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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

By

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

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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

by

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

S U M M A R Y

The effects of forebody warp on longitudinal stability, spray, directional stability and elevator effectiveness are deduced from the results of tests on three models of length/beam ratio 11, which were alike in every respect except that of forebody warp, the deadrise angle being increased at the rate of 0°, 4° and 8° per beam, respectively.

It was found that forebody warp considerably improved longitudinal stability and spray characteristics, impaired directional stability slightly and increased elevator effectiveness. The best configuration was that with 8° of forebody warp per beam.

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1. INTRODUCTION

In this report the effects of forebody warp (progressive increase in angle of deadrise from step to bow) on the hydrodynamic stability and spray characteristics of a high length/beam ratio flying boat are deduced from the results of tests on the first three models of the series detailed in Reference 1 and listed in Table I. These models, A, B, and C, with which this report is concerned, constitute the first phase of the current investigation, i.e. the determination of the effects of forebody warp. They are identical except in respect of forebody warp and this single parameter is varied in the following manner:

- Model A 0° forebody warp per beam (basic model),
- Model B 4° forebody warp per beam,
- Model C 8° forebody warp per beam.

The effect of this variation on the forebody planing bottom shape can be seen in Figure 1, which is a comparison of hull lines, and the deadrise angle distributions are compared in Figure 2. Hydrodynamic and aerodynamic data common to the three models are given in Tables II and III, but it may be mentioned here that the length/beam ratio of each model is 11 (the forebody being 6 beams in length and the afterbody 5 beams), the afterbody to forebody keel angle is 6° and the step is a straight transverse type with no fairing and a depth of 0.15 beams. 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 at one or more loadings, one of which in every case was that equivalent to a $C \Delta_0$ of 2.75. Full details of the results of the tests carried out on each model are reported separately in References 3, 4 and 5; only stability limits and sufficient illustrations to indicate trends are given here.

Throughout the report conclusions are drawn from comparisons of results at $C \Delta_0 = 2.75$ and, where possible, substantiation is obtained from the other weight cases. Reference is also made to a high length/beam ratio investigation made by the N.A.C.A. and to earlier work on a hull of low length/beam ratio with a low beam loading.

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 and disturbed limits for models A, B and C at different weights are compared in Figures 3, 4 and 5.

In the undisturbed case, the effect of forebody warp on the stability limits for $C_{\Delta_0} = 2.75$ is clearly shown in Figure 3(a). The result of increasing forebody warp from 0° to 8° per beam is to give a large increase in the stable planing region; the lower limit is everywhere lowered by at least 2° and the upper limit by about $\frac{1}{2}^\circ$.

Considering only the first increment of warp, from 0° to 4° per beam, a fairly large improvement in stability is still obtained; the lower limit is lowered by about 1.3° generally and the vertical band of instability occurring just after hump speed with 0° warp is removed. The upper limit is lowered by half a degree, but the overall change is a useful increase in the extent of the stable region.

Confirmation of this change can be obtained from Figure 4(a) which is for a higher load, $C_{\Delta_0} = 3.00$, but before a direct quantitative comparison can be made with Figure 3(a) the effect of load must be considered. One of the conclusions of Reference 4, which can be extended to the present case, was that in the undisturbed stability 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 an increase in C_{Δ_0} of 0.25 on the stability limits for 0° and 4° warp respectively 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 forebody warp and, because of the equality of the load effects, Figures 3(a) and 4(a) are directly comparable and should show the same manner and magnitude of change with respect to forebody warp, as is in fact the case. There is a minor discrepancy, in this comparison however, at near-hump speed in Figure 4(a). At this weight, $C_{\Delta_0} = 3.00$, the formation of a neck of instability in the 4° warp case can be seen to be just beginning, but a slight decrease in weight would remove this tendency⁴ so in the comparison it should not be given too much importance. It does show though, that increase of forebody warp helps to prevent instability in this region.

The effect of the second increment of forebody warp (from 4° to 8° per beam) on the stability limits is shown by the curves B and C in Figure 3(a) for $C_{\Delta_0} = 2.75$. There is a lowering of the lower limit by about 0.8° , but the upper limit is unaltered. By the same reasoning as before direct comparison can be made with the limits for 4° and 8° warp at $C_{\Delta_0} = 2.25$ in Figure 5(a). (Model A, with 0° warp, was not tested at this lower loading as weight could not be sufficiently reduced). The lower limits here show the same order of improvement in each case, but the upper limit for 4° warp has been lowered more than that for 8° . It should be noted, however, that the upper limits in general are not so accurate as the lower limits, being based on fewer points which in themselves are difficult to obtain due to the proneness of the model to become airborne in this region. Further, if the comparison of undisturbed upper limits for different weights for Model B be examined (Reference 4) it will be seen that the limit for $C_{\Delta_0} = 2.25$ is apparently too low within its own set. The discrepancy in upper limit positions therefore should not be given undue importance.

For the disturbed case, the effects of forebody warp are shown in Figure 3(b). Before discussing them, however, a few points on technique should be considered⁴. In all tests the maximum possible disturbance was given to the model; as the critical disturbances in the mid-planing region were small, 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

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 just before the completion of one cycle; 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, the total effect of 8° forebody warp is to give a significant increase in the disturbed stable region, most of which accrues from the higher values of warp. The first increment of forebody warp, from 0° to 4° , produces only negligible change, both at $C_{\Delta_0} = 2.75$ and 3.00 (Figures 3(b) and 4(b)), while the second, from 4° to 8° , gives a definite improvement in disturbed stability, which is of similar order in both weight cases, $C_{\Delta_0} = 2.75$ and 2.25 (Figures 3(b) and 5(b)).

The effects of forebody warp on the stability limits are shown in a different light in Figure 6 (which is for one loading, $C_{\Delta_0} = 2.75$), where elevator angles replace keel attitudes as ordinates. In this diagram the undisturbed limits are grouped together, and the lower limits all lie more or less along the same elevator setting, a point which was made in Reference 2. Where a vertical band of instability must be crossed during take-off, as in the case of 0° warp, it is emphasised by this type of presentation. It can be concluded that when, in the undisturbed case, there is a completely stable take-off path for this type of hull, the application of forebody warp does not materially alter the elevator setting at which instability is encountered.

Little can be said about the disturbed case, except that an increase in the stable region with application of forebody warp is indicated.

During the tests just considered the pitching moments of inertia of Models A, B and C were 22.90, 21.30 and 23.75 lb. ft.² respectively, i.e. all within 12% of the value for Model B. By the conclusions of Reference 2, moment of inertia increases of up to 40% have no appreciable effect on the limits, so the differences in moment of inertia values do not affect the foregoing discussion.

Trim curves for $\eta = 0^\circ$ are compared in Figure 7 for different weights. The effects of increasing forebody warp from 0° to 8° are to reduce trim generally. Static floating trim is reduced by 1.4° and this order of separation continues over most of the displacement speed range. In this range buoyancy forces predominate and trim is almost unaffected by elevator setting. At the hump, attitude is decreased by 0.7° and in the planing speed range, by about 2° , although when planing the reduction varies with speed and is altered by elevator setting (References 3, 4 and 5). The attitude changes due to warp are roughly linear over the greater part of the displacement range, but when planing most of the effects are due to the first increment of warp, 0° to 4° , the trim curves for 4° and 8° warp being disorderly and lying close together from and including the hump.

These tendencies are confirmed in Figures 7(b) and (c), the differences in weight seeming to have little effect.

The effect of forebody warp on amplitudes of porpoising in both undisturbed and disturbed cases is shown for one load ($C_{\Delta_0} = 2.75$) in Figure 8. In the undisturbed case, there is no obvious change in the general level of porpoising amplitudes. In the disturbed case, however, with 4° warp (Figure 8 (b)) values are in general less than those for both no warp

/ and

and 8° warp, but the difference is small. In Reference 2 it is concluded that increase of the radius of gyration at constant mass has the effect of increasing the amplitudes of porpoising, particularly in the undisturbed case. It may therefore be that the lower amplitudes obtained with 4° warp are directly attributable to the fact that Model B has the lowest moment of inertia. The data in the undisturbed cases of Figure 8 are rather sparse, but in general it appears that forebody warp does not produce any significant change in the amplitudes of porpoising.

2.2. Previous investigations

Although there are numerous references to the effects of forebody warp in various reports, only two available experimental investigations are concerned directly with this subject. The first, by Carter and Weinstein, deals solely with forebody warp effects on the hydrodynamic qualities of a high length/beam ratio hull and the second, by Davidson and Locke, treats these effects as part of a fuller investigation into the porpoising characteristics of hulls of lower length/beam ratio. As both reports are American, it may be recalled that the tank techniques used in these model tests differ from those used in the current programme. These differences in techniques are discussed in References 8 and 9 whence it appears that comparison of results should be made on the basis of steady 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 (as far as it goes) to the M.A.E.E. limit(s) with disturbance.

In Reference 6 the hull used had a length/beam ratio of 15 and was tested at $C_{\Delta 0} = 5.88$. The forebody, which was 8.6 beams in length, was warped at the rate of $7\frac{1}{2}^\circ$ per beam (this is described as extreme warping), incorporated chine flare and had a main step deadrise of 20° . It differed from its basic forebody in the same general manner as that of Model C from that of Model A in the present tests. The conclusions reached are general and indicate that an appreciable increase in the stable range of trim between limits results from forebody warping, with no appreciable effect on the maximum amplitudes of porpoising.

Examination of Figure 6 of Reference 6, however, shows that warp has lowered the lower limit by an average value of just over 2° and has lowered the upper limit by a very small amount. This is in very good agreement with the present findings in the undisturbed case with 8° of warp per beam. It is probable that differences in the aerodynamics of the two sets of models will have negligible effect on changes due to warp in the case of the lower limit, except at the high speed end, and the smaller change in the upper limit of Reference 6 may be due to the use of slipstream in these tests. The upper limits decreasing trim can only show a tendency, but even so the indications are that the limit with warp would give the larger stable region. This agrees with the current results obtained for warp in the disturbed case.

Figure 7 of this reference shows that with warp there is a reduction of static floating trim of about 1.3° and a general reduction in planing attitudes for a given elevator setting; again agreement with the current investigation is good.

The values of the amplitudes of porpoising shown in Figure 8 of Reference 6 agree generally with those obtained in the present tests in the determination of undisturbed limits but, as in Reference 6 there is nothing corresponding to the lower part of the disturbed limit, there is no note of the large amplitudes (up to 12° , Figure 8) which can be obtained in this region with disturbance.

In the forebody warp investigation of Reference 7 the model used had a length/beam ratio of 6.2 and was tested at $C_{\Delta_0} = 0.89$. The forebody, which was 3.44 beams in length, was warped at several rates but only that of 8.1° per beam will be considered in detail. It also incorporated chine flare and had a main step deadrise angle of 20° . The differences between basic and warped forebodies were obtained in the same general manner as those of the previous reference. The conclusions state that "increasing the warping of the forebody bottom very appreciably lowers the lower limit at high speeds but only slightly at speeds just beyond the hump. The upper limit is also lowered, but to a very much less extent. Increasing the warping of the forebody lowers the free to trim track at high speeds." Referring to Figure 25 of this report it can be seen that the effects of 8.1° of forebody warp are to lower the lower limit by 2° , except at its extremities, to lower the upper limit by just over $\frac{1}{2}^\circ$, to decrease the static floating trim by 1.3° and to decrease planing trims by amounts of similar order. It may also be noted that the hump trims are confused and out of order and that the rate of change of the position of the lower limit with respect to warp is not even regular.

All of these details agree well with the corresponding ones of the present investigation in the undisturbed case. It is interesting, however, that in the description of test procedure in Reference 7 the necessity for a disturbance is assumed and, while acknowledging the fact that the transient cycles depend upon the amplitudes of the initial disturbances which start porpoising, the authors go on to state that the amplitude of the final steady-state cycle is largely unaffected by the magnitude of the initial disturbances. The implication is that there is only one type of hydrodynamic longitudinal instability; this, as shown by M.A.E.E. experience, is not the case¹. There are two types of instability recognised by M.A.E.E. and R.A.E., defined as undisturbed and disturbed. In the general case, if a given configuration is unstable in the undisturbed sense, a porpoising oscillation will build up naturally to a given amplitude in a steady speed run without any external aid; if the same configuration develops disturbed type instability following the application of a disturbance, the oscillation will reach a steady amplitude which is much greater than that obtained without disturbance (see Figure 8). In order to induce disturbed type instability, the applied disturbance must exceed a certain critical magnitude, which differs from point to point on the stability diagram and, if this critical value is not exceeded, the motion subsides to its original state without disturbance. Not only is the magnitude of disturbance critical, but so is its manner of application; and both must be considered together.

The disturbance currently used by M.A.E.E. is caused by a sudden pull on the aft guide string attached to the model, while that of Reference 7 was applied by accelerating the model over a distance of about three or four times its own length. It is felt that in the latter case the combined effects of magnitude and manner of application were insufficient to induce disturbed instability and the resulting diagrams can be compared quite fairly with those obtained without disturbance by M.A.E.E.

2.3. Discussion

As the aim of the present investigation is to provide design information, variation of the hull parameters has been kept within practical limits, with occasional exceptions to aid in the fuller understanding of a phenomenon, and the conclusions drawn will in general hold only within these limits. The adequacy of the variations of forebody warp tested thus deserves some comment.

The main step deadrise angle, 25° , is a compromise, chosen as the optimum on experience of impact, resistance, stability and final hull shape considerations. The range of warps tested, up to 8° per beam, is considered adequate. If, for instance, 12° per beam had been used, the section halfway along the forebody would have had a deadrise angle of 61° and to obtain a forebody length of 6 beams, the rate of warping forward of this section would have to be considerably reduced, giving rise to concave buttock and water lines, which would result in small forebody stowage volume, and a possible increase in aerodynamic pressure drag. It is also known that hydrodynamic resistance is increased slightly by forebody warping.^{6,7} These criticisms of course apply in the case of 8° of warp per beam, but the effects will be relatively small.

In each case tested, the forebody warp was uniform for three beams forward of the step and then varied to give good lines with a deadrise angle of 63° at the forward perpendicular. The half of the forebody planing bottom nearer the step is the important part from a stability point of view, and as the buttock lines here are approximately straight, the question of what effects a non-uniform rate of change of deadrise angle may have is raised. If non-uniform warp were applied so that the planing bottom developed a slight concave camber, the lower limit would probably be lowered (Reference 10) thus improving stability, but aerodynamic drag would be increased; if the warp variation were such that the planing bottom camber was convex, drag would be improved but hydrodynamic stability would probably be impaired (Reference 11). The configurations with uniform warping are therefore considered to be good compromises.

The present investigation of forebody warp effects on a high length/beam ratio model covers a range of warps which was tested at at least two weights and under different representative operational conditions. The investigations of Reference 6, which is for one warp change at one weight under calm water conditions on a model of higher length/beam ratio, and Reference 7, which covers a range of warps at one weight also for calm water on a hull of low length/beam ratio, allow the conclusions of the present investigation to be extended in scope.

Considering the effects of forebody warp in the lower limit undisturbed case, as instability here is a function of the forebody only, the only effect of the afterbody being to determine the low speed end of the limit, and as, in the present case, the forebodies tested were of identical length and beam, the changes in the lower limit are solely due to forebody warp. It may be concluded that applying 8° per beam of warp to an unwarped forebody will lower the undisturbed lower limit by approximately 2° , the rate of change being non-linear. By taking note of the model configurations tested in the three investigations, References 6 and 7 and the present one, it will be seen that ranges of three parameters have been covered, viz: length/beam ratio = 6.2 to 15, forebody length = 3.44 to 8.6 beams and static load coefficient = 0.89 to 5.88. The foregoing conclusion may therefore be extended, i.e. it is independent of length/beam ratio, or of forebody length, as only the forebody is concerned, and of static beam loading within the above mentioned ranges, providing that load coefficient is a function of length/beam ratio as indicated in Reference 12. This proviso implies that the configuration considered is a practical one.

In the upper limit undisturbed case the effects of forebody warp are not so clear cut. Firstly, as instability here is of the two step kind, the afterbody must be considered in conjunction with the forebody. The application of forebody warp alters the forebody pressure distributions and gives rise to different wake shapes, so, although the afterbodies are identical in this case, they are affected by different flows. Secondly, there is the possible inaccuracy in the determination of the limit

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mentioned in Section 2.1. Comparison with References 6 and 7, however, shows that in all cases forebody warp has lowered the upper limit by amounts which are considerably less than those by which the corresponding lower limits were lowered.

The disturbed stability limits show that a useful increase in the stable region can be obtained by the use of 8° per beam of forebody warp, and this is supported by Reference 6.

The changes in trim and the absence of any significant change in the amplitudes of porpoising obtained with forebody warp in the present tests are in general agreement with the results of the two references, 6 and 7.

3. WAKE FORMATION

An examination of the individual wake photographs in References 3,4 and 5 failed to reveal any differences in the shape of the wake which might be directly attributable to forebody warp. What minor differences there were might well have been the result of slight variations in attitude from model to model.

The position of the afterbody relative to the wake and its association with instability in each case may be summarised in the following general manner.

Attitude	Speed	Afterbody position	Stability		Remarks
			Undisturbed	Disturbed	
High Low High Low	Low Low High High	Planing Clear Planing Well clear	Stable Stable Stable Stable	Unstable Unstable Stable Unstable - violent	} Every case } * A, B and C }
Mid-planing		Clear	Stable	Unstable	
Mid-planing		Clear	Stable	Stable	

* A 0° forebody warp per beam.

B 4° forebody warp per beam.

C 8° forebody warp per beam.

The only irregularity in this table is occasioned by the 8° warp case which unlike the 0° and 4° configurations, is stable with disturbance in the mid-planing region. In this region, the afterbody is clear of the wake for all the cases considered. The remarks are general, the clearances, etc., varying in degree because the original photographs were of representative configurations only, but it does seem that the question of whether the afterbody is planing or not bears little relation to stability either disturbed or undisturbed.

4. SPRAY

4.1. Present tests

The spray characteristics of the models were evaluated during the undisturbed longitudinal stability runs with $\eta = -8^\circ$, 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, this happening mainly at low displacement speeds (Figure 10), 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 for 0° , 4° and 8° forebody warp per beam, are compared in Figure 9.

The effects of forebody warp on spray are shown clearly at one weight ($C_{\Delta_0} = 2.75$) in Figure 9(a). The projection for 0° of warp is discontinuous because spray struck the model wing, while that for 4° of warp is continuous showing that the spray was at all times clear of the model. This is known to be only just the case, however, from observation, the spray at about $C_V = 6$ barely clearing the wing trailing edge. The 8° warp curve is similar in form to that for 4° of warp, but a considerable reduction in spray height is obtained where it is generally most needed i.e. where propellers are normally situated. It is clear that increasing forebody warp improves the spray characteristics. At taxiing speeds, where maximum spray heights are in the region $C_X = 4$, there is little difference in spray; at the higher displacement speeds, where spray normally gives most trouble, and the highest spray is between $C_X = 1$ and 2, the projection is lowered by the second increment of warp by 0.3 beams. The total improvement due to 8° of warp unfortunately cannot be measured, but it is obviously greater than this. At planing speeds the projections converge at $C_X = -2$, and beyond this the spray in every case is too high for the normal tailplane to be unaffected. With this type of hull therefore the tailplane must either be high on the fin to avoid interference, or stressed to take the resulting water loads. In Figures 9(b) and (c) the warp effects just considered are substantiated at $C_{\Delta_0} = 3.00$ and 2.25 respectively.

An examination of the individual spray photographs in the model data reports shows that in the displacement range at lower speeds, forebody warp causes the spray to develop a sweepback, i.e. it is less spread out laterally. This tendency decreases with speed until it becomes almost unnoticeable just below hump speed, where the attitude is high and only a small area of the planing bottom forward of the step is wetted. In this region differences in deadrise due to warp are very small and one would expect small or negligible differences in spray as a result. An example showing warp effects on spray at one speed, $C_V = 3.00$ approximately, is given in Figure 10.

The foregoing remarks apply mainly to main spray. Velocity spray is slight in all cases at higher planing speeds, and can be neglected, while at the lower displacement speeds it is practically inseparable from the main spray. In the case with 0° warp, lateral distribution of the spray is wide enough to affect wing tip floats at medium displacement speeds, when the spray origin is well forward, near the bow. This configuration, however, is not a practical one from considerations of stability and impact as well as spray. With 4° warp, possible spray interference with floats occurs only around one speed, about $C_V = 3.0$ and in a normal take-off the effect would be of such small duration that no damage would be expected. With 8° warp, floats would be clear of spray at all times.

4.2. Previous investigations

The only spray investigation available which seems to be at all comparable with the present case is that of Reference 6 for a hull of length/beam ratio 15. The data are presented differently, spray being assessed at several loads, but the conclusions state that bow spray characteristics were substantially better for the hull with the warped forebody than for the hull with the basic forebody; in smooth water a 25% increase in gross load was possible before spray in the propellers and on the flaps was equivalent to that of the basic forebody. Spray striking the tail was approximately the same with both forebodies. An examination of Figure 12 of this reference shows that for the design gross load of 75,000 lb. ($C_{A_0} = 5.88$) the warped model was untouched by heavy spray, but the basic model was struck, either on propellers or flaps, over a speed range of $C_V = 2.5$ to 4.5. In the present case spray photographs³ show that the mainplane of the basic model was wetted over a speed range of $C_V = 3$ to 5; had propellers and flaps been present this range would have been extended making the spray characteristics slightly worse than those of the basic model of Reference 6. From the projection for 8° of forebody warp in Figure 9(a) it would appear that propellers would be clear of spray but flaps would be wetted, were they present. One may conclude therefore that the differences in spray characteristics due to 8° forebody warp per beam are approximately the same in each case.

4.3. Discussion

Damage caused by spray normally occurs when propellers, flaps or tailplane are struck by main spray, or when spray enters jet intakes and causes corrosion. This latter type of damage may be eliminated by flushing the turbines through with fresh water immediately after contact with spray. Tailplane damage occurs in the planing speed range and, with a high length/beam ratio hull, it may be overcome by placing the tailplane high on the fin, thus avoiding the high spray plume occurring at these speeds, or it may be met by stressing the tailplane to take the water loads which will certainly occur if the tailplane is in the normal position. The height of this plume relative to the hull, is, for practical purposes, unaffected by forebody warp. The remaining causes of damage occur mainly in the displacement speed range. It is clear from the foregoing results that considerable benefit can be derived here from the use of forebody warp, 8° per beam giving the greatest reduction in spray height within the range tested.

As a practical design case the 8° warp configuration is interesting. With propellers a little spray might be sucked up and some would probably strike fully deflected flaps, but only in small amounts and for short periods during take-offs and landings. Accepting this possibility, the forebody as tested could be directly scaled up; there is no need for chine turn down or flare, so the risk of impact damage would be reduced, and similarly, there is no need for transverse planing curves. The plates forming the forebody planing bottom would thus have a minimum of curvature and construction would be simplified.

The present results generally confirm those of Reference 6, but, at a given speed, attitude has a large effect on spray and unless attitude changes due to warp are similar in each case, the agreement between changes in spray will not be mainly due to forebody warp effects. In the present case static floating trim was reduced by 1.4° with 8° of warp, this order of change continuing up to hump speed; the corresponding changes in Reference 6 are similar, static floating trim being reduced by 1.3° . It may be noted that the ratio of forebody length to forebody plus afterbody length is

/ approximately

approximately the same in each case, namely 0.56. If this ratio is preserved, attitude changes will be approximately equal for hulls of length/beam ratios between 11 and 15 and the same order of improvement in spray characteristics can be expected with the application of 8° of forebody warp. The indications of Figure 9 of this report are that load variations have little effect on changes due to forebody warp.

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 $\pm \frac{1}{2}^\circ$. 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 zero aerodynamic yawing moment, and it was found that the effects of load⁵, roll constraint³ and elevator³ on directional stability were small enough to be neglected. Stability diagrams for 0°, 4° and 8° of warp per beam are compared at one weight, $C_{\Delta_0} = 2.75$, in Figure 11.

There are only two effects of warp which are at all noticeable and these are of little practical significance. The first, at the low speed end of the diagram, is that the separation between the stable equilibrium line and the speed axis at $C_V = 3$, increases progressively with warp. The speed range affected is so small that the change is insignificant. The second change is found at high speeds in the region $C_V = 9$ to 10, where the annotations show a progressive tendency from stable to neutral equilibrium with increase of warp. This effect would be unnoticed in a practical case.

6. ELEVATOR EFFECTIVENESS

The effects of forebody warp on elevator effectiveness are shown in Figure 12(a) for $C_{\Delta_0} = 2.75$. The first 4° of warp has the greater effect, giving a mean increase in effectiveness of 0.045 approximately, while that due to the second increment is about 0.03. Corresponding changes in effectiveness shown in (b) and (c) for $C_{\Delta_0} = 3.00$ and 2.25 are somewhat less than these, but in each case warp increases elevator effectiveness, the greatest improvement being derived from the first increment of warp.

Elevator effectiveness may be increased by (i) improving the efficiency of the elevators themselves or (ii) reducing the opposing moments without modifying the elevators. It should be noted that in these tests the elevators were identical and the increase in effectiveness with application of forebody warp is an example of case (ii). For a specified reduction of attitude from a given datum attitude, less forebody volume and planing surface area will be immersed in the warped case and the resistance to an elevator moment will be correspondingly smaller. The effect will be most obvious at low attitudes when there is no afterbody immersion, i.e. in the region of the lower stability limits. At high planing attitudes little or no difference will be found in elevator effectiveness as the hull will be planing on the surface just forward of the step, where differences due to warp are small and the afterbody, which is identical in each case, may also be planing. These points are illustrated in the following table.

/ C_V

$C_{\Delta_0} = 2.75$		0° warp		4° warp		8° warp	
C_V	a_k	η	\bar{x}_E	η	E	η	E
7	8	+4	0.16	-5	0.23	-6	0.30
8	6	+5	0.20	-1	0.28	-2	0.37
9	4	+10	0.10	+2	0.24	+2	0.32
9	8	-4	0.53	-7	0.50	-6	0.50

\bar{x}_E - elevator effectiveness.

At each speed an attitude in the region of the lower limit was chosen and at the highest speed a higher attitude was included. In each warp case the elevator setting for this attitude and speed was found, and the specific elevator effectiveness read off the diagram for that speed (References 3, 4 & 5). (The values of elevator effectiveness in Figure 12 are mean values for the whole attitude range at a given speed). It can be seen that for the first three attitudes, those nearer the lower stability limit, the effectiveness increases with warp, whereas, at the higher attitude and speed, there is little difference.

Returning to the presentation of longitudinal stability limits with elevator angles replacing keel attitudes as ordinates in Figure 6(a), apart from the neck of instability in the case of Model A, there is no significant change in the limits due to warp. To obtain a complete representation this diagram must be considered in conjunction with Figure 12(a) where the benefit derived from warp is shown as an increase in elevator effectiveness.

7. CONCLUSIONS

The results of the present investigation show that the effects of forebody warp are to considerably improve hydrodynamic longitudinal stability and spray characteristics, to impair directional stability very slightly and to increase elevator effectiveness. Of the configurations tested that with 8° forebody warp per beam will give the optimum improvement in water performance, but this might be bettered particularly from the spray point of view, in other cases when a further increase in the degree of warping is feasible.

Accepting 8° of warp as the optimum value in the present case, the following detailed improvements result from its application.

- (i) The undisturbed lower longitudinal stability limit is lowered by approximately 2°. This is independent of load.
- (ii) The undisturbed upper longitudinal stability limit is lowered by a small amount which is not more than $\frac{1}{2}$ °.
- (iii) The disturbed stable region is increased significantly.
- (iv) Trim is reduced by the order of $1\frac{1}{2}$ ° in the displacement range and, by about 2° in the planing range with $\eta = 0^\circ$.
- (v) Porpoising amplitudes are not significantly affected.

/ (vi) The

- (vi) The elevator setting at which instability is encountered is materially unaltered.
- (vii) At taxiing speeds and at planing speeds spray is not significantly affected; at other speeds in the displacement range however, the spray height, in the propeller plane in particular, is decreased by more than 0.3 beams. Below hump speed the spray is less spread out laterally. These effects appear to be independent of load.
- (viii) Directional stability is slightly impaired at both low and high speeds, but the changes are of such a nature as to allow them to be neglected.
- (ix) Elevator effectiveness is substantially increased.

Of the above results (i) to (v) are substantiated by either Reference 6 or 7 or both. General agreement with (vii) is obtained in Reference 6.

It may be noted that 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 forebody warp in waves and to correlate them, if possible, with the effects of disturbance.

/ LIST OF SYMBOLS

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 = Δ /wb^3 (Δ = load on water and w = weight per unit volume of water)
C_{Δ_0}	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

<u>No.</u>	<u>author(s)</u>	<u>Title</u>
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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.
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/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	Unfaired transverse. Step depth 0.15 beam.	
A	0	5	6		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'		
Length of afterbody (7b)	3.325'		
Angle between forebody and afterbody keels	6°		
Forebody deadrise at step	25°		
afterbody deadrise	30°		
		(decreasing to 26° at step over forward 40% of afterbody length).	
Model	A	B	C
Forebody warp (per beam)	0°	4°	8°
Pitching moment of inertia (lb.ft. ²)	22.90	21.30	23.75

/ TABLE III

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
Sweepback	
	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.

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

by

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

Following the publication of M.A.E.L. Report No. F/Res/240, in which the effects of forebody warp on stability and spray are considered, an addendum to Part 3 of this series (data report on Model A) has been issued. It contains results on Model A at a low weight, $C_{\Delta_0} = 2.25$, and this additional evidence is incorporated in the present addendum.

This addendum consists of four of the original figures modified by the addition of the extra curves. These figures, apart from one or two minor differences which it is felt are insufficient to warrant comment, further substantiate the conclusions already reached in F/Res/240.

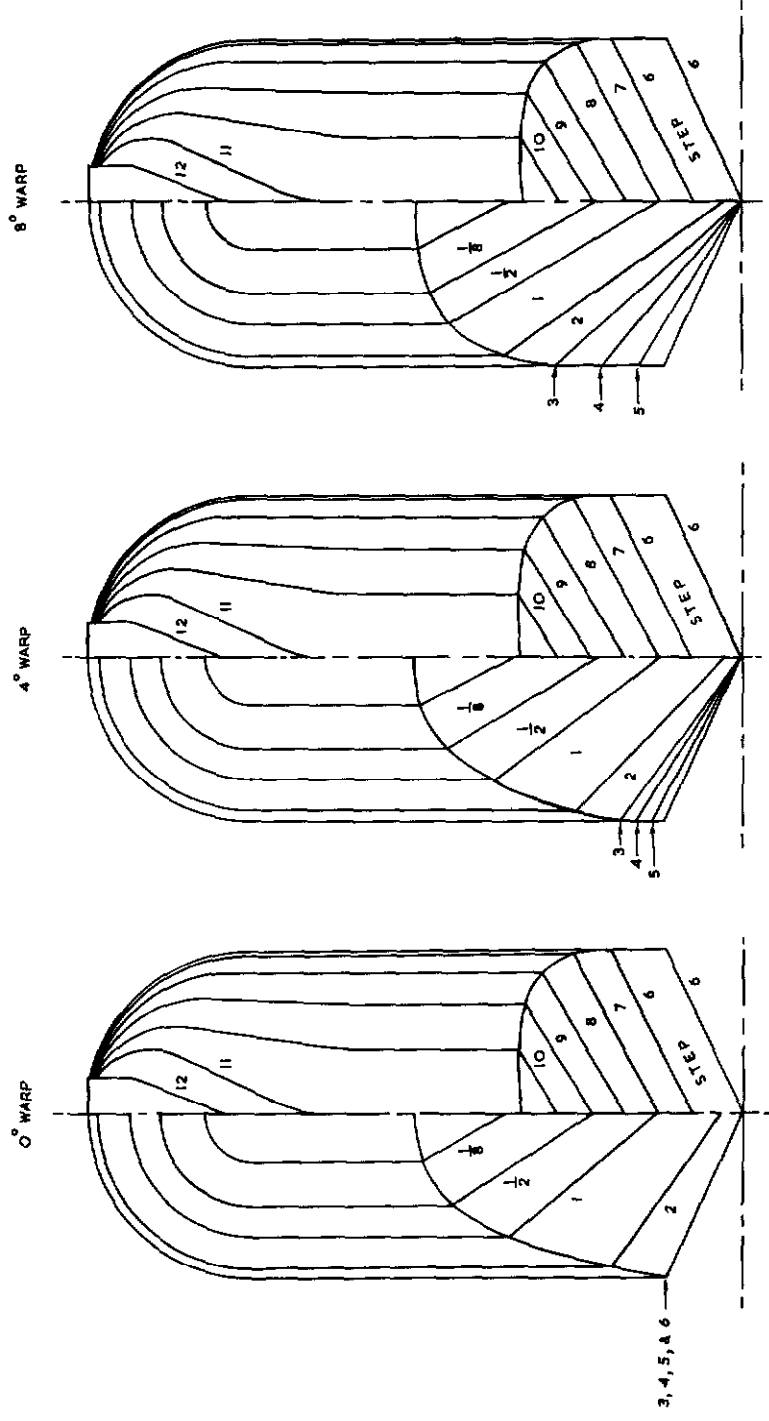
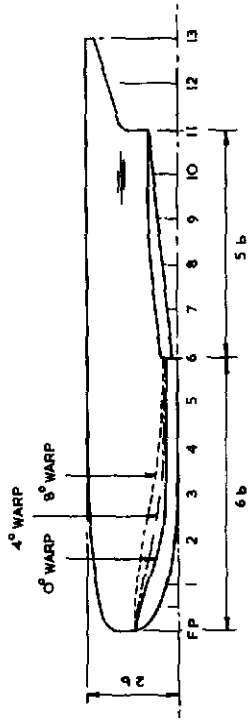
The titles of the figures are given below for convenience and are identical with the corresponding Figures of F/Res/240.

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Effect of forebody warp on stability limits, $C_{\Delta_0} = 2.25$	1
Effect of forebody warp on trim curves, $\eta = 0^\circ$	2
Effect of forebody warp on spray projections	3
Effect of forebody warp on elevator effectiveness	4

Note: Instead of reproducing these figures, the additional curves for Model A at $C_{\Delta_0} = 2.75$ have been incorporated in the corresponding original figures.

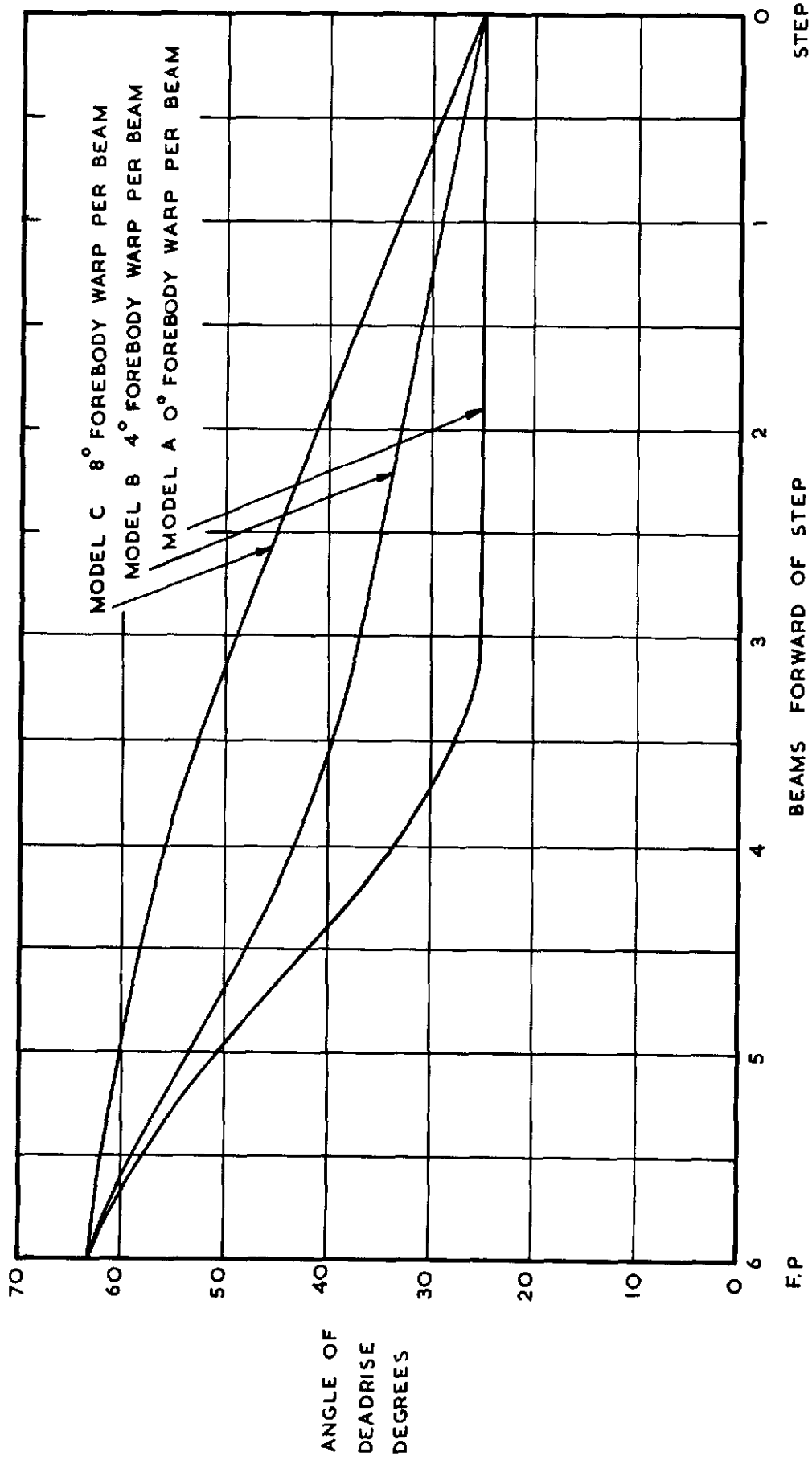
FIG. 1.



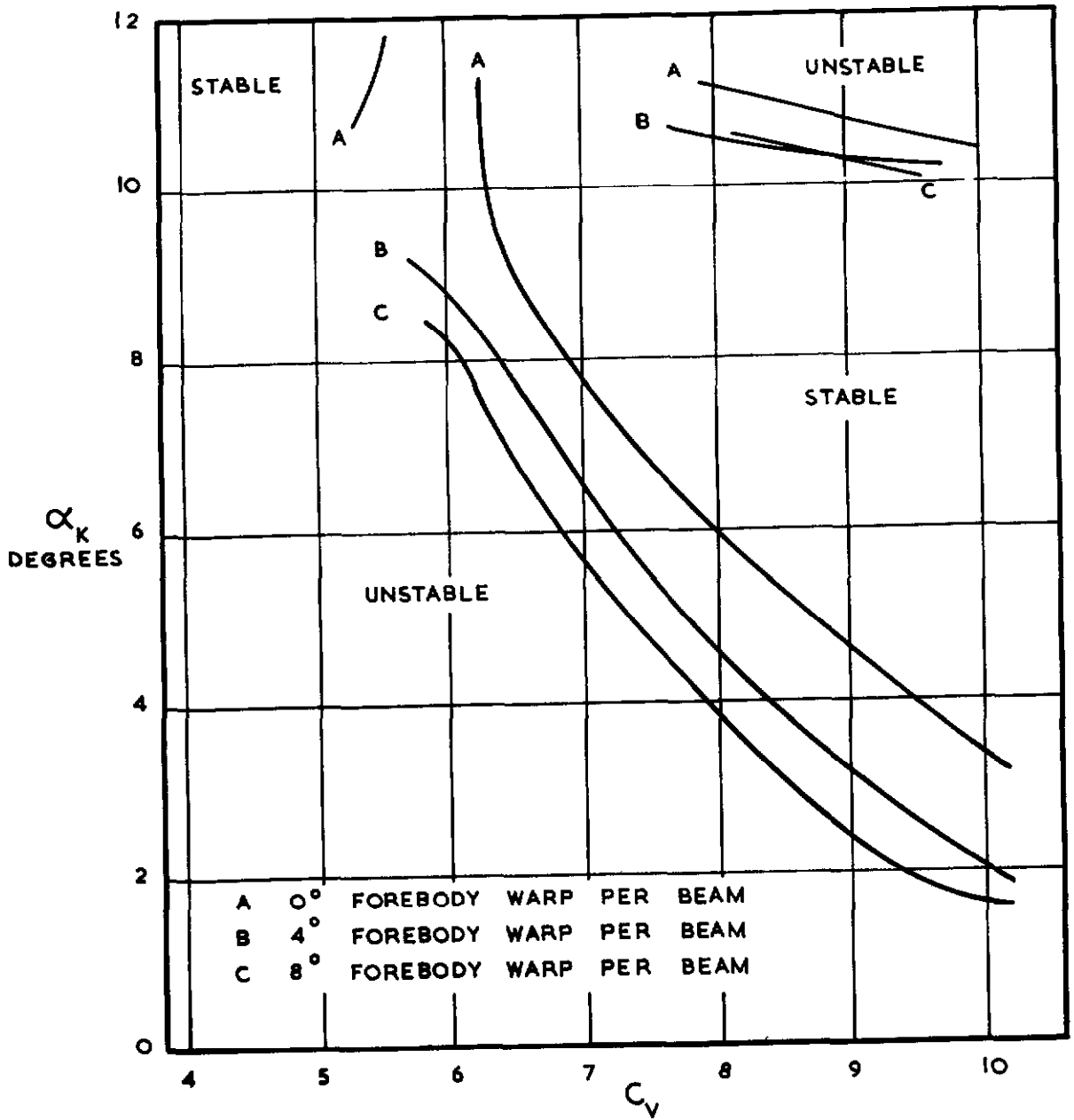
HALF MODEL SCALE

COMPARISON OF HULL LINES

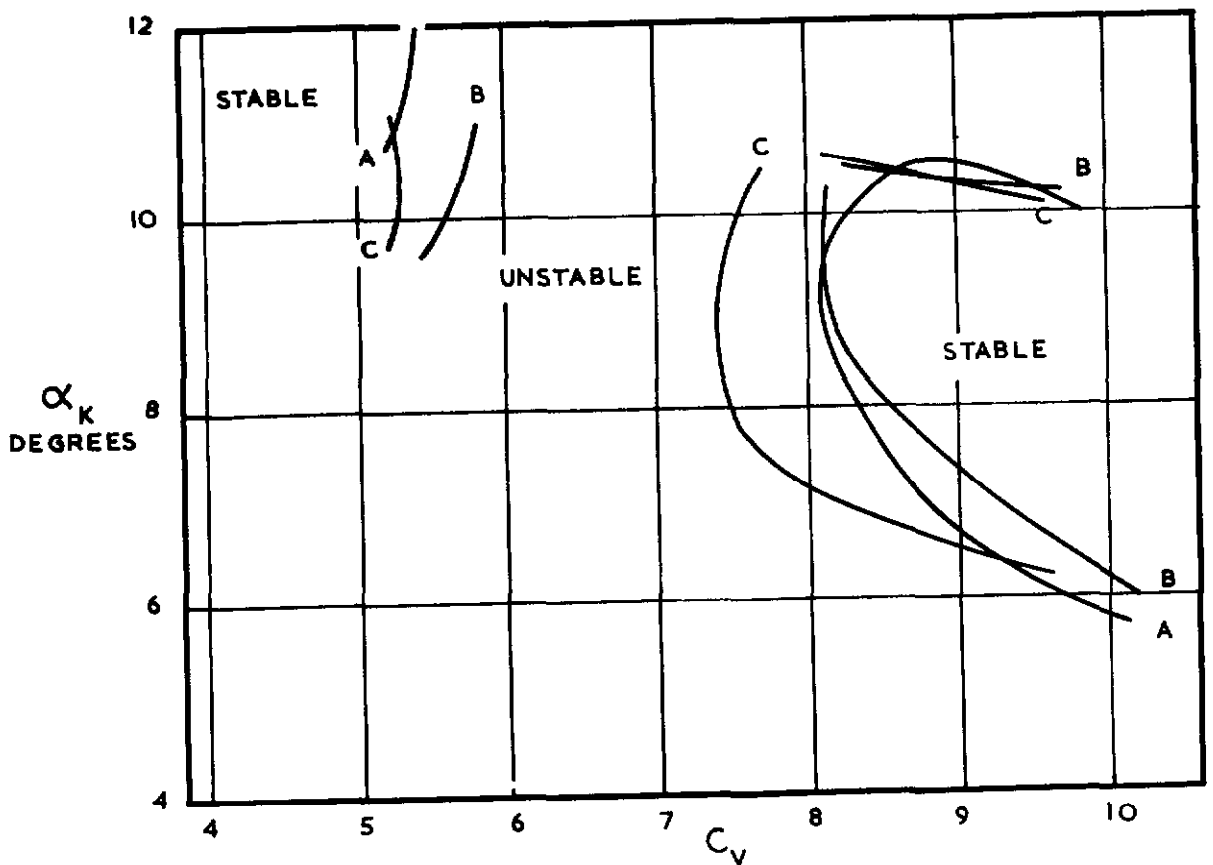
FIG. 2.



COMPARISON OF DEADRISE ANGLE DISTRIBUTIONS



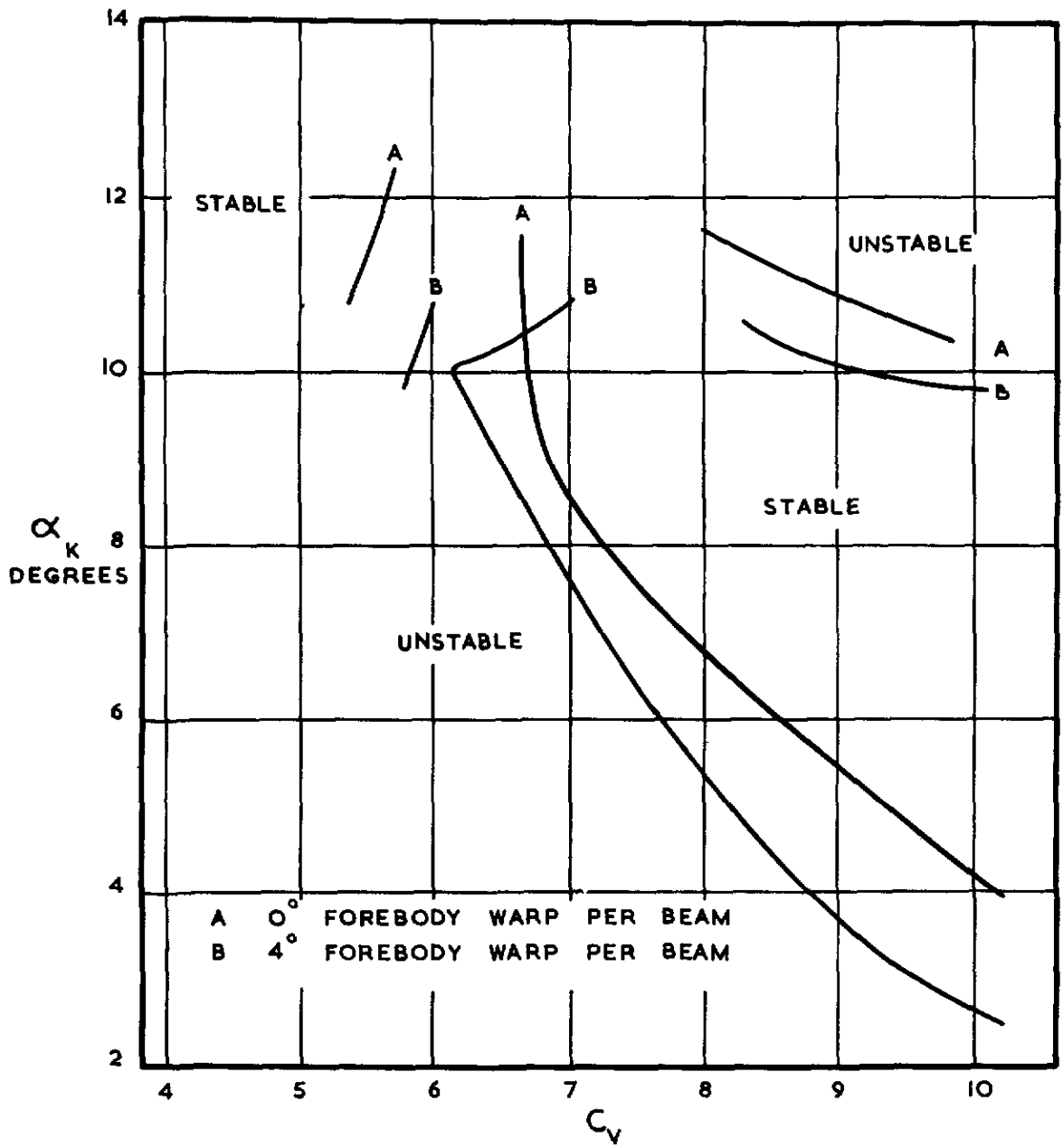
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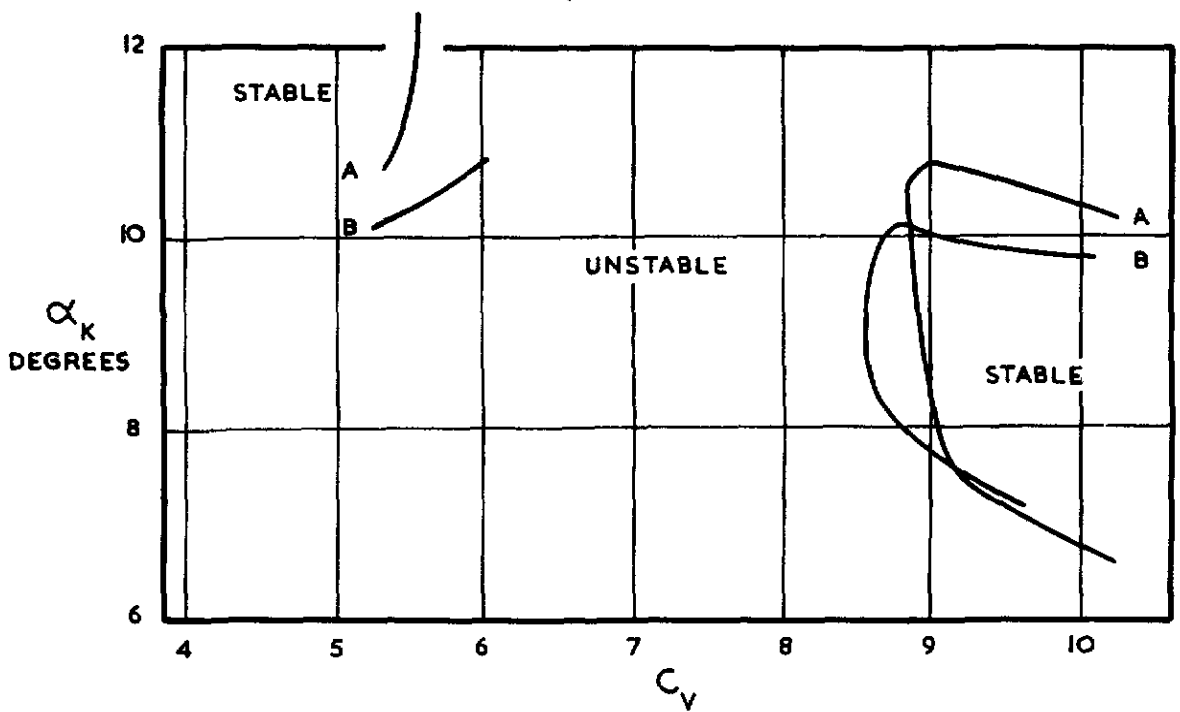
(b) DISTURBED

EFFECT OF FOREBODY WARP ON LONGITUDINAL STABILITY LIMITS
 $C_s = 2.75$

FIG. 4.



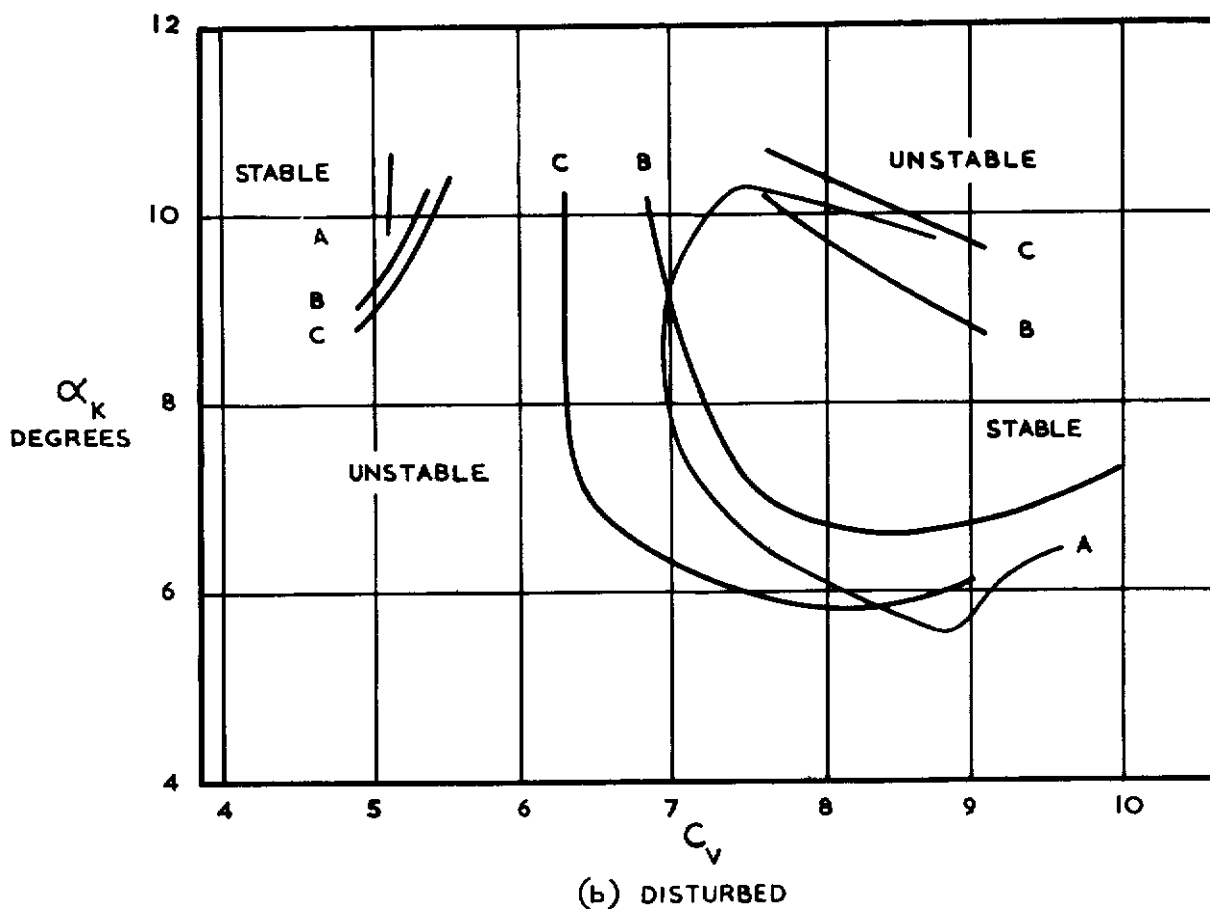
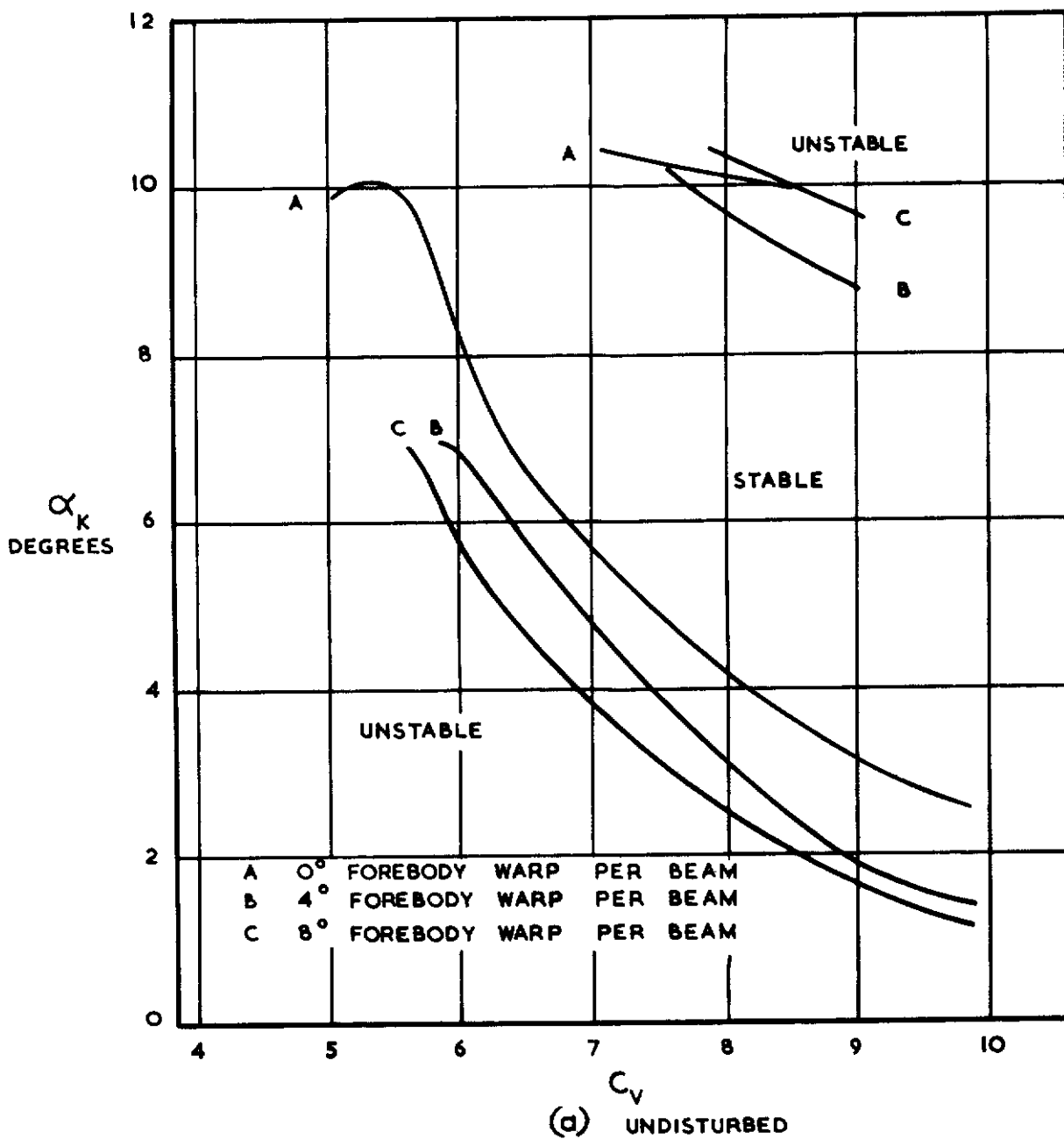
(a) UNDISTURBED



(b) DISTURBED

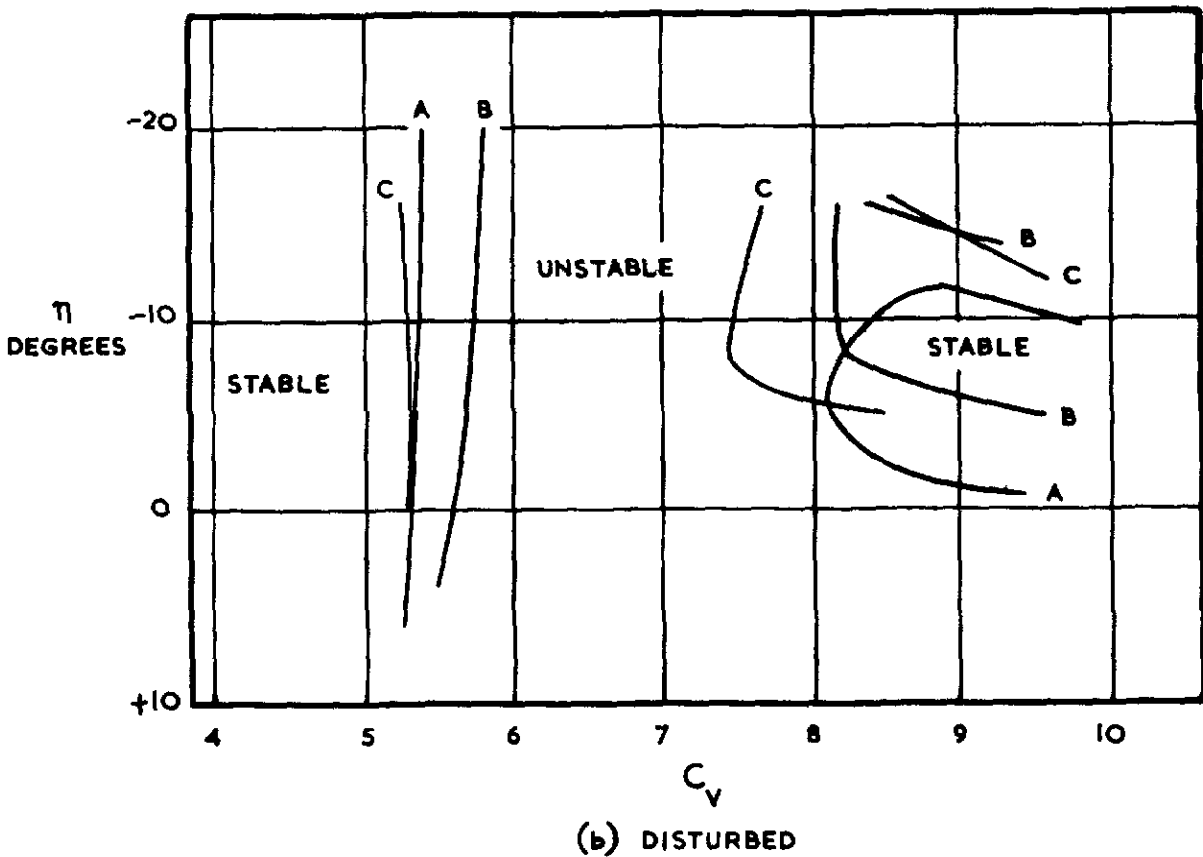
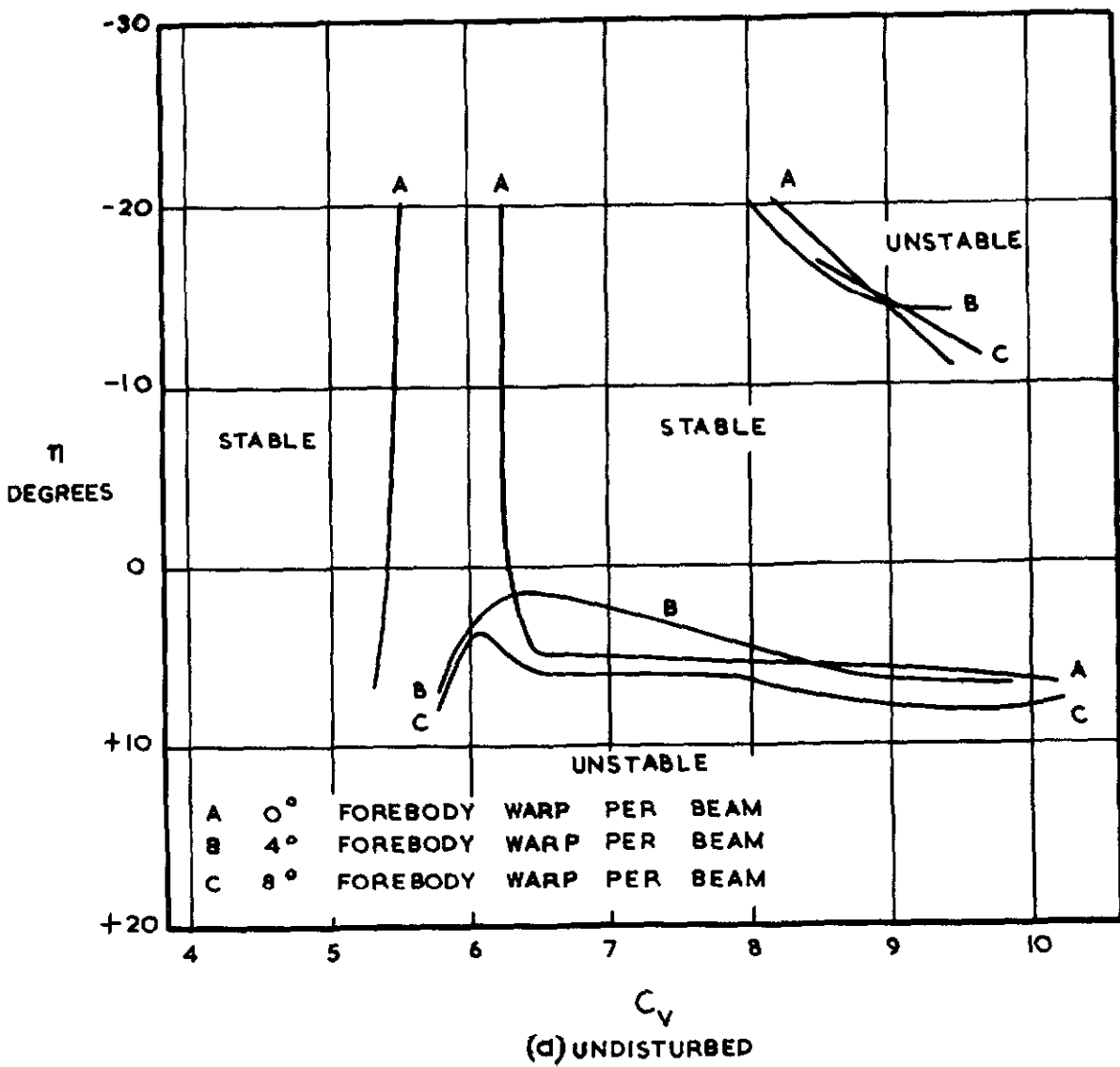
EFFECT OF FOREBODY WARP ON LONGITUDINAL STABILITY LIMITS

$$C_{\Delta_0} = 3.00$$



EFFECT OF FOREBODY WARP ON LONGITUDINAL STABILITY LIMITS
 $C_{\Delta_0} = 2.25$

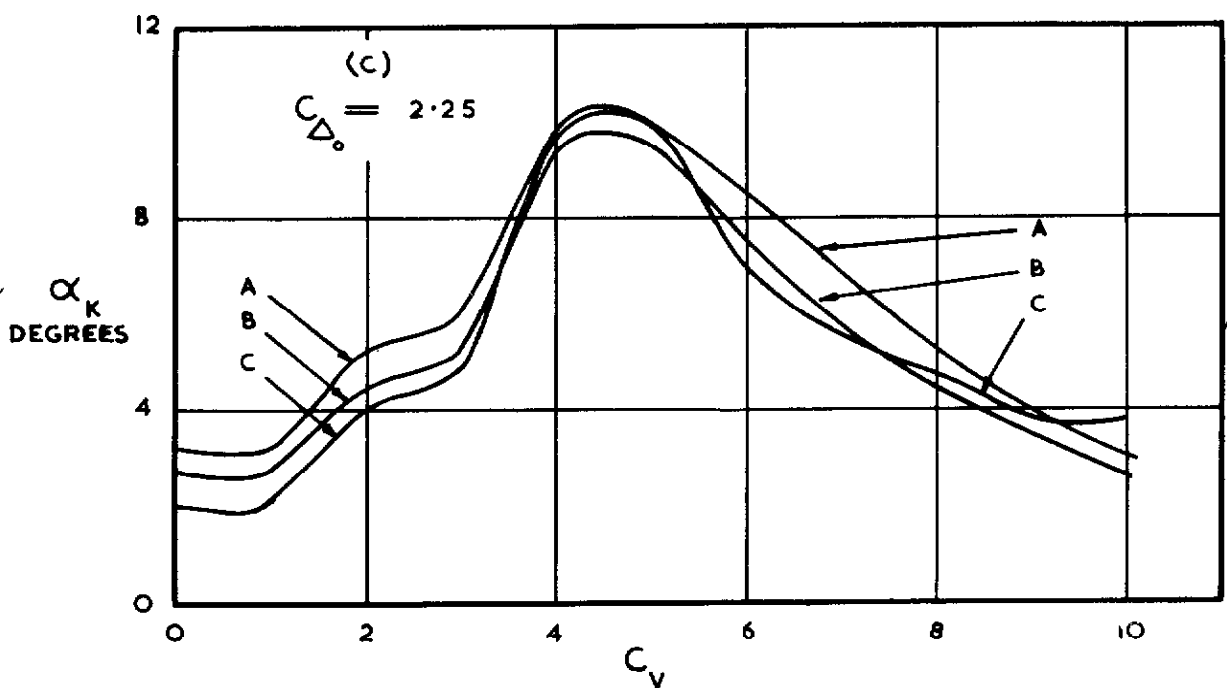
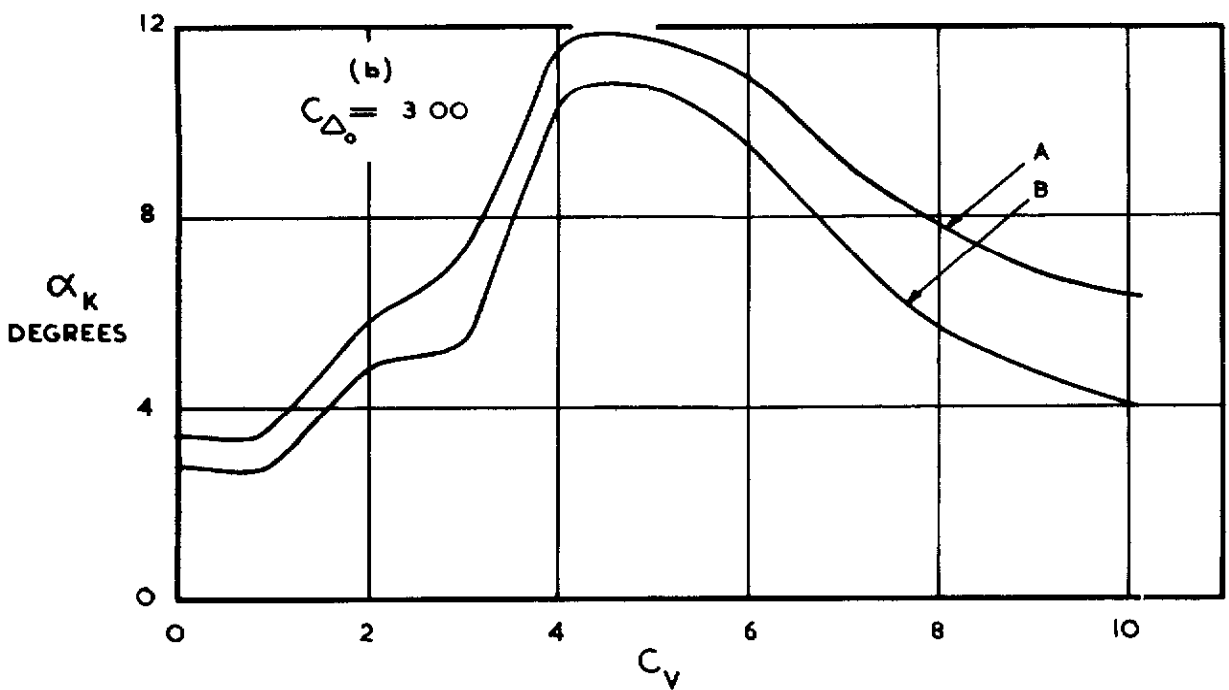
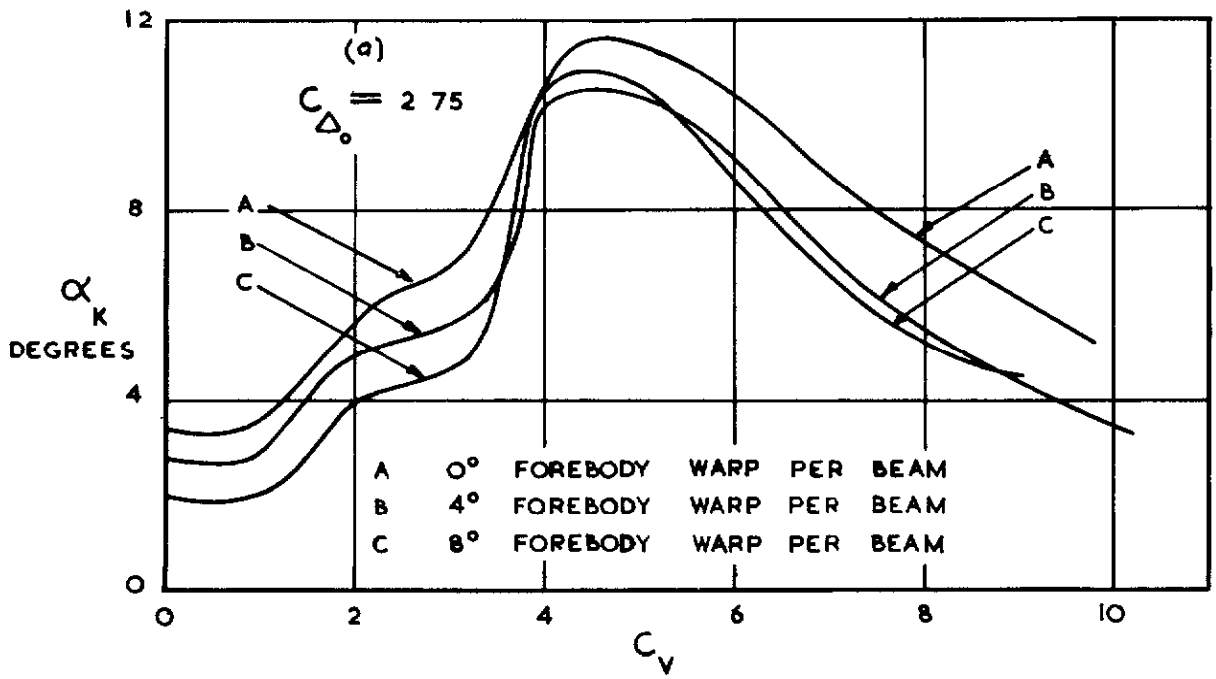
FIG. 6.



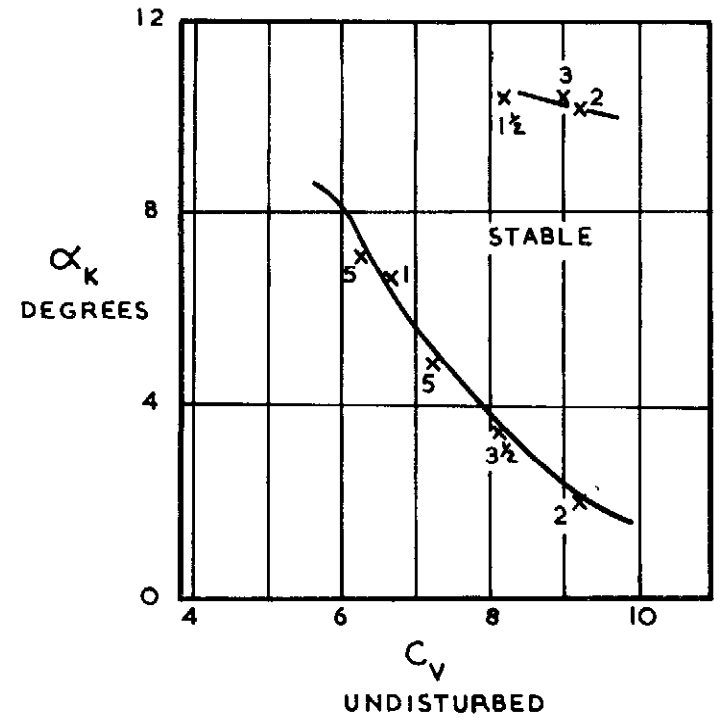
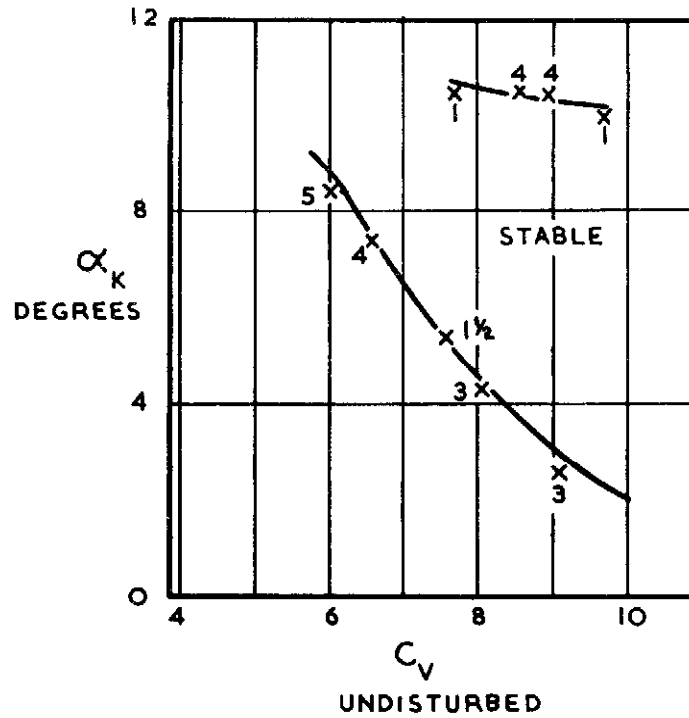
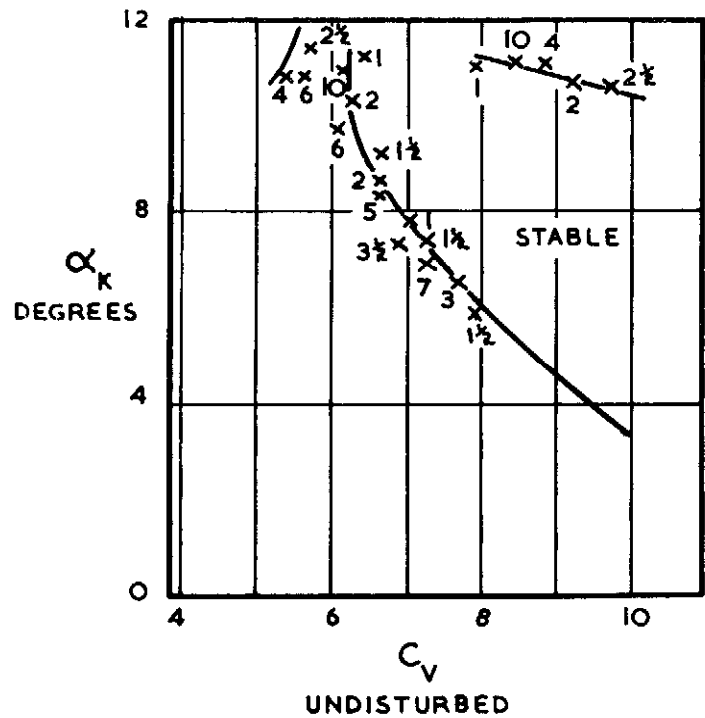
RELATION BETWEEN ELEVATOR SETTING AND STABILITY LIMITS

$$C_v = 2.75$$

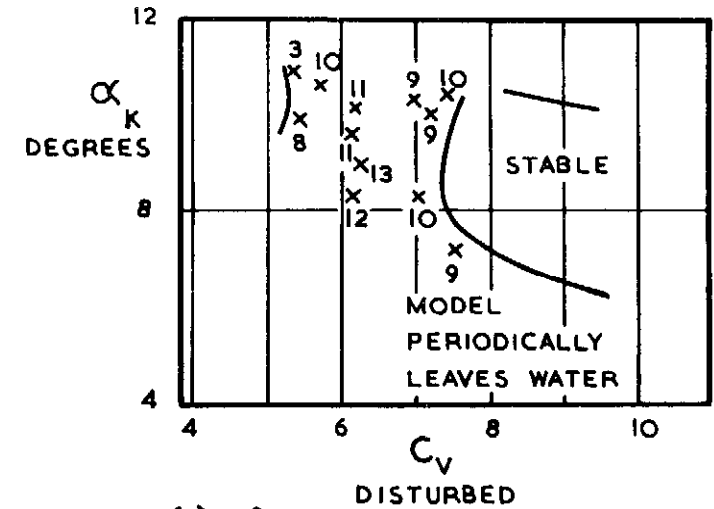
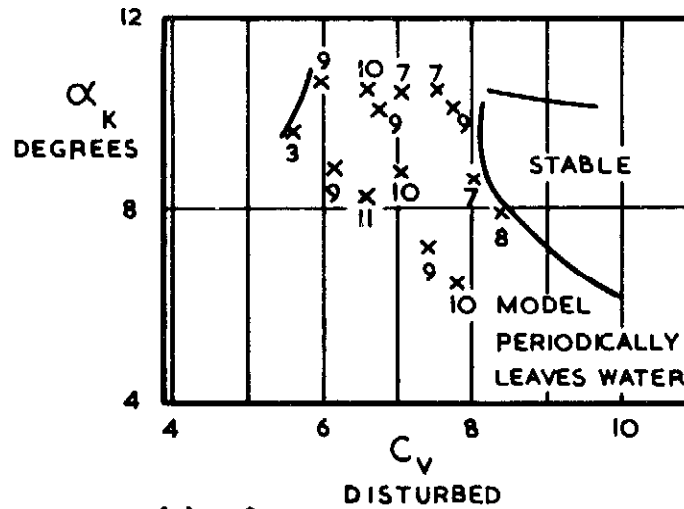
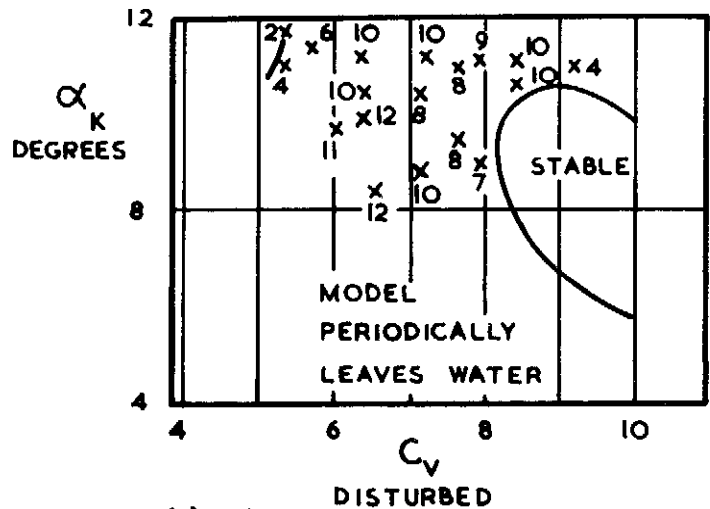
Δ_0



EFFECT OF FOREBODY WARP ON TRIM CURVES, $\eta = 0^\circ$



FIGURES INDICATE AMPLITUDES OF PORPOISING IN DEGREES



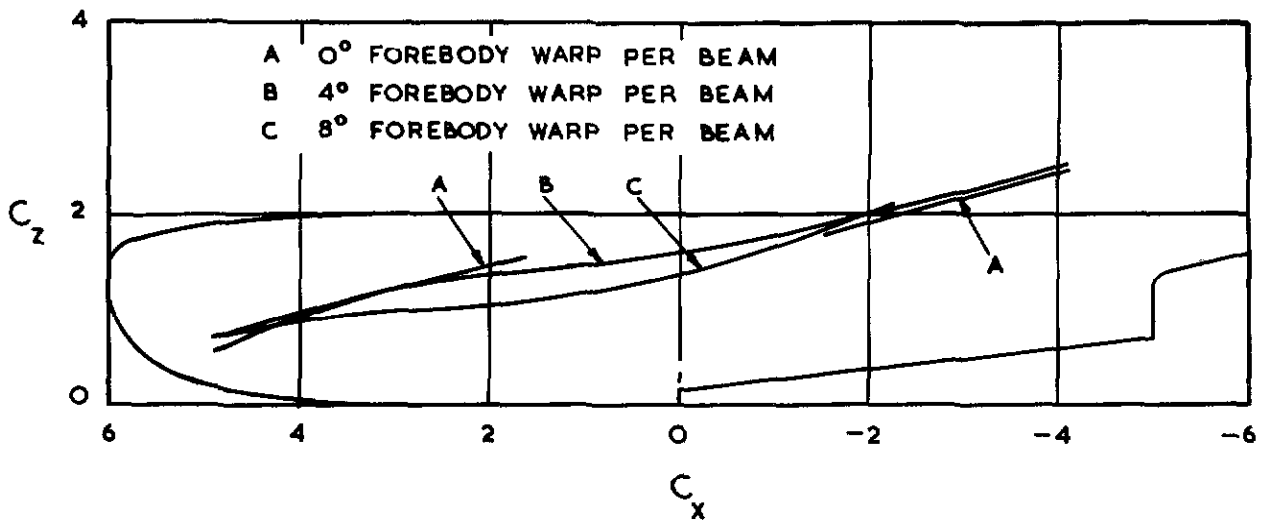
(a) 0° FOREBODY WARP PER BEAM

(b) 4° FOREBODY WARP PER BEAM

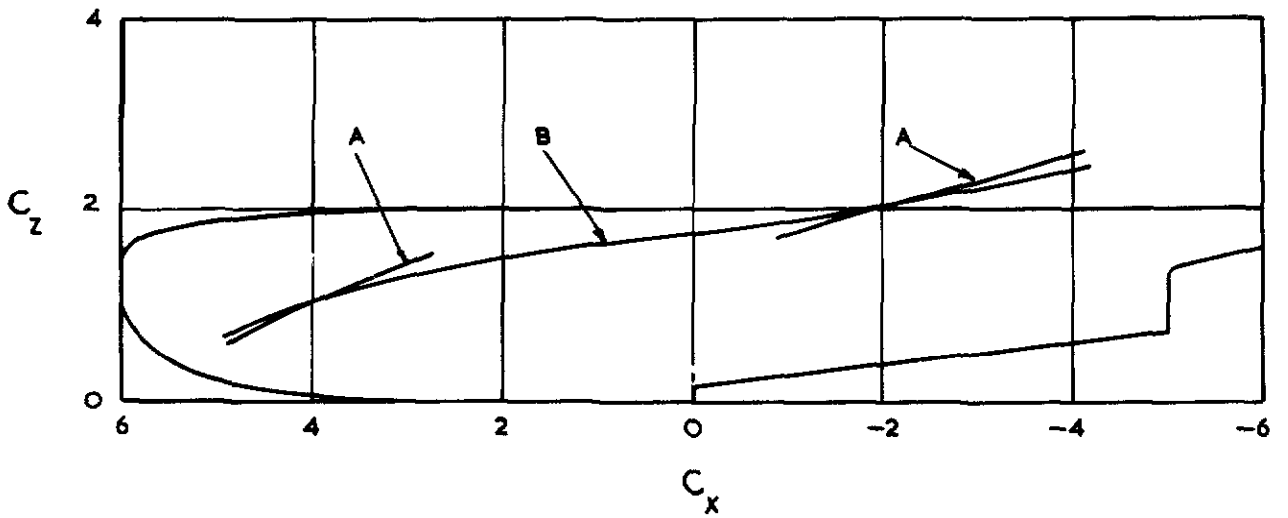
(c) 8° FOREBODY WARP PER BEAM

EFFECT OF FOREBODY WARP ON AMPLITUDES OF PORPOISING, $C_{\Delta} = 2.75$

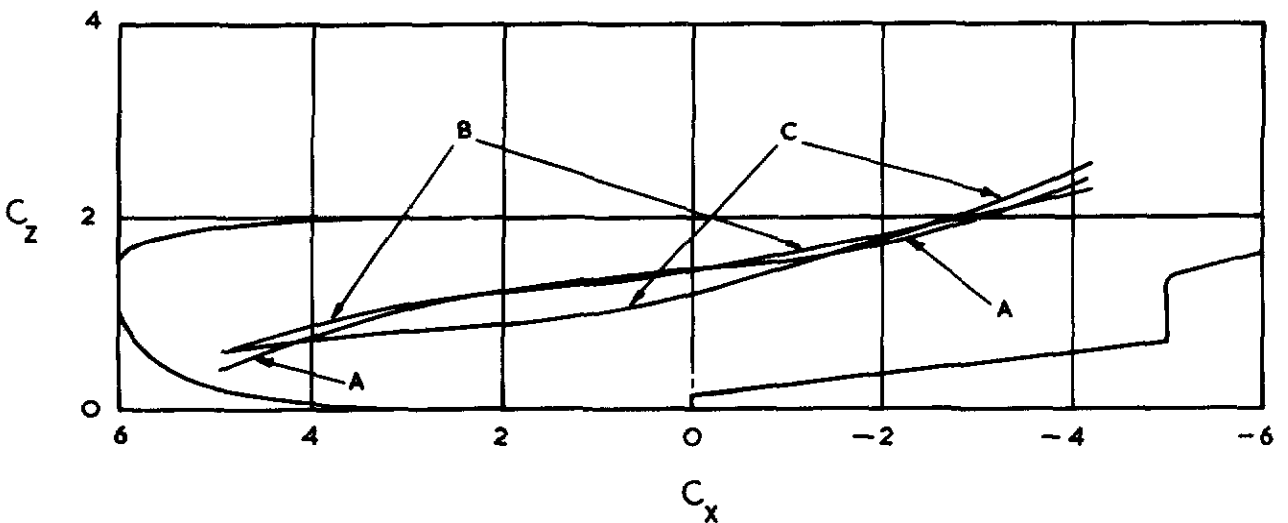
FIG. 9.



(a) $C_{D_0} = 2.75$

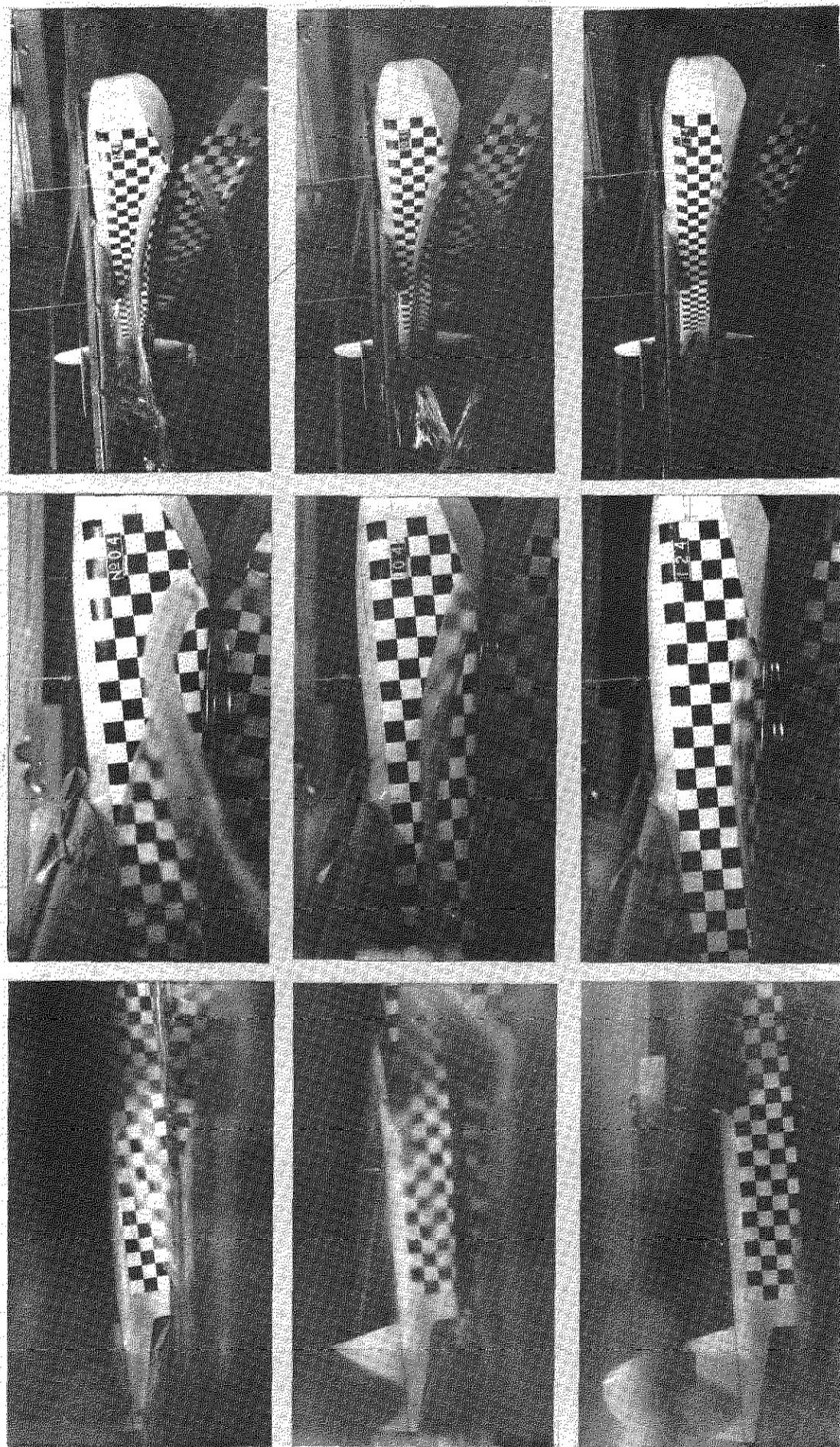


(b) $C_{D_0} = 3.00$



(c) $C_{D_0} = 2.25$

EFFECT OF FOREBODY WARP ON SPRAY PROJECTIONS



$\eta = -8^\circ$
 $C_V = 3.07$
 $\alpha_x = 6.9^\circ$

$\eta = -8^\circ$
 $C_V = 3.18$
 $\alpha_x = 5.7^\circ$

$\eta = -8^\circ$
 $C_V = 3.1$
 $\alpha_x = 4.7^\circ$

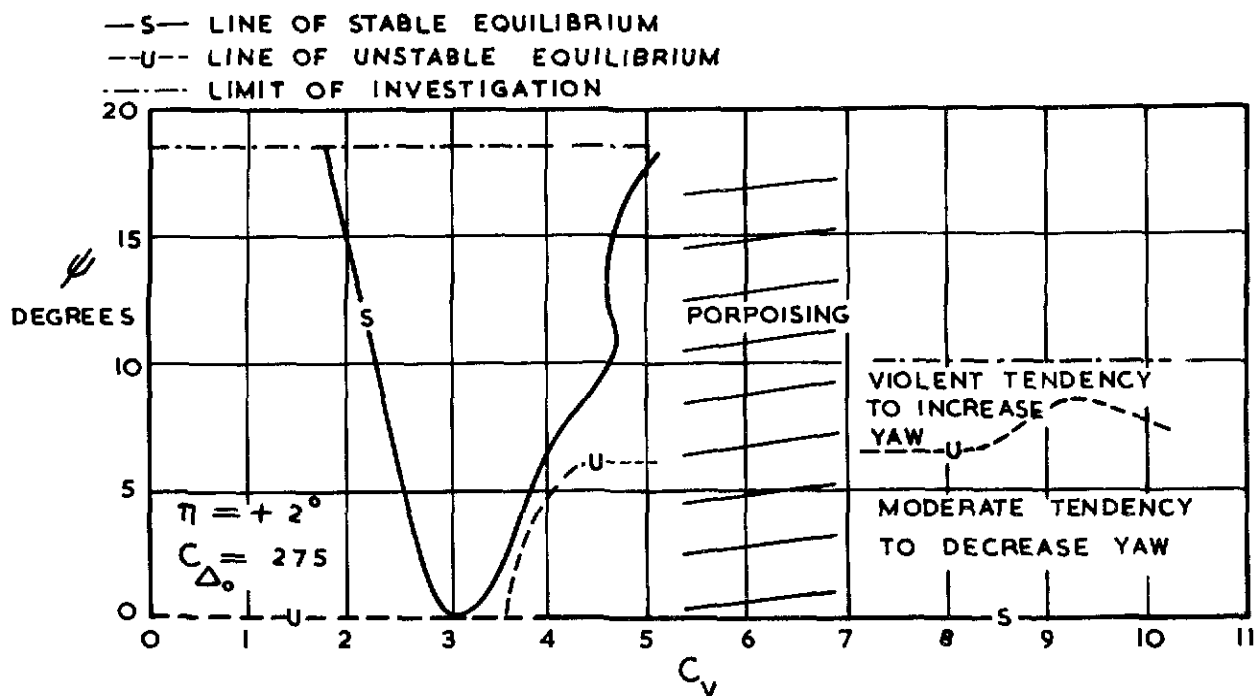
0° OF
 FOREBODY WARP

4° OF
 FOREBODY WARP

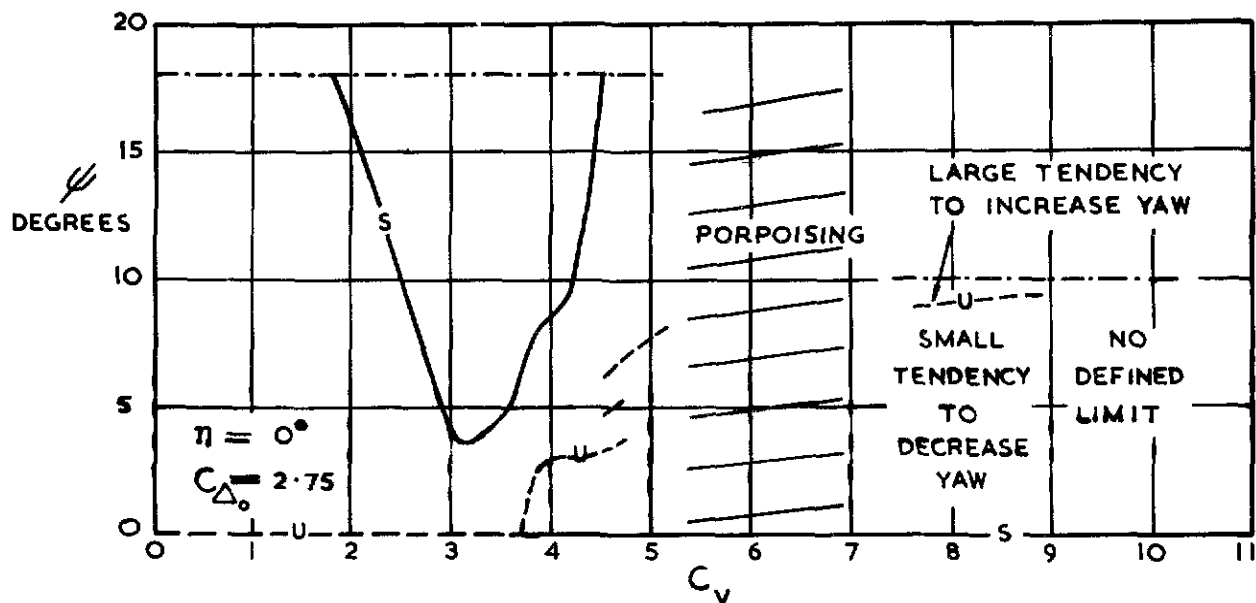
8° OF
 FOREBODY WARP

FIG. 10.

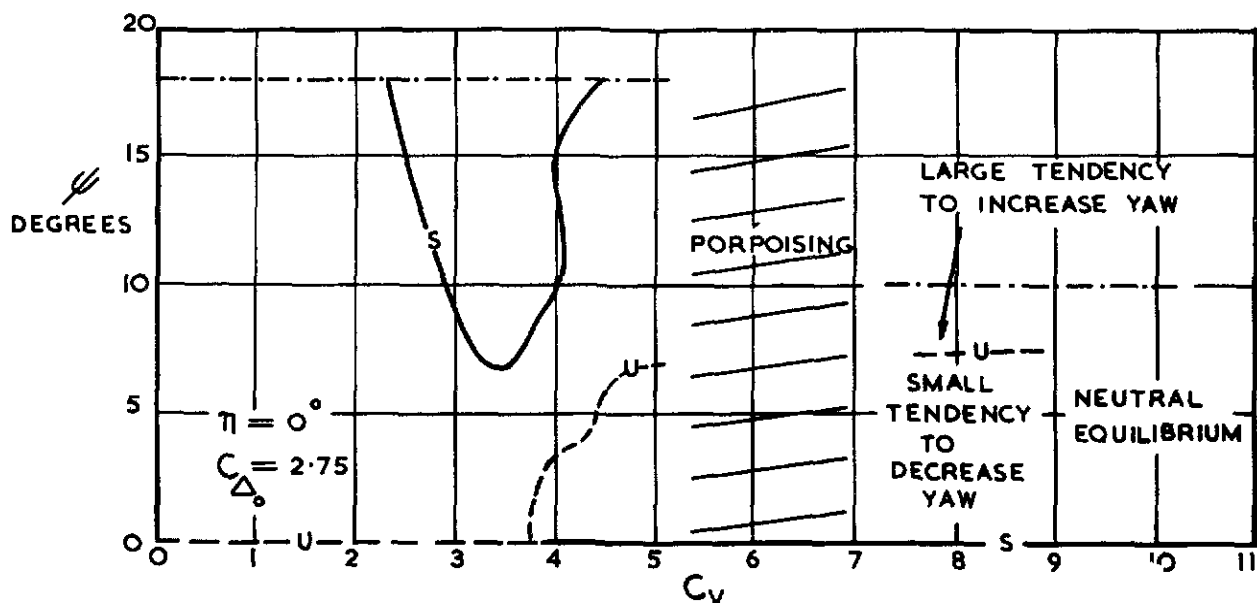
EFFECT OF FOREBODY WARP ON SPRAY, $C_{\Delta_0} = 2.75$.



(d) 0° FOREBODY WARP PER BEAM



(b) 4° FOREBODY WARP PER BEAM

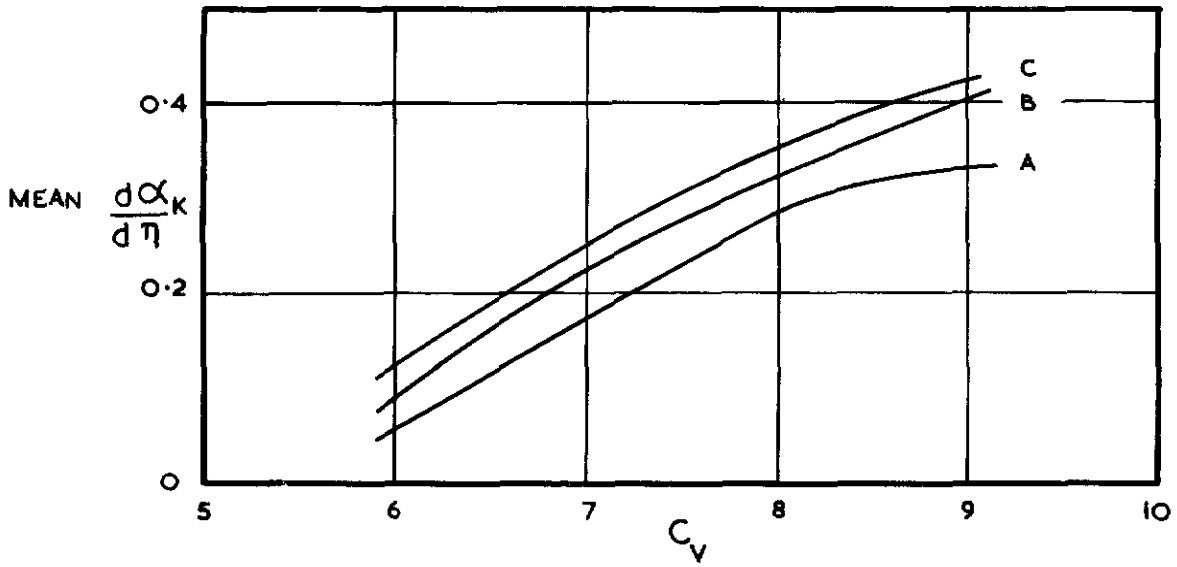


(c) 8° FOREBODY WARP PER BEAM

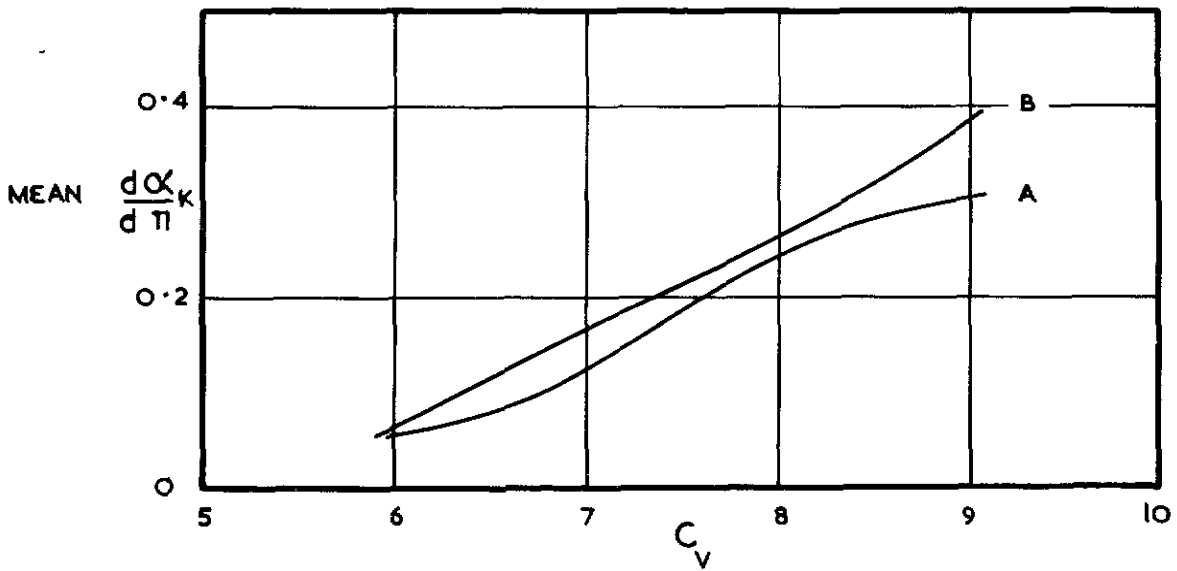
EFFECT OF FOREBODY WARP ON DIRECTIONAL STABILITY

FIG. 12.

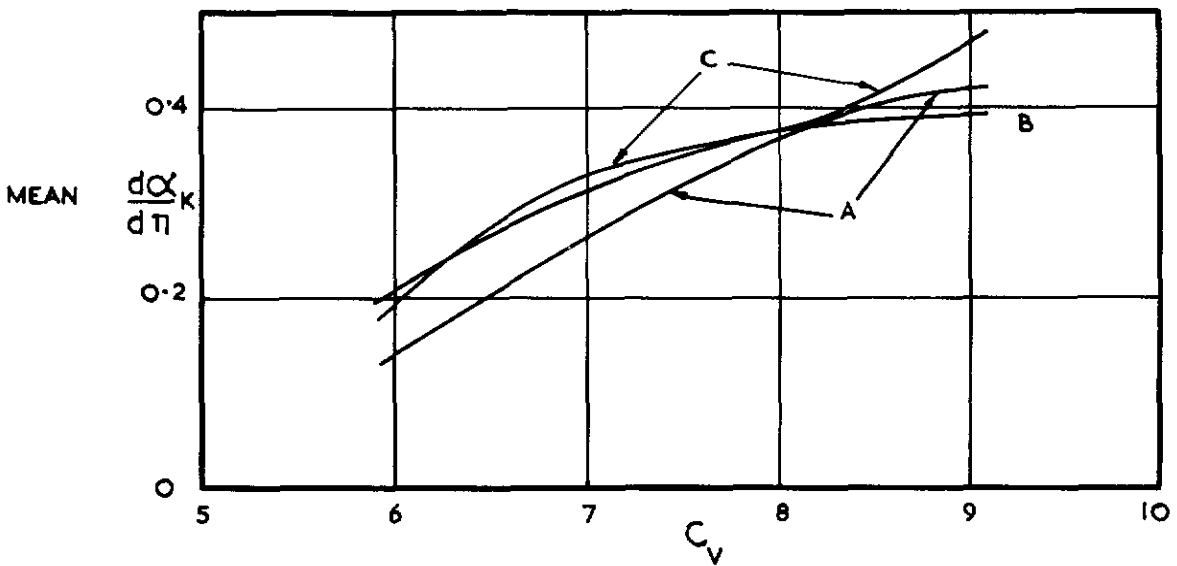
- A 0° FOREBODY WARP PER BEAM
- B 4° FOREBODY WARP PER BEAM
- C 8° FOREBODY WARP PER BEAM



(a) $C_{\Delta_0} = 2.75$



(b) $C_{\Delta_0} = 3.00$



(c) $C_{\Delta_0} = 2.25$

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