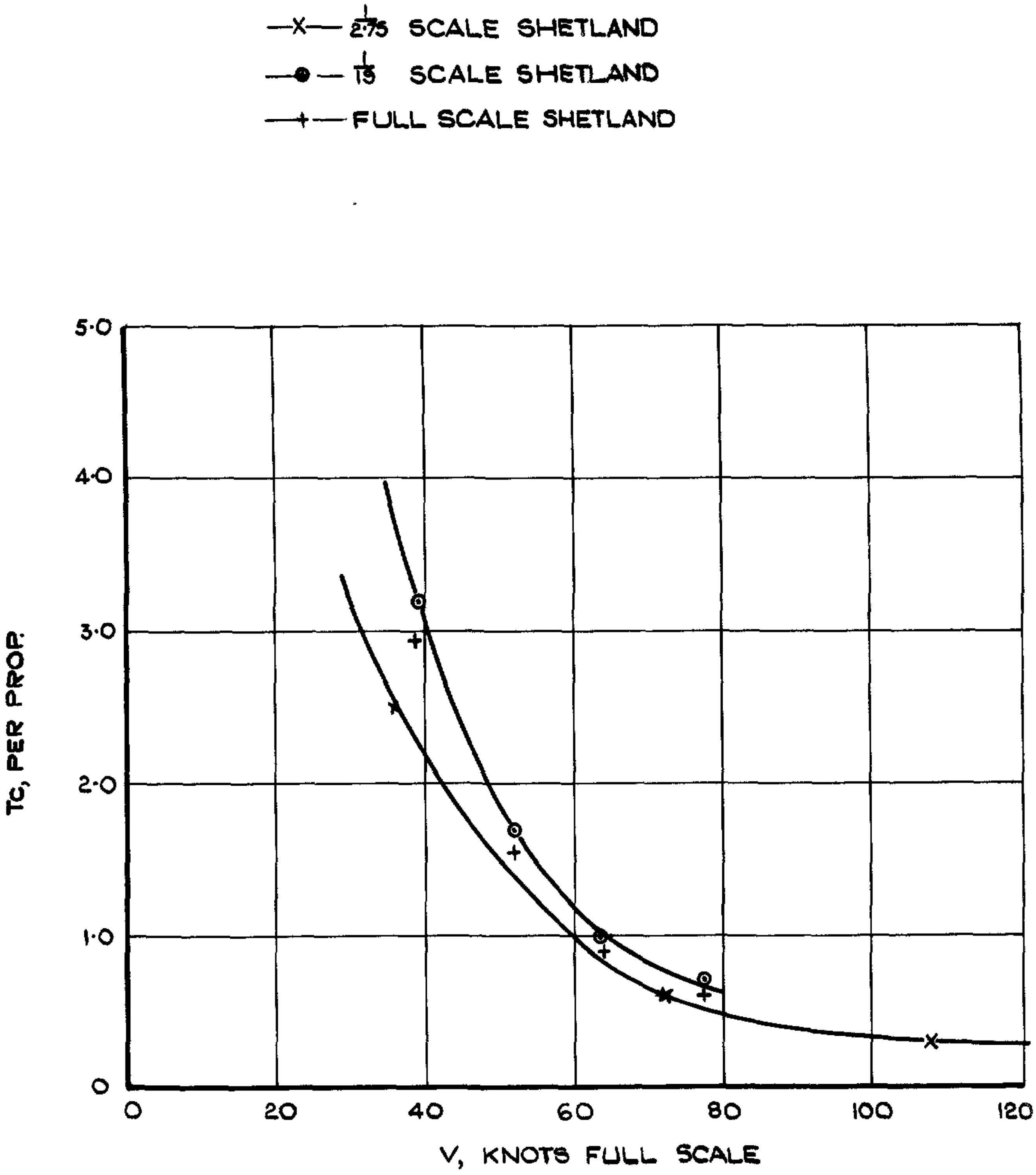
FIG. 7.



SHETLAND MEASURED & CALCULATED LIFT INCREMENTS DUE TO SLIPSTREAM.

SHETLAND.

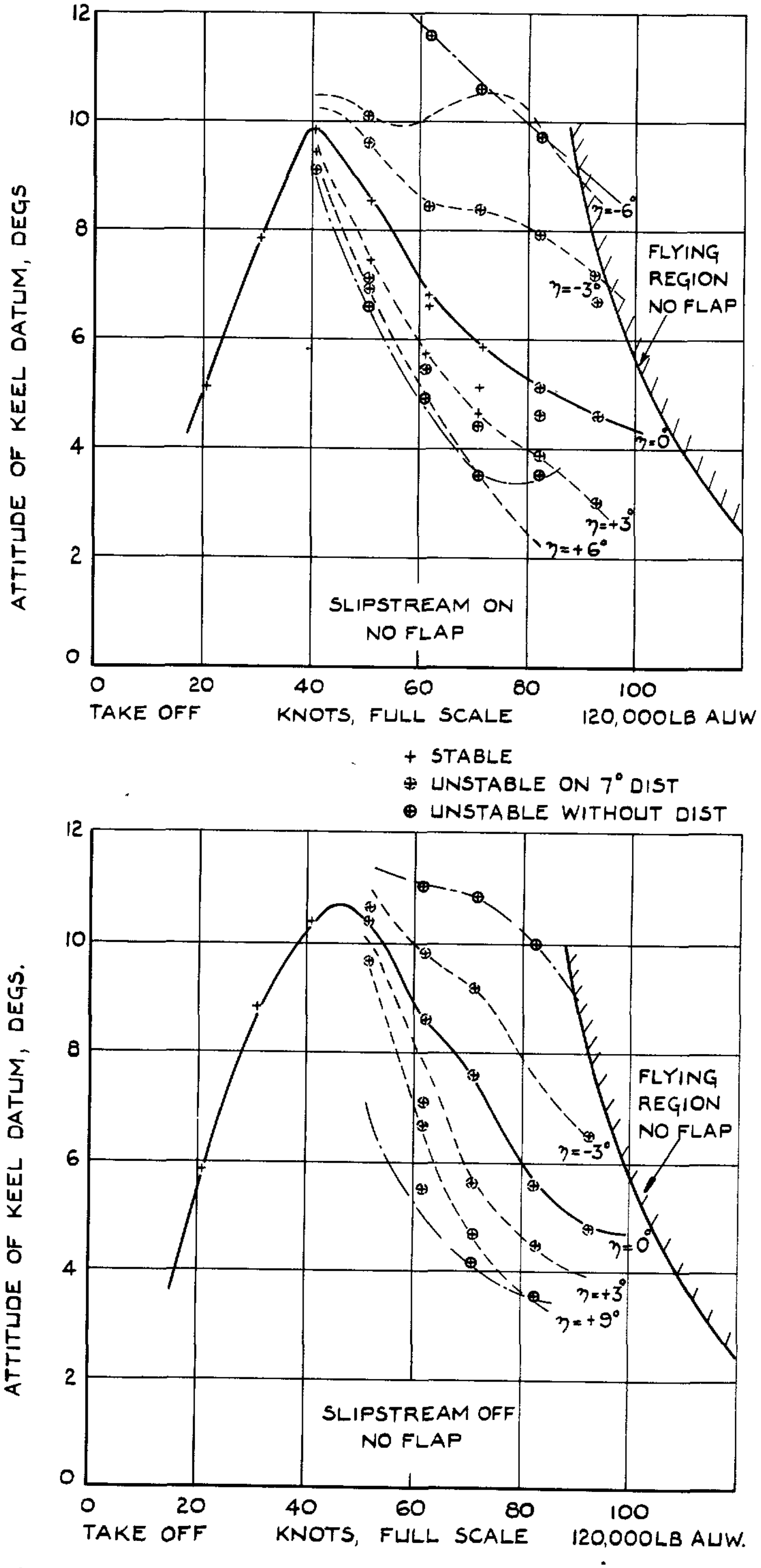
FIG 8.



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

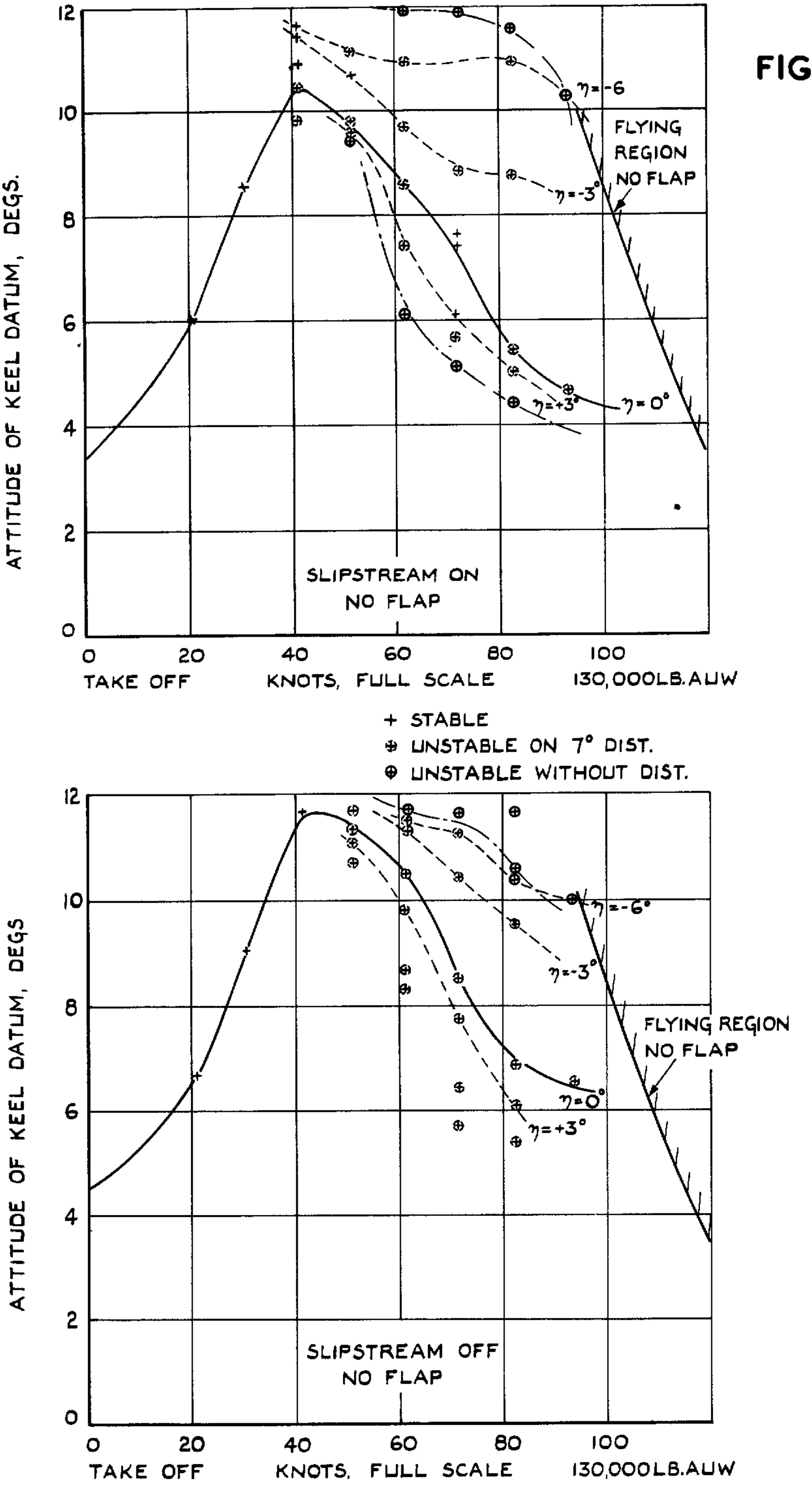
SHETLAND.

FIG. 9



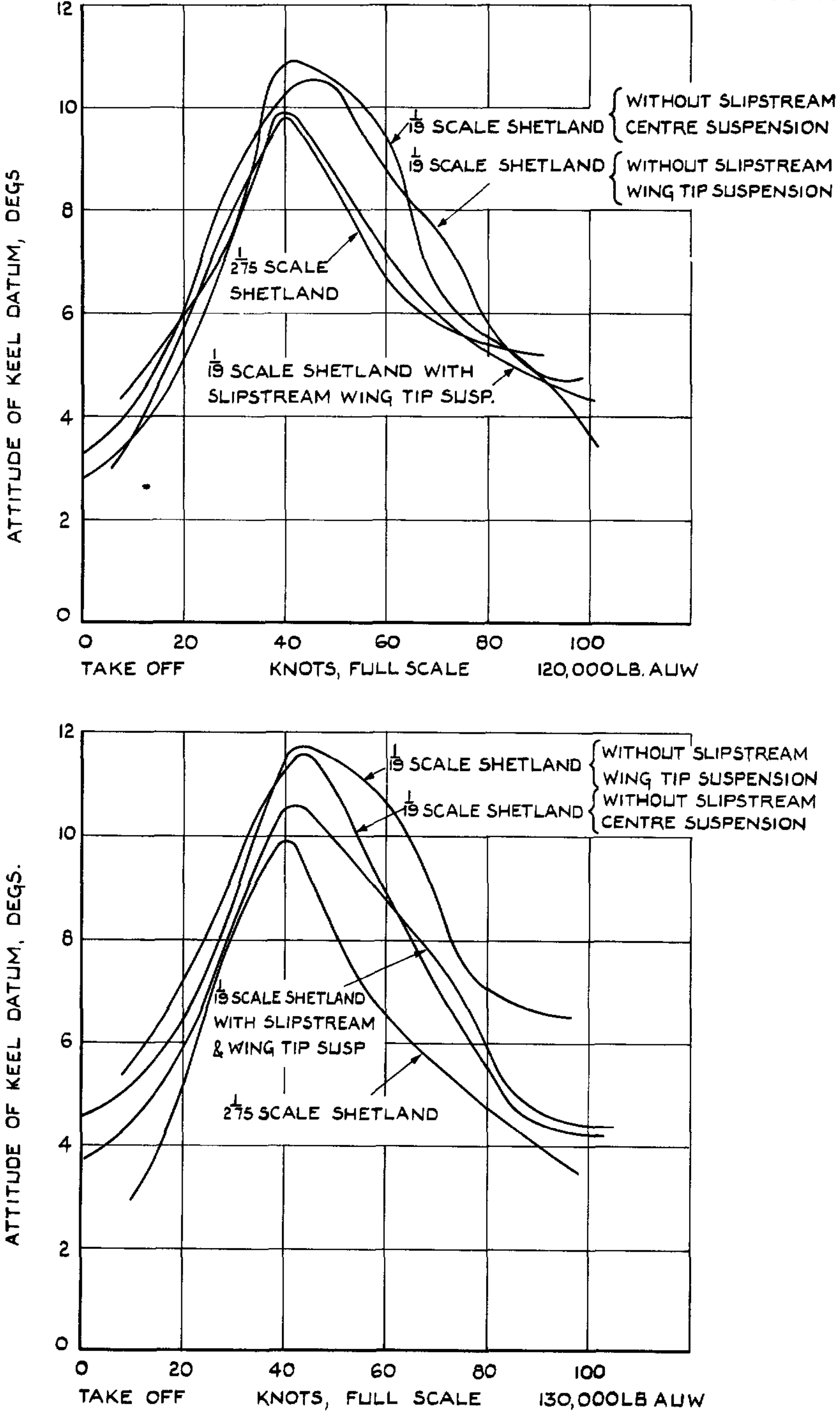
PORPOISING STABILITY OF SHETLAND WITH AND WITHOUT SLIPSTREAM

FIG. 10



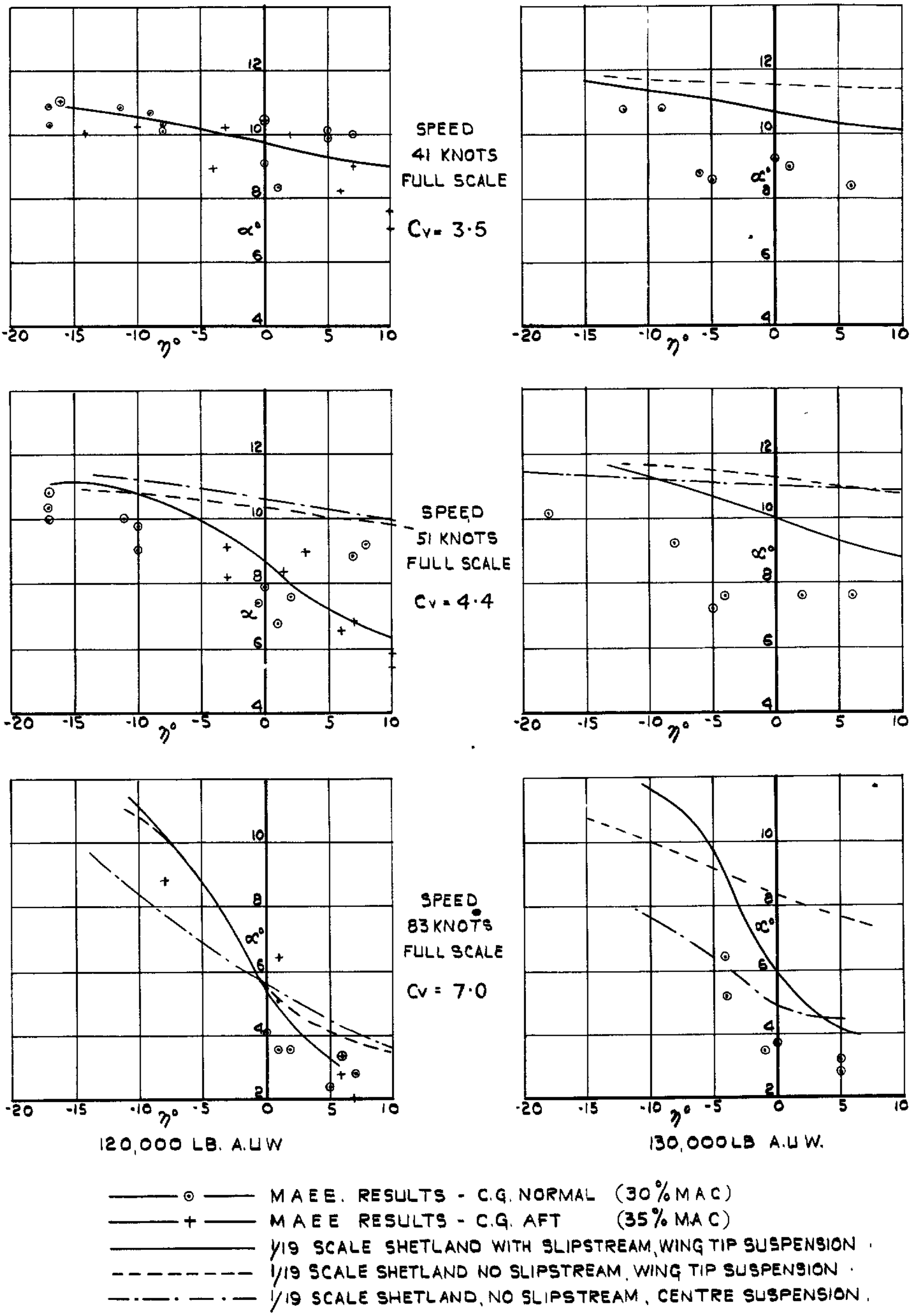
PORPOISING STABILITY OF SHETLAND WITH AND WITHOUT SLIPSTREAM

FIG 11.



SHETLAND—FREE TO TRIM ATTITUDES, MODEL AND FULL SCALE.

FIG.12.



SHETLAND – TRIM CURVES

SHETLAND

SHETLAND - STABILITY LIMITS MODEL AND FULL SCALE . 120,000 LB AUW

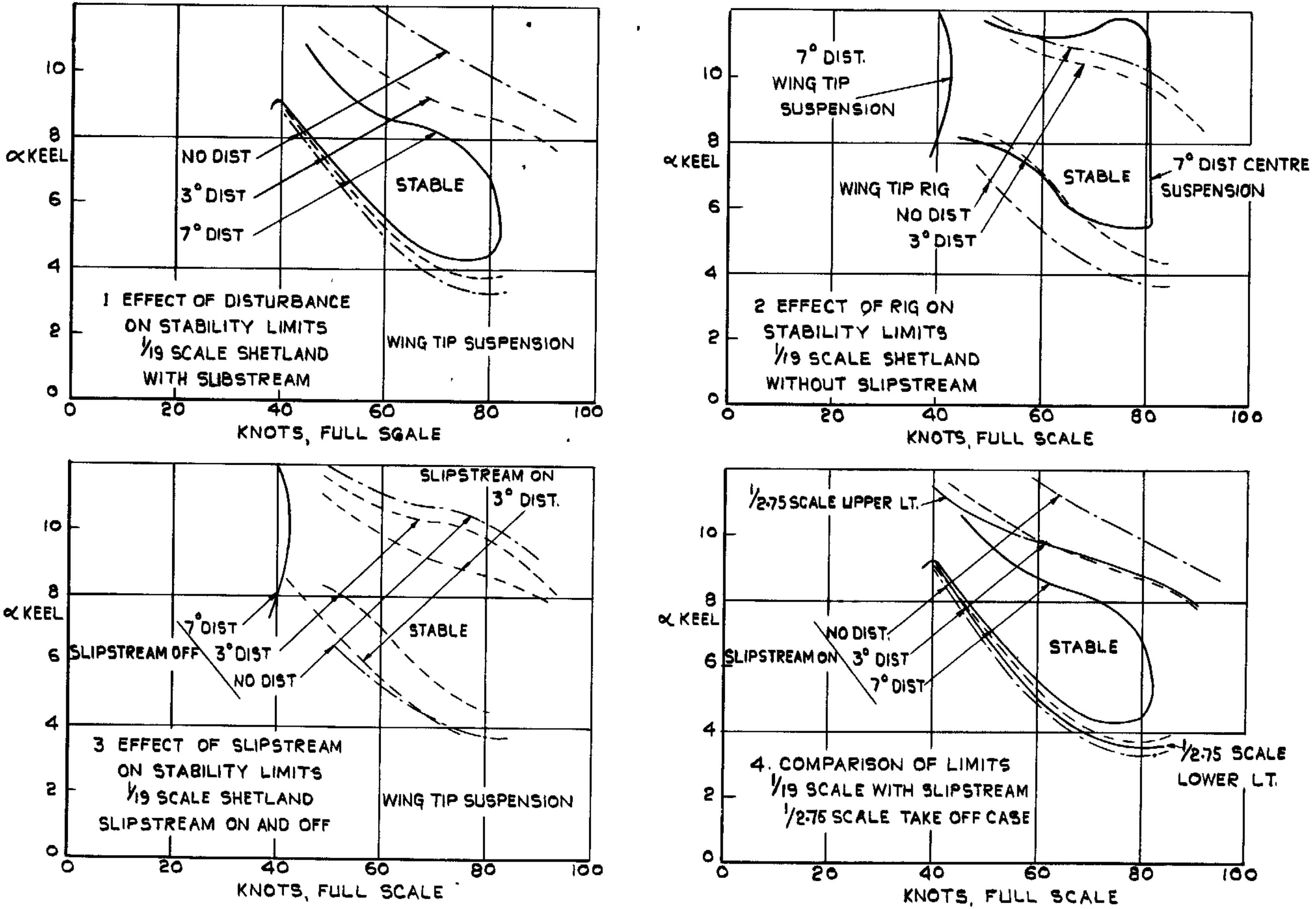


FIG.13.

SHETLAND

SHETLAND - STABILITY LIMITS MODEL AND FULL SCALE 130,000 LB AUW

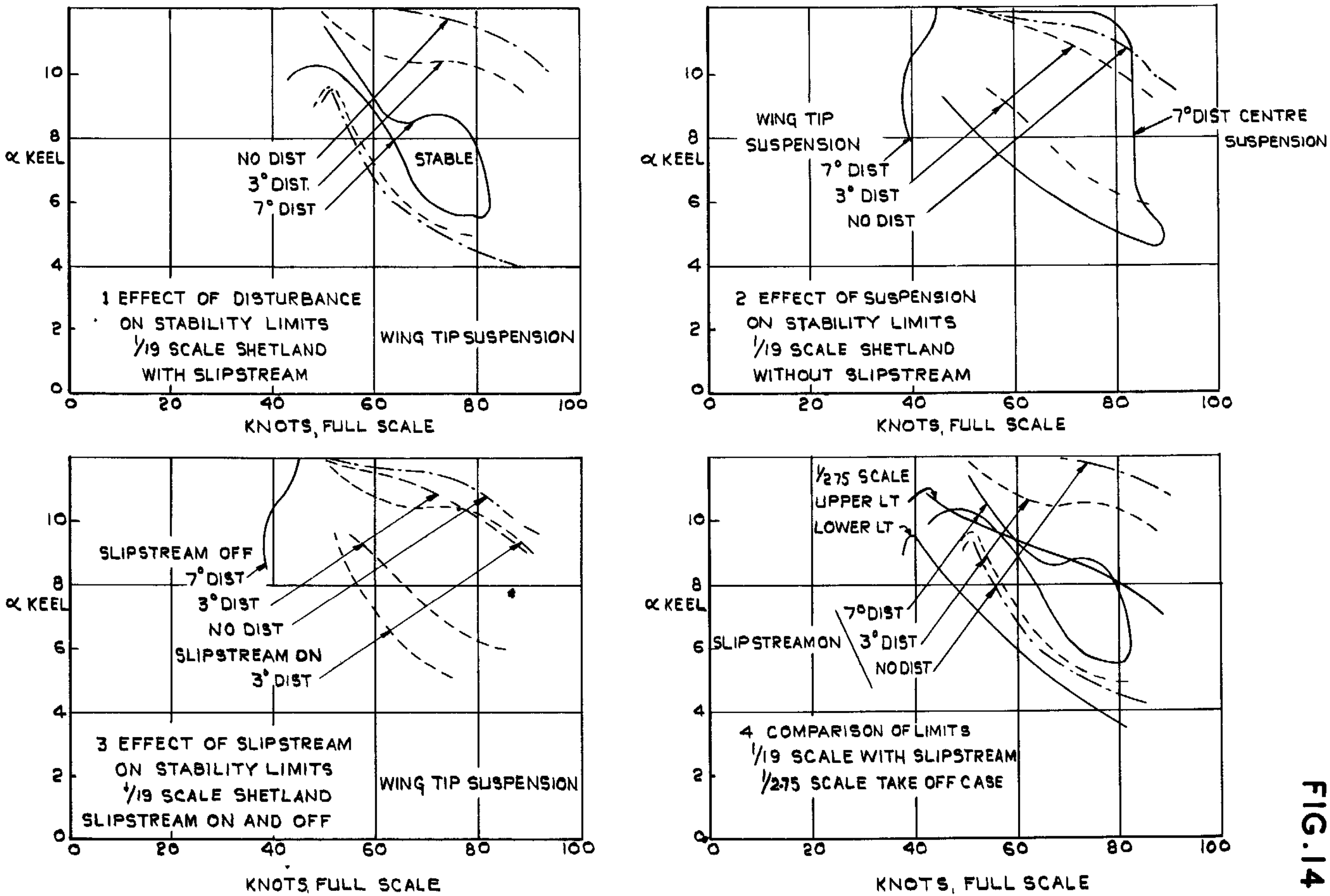
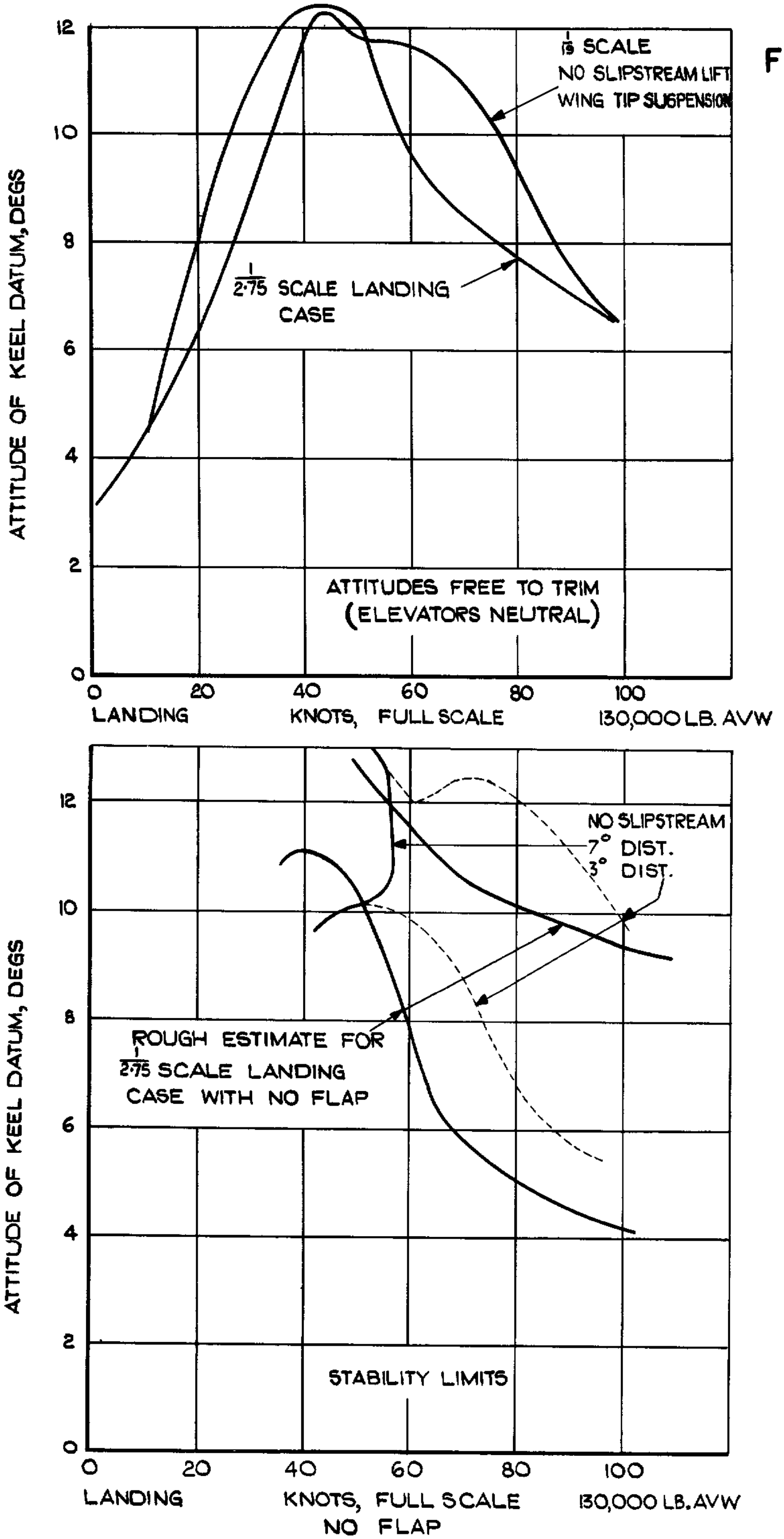


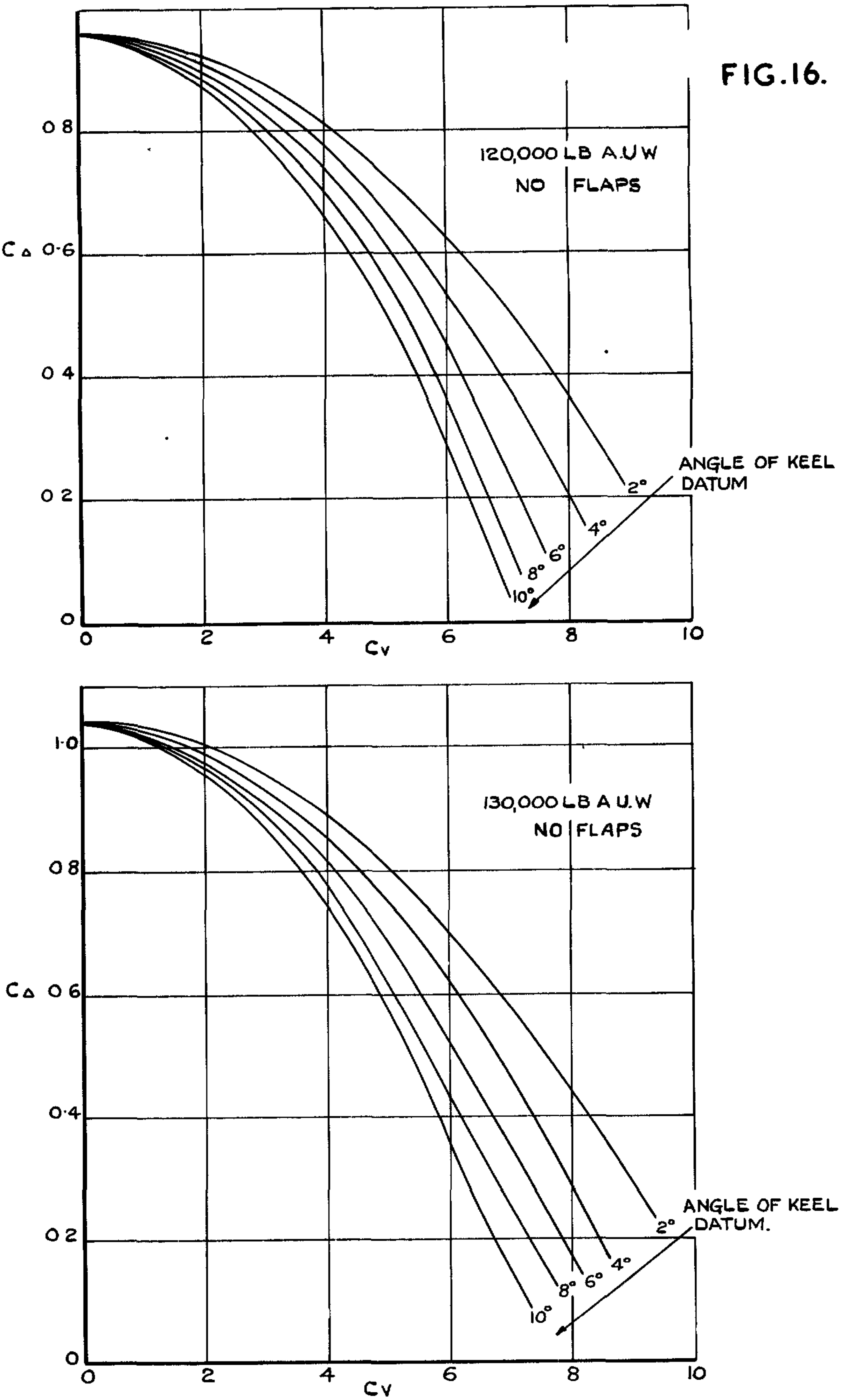
FIG. 14

FIG 15.



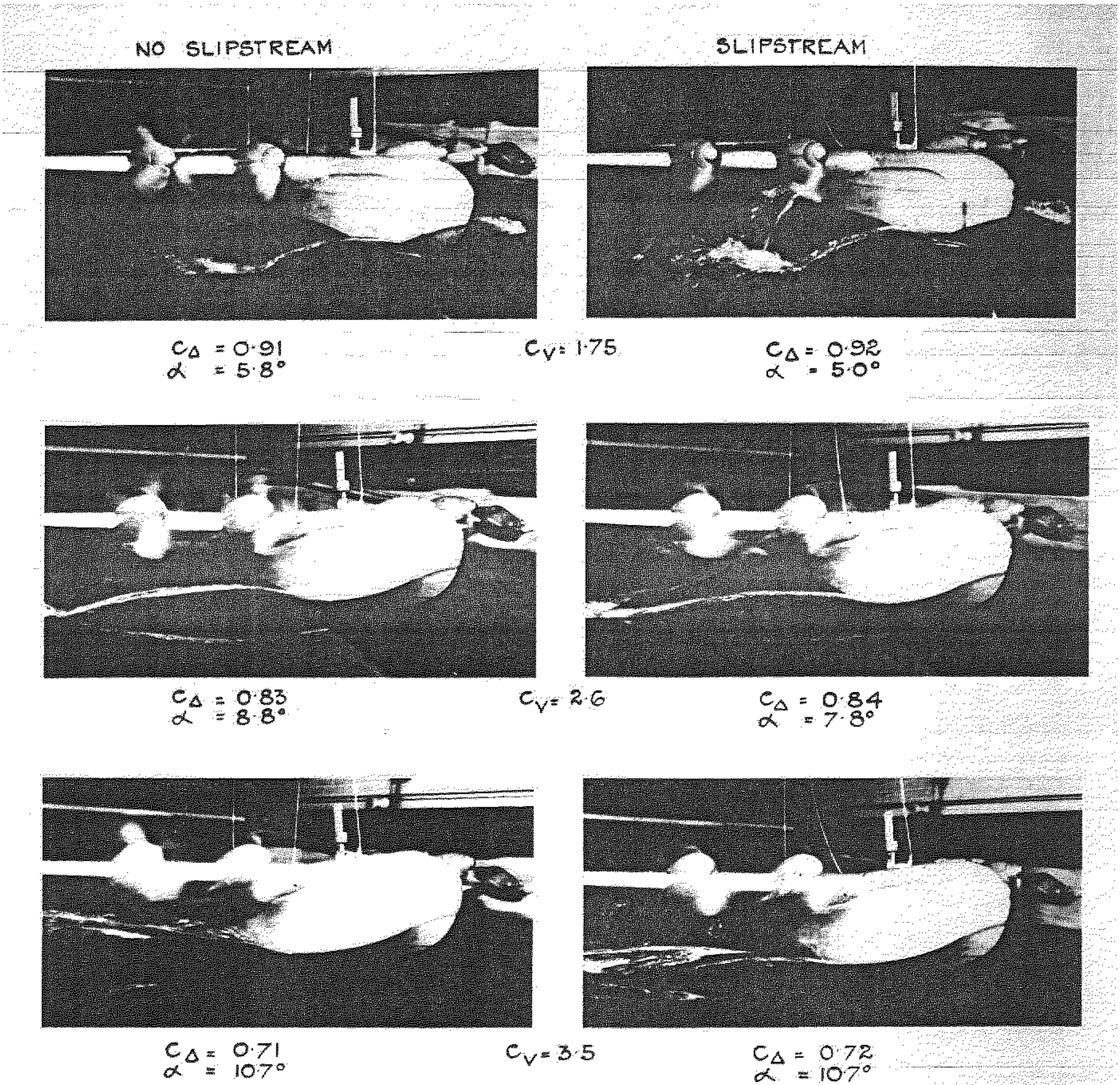
SHETLAND

FIG. 16.



CURVES OF C_Δ AGAINST Cv DURING TAKE-OFF.

SHETLAND.



$C_\Delta = 0{\cdot}91$
$\alpha = 5{\cdot}8°$

$C_V = 1{\cdot}75$

$C_\Delta = 0{\cdot}92$
$\alpha = 5{\cdot}0°$

$C_\Delta = 0{\cdot}83$
$\alpha = 8{\cdot}8°$

$C_V = 2{\cdot}6$

$C_\Delta = 0{\cdot}84$
$\alpha = 7{\cdot}8°$

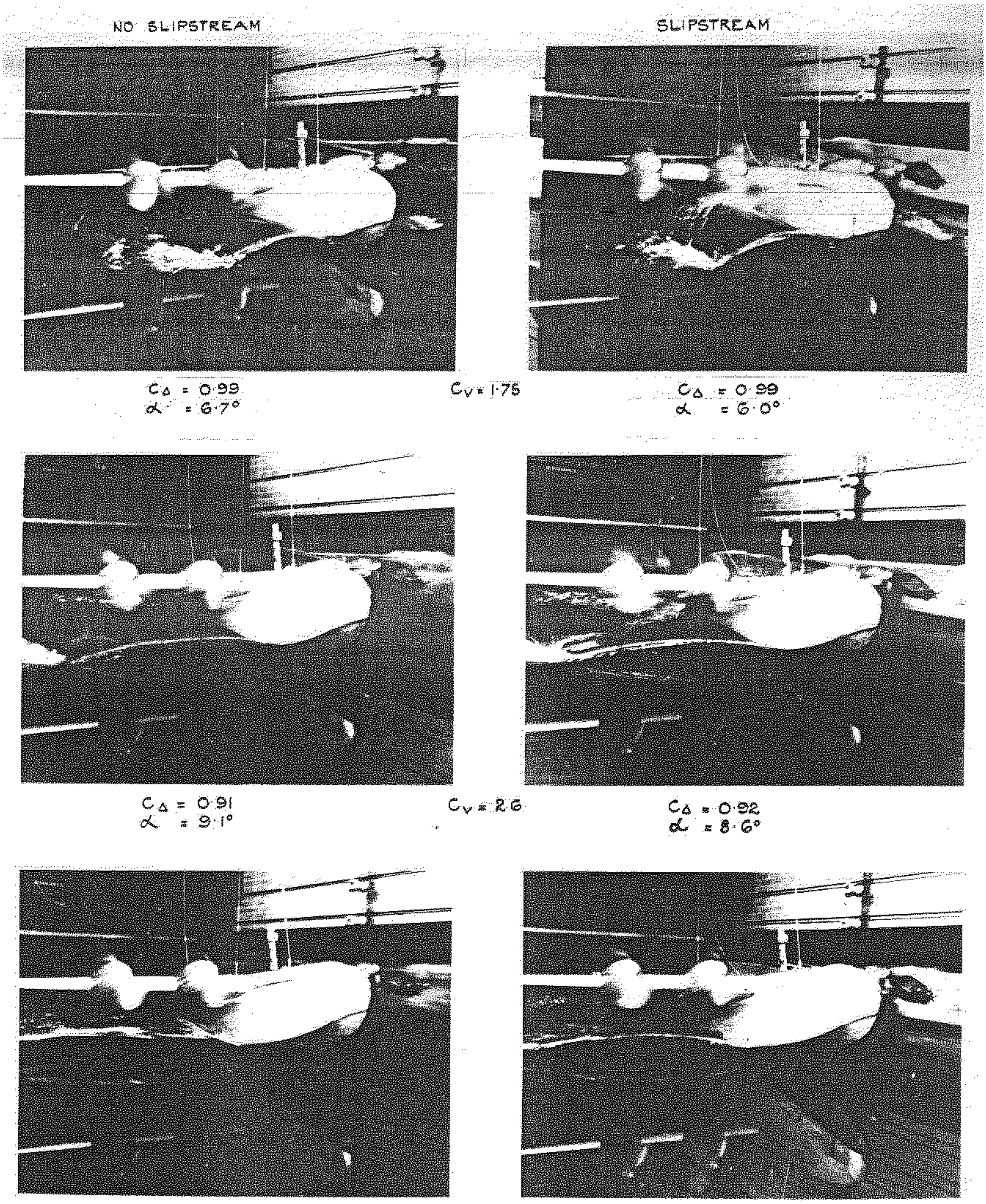
$C_\Delta = 0{\cdot}71$
$\alpha = 10{\cdot}7°$

$C_V = 3{\cdot}5$

$C_\Delta = 0{\cdot}72$
$\alpha = 10{\cdot}7°$

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

SHETLAND



$C_\Delta = 0.99$
$\alpha = 6.7°$

$C_V = 1.75$

$C_\Delta = 0.99$
$\alpha = 6.0°$

$C_\Delta = 0.91$
$\alpha = 9.1°$

$C_V = 2.6$

$C_\Delta = 0.92$
$\alpha = 8.6°$

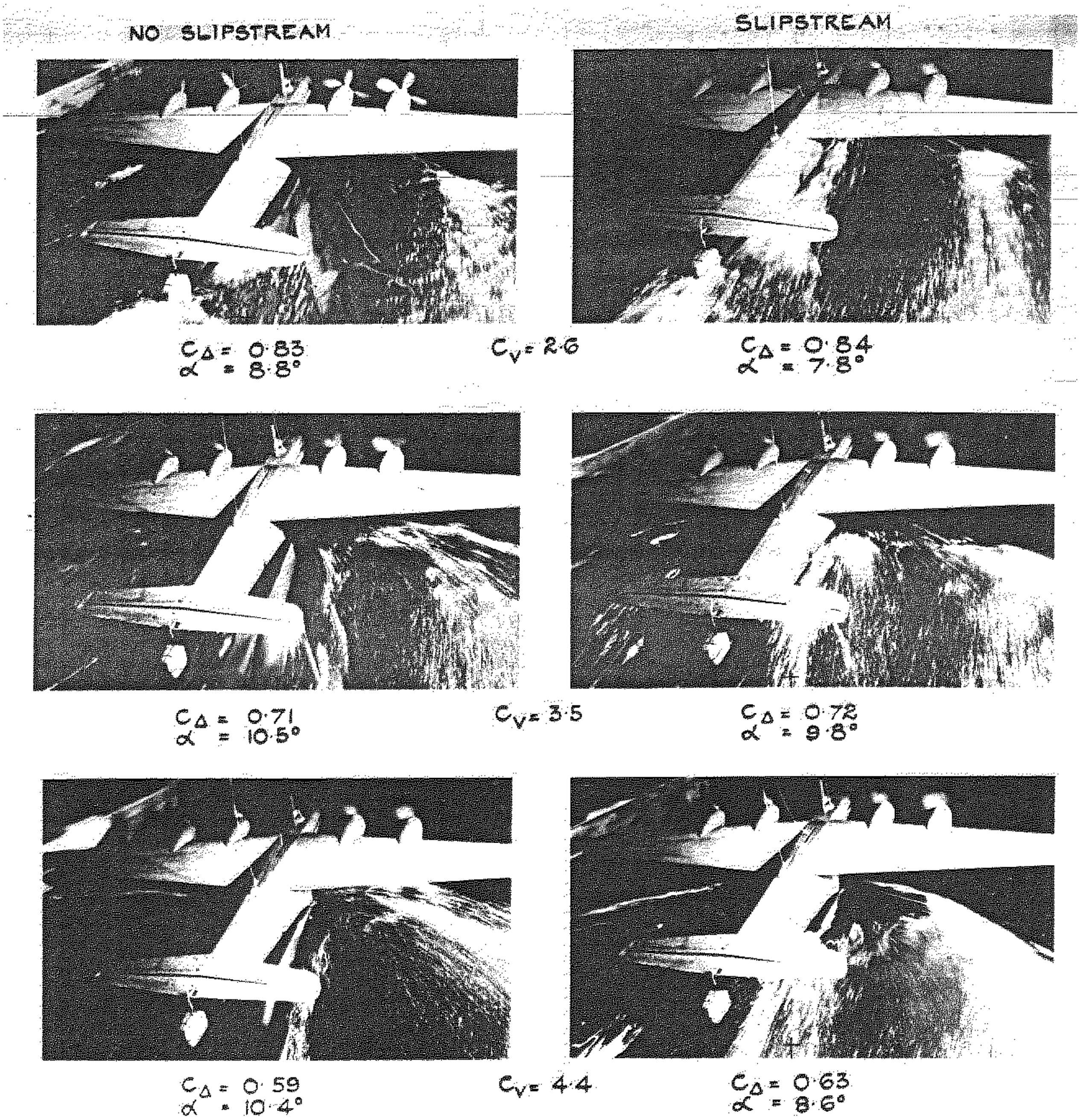
$C_\Delta = 0.79$
$\alpha = 11.7°$

$C_V = 3.5$

$C_\Delta = 0.81$
$\alpha = 10.3°$

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

SHETLAND



NO SLIPSTREAM

SLIPSTREAM

$C_\Delta = 0{\cdot}83$
$\alpha = 8{\cdot}8^\circ$

$C_V = 2{\cdot}6$

$C_\Delta = 0{\cdot}84$
$\alpha = 7{\cdot}8^\circ$

$C_\Delta = 0{\cdot}71$
$\alpha = 10{\cdot}5^\circ$

$C_V = 3{\cdot}5$

$C_\Delta = 0{\cdot}72$
$\alpha = 9{\cdot}8^\circ$

$C_\Delta = 0{\cdot}59$
$\alpha = 10{\cdot}4^\circ$

$C_V = 4{\cdot}4$

$C_\Delta = 0{\cdot}63$
$\alpha = 8{\cdot}6^\circ$

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

SHETLAND

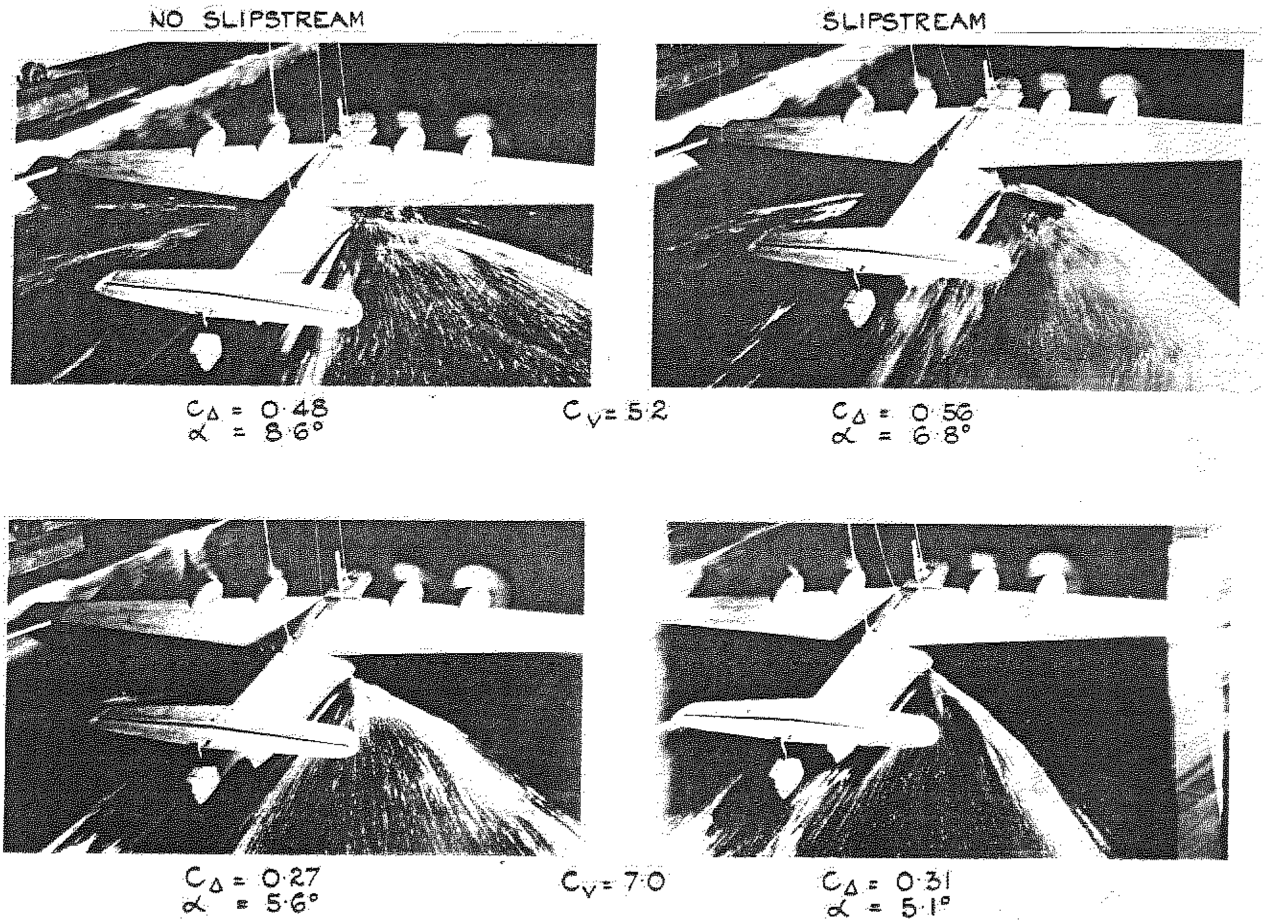


FIG.20. EFFECT OF SLIPSTREAM ON MAIN BLISTER
120,000 lb. A.U.W.

SHETLAND

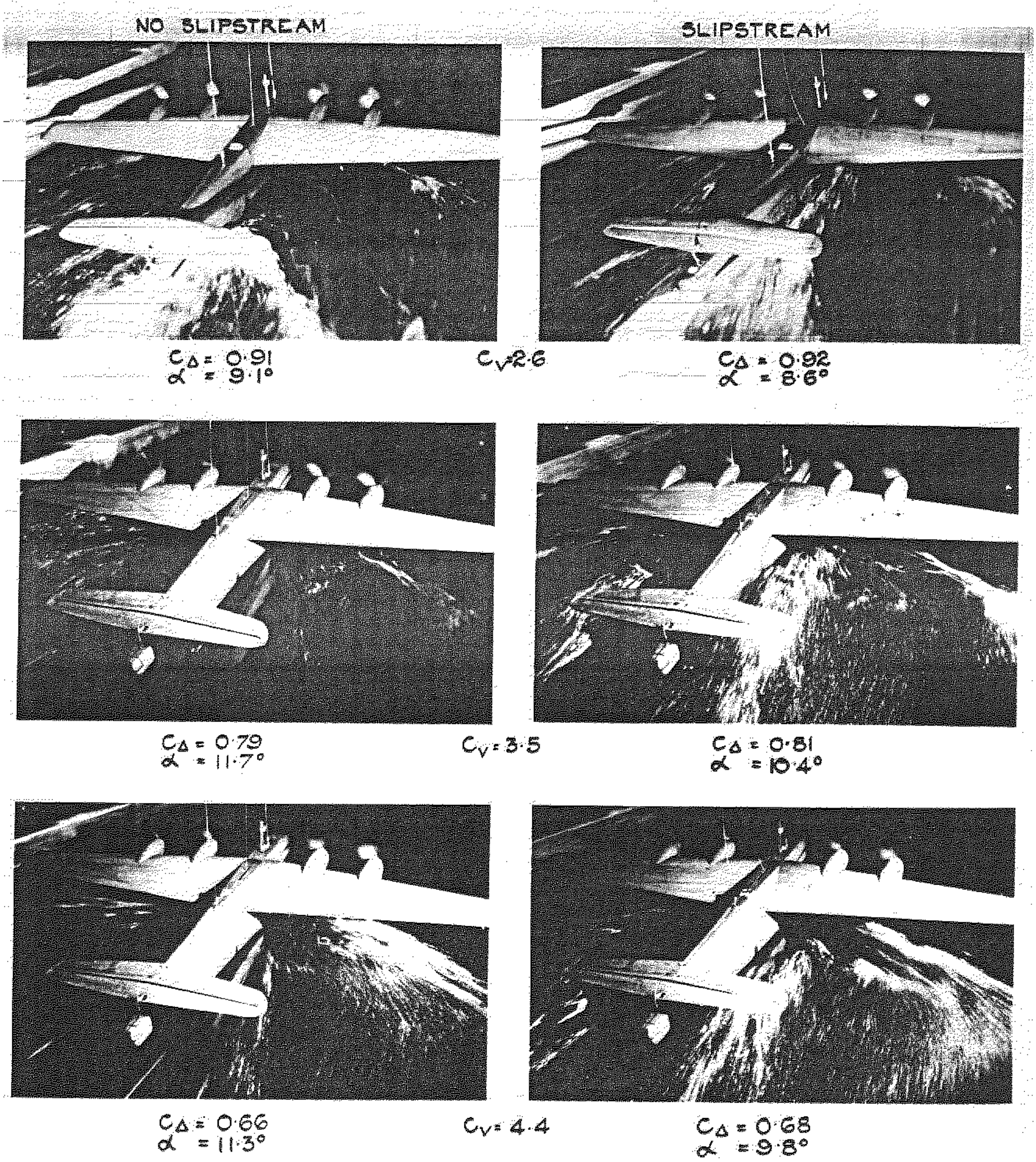


FIG.21. EFFECT OF SLIPSTREAM ON MAIN BLISTER
130,000 lb. A.U.W.

SHETLAND

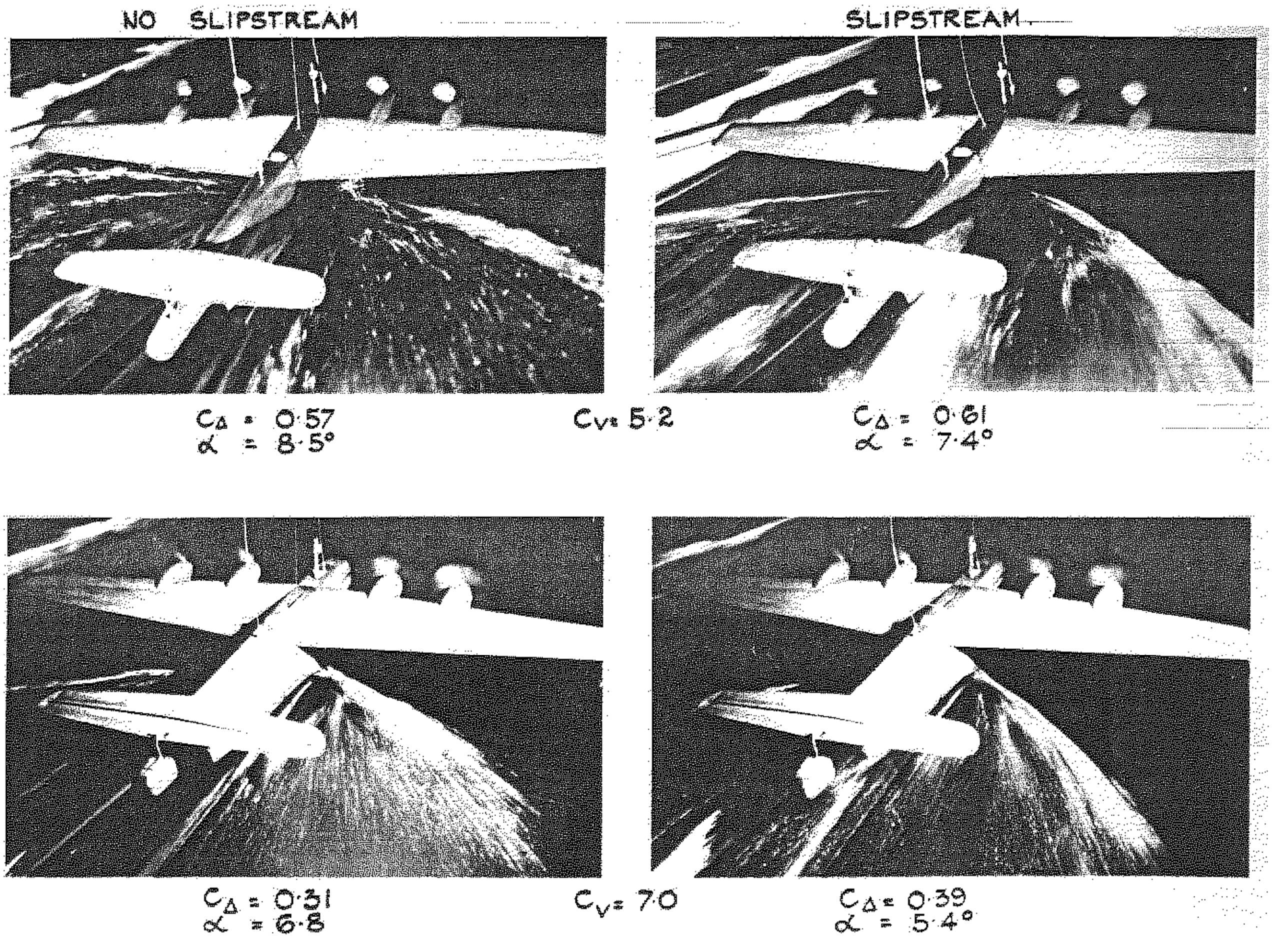


FIG.22. EFFECT OF SLIPSTREAM ON MAIN BLISTER
130,000 lb. A.U.W.

SHETLAND

FIG.23

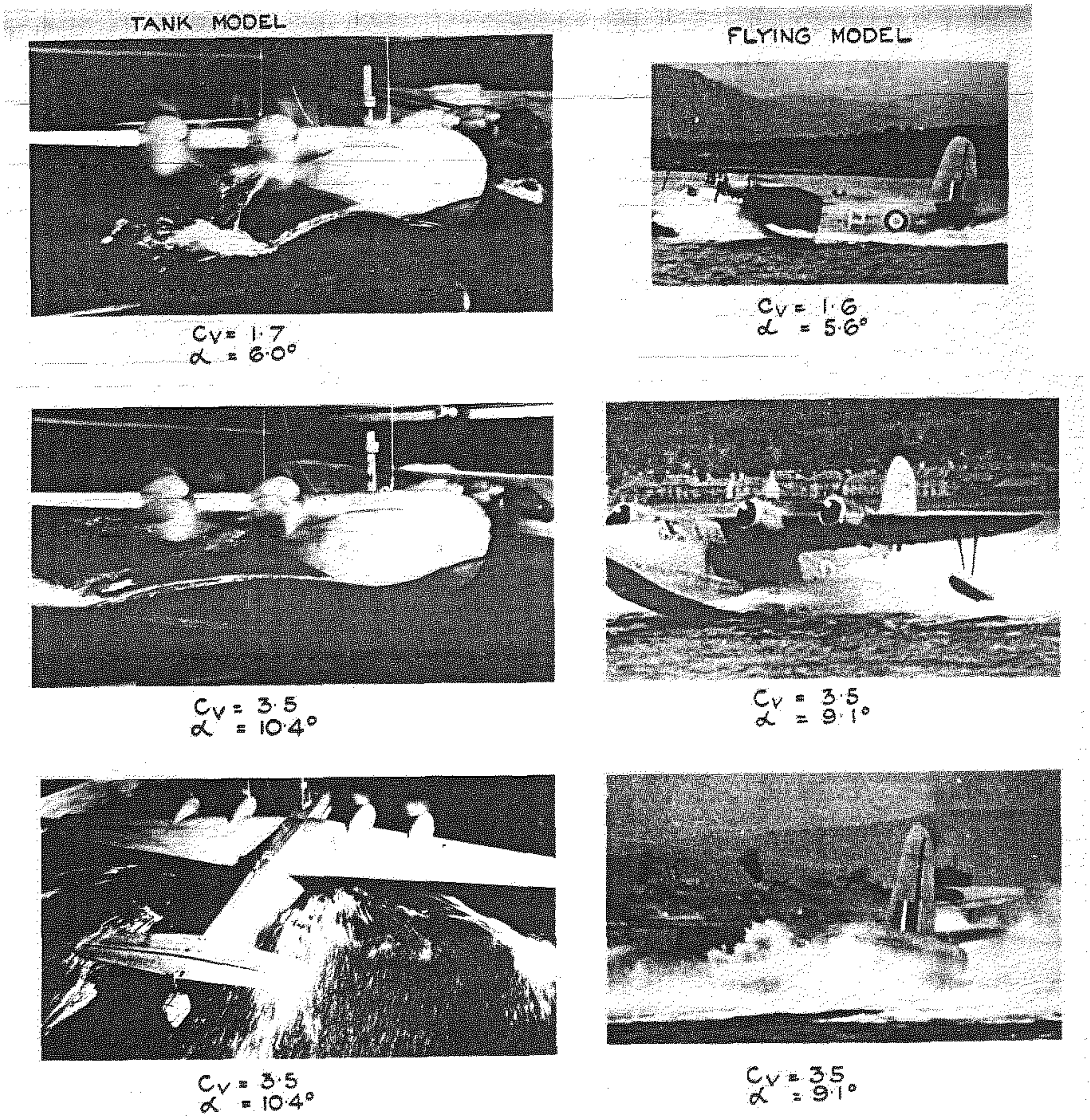


FIG.23. COMPARISON OF SPRAY ON TANK MODEL AND FLYING MODEL. SLIPSTREAM ON 130,000 lb. A.U.W.

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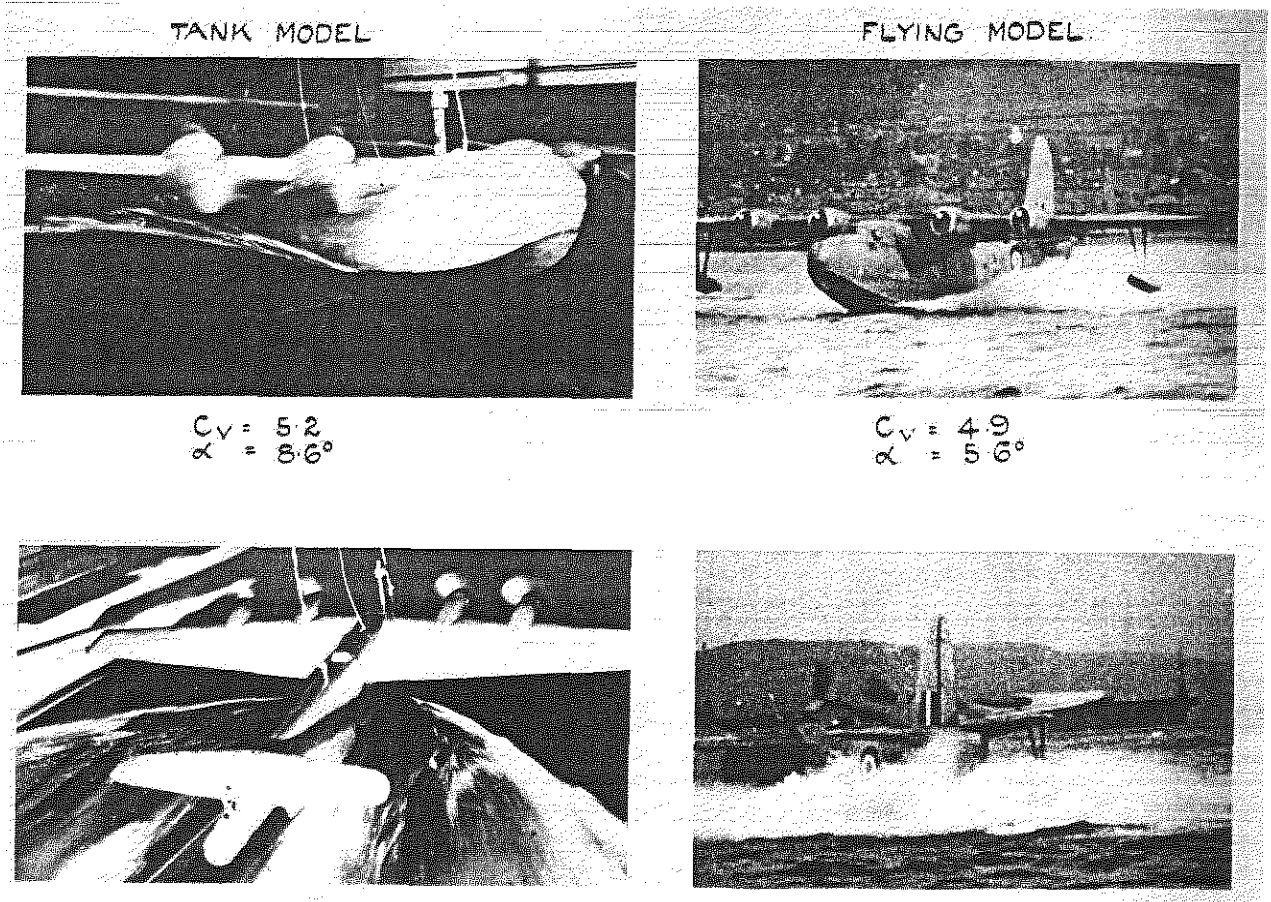

TANK MODEL

FLYING MODEL

$C_V = 5{\cdot}2$
$\alpha = 8{\cdot}6°$

$C_V = 4{\cdot}9$
$\alpha = 5{\cdot}6°$

$C_V = 5{\cdot}2$
$\alpha = 8{\cdot}6°$

$C_V = 4{\cdot}9$
$\alpha = 5{\cdot}6°$

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

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