C.P. No. 204
(17,033)
A.R.C. Technical Report

C.P. No. 204
(17,033)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings

Hydrodynamic Stability Part 10

The Effect of Afterbody Length on Stability and Spray Characteristics

By

D. M Ridland, A.F.R.Ae.S., G.I.Mech.E.

LONDON : HER MAJESTY'S STATIONERY OFFICE

1955

PRICE 3s 6d NET

C.P. No. 204

Report No. F/Res/244

August 1954

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT, FELIXSTOWE, SUFFOLK

INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 10

THE EFFECT OF AFTERBODY LENGTH ON STABILITY AND SPRAY CHARACTERISTICS

by

D.M. RIDLAND, A.F.R.Ae.S., G.I.Mech.E.

S U M M A R Y

The effects of afterbody length on longitudinal stability, spray, directional stability and elevator effectiveness are deduced from the results of tests on four models of the series which were alike in every major respect except that of afterbody length. The models had afterbody lengths of 4, 5, 7 and 9 beams respectively.

It was found that increasing afterbody length improved the disturbed stability characteristics considerably, made no effective over-all change in the undisturbed qualities and reduced trim generally; it impaired spray characteristics and directional stability and reduced elevator effectiveness.

/LIST OF CONTENTS

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

In this report the effects of afterbody length (the distance from main step to rear step measured parallel to hull datum) on the hydrodynamic stability and spray characteristics of a high length/beam ratio flying boat are deduced from the results of tests on four models of the series detailed in Reference 1 and listed in Table I. These models, A, D, E and F, with which this report is concerned, constituted the second phase of the present investigation i.e. the determination of the effects of afterbody length. They were identical except in respect of afterbody length and this single parameter was varied in the following manner:

Model D	Afterbody length 4 beams
Model A	Afterbody length 5 beams (basic model)
Model E	Afterbody length 7 beams
Model F	Afterbody length 9 beams

The effect of this variation on the hull shape generally can be seen in Figure 1, which is a comparison of hull lines. Hydrodynamic and aerodynamic data commom to the four models are given in Tables II and III, but it may be mentioned here that for each model the forebody was 6 beams in length and had no warp, the afterbody to forebody keel angle was 6° and the step was of straight transverse type with no fairing and a depth of 0.15 beams. Hull length/beam ratio varied between 10 and 15, depending on afterbody length. Further details of considerations affecting the design of the models are given in Reference 1.

The same techniques were employed consistently throughout the tests and they are discussed fully, together with the presentation of results, in References 1 and 2. A résumé of the details will be given in relevant sections as the need arises, but several common major factors may, with advantage, be stated here.

All the tests now under consideration were made with zero flap, no slipstream, one C.G. position and, except for the directional stability assessment, at the two beam loadings C_{Δ_0} = 2.75 and 2.25; directional tests were made only at C_{Δ_0} = 2.75. Full details of the results of the tests carried out on each model are given separately in References 3, 7, 8 and 9; only stability limits and sufficient illustrations to indicate the main trends are given here.

Throughout the report conclusions are drawn from comparisons of results at C_{Δ_0} = 2.75 and, where possible, substantiation is obtained from the other weight case. Reference is also made to a high length/beam ratio investigation carried out by the N.A.C.A. and to earlier work on hulls of lower length/beam ratios.

2. LONGITUDINAL STABILITY

2.1. Present Tests

Longitudinal stability tests were made by towing the model from the wing tips on the lateral axis through the centre of gravity, with the model free in pitch and heave. The elevator setting was selected before each run and the model towed at constant speed. The angle of trim was noted in the steady condition, and if the model proved stable at the speed selected it was given nose-down disturbances to determine whether instability could be induced, the largest amounts of disturbance being required in the high speed undisturbed lower limit region. In each case the motion was defined as unstable when the resulting oscillation (if any) was apparently divergent or had a constant amplitude of more than 2°. Stability limits were built up by these methods, the disturbed limits representing the worst possible disturbed case. Both

/undisturbed

undisturbed and disturbed limits for models A,D,E and F at the two different weights are compared in Figures 2 and 3.

The effects of afterbody length on the stability limits for $C_{\Delta_0} = 2.75$ in the undisturbed case are shown in Figure 2(a). With increasing afterbody length, maximum lower critical trim (maximum trim attained on the lower limit) is found at progressively lower attitudes and slightly higher speeds; apart from this the position of the limit is almost unchanged. The vertical band of instability which occurs with the shorter afterbodies at this weight and extends across the take-off path is removed at the higher lengths, while the upper limit is progressively lowered and the mean speed at which upper limit instability is encountered with the elevators used is increased. At the same time, the extent of the upper unstable region is decreased, until, with the longest afterbody, no upper limit instability is obtained. (It is essential that the reader appreciates the viewpoint from which conclusions are drawn, here and throughout the remainder of the report; it is indicated, in essence, by the phrase "with the elevators used", earlier in this paragraph. The tests were made with complete dynamic models (as opposed to hulls alone) and only trimming moments available from the elevators were utilised. As the total elevator area was greater than half that of the tailplane (Table III), it is felt that the range of trims obtained in each test would not differ significantly from that of a corresponding full scale design. Conclusions are therefore drawn directly from the evidence in the figures and no reference is made to possible effects beyond the trim ranges indicated).

Confirmation of these changes can be obtained from Figure 3(a) which is for a lower load, $C_{\Delta_0} = 2.25$, but before a direct quantitative comparison can be made with Figure 2(a) the effect of load itself must be considered. One of the conclusions of Reference 4, which it was shown can be extended to the present case, was that in the undisturbed case, the rate of change of critical trim (the trim at which instability sets in) with respect to load at constant speed is both approximately linear and positive. In addition to this, an examination of the effects of a decrease in C_{Δ_0} of 0.5 on the stability limits for the four models shows that the mean rates of change with load are equal within practical limits, although the degree of separation varies slightly with different speeds. It appears, therefore, that changes in limits due to load variations are unaffected by afterbody length and, because of the equality of the load effects, Figures 2(a) and 3(a) are directly comparable and should show the same manner and magnitude of change with respect to afterbody length. Apart from the fact that, in the case of the two short afterbodies, the vertical bands of instability cutting across the take-off path have been removed with the reduction in weight, good agreement is obtained.

The reduction in maximum lower critical trim with increase in afterbody length is shown approximately for the two loadings, $C_{\Delta_0} = 2.75$ and 2.25, in Figure 13. This diagram gives a rough idea of the maximum attitude reached on the lower limit for a given length of afterbody in the present case; these attitudes would probably be altered by a change of afterbody angle or forebody shape. The two points at $C_{\Delta_0} = 2.75$ for the 4 and 5 beam afterbody lengths are not indicated in Figure 13 because of the difficulty of defining maximum lower critical trim on the relevant set of stability limits (Figure 2(a)). This arises from the band of instability found across the take-off path in each case, when the maximum attitude on the lower limit is too high for normal forebody porpoising.

As lower limit porpoising is a function of the forebody only [10] and the forebodies used in these tests were identical, one might expect the lower limits to coincide. The main source of discrepancy, when the afterbody is clear of the water, is the airflow under the afterbody. Changes here may be expected to be of small order and to show a consistent trend from weight to weight; in both figures, 2(a) and 3(a), the limit for the 7 beam afterbody model is highest, but the remainder are disorderly and the separation of the

/limits

limits is so inconsistent, both with weight change and speed change, that most of it can reasonably be attributed to experimental error. It is felt that one mean limit for each loading would serve for all of the models.

Examination of the upper limits shows that, in both weight cases, increasing afterbody length from 4 to 7 beams lowers the limit by approximately 2° and increases its mean speed, while, with a further increase to 9 beams, upper limit instability is apparently avoided altogether. It is possible though that, had higher test speeds been feasible, an upper limit for the 9 beam afterbody model would have been found.

For the disturbed case the effects of afterbody length on the stability limits are shown in Figures 2(b) and 3(b). Before discussing them however, a few points on technique should be considered.[1] In all tests the maximum possible disturbance was given to the model; as the critical disturbances in the mid-planing region were generally below this maximum, instability was easily induced and the limit is that for maximum disturbance, i.e. there is negligible error; in the high speed lower limit region maximum disturbance was difficult to effect safely because either the attitude was low and the nose of the model would have been submerged or, with a disturbance, the resulting oscillation (which may have damped out) was often of such large amplitude that it was stopped by the operator; in the upper limit region disturbing the model was difficult because it often reached a semi-stalled condition clear of the water with the motion becoming predominantly aerodynamic. The disturbed limits are therefore not as precise as those obtained without disturbance, but within this limitation a very good idea of the susceptibility of the model to a large external disturbance is still obtained.

Considering orders then rather than absolute amounts of change, at $C_{\Delta_0} = 2.75$ (Figure 2(b)), the effect of increasing afterbody length is to reduce the area of disturbed instability until, with the longest afterbody, the disturbed stability limit differs only slightly from that obtained without disturbance. In the cases of the 4, 5 and 7 beam afterbody models respectively, the diagram shows vertical bands of instability which are decreased progressively in width and attitude since the * hump limit is found at higher speeds and lower attitudes. With the 9 beam afterbody the only significant effect of disturbance is to raise the high speed end of the lower limit. In references 3, 7, 8 and 9 it is stated that the greatest amounts of disturbance used were necessary in the high speed lower limit region. It follows that Model F is only susceptible to very large disturbances - far larger, in fact, than would normally be met in practice.

All the trends mentioned so far in connection with disturbance are verified at the lower loading, $C_{\Delta_0} = 2.25$ (Figure 3(b)). Stability is generally improved by the weight decrease but, in particular, the limits for the 7 beam afterbody show that the vertical band of instability found at the higher loading has been removed and the only effect of disturbance is to raise the lower limit at the higher speed end. Disturbance effects on the 9 beam afterbody model at this loading are similar, but even less pronounced. It may be concluded therefore, that lengthening the afterbody raises the general level of critical disturbances for the present basic model configuration, particularly in the mid-planing region.

The effects of afterbody length on the stability limits are shown in a different light in Figure 4 (which is for one loading, $C_{\Delta_0} = 2.75$), where elevator angles replace keel attitudes as ordinates. In this diagram the undisturbed lower limits are grouped together and, except for the vertical band of instability which must be crossed during take-off, they lie roughly

/along

---

* Hump limit - The longitudinal stability limit found on the low speed side of a band of instability crossing the take-off path just above hump speed.

along the same elevator setting. The upper limits are separated along the speed scale, instability being met at higher speeds with the longer afterbodies, but in each case the limit is found at the same maximum elevator setting. It can be concluded that when, in the undisturbed case, there is a completely stable take-off path for this type of hull, changes in afterbody length cause no significant alteration in the elevator setting at which instability is encountered. In the disturbed case, the high speed limits are clustered round a common stable area and the movement up the speed scale with increasing afterbody length of the hump limit is marked.

During the tests just considered the pitching moments of inertia of Models A, D, E and F were 22.90, 16.81, 25.02 and 40.25 lb. ft.^{2} respectively at $C_{\Delta_0} = 2.75$. In Reference 2, where the effects of moment of inertia changes at constant mass are considered, the range covered in the experimental investigation was 21.3 to 31.7 lb. ft.^{2}. Within the bounds of experimental error no change was found in the stability limits. It is felt that this result can reasonably be extended to cover the present range and moment of inertia effects on the stability limits may thus be considered negligible.

Trim curves for $\eta = 0^\circ$ are compared in Figure 5 for the two weights. The effects of increasing afterbody length are to reduce trim progressively, from and including the static floating condition up to speeds just past the hump, and to increase hump speed, while the trim curves tend to collapse at the higher speeds. The change in hump speed with afterbody length is almost unaffected by weight, but the reduction in hump attitude (Figure 14) decreases with weight, e.g. for an increase in afterbody length from 4 to 9 beams the decrease in hump attitude is $6\frac{1}{2}^\circ$ at $C_{\Delta_0} = 2.75$ and $5\frac{1}{2}^\circ$ at $C_{\Delta_0} = 2.25$.

The tendency for the trim curves to coincide at higher speeds may have been expected. As the afterbody is clear of the water, the configurations are virtually the same in each case, the only possible differences arising from aerodynamic suctions under the afterbody. These forces would tend to increase attitude and the effect would first become apparent with the longest afterbody, because of the greater effective moment arm. At $C_{\Delta_0} = 2.75$ (Figure 5(a)) the trim curves for the 4, 5 and 7 beam afterbody length models are in order, while that for the 9 beam shows a definite tendency to rise. At the lower weight, $C_{\Delta_0} = 2.25$ (Figure 5(b)), the increase in attitude is more pronounced, as might have been expected from the decreased load on water. The longest afterbody trim curve is well raised, the 7 beam curve shows a tendency to rise and only the remaining curves are in order. This effect, however, is of little practical significance and could easily be counteracted by a small movement of the elevator.

The effect of afterbody length on amplitudes of porpoising in both undisturbed and disturbed cases is shown for one load ($C_{\Delta_0} = 2.75$) in Figures 6 and 7. In the undisturbed case, there is no obvious change in the general level of porpoising amplitudes near the lower limit, but in the upper limit region a slight decrease is obtained with the longer afterbodies. In the case of the shortest afterbody, disturbance produces a considerable increase in the amplitudes of porpoising from the undisturbed case. As afterbody length is increased, this effect of disturbance is progressively reduced until, with the longest afterbody, there is no difference between the general levels of undisturbed and disturbed porpoising amplitudes. The annotated region, where the model porpoises clear of the water, is found at higher speeds and lower attitudes as afterbody length is increased. It was observed during tests that the frequency of forebody porpoising was greatly reduced with the longer afterbodies.

Results are much the same at the lower loading, $C_{\Delta_0} = 2.25$. There is no significant change in the undisturbed porpoising characteristics, while in the disturbed case there is a progressive reduction in the amplitudes with increasing afterbody leng".

/The

The tests were made at constant loading (C_{Δ_0} = 2.75) and the radii of gyration of the 4 and 9 beam afterbody models were 0.96 and 1.48 feet respectively. It is known from Reference 2 that increase of the radius of gyration at constant mass has the effect of increasing the amplitude of porpoising, particularly in the undisturbed case; these tests were made on a model with an afterbody length of 5 beams, but it is felt that had they been made on a long afterbody model with say a 9 beam afterbody, radius of gyration effects would be similar, but of lesser magnitude. It follows from the indication of no change in the undisturbed porpoising amplitude diagrams that the increase which might have been expected from the greater radius of gyration has been off-set by the increased afterbody length, while the reduction shown in the disturbed case is mainly due to the greater length of afterbody.

2.2. Previous investigations

Although there is a fair amount of literature on afterbody length variations, a large part of it does not isolate the effects of this parameter and only three reports will therefore be considered here. The first, by Kapryan and Clement,[11] deals solely with afterbody length effects on the hydrodynamic qualities of a high length/beam ratio model, the second, by Land and Lina,[12] considers these effects, together with those of associated parameters, on a low length/beam ratio model and the third, by Davidson and Locke,[13] treats afterbody length variations as part of a complete investigation into the porpoising characteristics of low length/beam ratio hulls. It should be noted that, as the three reports are American, the techniques used in the model tests differ from those used in the current programme. These differences have been considered in References 10 and 14, whence it appears that comparison should be made on the basis of steady speed runs; the N.A.C.A. lower limit and upper limit, increasing trim then correspond to M.A.E.E. undisturbed limits, and the N.A.C.A. upper limit, decreasing trim corresponds to part of the M.A.E.E. limit with disturbance.

In Reference 11, the hull used had a basic length/beam ratio of 15 and was tested at C_{Δ_0} = 5.88. The forebody, which was 8.6 beams in length, had no warp, incorporated chine flare and had a main step deadrise of 20°. Slipstream was used in the tests and the change investigated was an increase in afterbody length from 6.4 beams to 9.25 beams. With this change in afterbody length, the step depth was increased from 16.5% to 24% beam, (i.e. two parameters were changed simultaneously) so as to keep the stern-post angle constant at 6.9°. The afterbody angle was thus approximately $5\frac{1}{2}$° at both lengths. The conclusions state that the stable range of trim between the upper and lower trim limits of stability was greater for the extended afterbody at low and intermediate speeds, because of the lower hump of the lower trim limit and the virtual elimination of the upper limit at these speeds, and was slightly less (than that for the original model) for the extended afterbody at high speeds. The same conclusion is true for the present case, but a further examination of this reference (Figures 3 to 6) shows better agreement in that detailed tendencies are the same, although magnitudes of change are somewhat greater in the current tests. It may well be that the differences in magnitude of change are due to the increase in step depth in Reference 11. On the assumption that afterbody ventilation is adequate, the effect of increasing step depth may be roughly likened to an increase in afterbody angle and this is known to have effects which, in general, are opposite to those of an increase in afterbody length in the undisturbed stability case. The main effects of slipstream will be to reduce trim, to reduce load on water, thereby moving the limits bodily to lower speeds, and to reduce aerodynamic static stability. This latter effect may alter the upper limit position, but in general it is felt that the slipstream used in these tests will not greatly influence the afterbody length effects.

/In

In the investigation of Reference 12, a model of basic length/beam ratio 6.4 was tested at $C_{\Delta_0} = 0.87$ (based on maximum beam). The forebody of this model was 3.7 beams in length. It incorporated chine flare, had a main step deadrise of 20° and was unwarped. No slipstream was used in these tests, the mainplane being fitted with full span leading edge slats. Step depth and afterbody angle were constant at 5.5% beam and 5.5° respectively, and the range of afterbody lengths tested was from 1.61 to 3.11 beams. It is interesting to note that emphasis here is on shortening the afterbody rather than lengthening it, the normal afterbody length being 2.61 beams. The authors conclude that "the upper limits are raised to higher trims as the afterbody is shortened and an afterbody shorter than is conventional at the present time (1943) may therefore be expected to increase the stable trim range of a flying boat". This conclusion could be applied exactly to the undisturbed limits obtained in the present tests, but only to the undisturbed limits. Figures 14 and 15 of this reference show a similar lowering of the maximum lower critical trim and a lesser lowering of the mean upper critical trim with increase in afterbody length, than is obtained for a corresponding increase in afterbody length in the current investigation.

In Reference 13, a basic hull of length/beam ratio 6.2 was tested at $C_{\Delta_0} = 0.89$. The forebody was unwarped but had chine flare, a 20° main step deadrise angle and was 3.45 beams in length. The step depth was constant at 4.8% and the afterbody angle was 5.0°. The range of afterbody lengths tested was from 2.25 to 3.25 beams and dynamic hull models were used, aerodynamic moments and forces being fed in synthetically. The results are summarised in the statement that "decreasing the afterbody length raises the upper limit slightly and has only a very small effect on the lower limit at moderate speeds just past the hump; the speed range over which the free to trim track passes below the lower limit is lengthened slightly. The shortest afterbody tested stopped high-speed upper limit porpoising in the present instance. The effects are generally similar to those resulting from modifying the afterbody angle". These conclusions are similar to those of the preceding reference and show general agreement with the present undisturbed case. Detailed changes are also in fair agreement.

The reductions in maximum lower limit trim, mean upper limit trim and hump trim for the foregoing references are compared in Table IV with interpolated values for the current tests, by expressing afterbody length as a percentage of forebody length. Only orders of change should be considered, the table being intended merely as a convenient summary.

2.3. Discussion

As the aim of this investigation is to provide design information, variation of hull parameters has been kept within practical limits and the conclusions drawn will in general apply only within these limits. The range of afterbody lengths tested thus deserves some comment.

The shortest afterbody (4 beams) is considered a good minimum. At the design loading, $C_{\Delta_0} = 2.75$, undisturbed stability is poor and disturbed stability is bad, while the hump trim, 14°, is high and, unless a wing of low aspect ratio were used, might well result in wing stalling with consequent loss of lift and aileron control; a further decrease in afterbody length would worsen these already poor qualities. The longest afterbody (9 beams), on the other hand, has good stability characteristics, both disturbed and undisturbed, but hump speed ($C_V = 6.5$ or V = 67 knots at 150,000 lb.) is high and, because of the strong afterbody, maximum attitudes are limited to 8°, so take-off speeds are also high (of the order of 110 knots, $C_V = 10.6$). A further lengthening of the afterbody would increase these speeds and give even lower maximum attitudes. The best afterbody length of the four tested is therefore somewhere between 4 and 9 beams.

In the undisturbed case, it appears that for a practical low length/beam ratio hull configuration upper limit instability can be eliminated by sufficiently shortening the afterbody (Reference 13), while in the high length/beam ratio case, (Section 2.1) upper limit instability can be removed by lengthening the afterbody. (These apparently contradictory methods are quite simply related. Shortening the afterbody raises the upper limit; by continuing the process until the limit is above attitudes normally attained with elevators, upper limit instability is, for practical purposes, rendered non-existent. Lengthening the afterbody lowers the upper limit, but also lowers maximum attitudes at a greater rate so that the upper limit is progressively shortened from the low speed end. The region of upper limit instability is thus roughly a triangle enclosed by the maximum trim attainable with the elevators used, take-off speeds and the limit itself. The area of this triangle decreases to zero as the afterbody is lengthened giving effectively no instability). In the first instance, both hump attitude and maximum lower critical trim (the trim of a point on the lower stability limit) will be increased, hump speed will be decreased, there will be a much greater stable attitude range available at planing speeds, and low speed take-offs will be feasible. In the second case the effects are reversed, so, although lower limit instability is not met with the long afterbody until higher speeds are reached and there is little change in porpoising amplitudes with afterbody length, the shorter afterbody might appear initially to be preferable. If, however, an attempt is made to avoid upper limit instability with the high length/beam ratio hull by shortening the afterbody, there appears to be a minimum length below which a band of instability forms across the take-off path. Of the four afterbody lengths tested that of 7 beams is the shortest with which this band of instability can be avoided at the design loading of $C_{\Delta_0} = 2.75$. This phenomenon is not found at the lower loading, $C_{\Delta_0} = 2.25$, but this weight decrease is considerable. It is felt that the formation of this unstable band is not restricted to the high length/beam ratio class of hulls and that tests on low length/beam ratio hulls at higher loadings would produce similar results. There is thus little to choose between long and short afterbodies when only the undisturbed characteristics are considered.

In the disturbed case, the short afterbody exhibits very poor qualities. It is susceptible to small disturbances (Figure 8, Reference 7) and with large disturbances the unstable region tends to cover the greater part of the planing speed range, leaving only a small area stable at the higher speeds. In addition, amplitudes of porpoising show a large increase over the undisturbed case and the frequency of porpoising is fairly high. With the longer afterbody, however, small disturbances have no effect and large disturbances only raise the high speed end of the lower limit, the region of upper limit instability remaining either very small or unattainable. Porpoising amplitudes are unchanged from the undisturbed case and, as the frequency of forebody porpoising is low, the motion is relatively gentle; a pilot could thus encounter instability and then take corrective action quite easily. It is obvious that, in the disturbed case, a configuration with a long afterbody is better.

As in undisturbed tests the conditions represented are ideal, they cannot be accepted as prevailing in the normal course of flying boat operations and unless operating conditions are exceptional, weight must be given to the disturbed results in selecting an afterbody length; this points towards a long afterbody. It should be noted, however, that the tests with disturbance are most rigorous and the disturbed conditions represented are worse than those likely to be met in practice, so the afterbody length initially chosen can be reduced by an amount compatible with the operating conditions expected, so lowering the high minimum take-off speed. This investigation is a calm water one and the disturbance tests are representative of operational conditions. They allow for such contingencies as crossing the wash of a boat, an inadvertent movement of the control column, a sudden yaw (which can bring on

/longitudinal

longitudinal instability) and the bad landing case - in fact, any general operating emergency. As no satisfactory correlation has yet been established between disturbance and wave effects on hydrodynamic longitudinal stability over the whole of the planing speed range, further work is necessary. It is therefore proposed to determine the effects of afterbody length in waves and to correlate them, if possible, with the effects of disturbance. Excluding the wave or swell case then, of the configurations tested in the present investigation the 7 beam afterbody appears to be the best compromise for average operating conditions. From stability considerations both the 7 and 9 beam afterbodies are good, while the 4 and 5 beam afterbodies are, at the best, mediocre. With the 7 beam configuration however, maximum planing attitudes are 10° as against 8°, for the 9 beam giving a lower possible take-off speed, and hump speed is reduced from $C_V = 6.5$ to $C_V = 5.6$. This means a shorter run in the displacement region at slightly higher attitudes, when damage due to spray will be less and both take-off distance and time will probably be reduced.

As the conclusion that a long afterbody is preferable, is the opposite of that of Reference 12 it may be enlightening to consider the reasons for this difference. The actual test results in References 11, 12, 13 and the present undisturbed case are in good agreement and the main bias towards a long afterbody has come from the disturbed results - this type of test is not made by the Americans and it would seem that little consideration is given to their upper limits, "decreasing trim". In Reference 12, however, the recommendation for a short afterbody is also based on the results of simulated landing tests where the criterion was the number of skips made after touchdown (the greater the number of skips the poorer the landing stability). A comparison of the landing attitudes and skipping characteristics of the longest afterbody model of this reference with its corresponding stability diagram, shows that up to 4° trim the model does not skip and there is an equivalent stable trim range at high speed; from 4° to 10° trim a large number of skips are obtained and at 12° the number is reduced. Landings at trims above 4° are, however, within the upper unstable region decreasing trim, i.e. the disturbed region, so with a disturbance one would expect instability. It is possible that the rate of descent coupled with the nose down angular motion induced at touch-down at high attitudes would constitute the necessary disturbance and if landings were made in the disturbed stable region no instability would result. In the case considered (Reference 12) the model was of low length/beam ratio and even the longest afterbody tested was shorter than the forebody, so that in the tests with the longer afterbodies large regions of upper limit instability, "decreasing trim" were still obtained. The restriction that touch-downs be made in the disturbed stable region would therefore result in fast landings at trims between 0° and 4°. The combined evidence thus leaves the designer with a difficult compromise and, if calm water operation only, with negligible disturbance, be envisaged, the conclusion reached (in Reference 12) would appear correct, but such conditions would in general be very restrictive.

In the present investigation with a high length/beam ratio hull and longer afterbodies the region of upper limit instability is small or has not been reached. Landings could therefore be made fast at low attitudes, as in the previous case, or slow at high attitudes. In this latter case the attitudes would be higher than the maximum obtainable on the water and the final approach would be made with considerable power. On closing the throttles the aircraft would virtually drop onto the water, when the long afterbody would cause an immediate reduction in attitude, with consequent loss of lift, and keep the attitude down, which, with the initial low speed, would render the subsequent motion stable, upper limit instability having been avoided. Such a landing would depend for its success on the long afterbody to keep maximum planing attitudes low, and the low landing speed. The take-off too would be simple. All the pilot would need to do to guarantee avoiding trouble from instability would be to keep the stick right back. If a little upper limit instability were met the speed would be such that the extra lift obtained from the attitude increase during the first or second oscillation would render the aircraft airborne; the speed would also be high enough for adequate control.

/The

The foregoing consideration of afterbody length effects on longitudinal hydrodynamic behaviour show that increasing afterbody length makes little overall difference to the undisturbed characteristics (e.g. the advantages of reduced porpoising amplitudes are offset by the disadvantages of higher take-off speeds, etc.), while in the disturbed case, the longer afterbodies are nowhere near as susceptible to external disturbances as are the short ones. For normal operation the long afterbody is thus better; little risk of trouble from instability is incurred during take-off and low speed as well as normal landings are feasible.

It should be noted that all of the hulls considered in this report (including References 11, 12 and 13) have unwarped forebodies and afterbody angles of the order of 6°, while step depths vary. If any of these parameters were radically altered it is possible that the foregoing conclusions would require some modification, mainly to account for differences in amounts of change.

3. WAKE FORMATION

As all the models now under consideration (Models A, D, E and F) have identical forebodies, then under given conditions of attitude, speed and load, when the afterbody is clear of the water, the wake shapes will be identical. It is thus possible to determine the effect of attitude at several speeds on the shape of the wake for the basic forebody. The wake photographs (References 3, 7 8 and 9) are difficult to assess, but at each speed it would appear that an increase in attitude results in a narrowing of the wake cross section, although the change is small, and a fanning out of the velocity spray.

Whether the afterbody is planing or not seems, from the wake photographs, to be consistent from model to model, but little else can be said that does not follow directly from the stability diagrams.

4. SPRAY

The spray characteristics of the models were evaluated during the undisturbed longitudinal stability runs, mainly over the displacement range of speeds, by taking three simultaneous photographs at each speed. The cameras used were positioned off the starboard bow, the starboard beam forward of the wing and the starboard beam aft of the wing. A chequered pattern, consisting of alternate black and white squares of $\frac{1}{4}$ beam side, with the step point as origin, was painted on the starboard side of each model to aid in the analysis, which consisted of obtaining projections of the spray envelopes on the median plane only. In plotting the projections velocity spray was included when it was integral with the main spray blister, otherwise it was ignored. The profiles used were taken straight from the side view photographs and a limited parallax error was accepted; where this error tended to become large the curves were not drawn. These projections are compared in Figure 8. It may be noted that the spray photographs for the 4, 5 and 7 beam afterbody models were obtained with $\eta = -8°$, but those for the 9 beam afterbody model were taken with $\eta = 0°$. This will make no difference to attitudes in the displacement range, affecting only the high speed result which is representative in any case. The change was made to avoid running Model F at its maximum planing attitude, which is obtained with $\eta = -8°$.

The effects of afterbody length on spray are shown at the higher weight ($C_{\Delta_0} = 2.75$) in Figure 8(a). Only in the case of the shortest afterbody is there a complete projection, indicating that little or no main spray strikes the wing; it can be seen from the photographs of Reference 7, however, that over a small speed range considerable velocity spray strikes the wing.

As afterbody length is increased, these qualities deteriorate; the spray projections are discontinuous, progressively more spray hitting the wing, the spray origin is moved forward, increasing the height of the bow spray at low speeds, and the spray plume at the tail is lowered. These trends are confirmed at the lower weight (Figure 8(b)) and good qualitative agreement is obtained from Reference 11.

The deterioration in spray characteristics with increasing afterbody length is due mainly to the decreased attitudes, which result from the increased afterbody strength. There will be minor changes in draught, but these should only have a small effect on the spray. The movement forward of the spray origin, at a given speed, with the decrease in attitude can easily be seen by comparing the individual spray photographs; an example is given in Figures 9 and 10 at $C_V = 3.0$ approximately for $C_{\Delta_0} = 2.75$.

The good spray characteristics of the shortest afterbody model accrue only from the high attitudes associated with the short afterbody, which gives rise to unacceptable disturbed stability. Use of the longer afterbodies to obtain good stability in the present tests results in unacceptable spray qualities. A similar long afterbody design must therefore incorporate forebody warp [6] or some other modification to give acceptable spray.

5. DIRECTIONAL STABILITY

For directional stability tests each model was towed from and pivoted at the C.G. so that it was free in pitch, yaw and heave, but constrained in roll. Steady speed runs were made over a range of speeds from 4 to 40 feet per second and at each speed the model was yawed up to not more than 18°, moments to yaw the model being applied by means of strings attached to the wing tips level with the C.G. The direction and order of magnitude of the resulting hydrodynamic moment was judged by the operator through the pull in the strings and the angle of yaw was read off a scale on the tailplane with an accuracy of about $\pm \frac{1}{2}°$. The general form of the resulting stability diagram is considered in Reference 1, but it may be mentioned here that the model will swing towards a position of stable equilibrium and away from one of unstable equilibrium. The tests were made with no rudder trimming tab, and it was found that the effects of load,[5] roll constraint[3] and elevator [3] on directional stability were small enough to be neglected. Stability diagrams for models with 4, 5, 7 and 9 beam afterbody lengths are compared at one weight, $C_{\Delta_0} = 2.75$, in Figure 11.

The most obvious effect of increasing afterbody length is the progressive change in the low speed, stable equilibrium line and the corresponding movement up the speed axis of the low speed, unstable equilibrium line. The most significant results of these changes is the increase in the minimum speed at which inherent directional stability is obtained. Below this speed careful directional control must be exercised by the pilot and, as the speed is raised from $C_V = 3.1$ to 4.8 over the range of afterbody lengths considered, some difficulty may be encountered full scale with the longest afterbody. This greater tendency to yaw with long afterbodies may, however, be useful when manoeuvring on the water. At high speeds the effects of afterbody length are small and of no practical significance. It is interesting to note that the effects on directional stability of increasing afterbody length are very similar to those obtained by increasing forebody warp (Reference 6).

6. ELEVATOR EFFECTIVENESS

The effects of afterbody length on elevator effectiveness are shown in Figure 12(a) for $C_{\Delta_0} = 2.75$. The mean slopes of the curves are approximately equal and as afterbody length is increased there is a progressive reduction in effectiveness at a given speed. The same effects are shown in Figure 12(b) for $C_{\Delta_0} = 2.25$, the only significant difference between the two diagrams being the overall increase in effectiveness due to the decreased load.

/The

The values of elevator effectiveness given in Figure 12 are mean values for the whole attitude range; a more detailed examination of the elevator effects may therefore prove helpful (References 3, 7, 8 and 9). From Section 2.1, at a given weight ($C_{\Delta o} = 2.75$) the lower stability limits collapse virtually on the same trim curve. The forebodies of the models and the elevators are identical so that in the region of the lower limit when the afterbody is clear of the water, one can expect the value of elevator effectiveness at a given speed to be the same in each case. This point is illustrated below.

Model		D		A		E		F	
Afterbody Length		4 beams		5 beams		7 beams		9 beams	
C_V	α_k	η	*E	η	E	η	E	η	E
7	8	+4	0.20	+4	0.16	+4	0.05	-12	0.02
8	6	+4	0.22	+5	0.20	+4	0.15	+ 5	0.37
9	5	+4	0.20	+4	0.22	+3	0.20	+ 4	0.20

* E - elevator effectiveness

In the table, elevator effectiveness is the same at $C_V = 9$ for the four models, at $C_V = 8$ for Models D and A and at $C_V = 7$ for Model D. The other values differ because of afterbody immersion owing to the proximity of the hump, which is found at higher speeds with the longer afterbodies.

With increasing attitude, the constant value of effectiveness found near the lower limit at $C_V = 9$, first increases and then tends to zero as the maximum attitude is approached. The effects of increasing afterbody length are to reduce the attitudes for maximum elevator effectiveness and to nullify the effect of elevator at progressively lower attitudes. This is shown in the following table.

Model		D		A		E		F	
Afterbody Length		4 beams		5 beams		7 beams		9 beams	
C_V	α_k	η	*E	η	E	η	E	η	E
9	8	-4	0.50	-4	0.59	-6	0.52	-12	0.02
9	9	-6	0.56	-7	0.20	-8	0.25	-	0
9	10	-8	0.44	-8	0.15	-14	0.08	-	0
9	11	-10	0.30	-20	0.07	-	0	-	0

* E - elevator effectiveness

/Returning

Returning to the presentation of longitudinal stability limits in Figure 4(a), where elevator angles replace keel attitudes as ordinates, apart from the vertical neck of instability in the case of the shorter afterbodies, there is little regular change due to afterbody length. For a complete representation this diagram should be considered in conjunction with Figure 12(a), when the effects of afterbody length are shown as a change in elevator effectiveness.

7. CONCLUSIONS

The results of the present investigation show that the effects of increasing afterbody length are

(i) to reduce maximum lower critical trim and raise the speed at which it occurs,

(ii) to reduce trim generally and, in particular, to reduce both hump trim and the maximum trim obtainable with normal elevators,

(iii) to lower the upper stability limit and move the upper unstable region to higher speeds,

(iv) to increase resistance to disturbance,

(v) to reduce disturbed amplitudes of porpoising,

(vi) to lower the frequency of forebody porpoising,

(vii) to move the spray origin forward, giving rise to poor spray characteristics (associated with (ii)),

(viii) to worsen directional qualities at speeds just below the hump,

(ix) to reduce elevator effectiveness and

(x) to leave materially unaltered the elevator setting at which undisturbed instability is encountered.

The afterbody length effects listed above are, except for some minor differences, independent of load. Results (i) to (iii) are substantiated by References 11, 12 and 13 and, as magnitudes of change are of the same order for corresponding afterbody length increases when afterbody length is expressed as a percentage of forebody length, may be said to be independent of actual length/beam ratio.

As the qualities listed are not all desirable, the choice of afterbody length must be a compromise; in the present case, of the four configurations tested, that with an afterbody length of 7 beams is the optimum, but some forebody or other modification is necessary to offset the poor spray characteristics. With a long afterbody more time would be spent in the displacement speed range during take-off than with a short afterbody; this means more wear and tear generally and probably a longer take-off run. There would be little or no risk of upper limit instability and recovery from lower limit porpoising would be easy. The long afterbody hull, unlike that with a short afterbody would give negligible trouble from the effects of external disturbances, while making either normal or very slow landings feasible.

This investigation is a calm water one with representative tests for operational conditions, i.e. disturbance tests. No satisfactory correlation, however, has yet been established between disturbance and wave effects on hydrodynamic longitudinal stability over the whole of the planing speed range; further work is therefore proposed to determine the effects of afterbody length in waves and to correlate them, if possible, with the effects of disturbance.

LIST OF SYMBOLS

b	beam of model
C_L	lift coefficient $= L/\frac{1}{2}\rho SV^2$ (L = lift, ρ = air density)
C_V	velocity coefficient $= V/\sqrt{gb}$
C_Δ	load coefficient $= \Delta/wb^3$ (Δ = load on water and w = weight per unit volume of water)
C_{Δ_o}	load coefficient at $V = 0$
C_X	longitudinal spray coefficient $= x/b$
C_Y	lateral spray coefficient $= y/b$
C_Z	vertical spray coefficient $= z/b$
	{(x,y,z) co-ordinates of points on spray envelope relative to axes through step point}
S	gross wing area
V	velocity
α_K	keel attitude
η	elevator setting
ψ	angle of yaw

/LIST OF REFERENCES

LIST OF REFERENCES

Reference No.	Author(s)	Title
1	D. M. Ridland J. K. Friswell A. G. Kurn	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 1: Techniques and presentation of results of model tests. Current Paper No. September, 1953.
2	J. K. Friswell A. G. Kurn D. M. Ridland	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 2: The effect of changes in the mass, moment of inertia and radius of gyration on longitudinal stability limits. Current Paper No. . September, 1953.
3	D. M. Ridland J. K. Friswell A. G. Kurn	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 3: The stability and spray characteristics of Model A. M.A.E.E. Report F/Res/237. A.R.C. 16,627. February, 1954.
4	D. M. Ridland A. G. Kurn J. K. Friswell	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 4: The stability and spray characteristics of Model B. M.A.E.E. Report F/Res/238. A.R.C. 16,761. March, 1954.
5	J. K. Friswell D. M. Ridland A. G. Kurn	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 5: The stability and spray characteristics of Model C. M.A.E.E. Report F/Res/239. A.R.C. 16,672. October, 1953.
6	D. M. Ridland	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 6: The effect of forebody warp on stability and spray characteristics. Current Paper No. . May, 1954.
7	J. K. Friswell	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 7: The stability and spray characteristics of Model D. M.A.E.E. Report F/Res/241. A.R.C. 16,753. November, 1953.
8	D. M. Ridland	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 8: The stability and spray characteristics of Model E. M.A.E.E. Report F/Res/242. A.R.C. 16,791. December, 1953.

LIST OF REFERENCES (CONTD.)

Reference No.	Author(s)	Title
9	A. G. Kurn	Investigation of high length/beam ratio seaplane hulls with high beam loadings: Hydrodynamic stability Part 9: The stability and spray characteristics of Model F. M.A.E.E. Report F/Res/243. A.R.C. 17,034. February, 1954.
10	A. G. Smith H. G. White	A review of porpoising instability of seaplanes. R. & M. 2852. February, 1944.
11	W. J. Kapryan E. P. Clement	Effect of increase in afterbody length on the hydrodynamic qualities of a flying boat hull of high length-beam ratio. N.A.C.A. TN. 1853 (U.S.A.). April, 1949.
12	N. S. Land L. J. Lina	Tests of a dynamic model in N.A.C.A. tank No. 1 to determine the effect of length of afterbody, angle of after-body keel, gross load, and a pointed step on landing and planing stability. N.A.C.A. ARR. WR-L-400 (U.S.A.). March, 1943.
13	K. S. M. Davidson F. W. S. Locke	Some systematic model experiments on the porpoising characteristics of flying boat hulls. N.A.C.A. ARR. 3F12 (U.S.A.). June, 1943.
14	J. P. Gott	Note on the comparison of British and American methods of tank testing dynamic models of flying-boats. R.A.E. TN. Aero. 1197. A.R.C. 6892. May, 1943.
15	A. G. Smith J. E. Allen	Water and air performance of seaplane hulls as affected by fairing and fineness ratio. R. & M. 2896. August, 1950.

/TABLE I

TABLE I

Models for hydrodynamic stability tests

Model	Forebody warp	Afterbody length	Afterbody-forebody keel angle	Step form	To determine effect of
	degrees per beam	beams	degrees		
A	0	5	6	Unfaired transverse. Step depth 0.15 beam.	Forebody warp
B	4	5	6		
C	8	5	6		
D	0	4	6		Afterbody length
A	0	5	6		
E	0	7	6		
F	0	9	6		
G	0	5	4		Afterbody angle
A	0	5	6		
H	0	5	8		

/TABLE II

TABLE II

MODEL HYDRODYNAMIC DATA

Beam at step (b)	0.475'
Length of forebody (6b)	2.850'
Angle between forebody and afterbody keels	6°
Forebody deadrise at step	25°
Forebody warp (per beam)	0°
Afterbody deadrise	30° (decreasing to 26° at main step over forward 40% of afterbody length).

Model	D	A	E	F
Afterbody length (beams)	4	5	7	9
Afterbody length (feet)	1.900	2.375	3.325	4.275
Pitching moment of inertia (lb.ft.^{2})	16.81	22.90	25.02	40.25

/ TABLE III

TABLE IV

Comparison of Main Afterbody Length Effects

Case	Load Coef-ficient	Basic Length/Beam ratio	Forebody Length	Afterbody length increase	Reduction in maximum lower critical trim	Lowering of upper stability limit	Reduction in hump trim	Remarks
	C_{Δ_o}	L/b	beams	beams	degrees	degrees	degrees	
Ref. 11	5.88	15	8.6	6.4 to 9.25	$1\frac{1}{2}$	1	2	With slipstream
*Present tests	2.25	11	6.0	same % increase	2	$1\frac{1}{2}$	2	No slipstream, but with full span L.E. slats
Ref. 12	0.87	6.4	3.7	2.11 to 3.11	2	$1\frac{1}{2}$	-	No slipstream, but with full span L.E. slats
*Present tests	2.25	11	6.0	same % increase	2	2	-	
Ref. 13	0.89	6.2	3.45	2.25 to 3.25	$2\frac{1}{2}$	$1\frac{1}{2}$	2	Aerodynamic forces and moments fed in synthetically
*Present tests	2.25	11	6.0	same % increase	2	$1\frac{1}{2}$	3	No slipstream, but with full span L.E. slats

*Present tests refers here to the undisturbed case. The lower loading, $C_{\Delta_o} = 2.25$, was used for comparison as the limits concerned are all of the same form i.e. there is no vertical band of instability right across the diagram, and the loading in general has only small effect on the changes due to afterbody length. The 'same % increase' is based on forebody length.

TABLE III

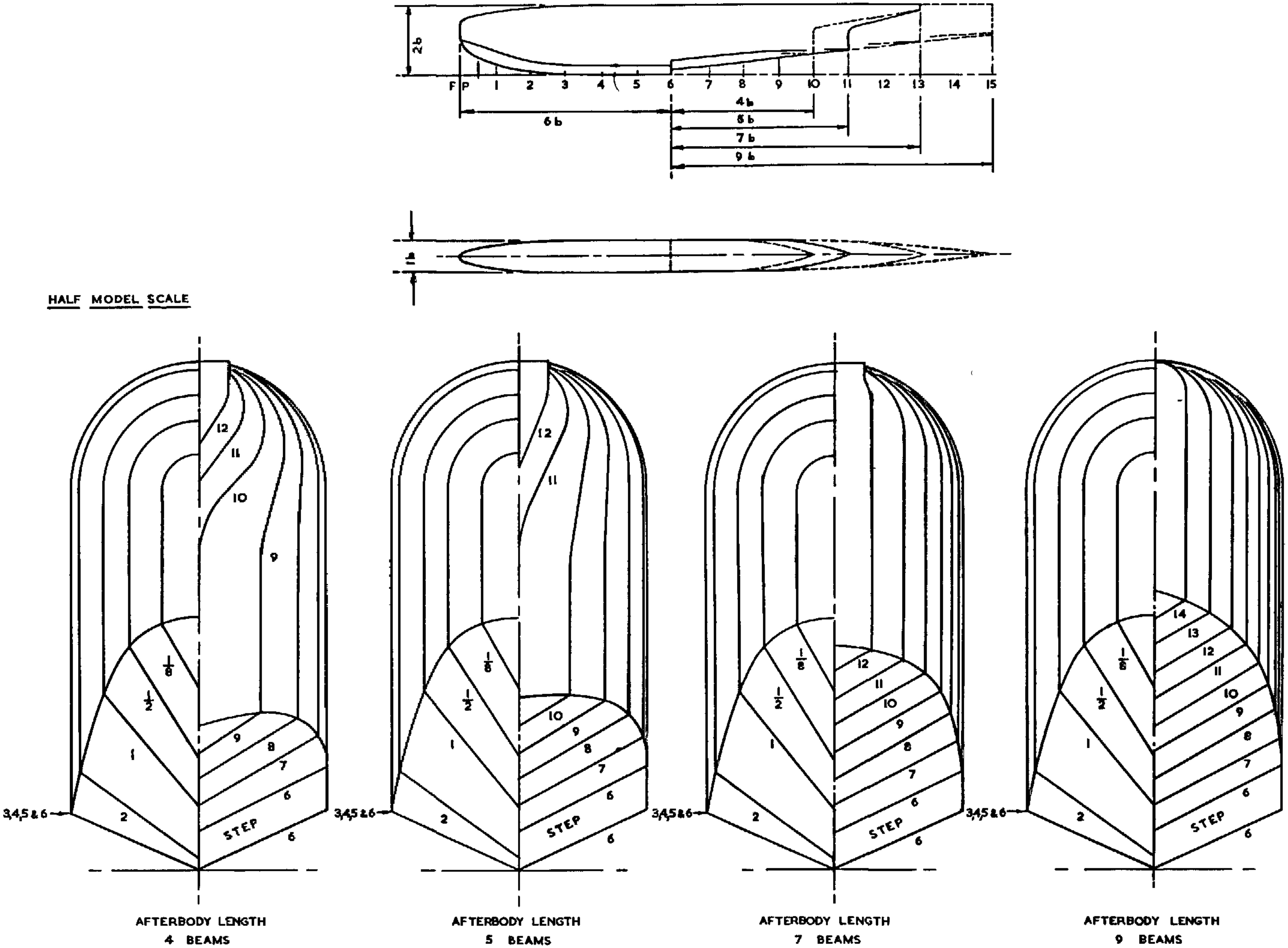
Model Aerodynamic data

Mainplane	
Section	Gottingen 436 (mod.)
Gross area	6.85 sq. ft.
Span	6.27 ft.
S.M.C.	1.09 ft.
Aspect ratio	5.75
Dihedral } on 30% spar axis	3° 0'
Sweepback } on 30% spar axis	4° 0'
Wing setting (root chord to hull datum)	6° 9'
Tailplane	
Section	R.A.F. 30 (mod.)
Gross area	1.33 sq. ft.
Span	2.16 ft.
Total elevator area	0.72 sq. ft.
Tailplane setting (root chord to hull datum)	2° 0'
Fin	
Section	R.A.F. 30
Gross area	0.80 sq. ft.
Height	1.14 ft.
General	
*C.G. position	
distance forward of step point	0.237 ft.
distance above step point	0.731 ft.
*$\frac{1}{4}$ chord point S.M.C.	
distance forward of step point	0.277 ft.
distance above step point	1.015 ft.
* Tail arm (C.G. to hinge axis)	3.1 ft.
* Height of tailplane root chord L.E. above hull crown	0.72 ft.

* These distances are measured either parallel to or normal to the hull datum.

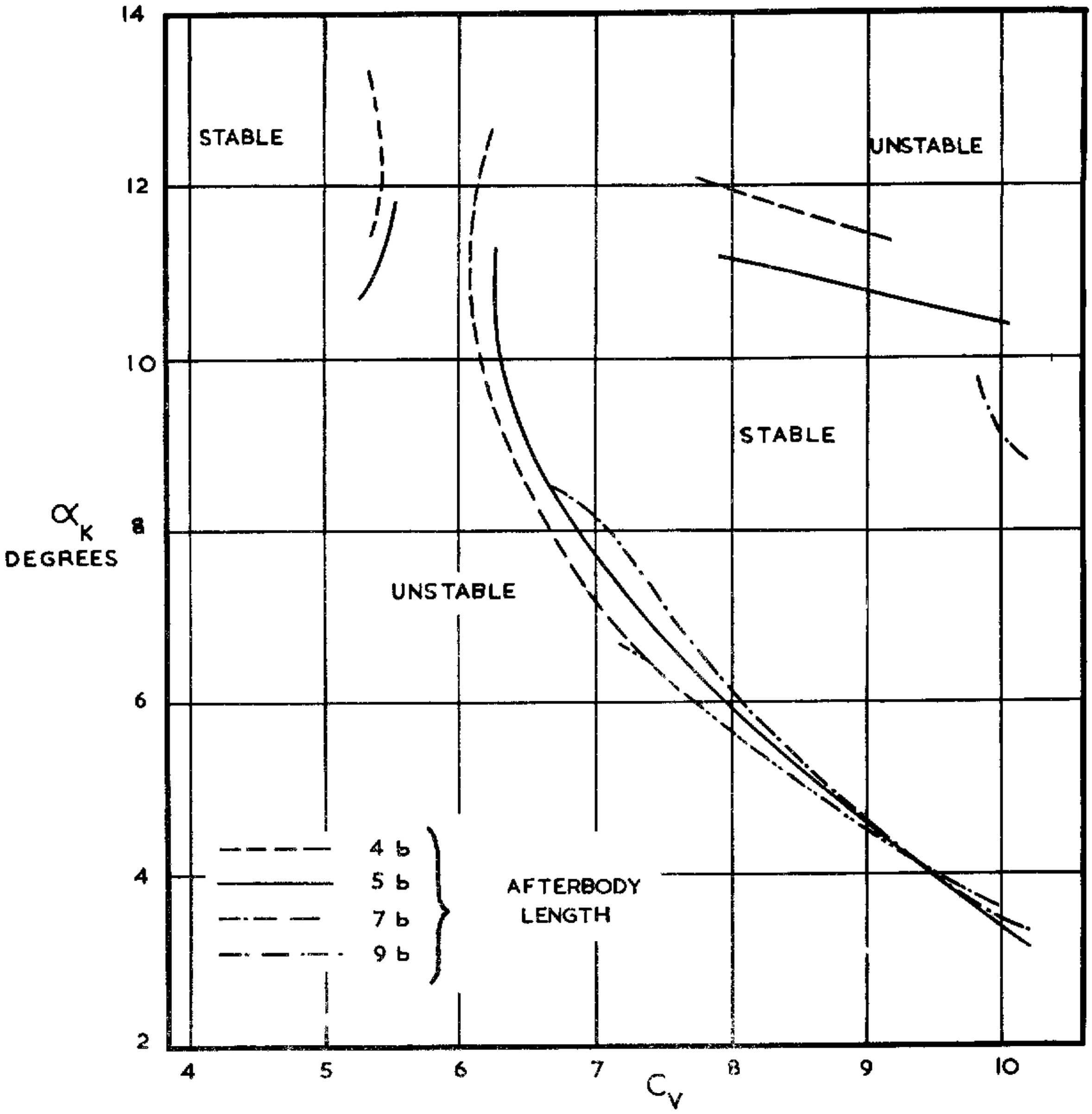
/TABLE IV

FIG. 1.

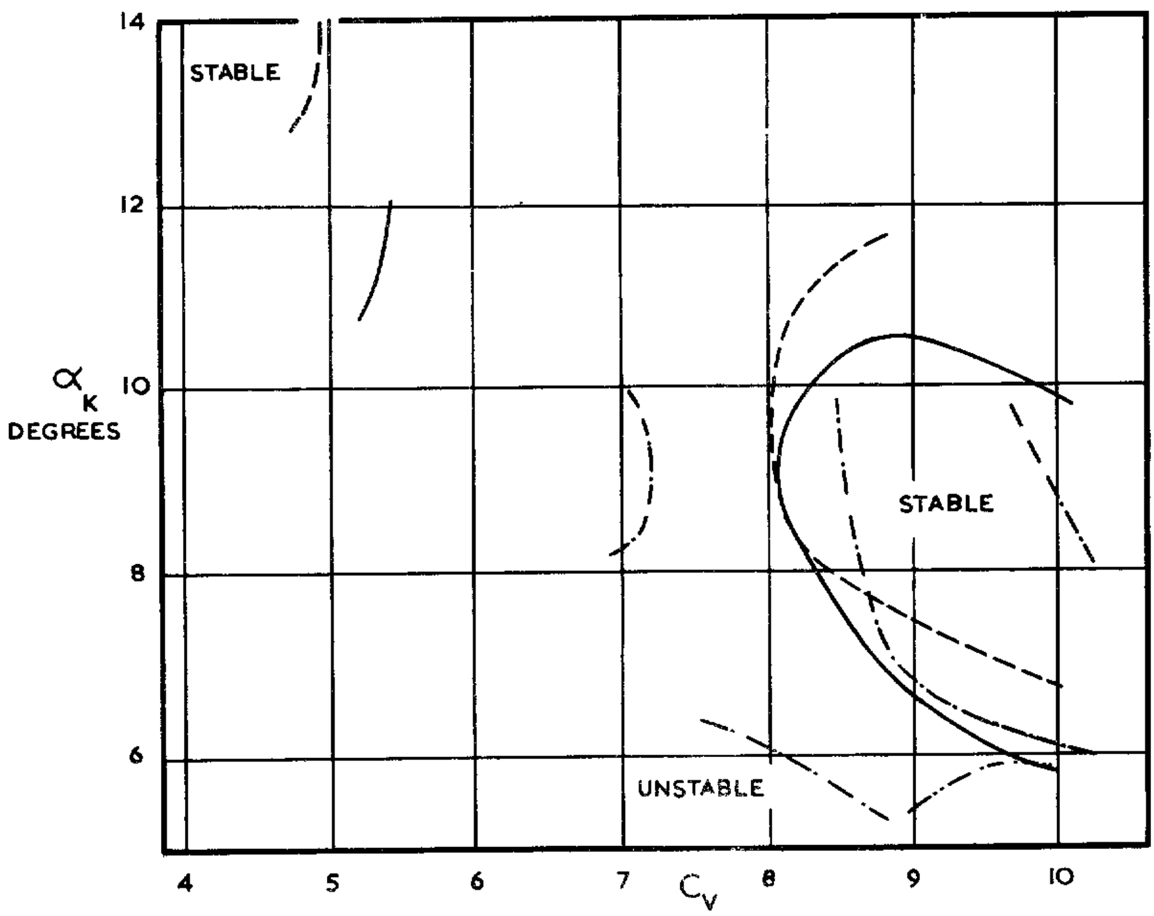


COMPARISON OF HULL LINES

FIG. 2.



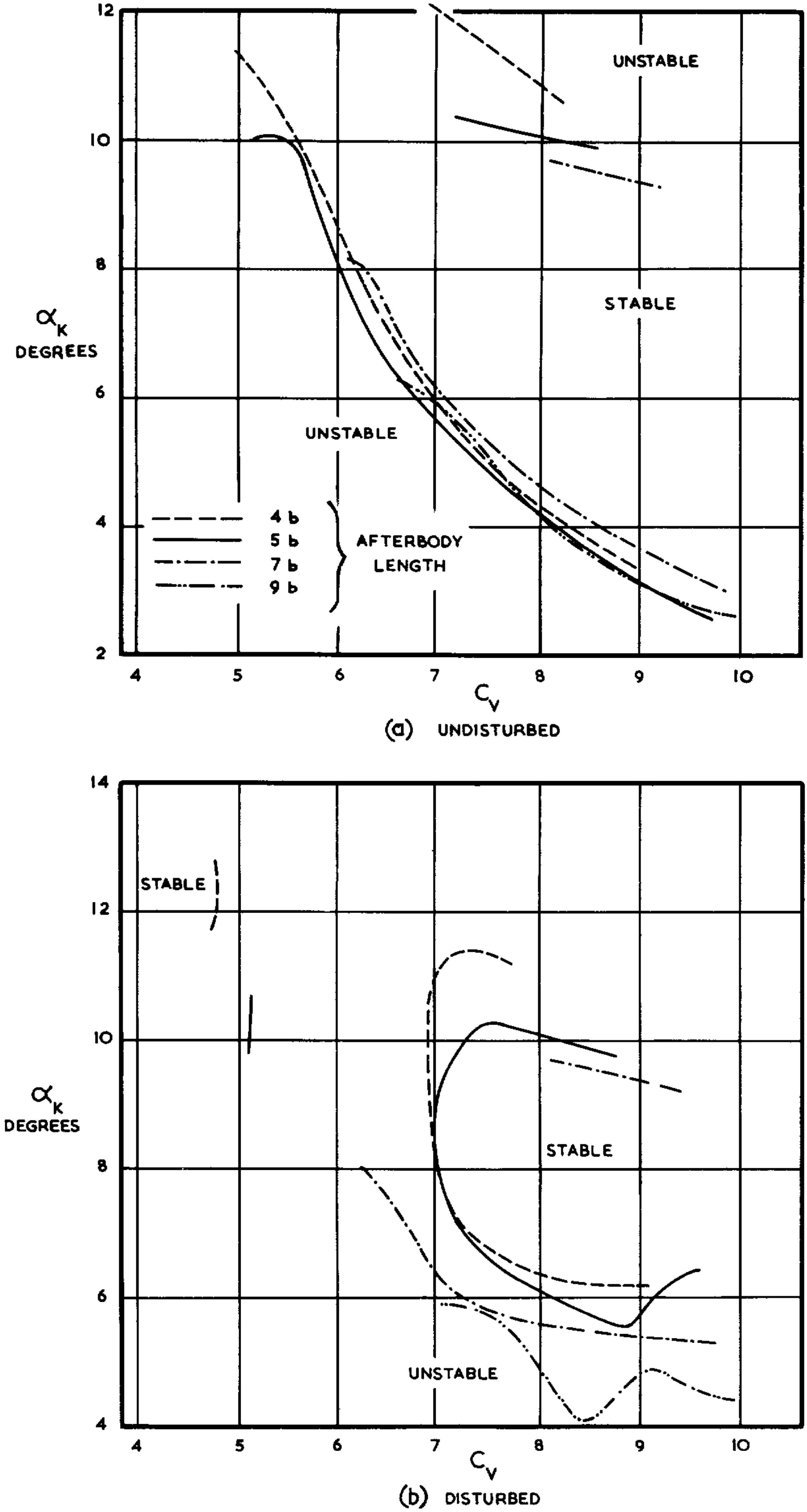
(a) UNDISTURBED



(b) DISTURBED

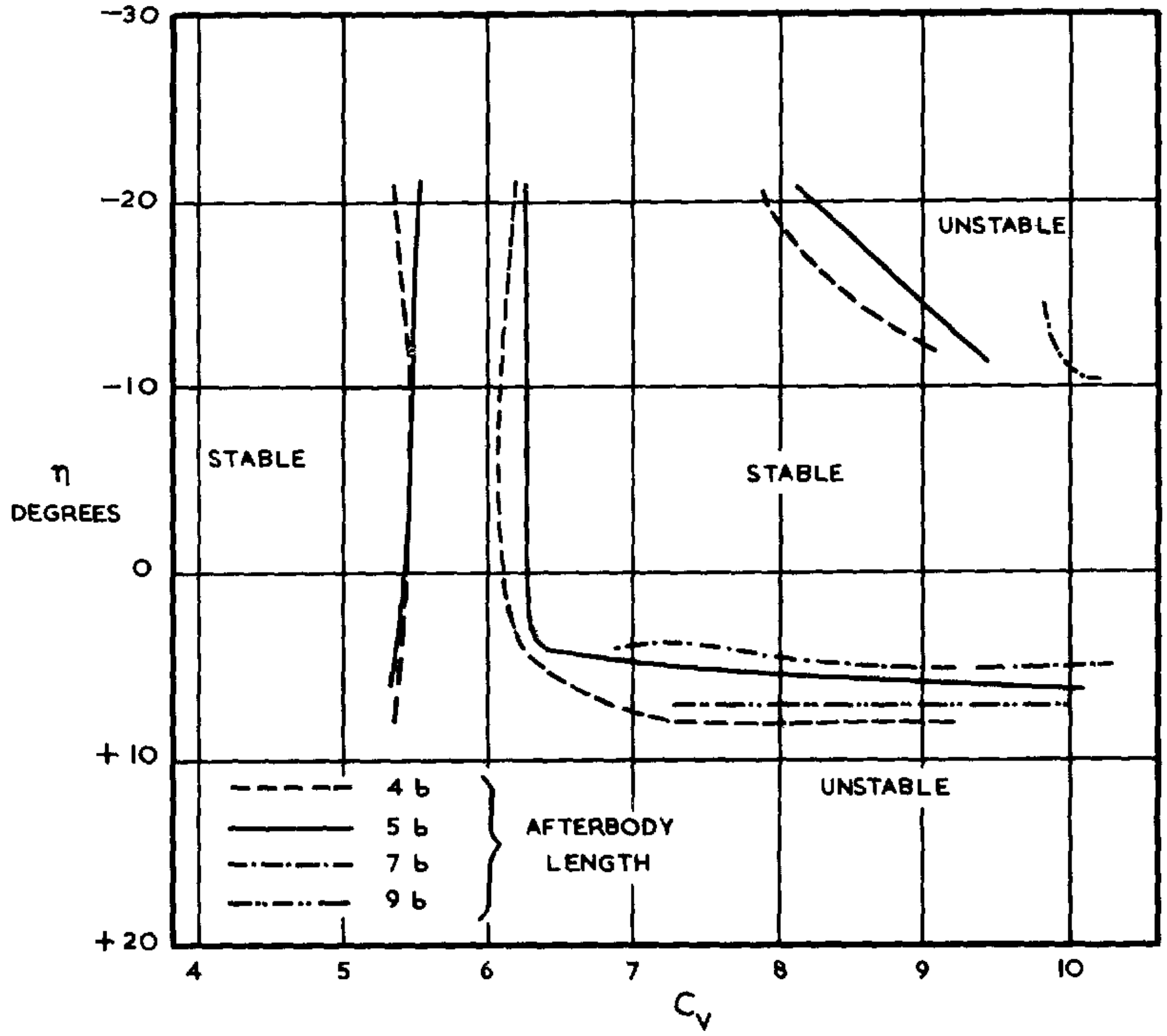
EFFECT OF AFTERBODY LENGTH ON LONGITUDINAL STABILITY LIMITS, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 3.

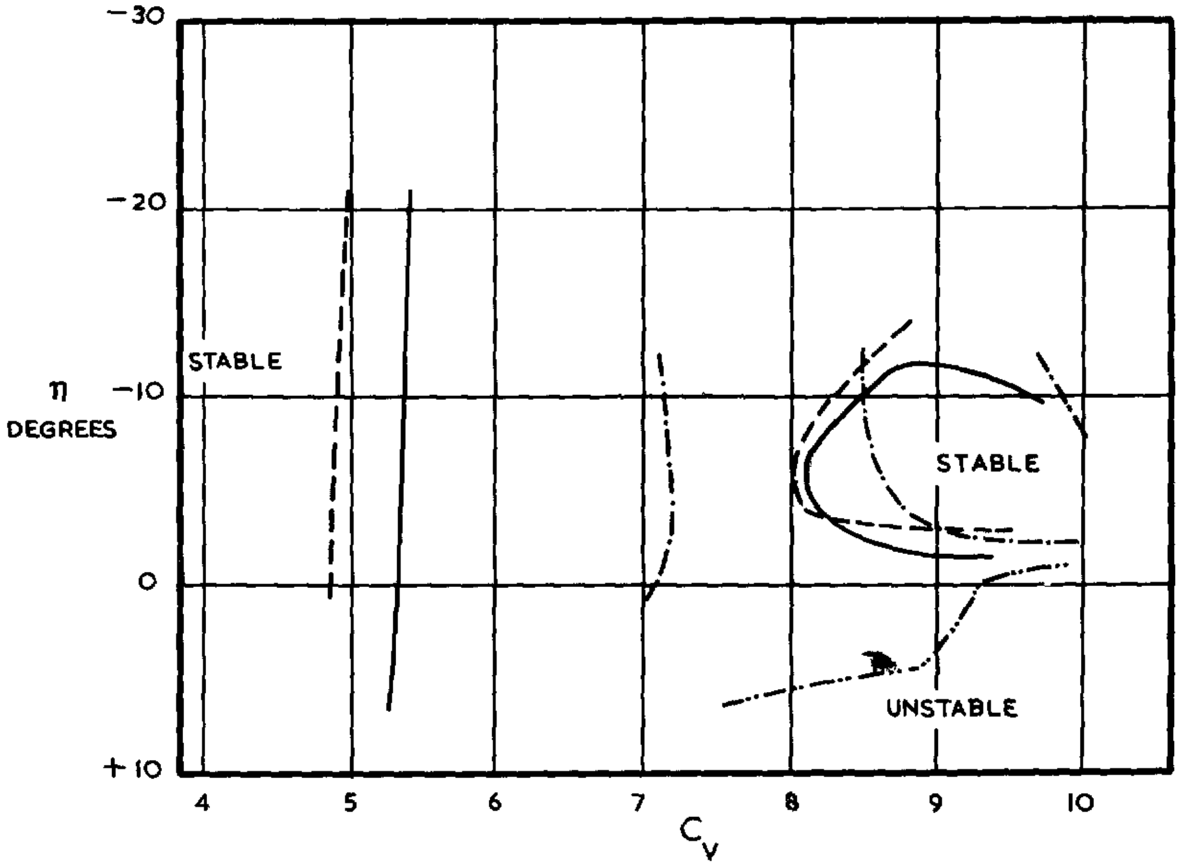


EFFECT OF AFTERBODY LENGTH ON LONGITUDINAL STABILITY LIMITS, $C_{\Delta_0} = 2{\cdot}25$.

FIG. 4.

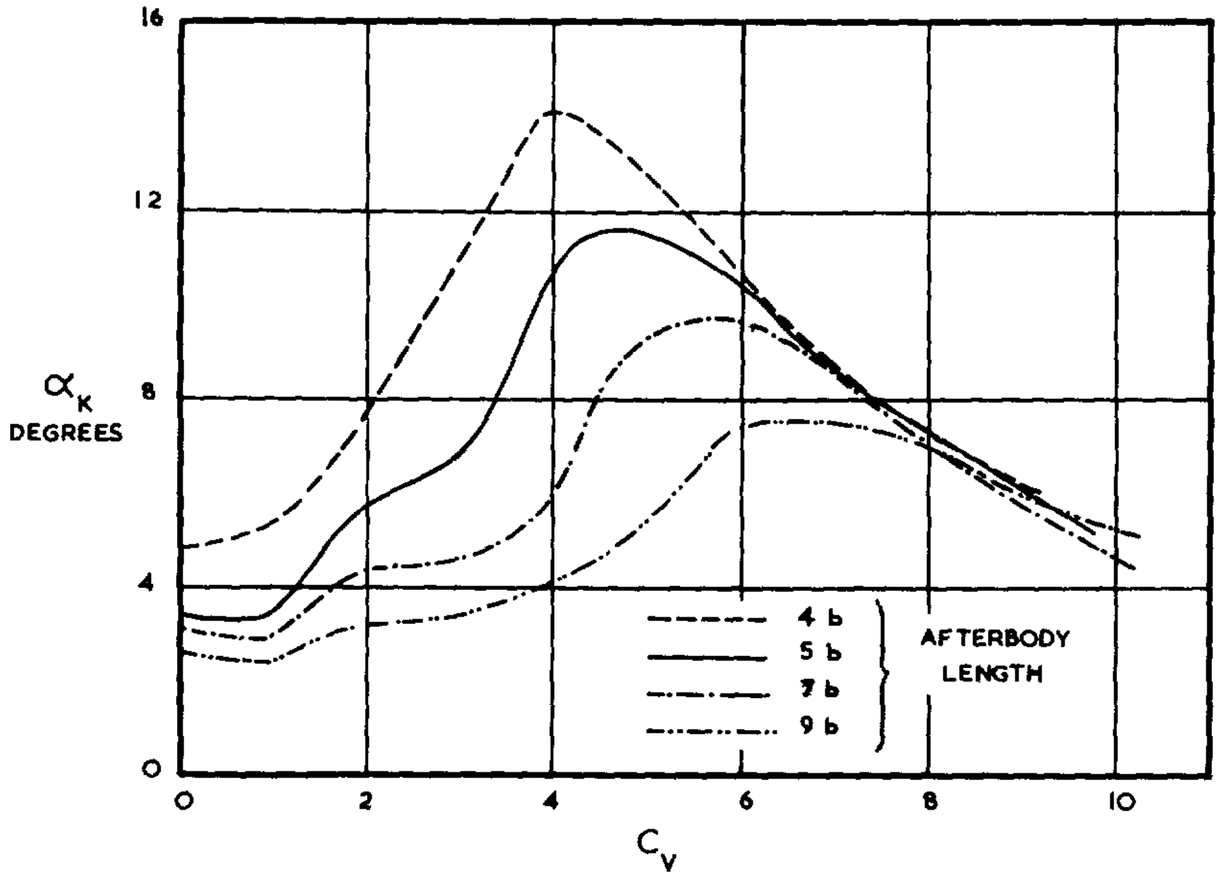


(a) UNDISTURBED

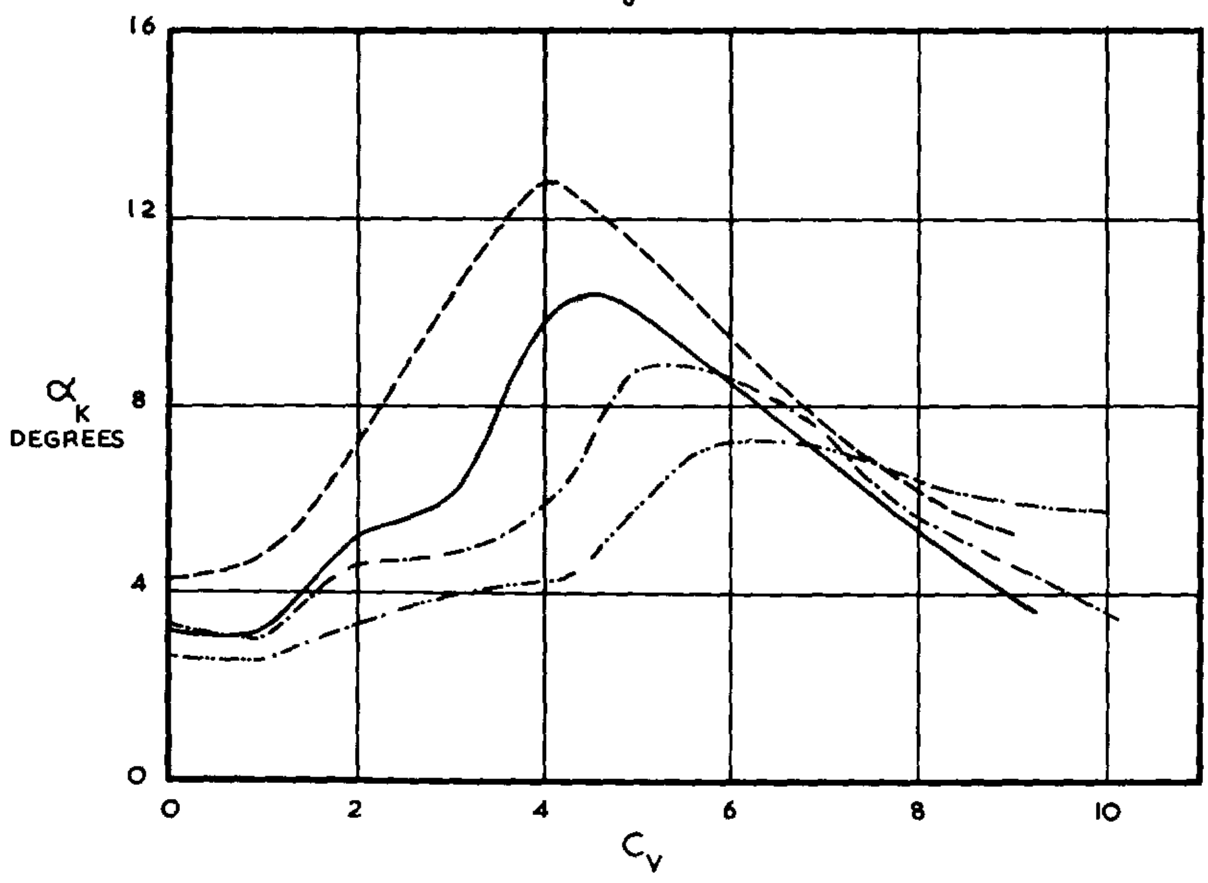


(b) DISTURBED

RELATION BETWEEN ELEVATOR SETTING AND STABILITY LIMITS, $C_{\Delta_0} = 2 \cdot 75$.



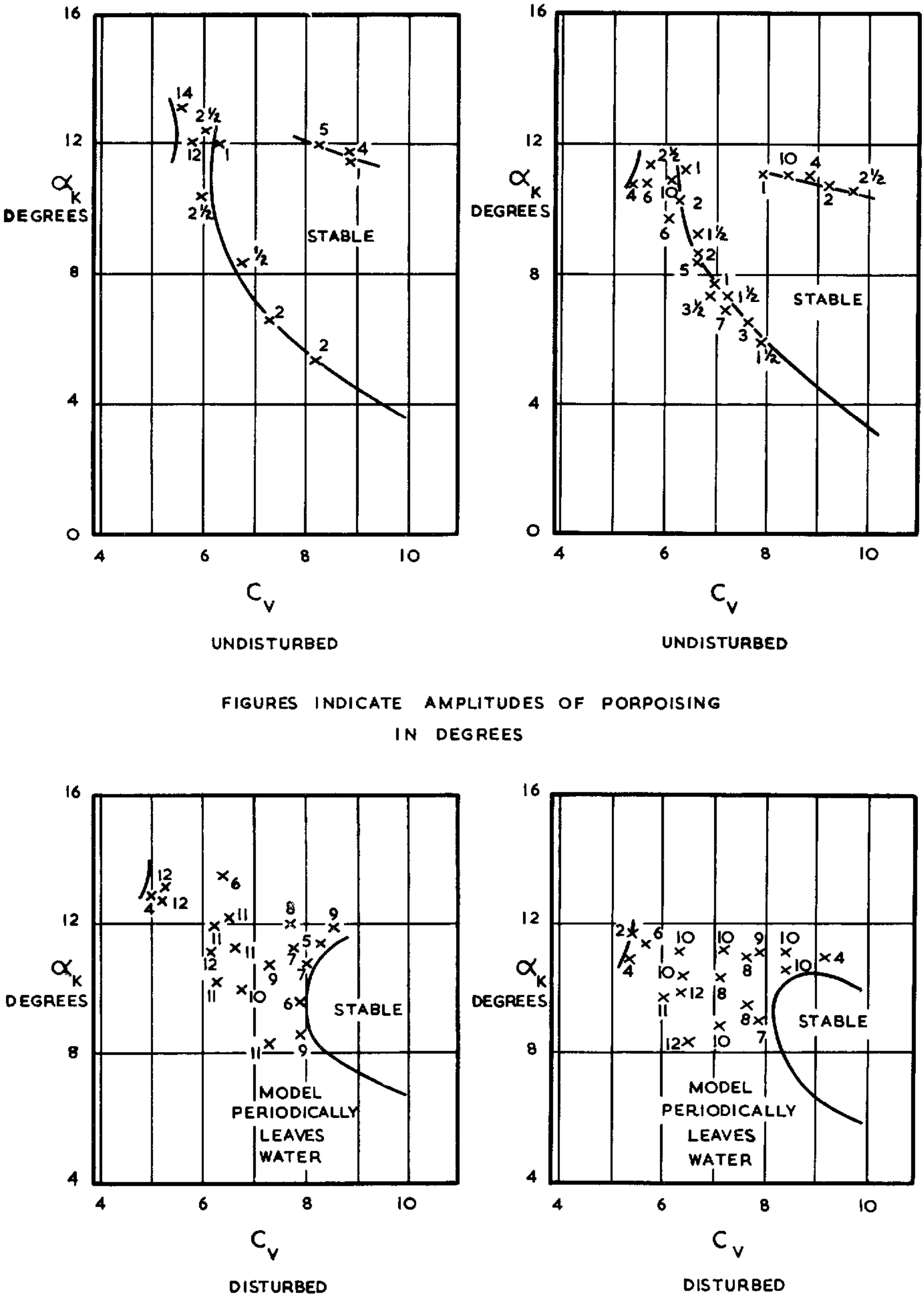
(a) $C_{\Delta_o} = 2\ 75$



(b) $C_{\Delta_o} = 2{\cdot}25$

EFFECT OF AFTERBODY LENGTH ON TRIM CURVES, $\eta = 0°$.

FIG. 6.



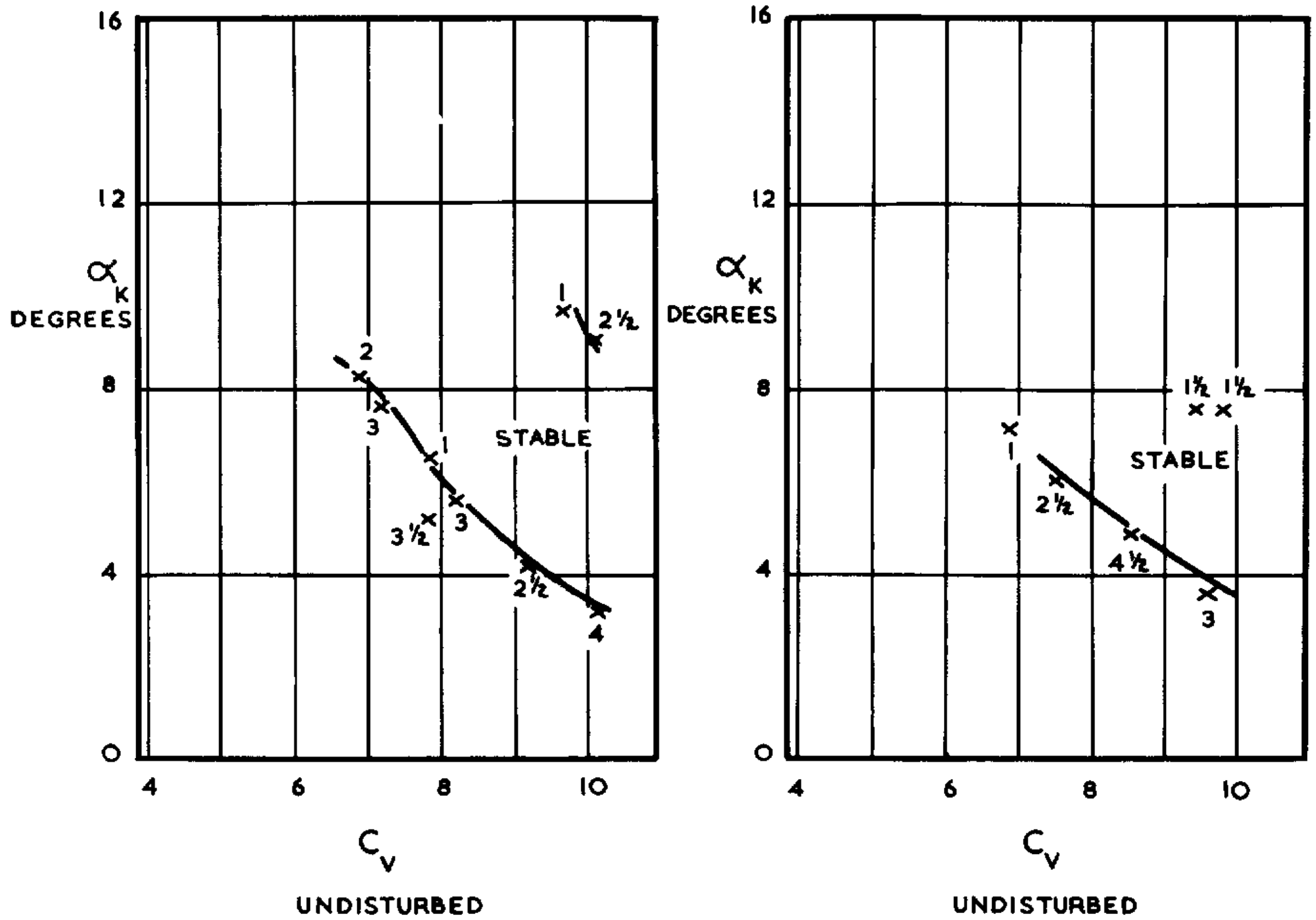
(a) AFTERBODY LENGTH 4b

(b) AFTERBODY LENGTH 5b

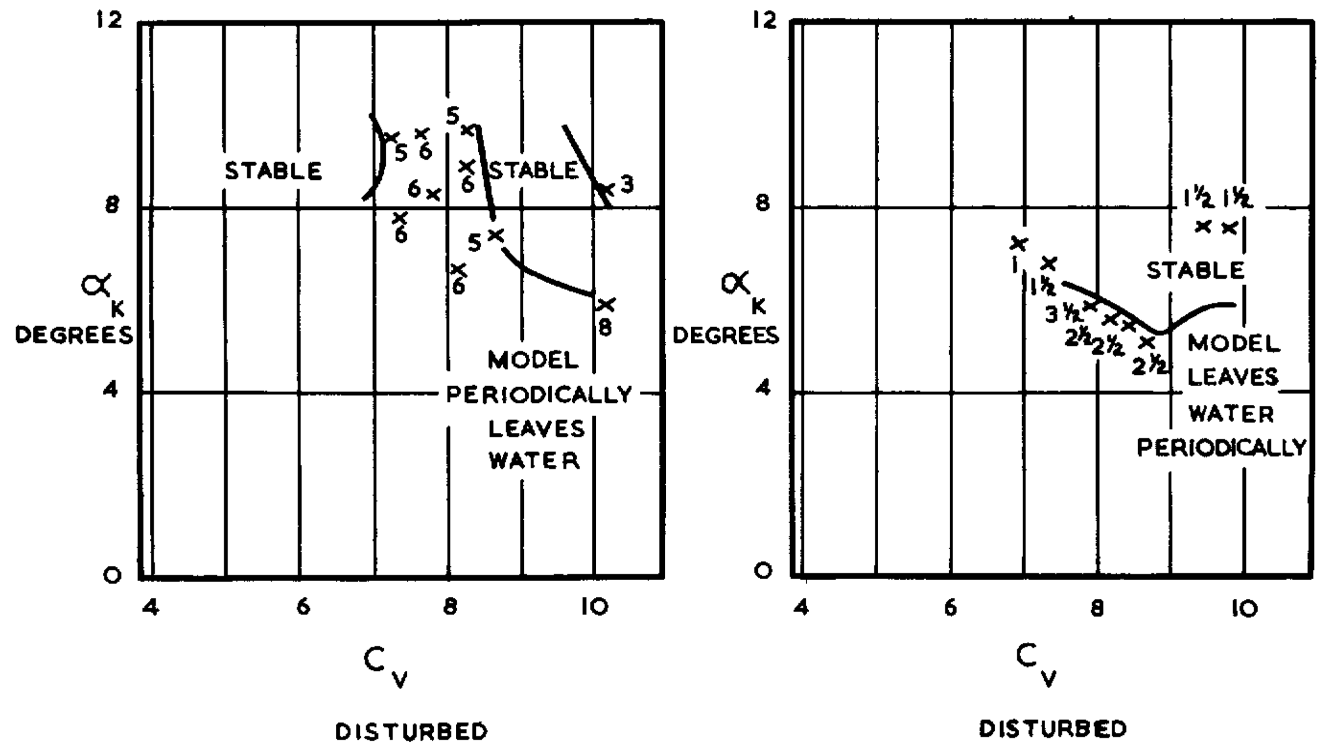
EFFECT OF AFTERBODY LENGTH ON AMPLITUDES OF PORPOISING

$C_{\Delta_0} = 2{\cdot}75$ (I)

FIG. 7.



FIGURES INDICATE AMPLITUDES OF PORPOISING IN DEGREES



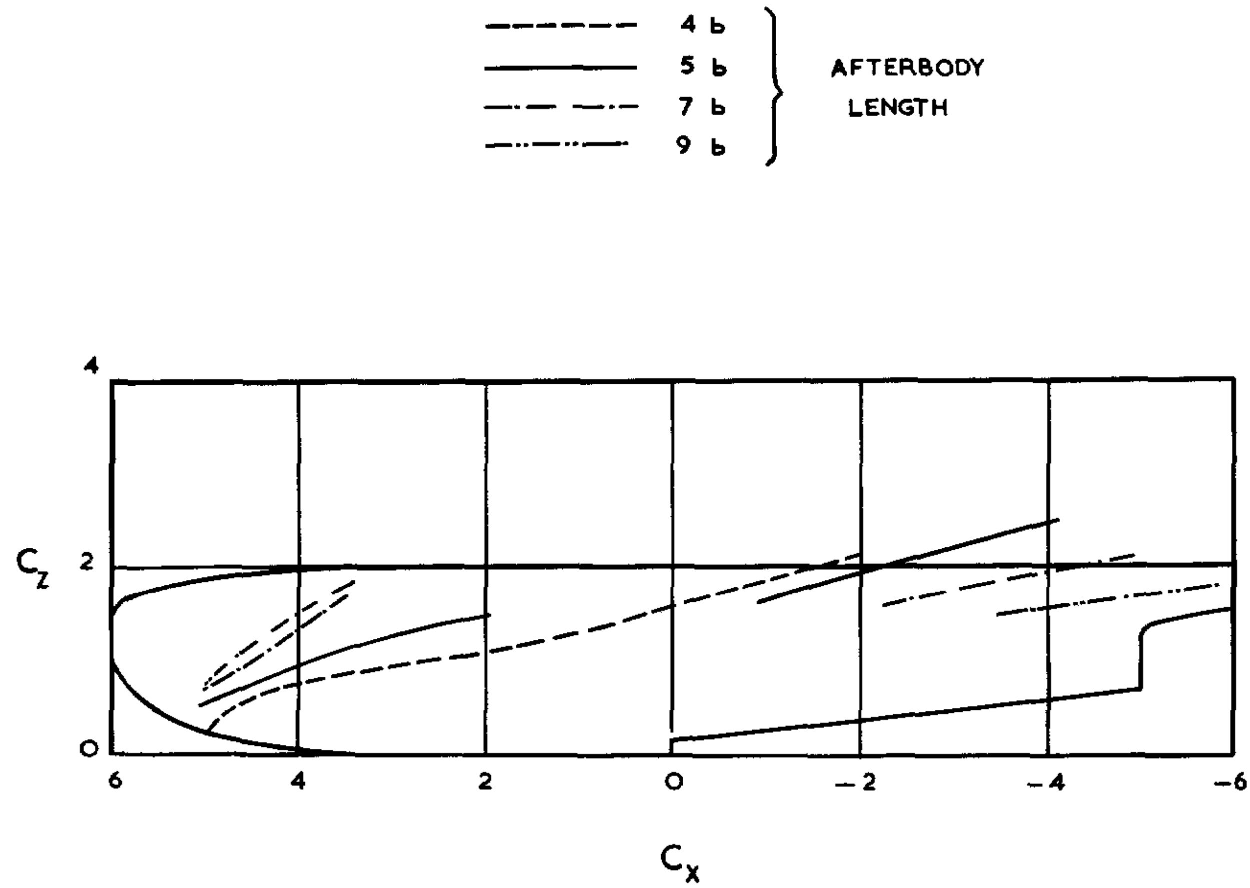
(a) AFTERBODY LENGTH 7 b

(b) AFTERBODY LENGTH 9 b

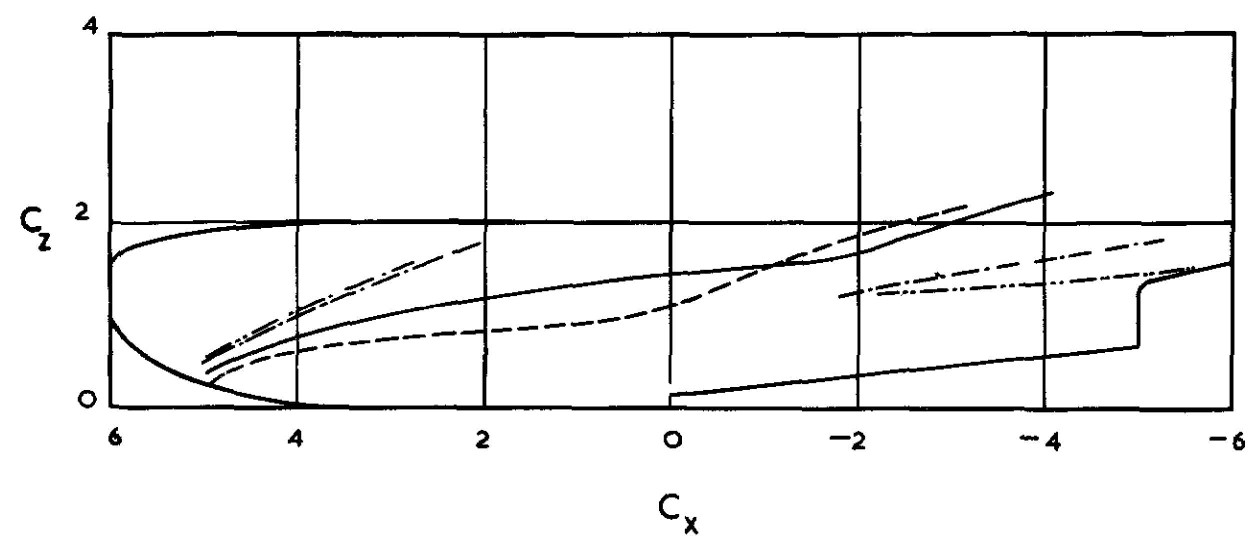
EFFECT OF AFTERBODY LENGTH ON AMPLITUDES OF PORPOISING

$C_{\Delta_0} = 2{\cdot}75$ (2)

FIG. 8.



(a) $C_{\Delta_0} = 2{\cdot}75$

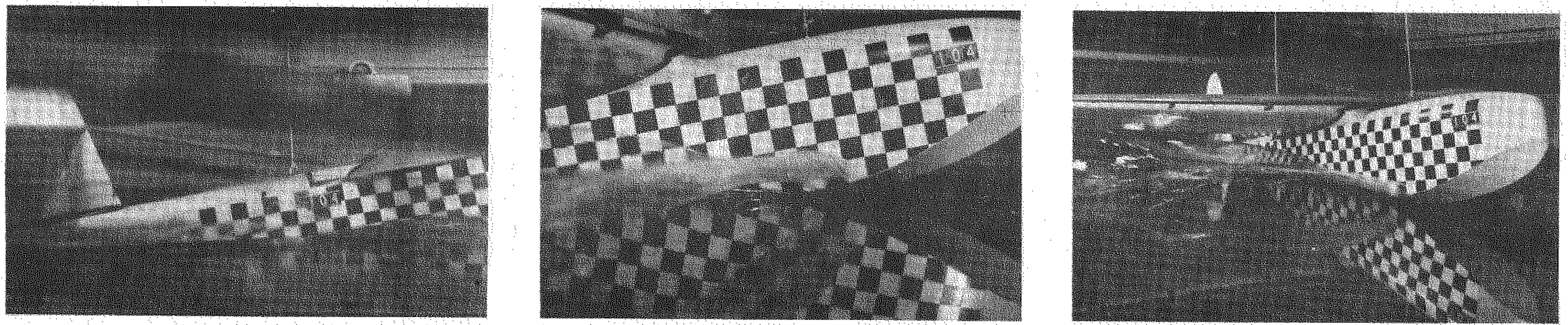


(b) $C_{\Delta_0} = 2{\cdot}25$

EFFECT OF AFTERBODY LENGTH ON SPRAY PROJECTIONS

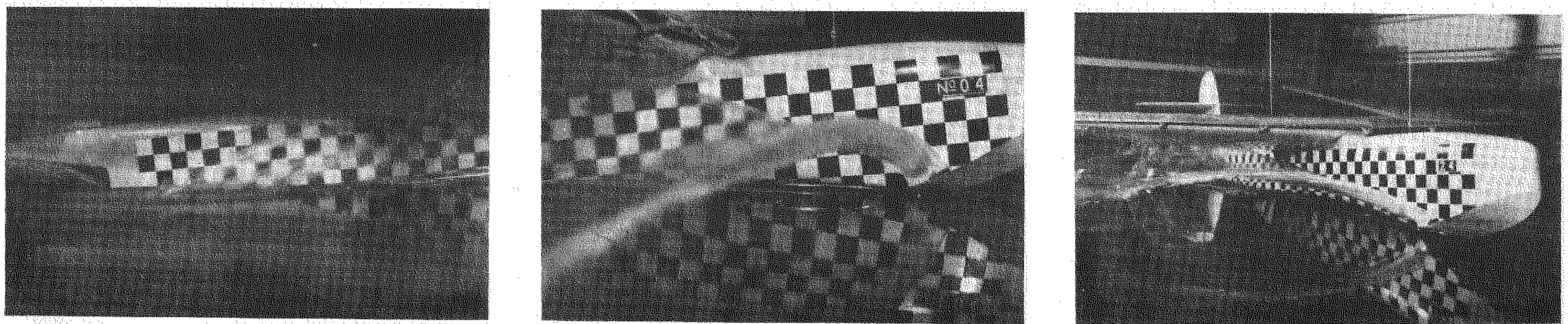
FIG. 9

$\eta = -8^\circ$
$C_v = 3 \cdot 07$
$\alpha_k = 11 \cdot 1^\circ$



MODEL D AFTERBODY LENGTH 4 BEAMS

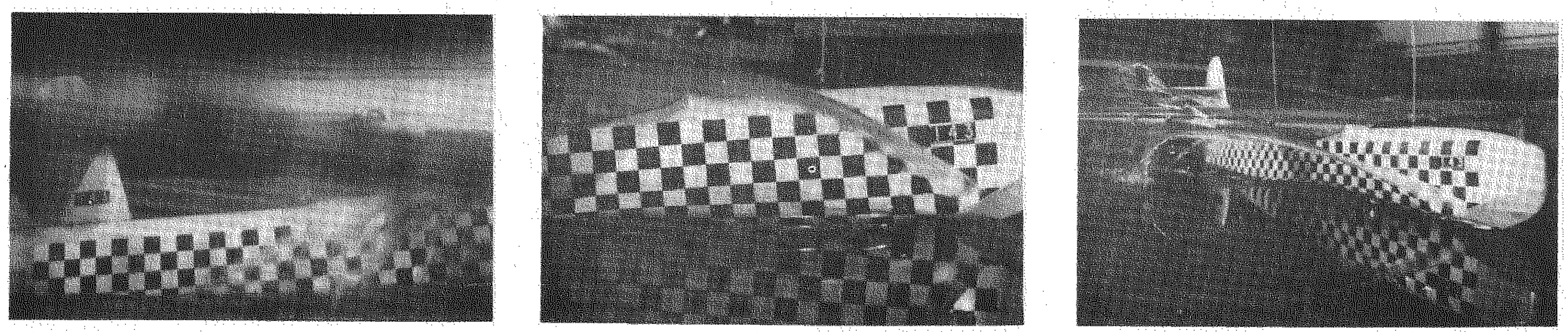
$\eta = -8^\circ$
$C_v = 3 \cdot 07$
$\alpha_k = 6 \cdot 9^\circ$



MODEL A AFTERBODY LENGTH 5 BEAMS

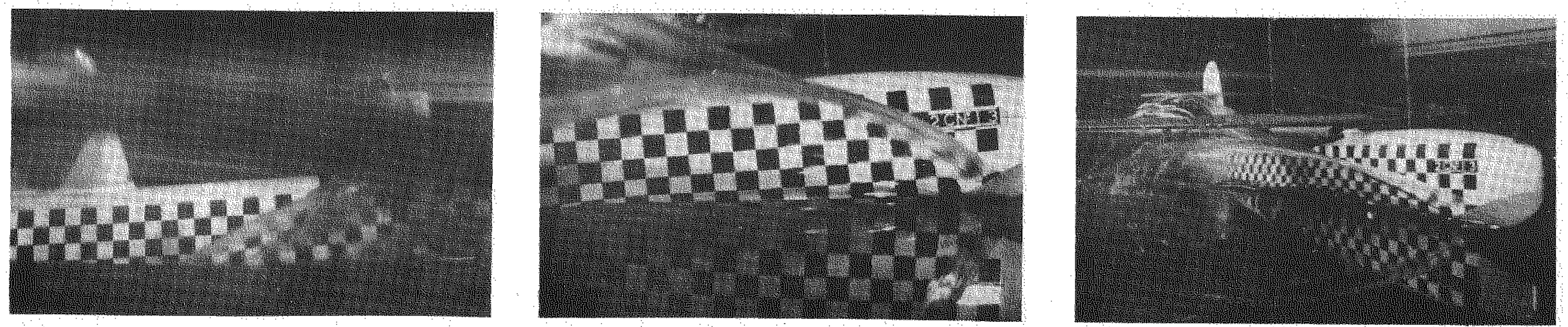
EFFECT OF AFTERBODY LENGTH ON SPRAY $C_{\Delta_0} = 2 \cdot 75$ (I)

$\eta = -8^\circ$
$C_v = 3 \cdot 15$
$\alpha_k = 4 \cdot 7^\circ$



MODEL E AFTERBODY LENGTH 7 BEAMS

$\eta = 0^\circ$
$C_v = 3 \cdot 07$
$\alpha_k = 3 \cdot 4^\circ$

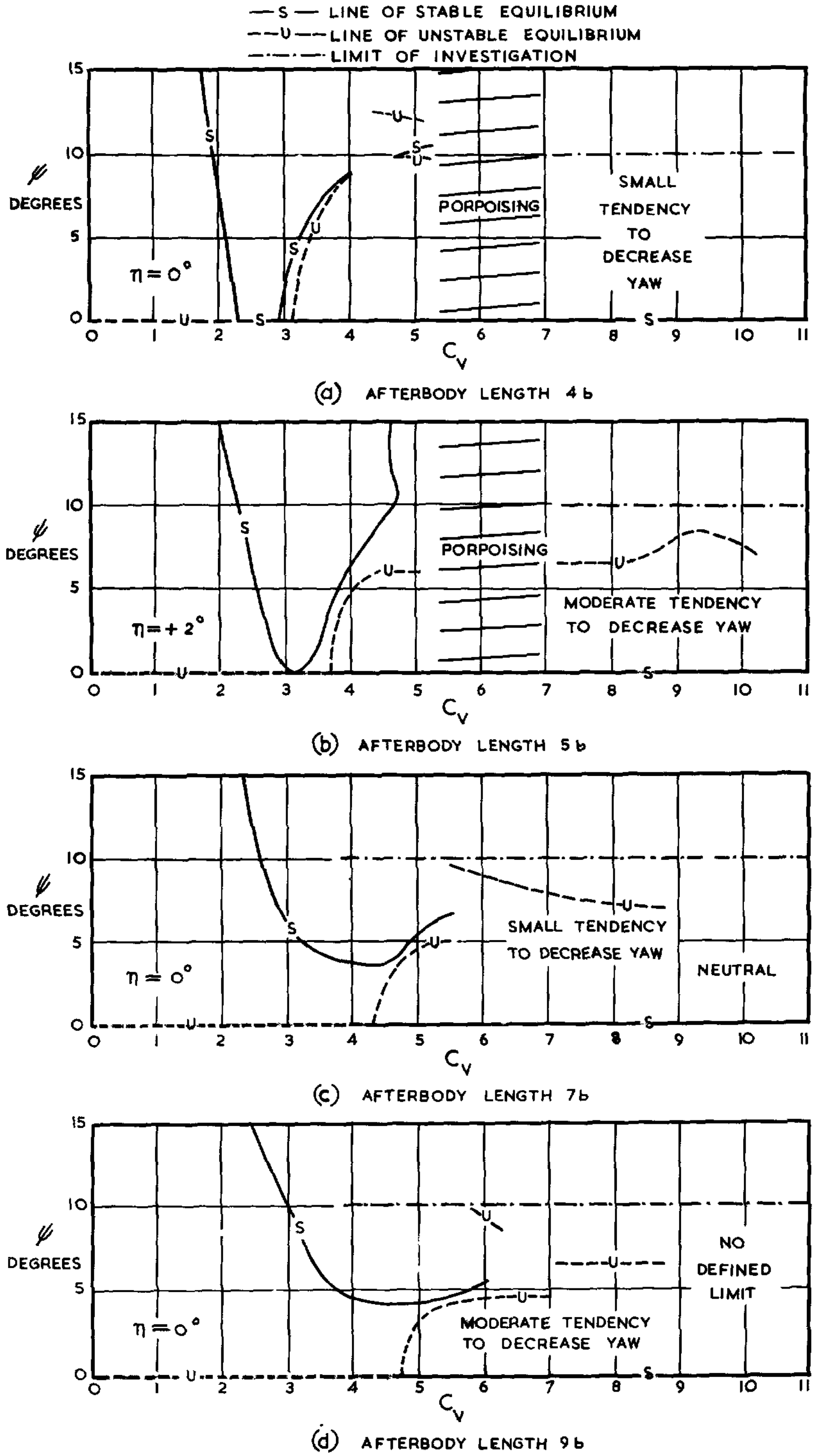


MODEL F AFTERBODY LENGTH 9 BEAMS

EFFECT OF AFTERBODY LENGTH ON SPRAY $C_{\Delta_0} = 2 \cdot 75$ (2)

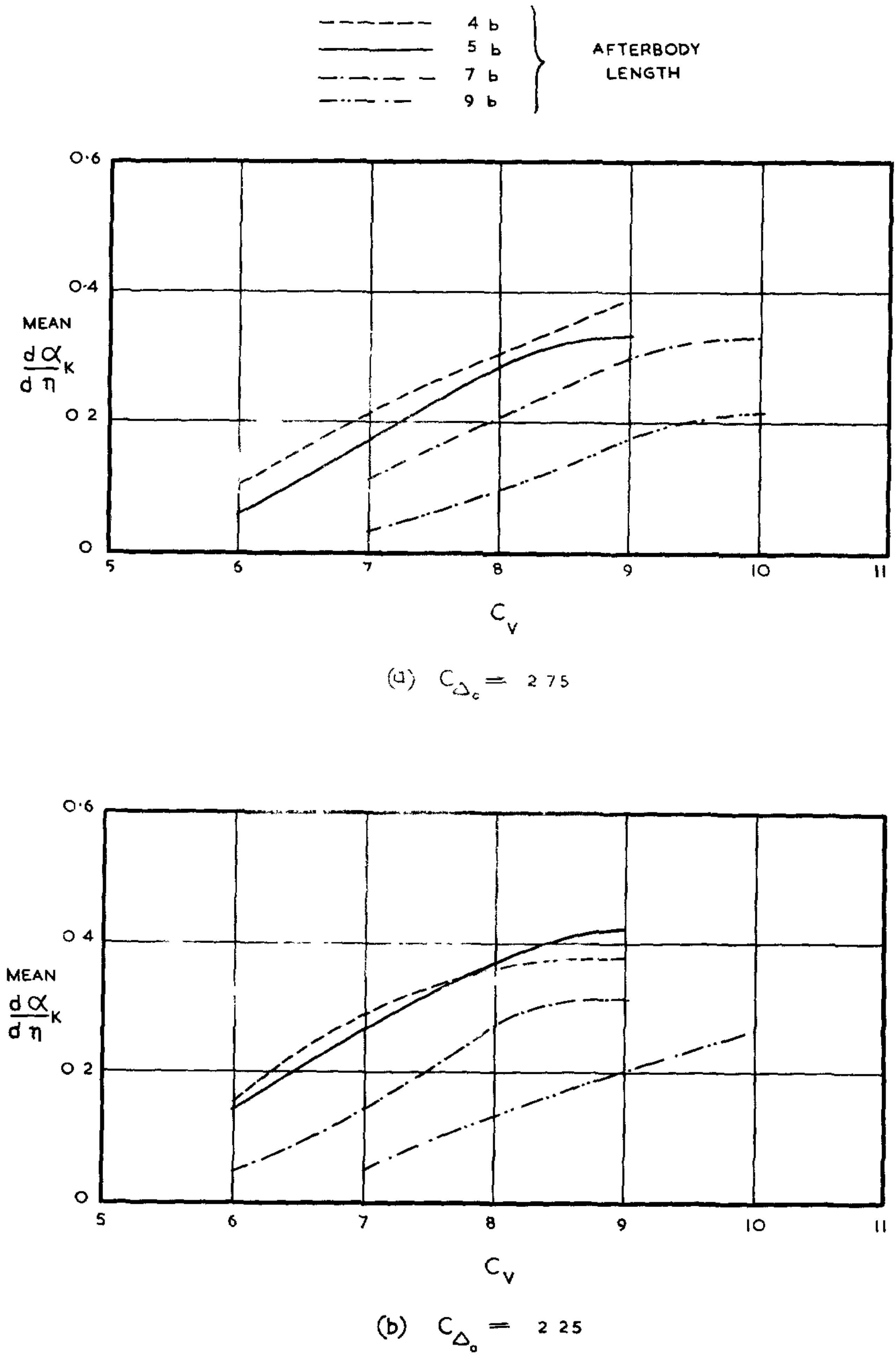
FIG. 10

FIG.11.



EFFECT OF AFTERBODY LENGTH ON DIRECTIONAL STABILITY, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 12.



EFFECT OF AFTERBODY LENGTH ON ELEVATOR EFFECTIVENESS

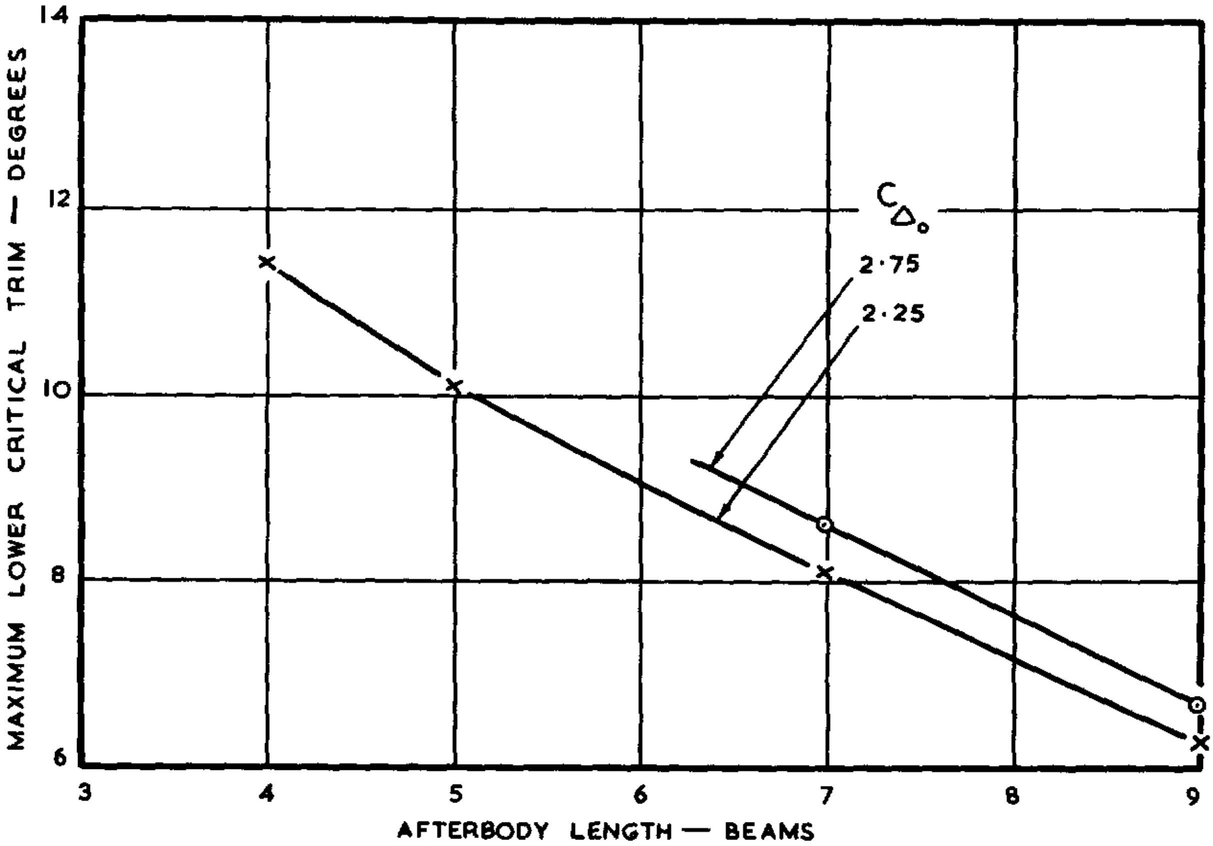


FIG. 13.

EFFECT OF AFTERBODY LENGTH ON MAXIMUM LOWER CRITICAL TRIM

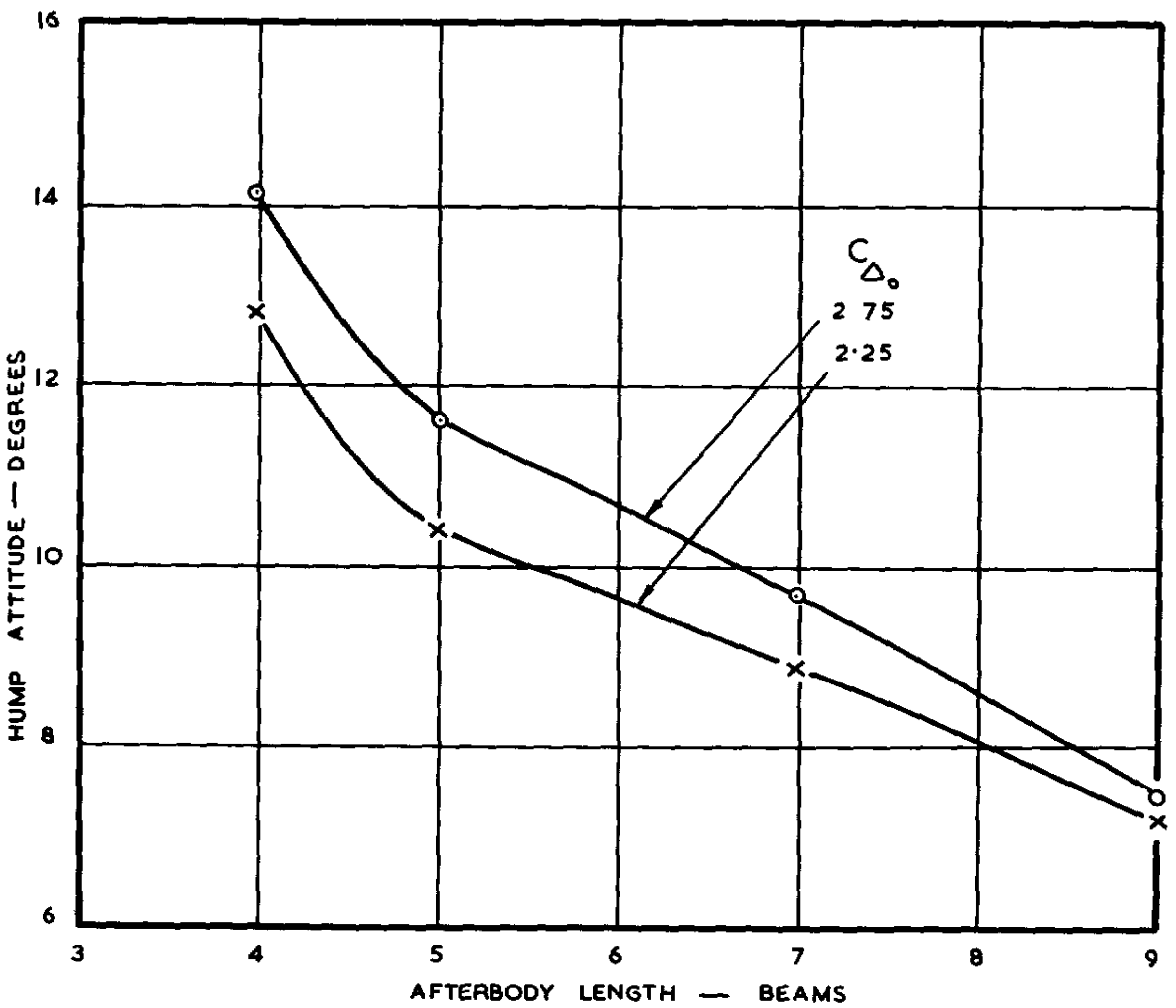


FIG. 14.

EFFECT OF AFTERBODY LENGTH ON HUMP ATTITUDE

C.P. No. 204
(17,033)
A.R.C. Technical Report

PRINTED AND PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W.C.2 423 Oxford Street, LONDON, W.1
P.O. Box 569, LONDON, S.E.1
13a Castle Street, EDINBURGH, 2 109 St. Mary Street, CARDIFF
39 King Street, MANCHESTER, 2 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 80 Chichester Street, BELFAST
or from any Bookseller
1955
Price 3s 6d net
PRINTED IN GREAT BRITAIN

S.O. Code No. 23-9009-4

C.P. No. 204