C.P. No. 352
(18,304)
A.R.C. Technical Report

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

Hydrodynamic Stability Part 19

The Interaction of the Effects of Forebody Warp, Afterbody Length and Afterbody Angle on Longitudinal Stability Characteristics

By

J. K. Friswell, B.Sc.

LONDON . HER MAJESTY'S STATIONERY OFFICE

1957

Price 6s 6d net

M.A.E.E. Report No. F/Res/255

September 1955

C.P. No. 352

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT, FELIXSTOWE, SUFFOLK

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

HYDRODYNAMIC STABILITY PART 19

THE INTERACTION OF THE EFFECTS OF FOREBODY WARP, AFTERBODY LENGTH AND AFTERBODY ANGLE ON LONGITUDINAL STABILITY CHARACTERISTICS

by

J. K. FRISWELL, B.Sc.

S U M M A R Y

In this report the interaction of the effects of the different parameters concerned in the investigation is considered. It is found that by a redefinition of stability it is possible to predict these interactions as far as the undisturbed lower limit is concerned, but that otherwise there seems to be no simple law governing them. Some broad generalisations are however possible.

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1. INTRODUCTION

In the earlier stages of the present investigation, the effects were examined of varying separately the parameters with which the investigation was primarily concerned, namely forebody warp, afterbody length and afterbody angle (References 1-13). Certain variations from the basic form were found to have beneficial effects on longitudinal stability characteristics and one might be inclined to assume that the most stable hull form which could be produced within the range of investigation would be that in which all the beneficial variations were made simultaneously. This is, however, by no means certain and there is very little evidence one way or the other from previous investigations. The question is closely linked with that as to whether or not the effect of varying any one hull parameter is independent of the values of the remaining parameters (within practical limits).

Accordingly it was decided to investigate the nature and extent of the interaction between the effects of the different parameters, with a view to developing a method of predicting the longitudinal stability characteristics of any given hull form from the known effects of varying the various parameters individually. If this could be done, then it would be simple to decide on an optimum hull form, within given ranges of the relevant parameters.

To this end three models were tested, for each of which the values of two of the fundamental parameters were varied simultaneously from those employed on the basic model of the series, and a fourth model was tested for which all the three parameters were varied simultaneously. The results of the individual tests on these models have already been reported (References 15-18), and in the present report the results are analysed and compared with those for the appropriate earlier models of the series.

2. DETAILS OF TESTS

The tank testing techniques employed in the various tests have already been described in detail in earlier reports of this series, and no further reference will be made to them here. It should, however, be mentioned that the tests performed on those models specially designed to give information on interaction were more limited in extent than those on the models of the main series. Longitudinal stability was only investigated at one value of the static beam loading coefficient, namely at $C_{\Delta_0} = 2.75$, and no directional stability tests were made. Spray and wake photographs were taken during the longitudinal stability tests, and photographs and spray profiles will be found in the appropriate model data reports. No analysis has however been made of the interaction of spray effects, as this was not considered to be of any great importance, though diagrams illustrating the interaction are included in the present report for reference purposes.

In selecting the variations from the basic form which were to be combined to produce the four "interaction" models already referred to, it was not felt desirable to use extreme values of the parameters concerned, as this could have led to a masking of the effects under consideration. Accordingly, the variations chosen were an increase of forebody warp from 0° to 4° per beam, an increase of afterbody length from 5 beams to 7 beams, and an increase in afterbody angle from 6° to 8°. Details of the geometry of the resulting models are given in Table I, in which table are also included details of the basic model and the three models of the main series which show the three variations separately. These are the eight models on which the analysis of the remainder of this report is based. Hull lines and other general details of the various models will be found in the appropriate model reports (References 3-18).

/ 3. ANALYSIS OF RESULTS

3. ANALYSIS OF RESULTS

The various models concerned fall naturally into four groups. Each of the first three groups consists of the basic model, two of the models in which only one parameter is varied in value from the basic model, and the "interaction" model, in which both the appropriate parameters are varied simultaneously. The fourth group consists of the four "interaction" models. For convenience in preparing the diagrams and ease of reading them, the results for the different groups have been plotted separately and the groups have been given index numbers, as follows.

Group I	Models A, B, E and L.
" II	" A, H, E and M.
" III	" A, B, H and K.
" IV	" K, L, M and N.

An incidental consequence of the tests on Models K to N is that they make possible the observation of the effects of varying each parameter separately at different fixed values of the remaining parameters from those in the main series of tests. Thus, for instance, variations of the amount of forebody warp in the main series were carried out with a 5 beam afterbody length and 6° afterbody angle, but by comparing the test results from Models H and K it is possible to determine the effect of a similar variation with an 8° instead of a 6° afterbody angle and, by comparing the results for Models E and L, that with a 7 beam instead of a 5 beam afterbody; similarly, Models M and N show the effect when the values of both subsidiary parameters differ from the corresponding ones in the main series. The extent to which comparisons of this kind confirm the evidence in References 6, 10 and 13 will be considered later in this report; the divisions of the models into groups is of less value for this purpose than in the direct determination of interaction effects, but it has been found convenient to retain the groupings and to derive the comparisons from the diagrams included to demonstrate the interaction effects.

3.1. Interaction effects

The undisturbed longitudinal stability limits for the various models on a C_v base, as obtained in the individual model tests, are plotted in Figure 1. It will be seen that, taking the limits as they stand, there is no simple connection between the positions of the limits in each group, except at the highest speeds in some cases. It is not for instance true in general that at a given speed the attitude difference between the limits for the basic model and an interaction model is the sum of the differences between the limits for the basic model and the two appropriate models of the main series. It is in fact true to a close enough extent for design purposes, where an accuracy of $\frac{1}{2}°$ or even 1° may be acceptable, but as the variations in limits encountered throughout the investigation have only been of the order of 1° it is clearly impossible to accept such a low level of accuracy for the present purpose.

In connection with this point some remarks should be made on the accuracy of the limits obtained for the various models. The experimental points defining the limits were determined to an accuracy of $C_V \pm 0.025$, $\alpha_K \pm 0.1°$, and enough points were obtained to make it reasonably certain that the resulting limits reached a similar standard of accuracy; this was achieved not only by regard to the positions of the actual test points but also by taking into consideration the amplitudes of porpoising at borderline and unstable points, and by maintaining the limits as smooth curves. Thus it should not be assumed that a sparsity of test points necessarily indicates

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possible local inaccuracies in the limits, though it is not of course claimed that there is no room for their modification.*

It is not however considered that permissible modifications can be made in such a manner as to yield simple relations between the limits, particularly as systematic rather than random alterations would be needed even to achieve limited results, and it is therefore necessary either to seek some law more complex than a direct addition law or to find some other method of plotting the existing undisturbed limits so that a simple law emerges.

The corresponding disturbed limits (Fig. 2) are even further removed from being related by a simple law than are the undisturbed ones. Here not only the positions but the nature of the limits vary in an apparently unpredictable way. It is possible only to draw very general conclusions, such as that if two beneficial hull variations are combined the result is better than that obtained from either variation by itself.

As replotting of the limits appears to be the more likely of the two approaches mentioned to lead to a useful result, the limits have first been transferred from the (α_K, C_V) to the (η, C_V) plane, Figures 3 and 4. This has been done for two reasons, firstly because it eliminates the differences between the mean running attitudes of the models, and secondly because it was noticed earlier in these tests (Ref. 2) that the lower stability limits occurred at about the same elevator settings in different cases. Unfortunately, although there is quite good agreement between the undisturbed lower limits at the higher speeds for a number of the models when plotted in this manner (notably Group I) the agreement is not universal, even allowing a generous margin for error because of the difficulty of interpolating accurately to determine elevator settings on the limits. At the lower speeds there is neither agreement nor systematic variation. The replotting does not add anything to the understanding of the variation of the disturbed limits.

Accordingly the limits have next (Figs. 5 and 6) been plotted in the $(\alpha_K, C_{\Delta}^{\frac{1}{2}}/C_V)$ plane, on a so-called "generalised" base. This method has been advocated by a number of authors, who assert that the undisturbed lower stability limits for a given hull at different weights will coincide or "collapse" when plotted in this way, since $C_{\Delta}^{\frac{1}{2}}/C_V$ is in effect the water load coefficient. Certain theoretical arguments have been put forward in support of this view, but are considered by the author of the present report to be unsound. Nevertheless experimental evidence shows the method to be fairly reliable in the absence of aerodynamic interference, and as the eight models which are being analysed here each have one of two forebody forms, it might be expected that the undisturbed lower limits for each forebody form would collapse onto one curve on the generalised base.

As will be seen, this does not in fact happen, there being relatively wide variations between the limits for different models. To examine the extent to which these variations can be eliminated by minor adjustments of the limits without amending the test points, the points defining the limits are plotted for the undisturbed case in Figure 7. It will be seen that in the planing region it is possible to draw a common limit for the models with 4° forebody warp in Groups I and III, but that otherwise it is virtually impossible to move the points within the limits of experimental error ($C_{\Delta}^{\frac{1}{2}}/C_V \pm 0.001$, $\alpha_K \pm 0.1^{\circ}$) in such a manner as to leave one distinct limit through all the points for one forebody form.

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* These remarks pertain more particularly to the lower than to the upper limits. Two of the interaction models possess no upper limits, within the range of investigation, and upper limits by their nature are in any event difficult to determine accurately, so that it is wiser not to draw direct conclusions from their positions, their main value being as a general guide.

The location of points denoted "borderline" points, with amplitudes of porpoising between 0° and 2°, is a crucial factor here. In tank testing it is conventional to define the stability limit as lying through points at which the porpoising (double) amplitude is 2°. This is however to some extent an arbitrary definition, being based on full-scale handling requirements. If defining the limit on a purely scientific basis one would normally classify all points at which porpoising occurred, of whatever amplitude, as unstable, and similarly exclude from the stable region points giving oscillations purely in heave. If such a definition is applied in the present case the result is as shown in Figures 8 and 9.

It is now possible to insert a common undisturbed lower limit in the planing region (between $C_{\Delta}^{\frac{1}{2}}/C_V = 0.10$ and 0.20 approximately) for each set of models with one forebody form, leaving only one or two points in each set on the wrong side of the limit; some points designated stable must be expected to be on the unstable side of the new limit as points with very small porpoising amplitudes would probably have been classed as stable during the tests, and aerodynamic interference could well account for some of the other discrepancies. The collapse is considered very good, particularly in view of the fact that the limits have had to be drawn on the basis of test data collected for another purpose. That collapse on the same basis could be obtained over an even wider range is illustrated by Figure 8C, where the test points defining the undisturbed lower limits for all the models with 4° forebody warp over a range of loads from $C_{\Delta 0} = 2.00$ to 3.00 are plotted together, using the new definition of stability. The common limit inserted on this figure is that used for the same models in Figures 8A and 8B. Only 4 of the 90 points are further on the wrong side of the limit than would be accounted for by experimental error of the magnitude already laid down, and they are all points at which there might have been porpoising of very small amplitude in the tests, as already remarked. Taken together, the results are felt to be conclusive, as far as the present investigation is concerned, and it would be of great interest to know whether the same method would be effective with a completely different form of hull.

In the case of the undisturbed upper limits it would be possible in several instances to draw common limits for two or more models, but this would be due rather to the scarcity of test points than to any real collapse. Accordingly the upper limits have been drawn as fairly as possible between what test points are available and no attempt has been made to combine them. As with the lower limits there are probably test points classed as stable which would be unstable by the new definition, particularly those with very small oscillations in heave only, and because of these considerations and of the inaccuracies in upper limits generally it is felt that no conclusions should be drawn from the redefined upper limits.

In the disturbed case the redefinition makes little significant difference, except that there is now a region of mid-planing instability for model H. Again some difficulty has been experienced in inserting the redefined limits accurately, because of the sparsity of test points in appropriate regions.

The success in collapsing undisturbed lower limits on a $C_{\Delta}^{\frac{1}{2}}/C_V$ base by a redefinition of stability leads one to consider whether a similar collapse would be possible on the original C_V base. Accordingly the limits of Figures 8 and 9 have been transposed to a C_V base and are plotted in Figures 10 and 11. It will be seen that there is an almost perfect collapse of the appropriate undisturbed lower limits in the planing region and again there is no apparent systematic variation of the upper or disturbed limits. Whether the C_V or $C_{\Delta}^{\frac{1}{2}}/C_V$ base would be the more convenient in any particular series of tests where no change in wing form was involved would depend on circumstances, and in particular on whether the tests involved determining the limits for any model at more than one load.

/ Finally,

Finally, the redefined limits have been plotted in Figures 12 and 13 against elevator setting. The agreement here is if anything worse than with the original definition, in both the disturbed and undisturbed cases.

It appears, then, that it is only possible to predict the interaction of the effects of the parameters under consideration as far as the undisturbed lower limit is concerned. Here, if stability is defined in a strictly mathematical sense, the position of the limit is determined entirely by the amount of forebody warp and is independent of afterbody length and angle. The remainder of the undisturbed limit and the whole of the disturbed limit seem to be governed by no simple law or working rule, and while, particularly in the disturbed case, it appears that the combination of two hull variations separately beneficial gives an even better overall result, there is no reason to suppose that this is generally true.

3.2. Range of validity of earlier results

As already observed, the results collected and compared in the present report can be used to examine the effects of varying each of the parameters concerned in the investigation at different fixed values of the remaining parameters from those in the main series of tests, and in this way it can be seen whether the conclusions of Refs. 6, 10 and 13 are generally applicable within the series or are more restricted. As tests were only made on Models K, L, M and N at $C_{\Delta_0} = 2.75$ no check on load effects is possible, but most of the other important factors can be investigated. Only the main conclusions of the earlier tests will be considered, as if no limitation were observed possible comparisons would be endless.

For each pair of models in the main series showing a particular hull variation, there are three other pairs of models, each containing at least one of the interaction models, also showing that variation, as follows:

(i) increase of forebody warp from 0° to 4°

Models	Afterbody length	Afterbody angle
A - B	5 beams	6° (main series)
E - L	7 "	6°
H - K	5 "	8°
M - N	7 "	8°

(ii) increase of afterbody length from 5 to 7 beams

Models	Forebody warp	Afterbody angle
A - E	0	6° (main series)
B - L	4° per beam	6°
H - M	0	8°
K - N	4° per beam	8°

(iii) increase of afterbody angle from 6° to 8°

Models	Forebody warp	Afterbody length
A - H	0	5 beams (main series)
B - K	4° per beam	5 "
E - M	0	7 "
L - N	4° per beam	7 "

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The effects of increasing forebody warp from 0 to 4^{o} per beam will be considered first. Those principally remarked on in Reference 6 which can be checked here were

(a) to lower the undisturbed lower limit on a C_V base by about 1.3^{o}.

(b) to lower the undisturbed upper limit on a C_V base by half a degree.

(c) to leave the disturbed limits almost unchanged.

(d) to reduce trim generally.

(e) to improve spray characteristics.

(f) to increase mean elevator effectiveness by about 0.045.

The lowering of the undisturbed lower limit is maintained with the other three relevant pairs of models (Fig. 1) but the magnitude of the change varies considerably, from over 2^{o} at some speeds between Models E and L and between H and K, to 0.2^{o} between M and N. Use of the redefined limits of Figure 10 removes this discrepancy, except that the limits for Models M and N coincide near the hump. Models K and L have no undisturbed upper limits within the range of investigation, so that only M and N are available for comparison in this case. The upper limits for these models coincide, and while they separate a little when redefined they do not do so sufficiently to reproduce the separation of the limits for Models A and B. The disturbed limits are not left unchanged in any of the three check cases, there being significant improvements in disturbed stability in all three, as can be seen clearly in Figure 2. (A similar effect was found when increasing warp from 4^{o} to 8^{o} per beam in the main series).

The remaining three effects are in general maintained with the other pairs of models (Figures 14-16), though the amounts of the changes vary appreciably from case to case. One exception is that elevator effectiveness is reduced by about 0.03 from Model M to N, though there are increases of 0.075 and 0.05 between Models E and L and between H and K respectively.

The corresponding effects of increasing afterbody length from 5 to 7 beams were found in Reference 10 to be

(a) to decrease maximum lower critical trim but otherwise to leave the undisturbed lower limit on a C_V base substantially unaltered.

(b) to lower the undisturbed upper limit on a C_V base and increase the mean speed at which upper limit instability is encountered, the net effect being to decrease the extent of the upper unstable region.

(c) to improve disturbed stability, principally by reducing the width of the unstable band in the mid-planing region.

(d) to reduce trim in the displacement region and increase hump speed.

(e) to cause spray characteristics to deteriorate.

(f) to reduce elevator effectiveness.

Neither the decrease in maximum lower critical trim nor the invariance of the undisturbed lower limit on a C_V base are found with all the other three appropriate pairs of models. Only between models B and L is there any significant reduction of maximum lower critical trim and between K and N there is actually an increase of 2^{o} (Figure 1). Similarly, while the lower

/ limits

limits for Models B and L coincide over part of their length, those for H and M are separated by about 0.7° and those for K and N by up to 2°. Here again, if the redefined limits of Figure 10 are used most of the lower limit discrepancies are resolved, but the limit for Model N is still considerably higher than that of Model K in the hump region.

The lowering of the undisturbed upper limit is maintained between Models H and M, the only pair which can be compared with A and E in the absence of upper limits for K and L, but there is now no increase in the mean speed at which upper limit instability is encountered. (The absence of the upper limits for K and L could in effect mean of course that the lowest speed, and hence the mean speed, in these cases is greater than that corresponding to $C_v = 10$, but it could equally well be that the limits occur at attitudes greater than 12°).

The improvement in disturbed stability is found with all the additional pairs of models in this set, and is in fact greater than that found in the main series, there being no necks of instability with any of Models L, M and N using the original stability definition, though one appears for Model M on the redefined basis.

All the remaining effects are reproduced completely by all pairs of models, except that the elevator effectiveness of Model M is greater than that of Model H.

Finally, the effects of increasing afterbody angle from 6° to 8° may be considered. These were (Reference 13)

(a) to raise the undisturbed upper limit on a C_v base considerably.

(b) to leave the undisturbed lower limit on a C_v base substantially unaltered.

(c) to improve disturbed stability characteristics.

(d) to increase trim in the displacement region.

(e) to give an overall improvement in spray characteristics.

(f) to leave elevator effectiveness unaltered.

As in the previous cases, it is only possible to achieve consistency between the various pairs of models as regards the undisturbed lower limit by using the redefined limits of Figure 10, as the original limits for Models E and M and for L and N are quite widely separated. Such upper limits as there are, however, confirm the tendency found in the main series on either basis. Disturbed stability also is improved by the change for all pairs of models, though it is a little difficult to compare the limits for Models L and N because of the attitude difference between them.

Trim and spray changes are likewise of the same nature for all pairs of models. Elevator effectiveness, on the other hand, does not vary consistently, that for Model M being about twice the corresponding figure for Model E, but there being little separation between the other pairs of models.

It appears, taking all three sets of results together, that only on a broad basis are the conclusions from the main series of tests generally applicable when the primary form used as a basis for variations differs from the basic model of the main series. Quite a number of exceptions to individual conclusions can be obtained by judicious choice of values of the various parameters, and while those relating to the undisturbed lower limit can in the main be removed by the adoption of the amended definition of stability advocated in section 3.1., enough exceptions remain elsewhere to make detailed prediction of the changes due to a particular hull variation hazardous.

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Fortunately the exceptions are usually not contradictions of other results but merely absences of particular effects, so that most broad conclusions, for example that disturbed stability characteristics are improved by some chosen variation, are still valid. Generally speaking, it is in connection with the undisturbed upper limit and with elevator effectiveness that the greatest care must be exercised.

4. CONCLUSIONS

The analysis shows that it is only possible to predict the interaction of the effects of the parameters under consideration as far as the undisturbed lower stability limit is concerned. Here, if stability is defined in a strictly mathematical sense instead of as at present, the position of the limit is determined entirely by the amount of forebody warp and is independent of afterbody length and angle. The remainder of the undisturbed limit and the whole of the disturbed limit seem to be governed by no simple law, though some overall generalisations are possible within the present investigation and in particular it seems generally advantageous to combine hull variations which have been found beneficial individually. This tendency should however be checked with a radically different parent form before it is taken to be generally applicable.

As a consequence of this a number of conclusions reached earlier in the tests as to the effects of various hull variations are subject to restrictions when applied to similar variations on different basic forms, and it is in general not possible to enumerate all the detailed effects (particularly quantitative effects) of any such modification regardless of the parent form, even with a closely related family of hulls of the type employed in the present tests.

Taken in conjunction, the results indicate that generalisations can be made only on the broad effects of a particular variation as applied to different hull forms, and that detailed conclusions based on any one form can be misleading, except possibly in relation to an undisturbed lower stability limit mathematically defined.

The selection of an optimum hull form within a given set of variations would therefore be a matter of predicting from available test results what the best general type of hull would be, and improving on this shape by experiment.

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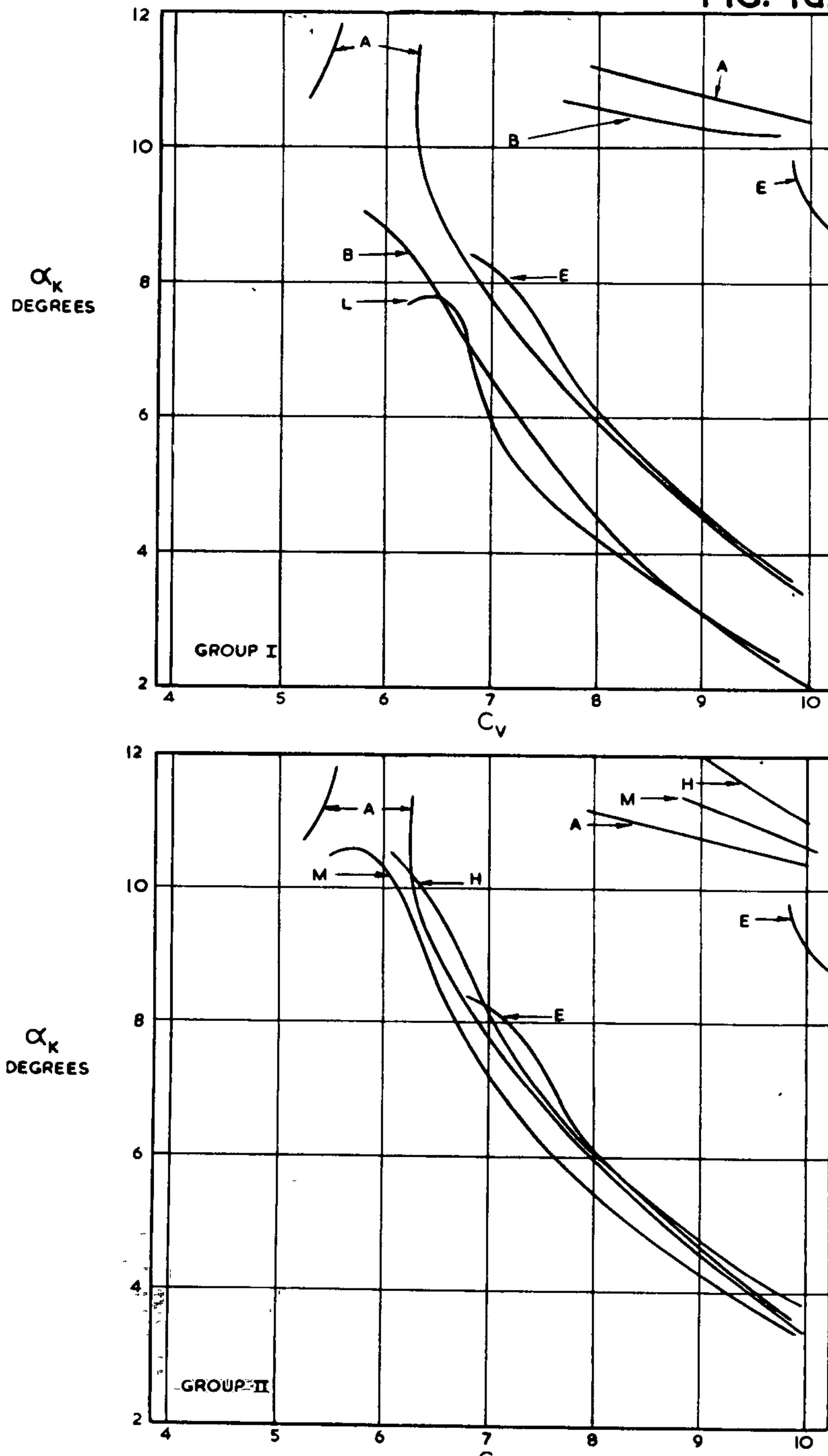
/ TABLE I

TABLE I

MODELS FOR HYDRODYNAMIC STABILITY TESTS

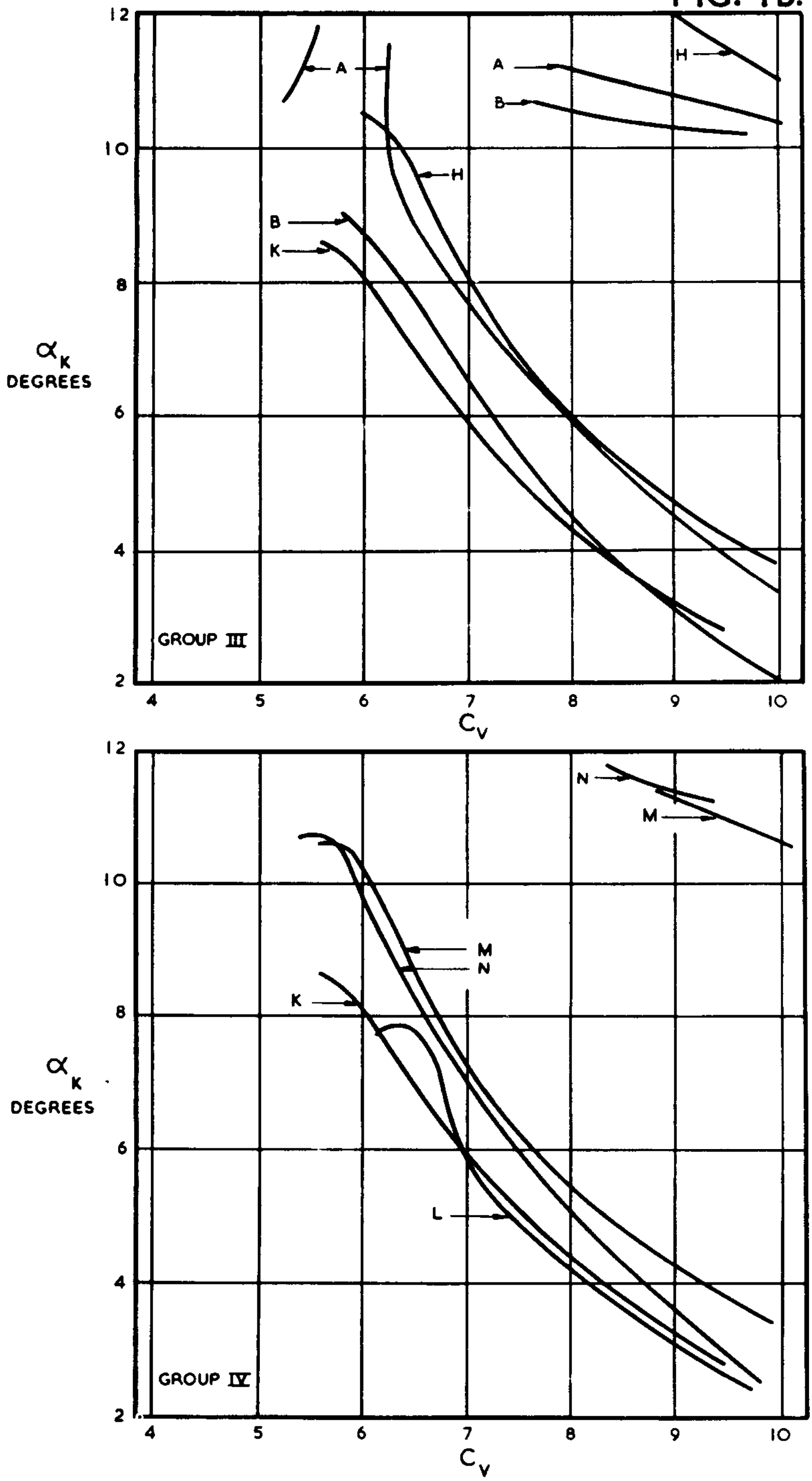
Model	Forebody warp	Afterbody length	Afterbody-forebody keel angle	Step form
	degrees per beam	beams	degrees	
A	0	5	6	Unfaired transverse. Step depth 0.15 beam.
B	4	5	6	
E	0	7	6	
H	0	5	8	
K	4	5	8	
L	4	7	6	
M	0	7	8	
N	4	7	8	

FIG. 1a.



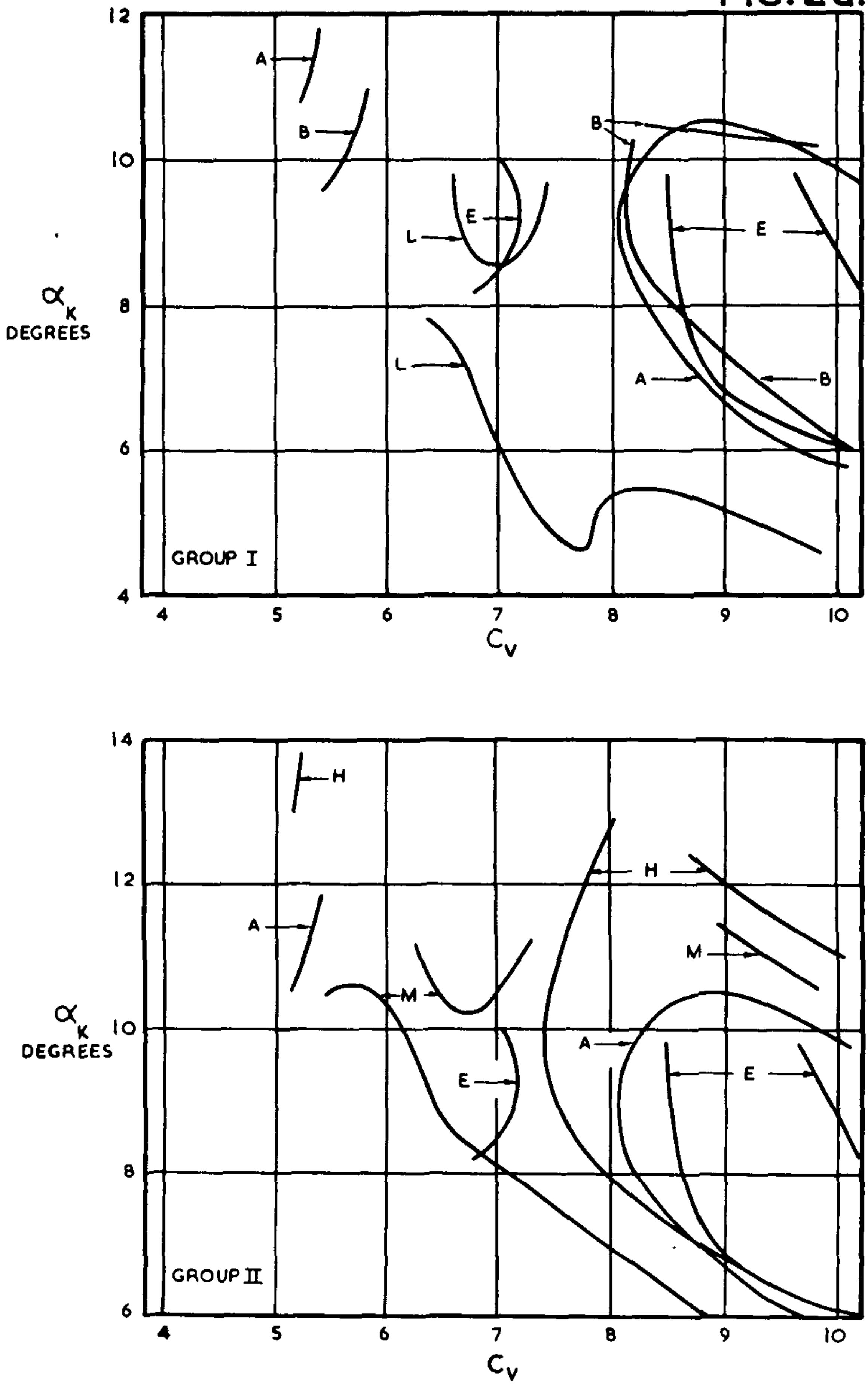
LONGITUDINAL STABILITY LIMITS ON A C_V BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

FIG. 1b.



LONGITUDINAL STABILITY LIMITS ON A C_V BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

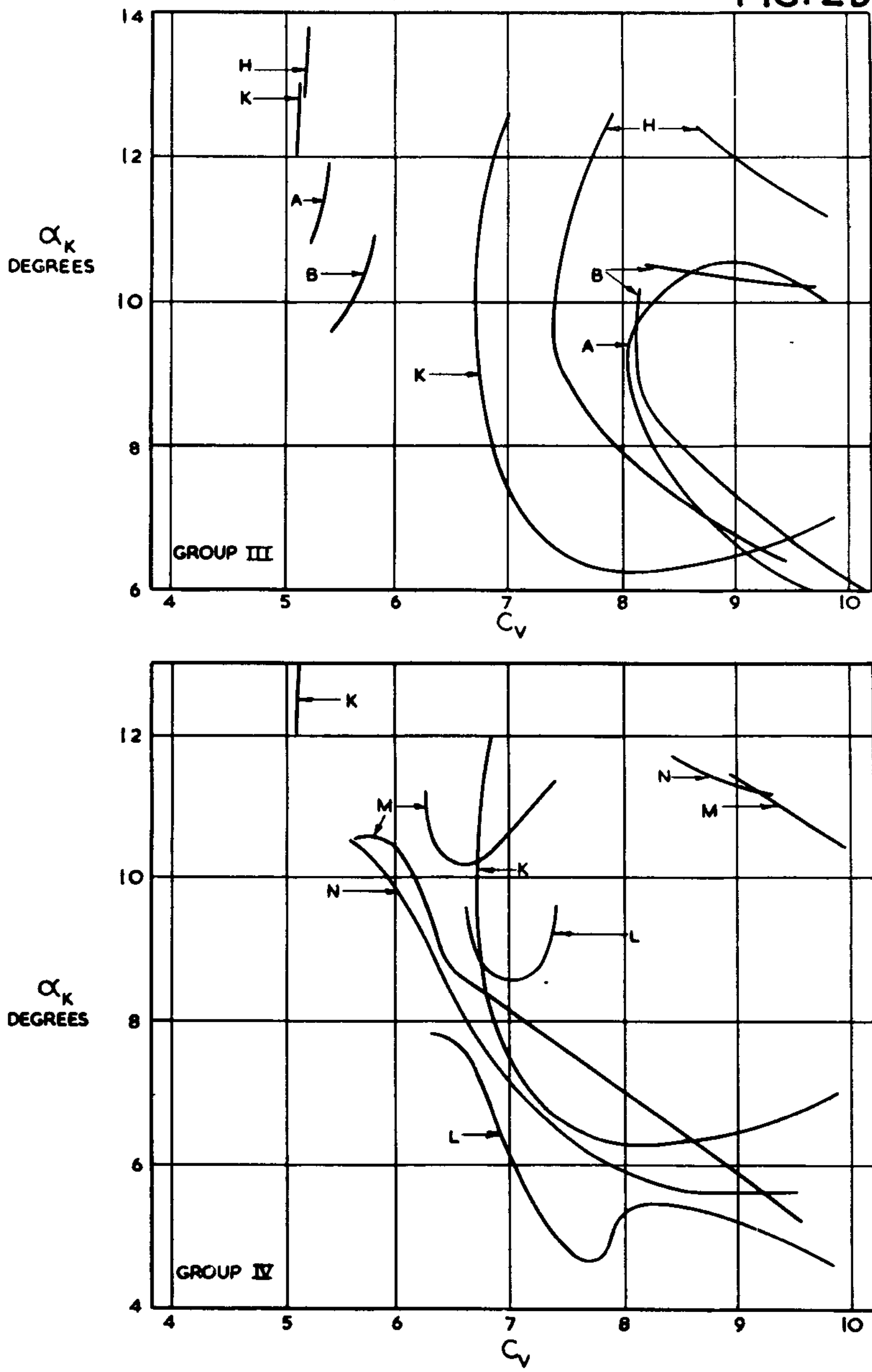
FIG. 2a.



LONGITUDINAL STABILITY LIMITS ON A C_V BASE,

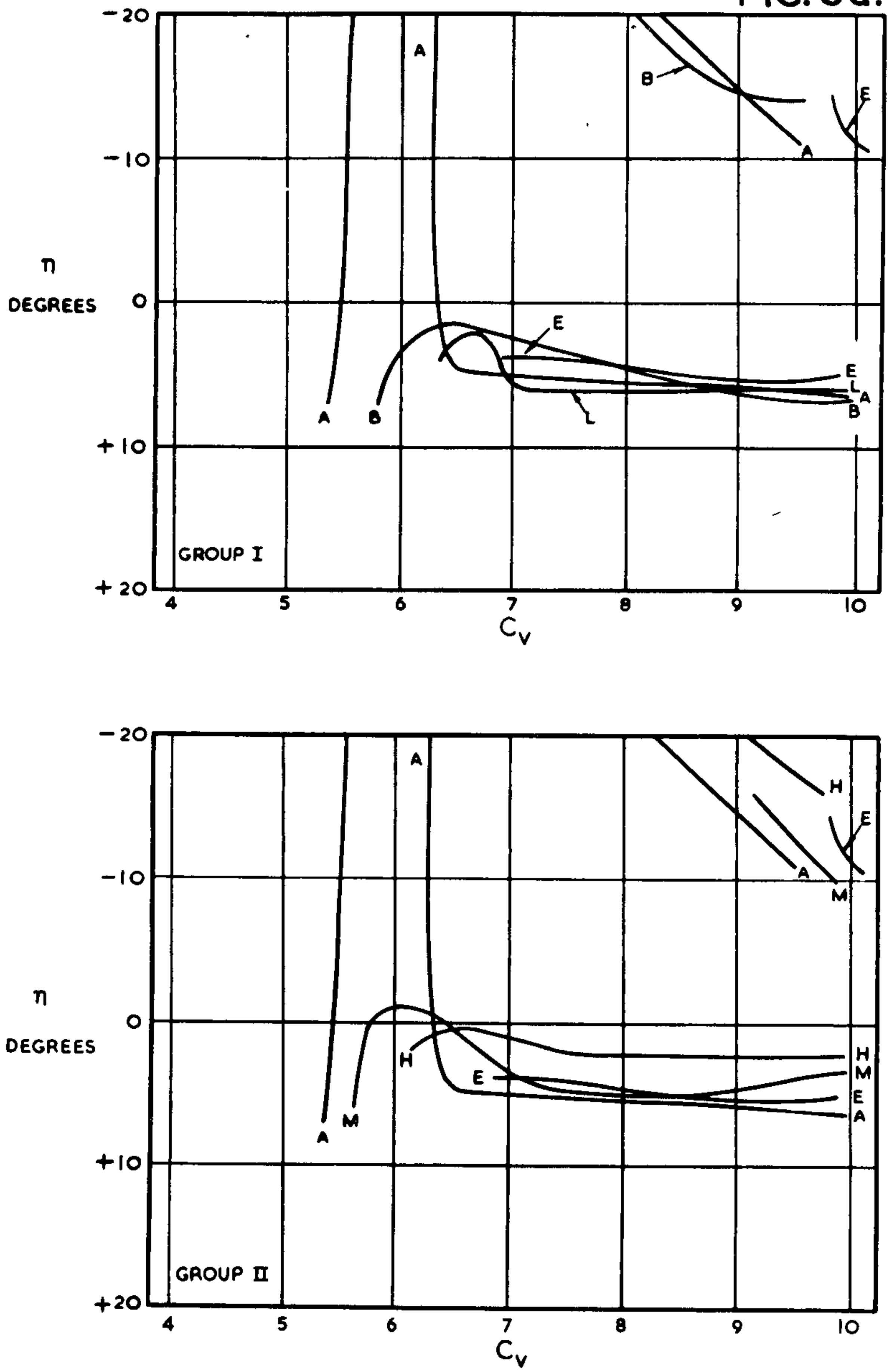
DISTURBED CASE, C_{Δ_0} = 2·75

FIG. 2b.



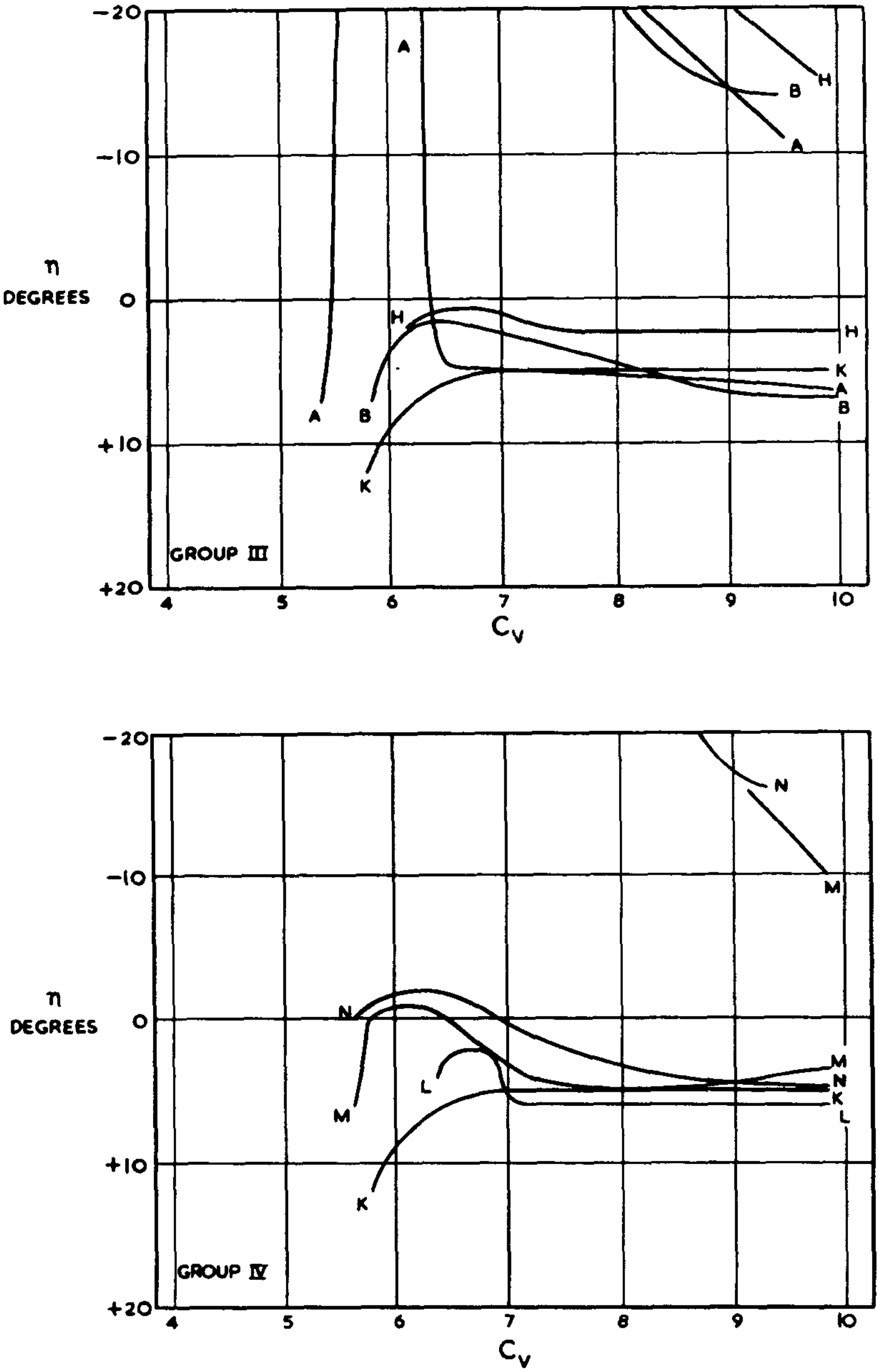
LONGITUDINAL STABILITY LIMITS ON A C_V BASE, DISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 3a.



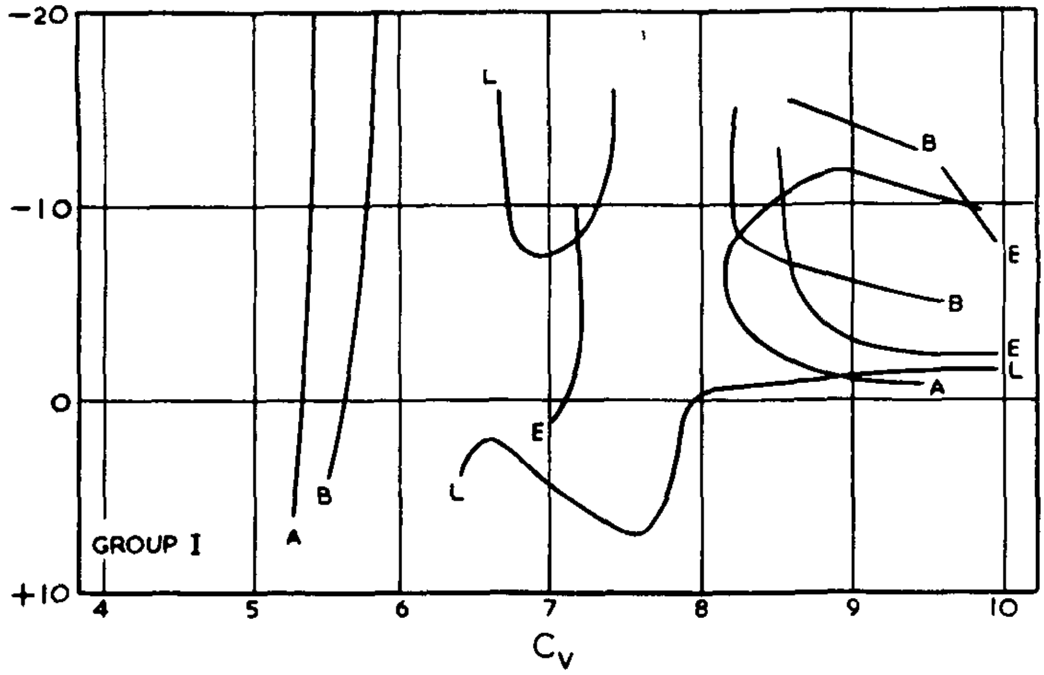
RELATION BETWEEN ELEVATOR SETTINGS AND STABILITY LIMITS, UNDISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

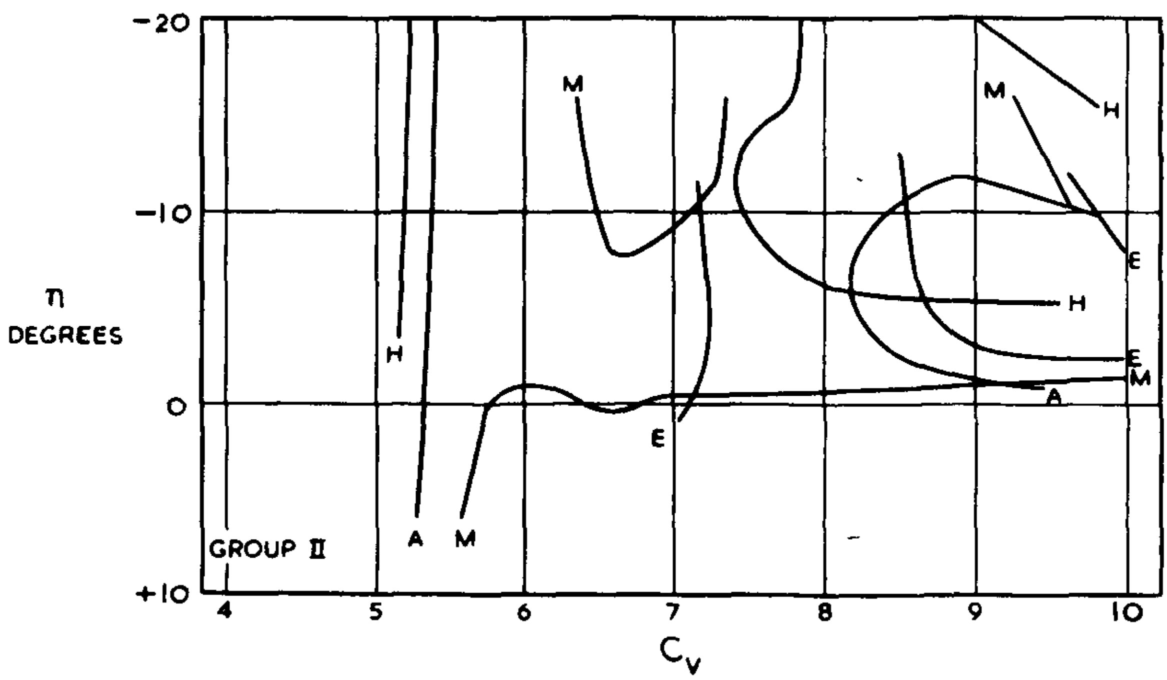
FIG. 3b.



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

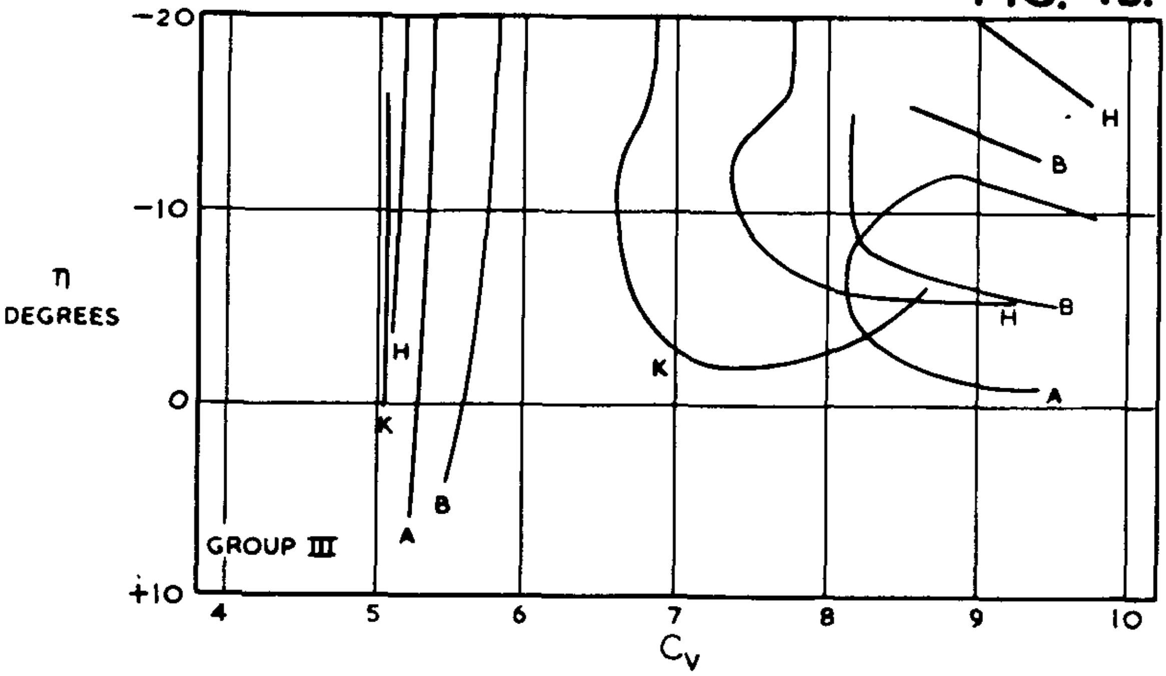
FIG. 4a.

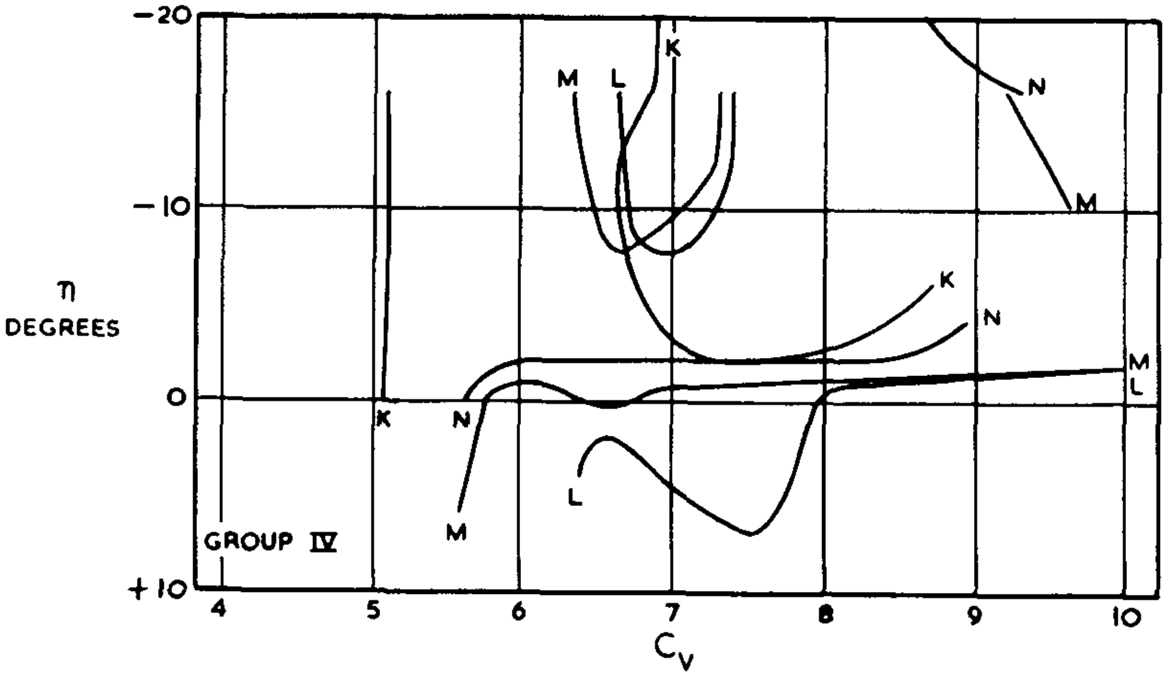




RELATION BETWEEN ELEVATOR SETTINGS AND STABILITY LIMITS, DISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

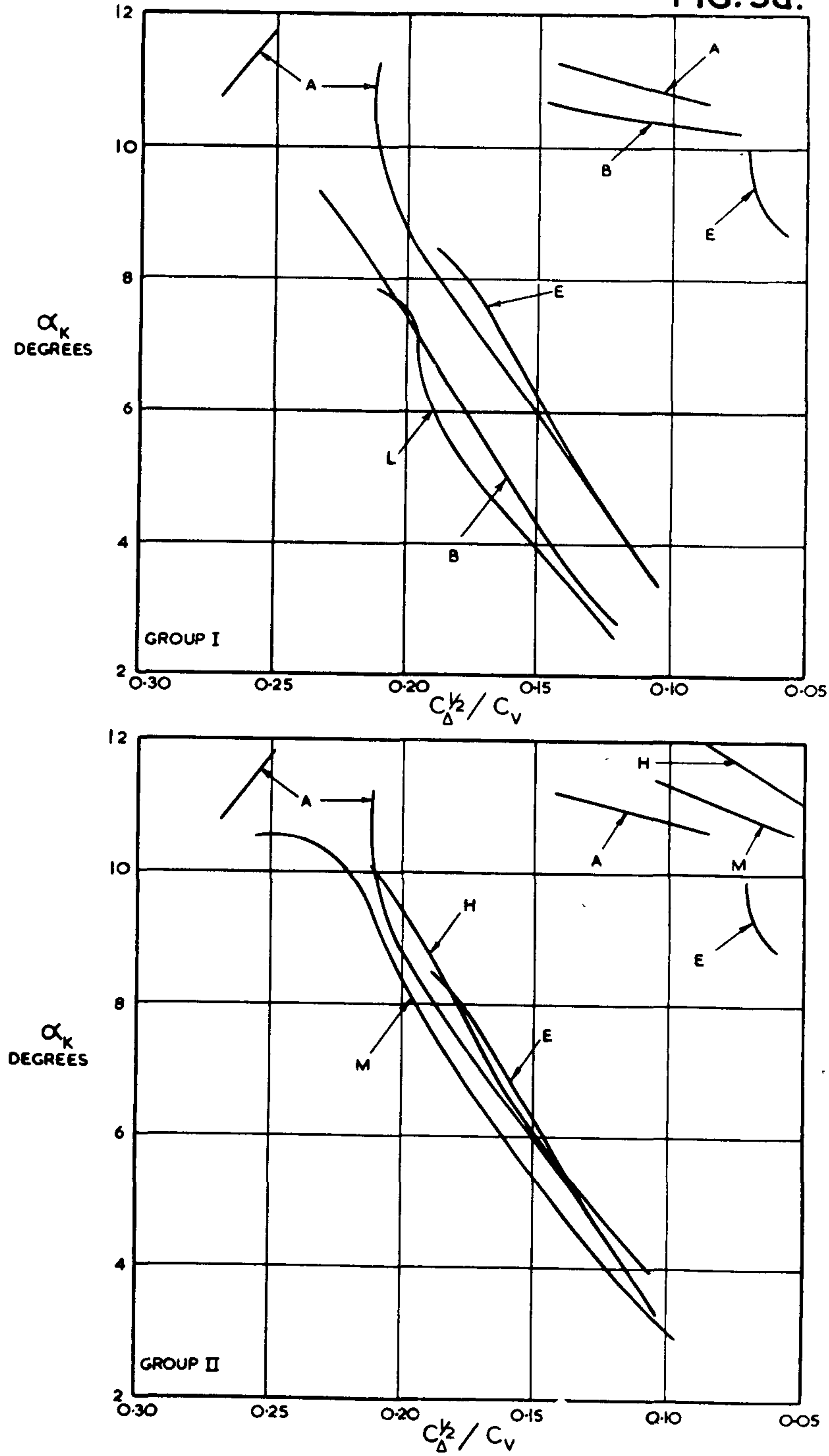
FIG. 4b.





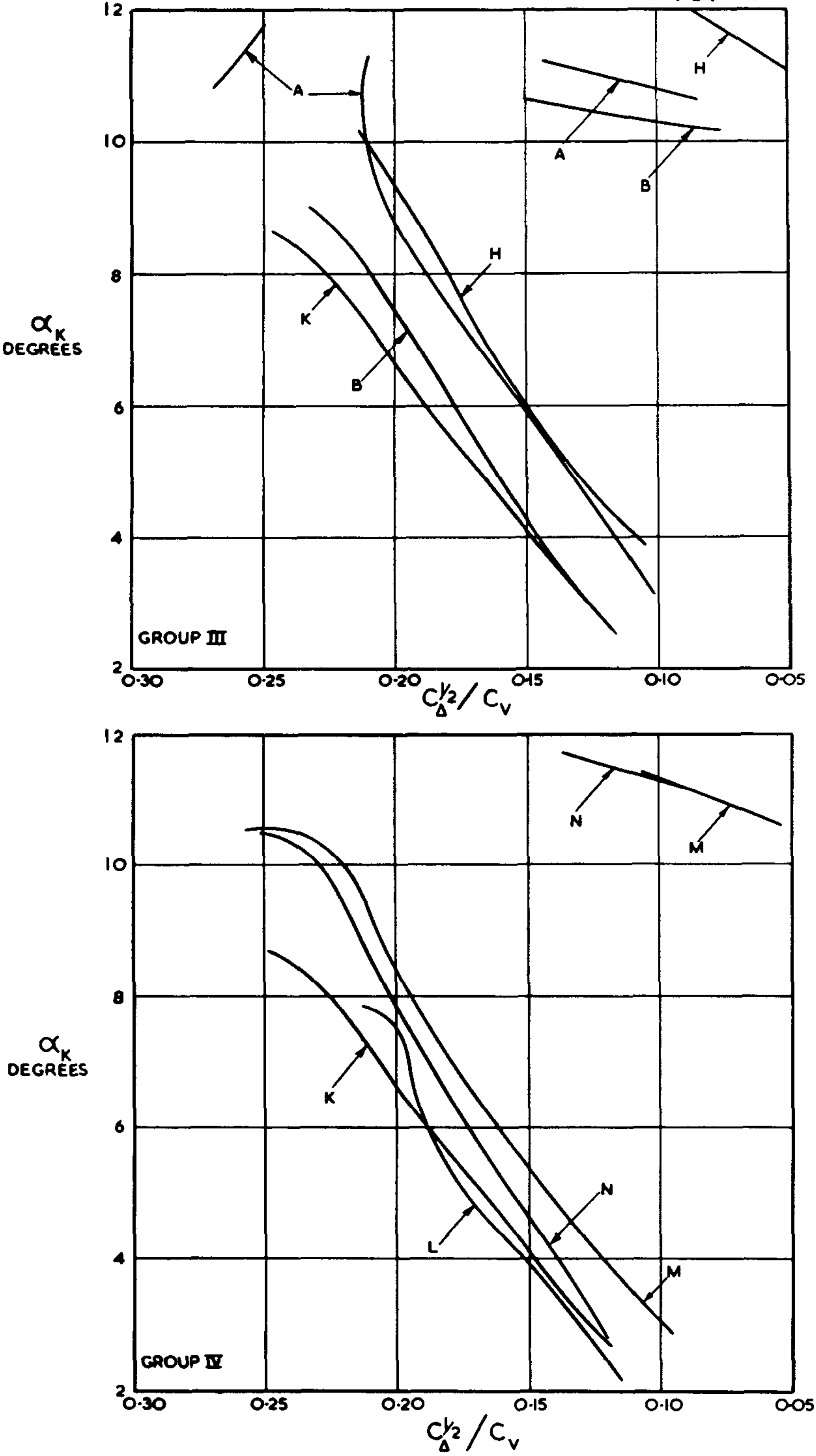
RELATION BETWEEN ELEVATOR SETTINGS AND STABILITY LIMITS, DISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

FIG. 5a.



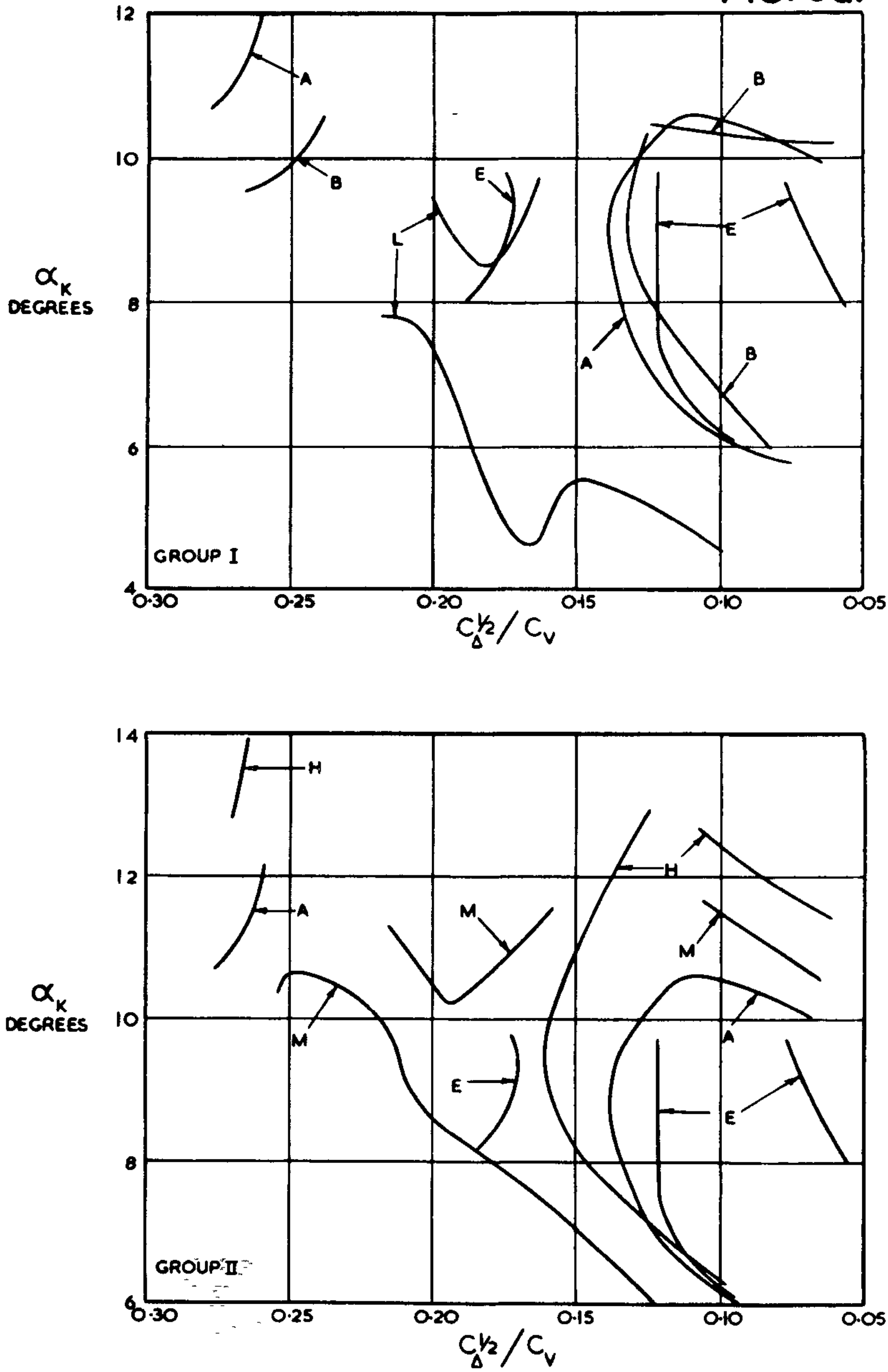
LONGITUDINAL STABILITY LIMITS ON A $C_{\Delta}^{1/2} / C_V$ BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

FIG. 5b.



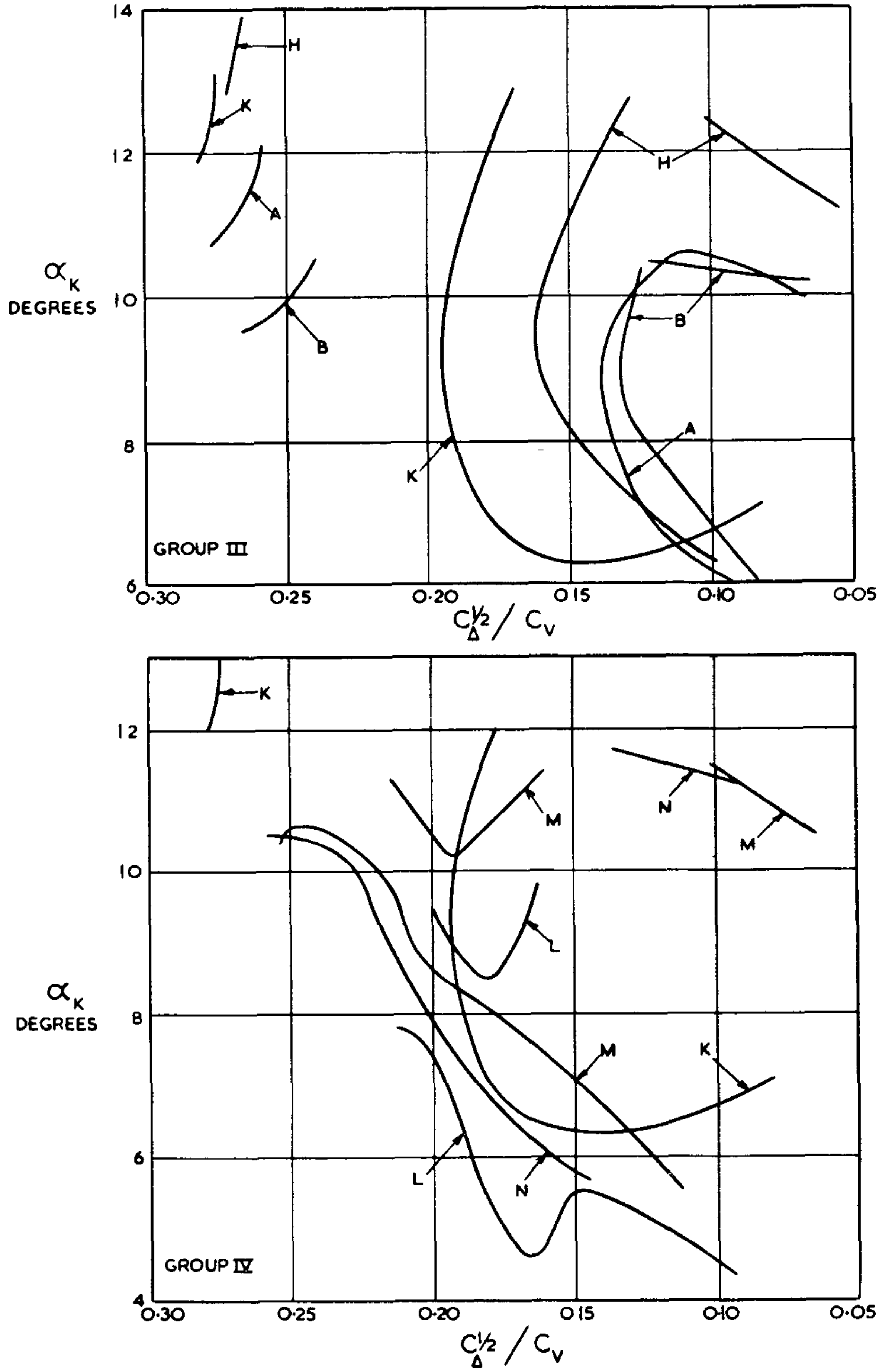
LONGITUDINAL STABILITY LIMITS ON A $C_\Delta^{1/2}/C_V$ BASE.
UNDISTURBED CASE, $C_{\Delta_0} = 2\cdot75$.

FIG. 6a.

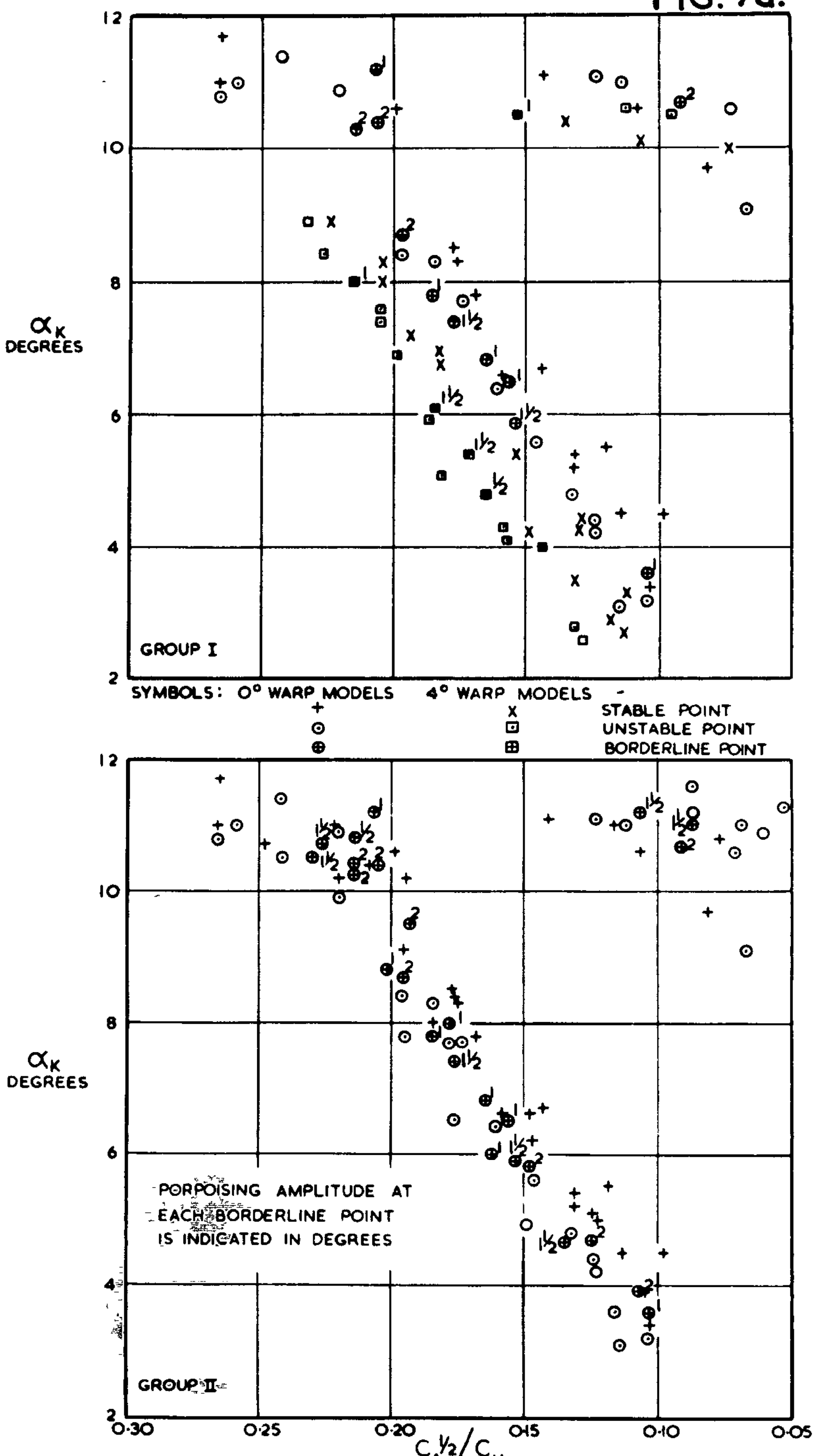


LONGITUDINAL STABILITY LIMITS ON A $C_{\Delta}^{1/2} / C_V$ BASE,
DISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

FIG. 6b.

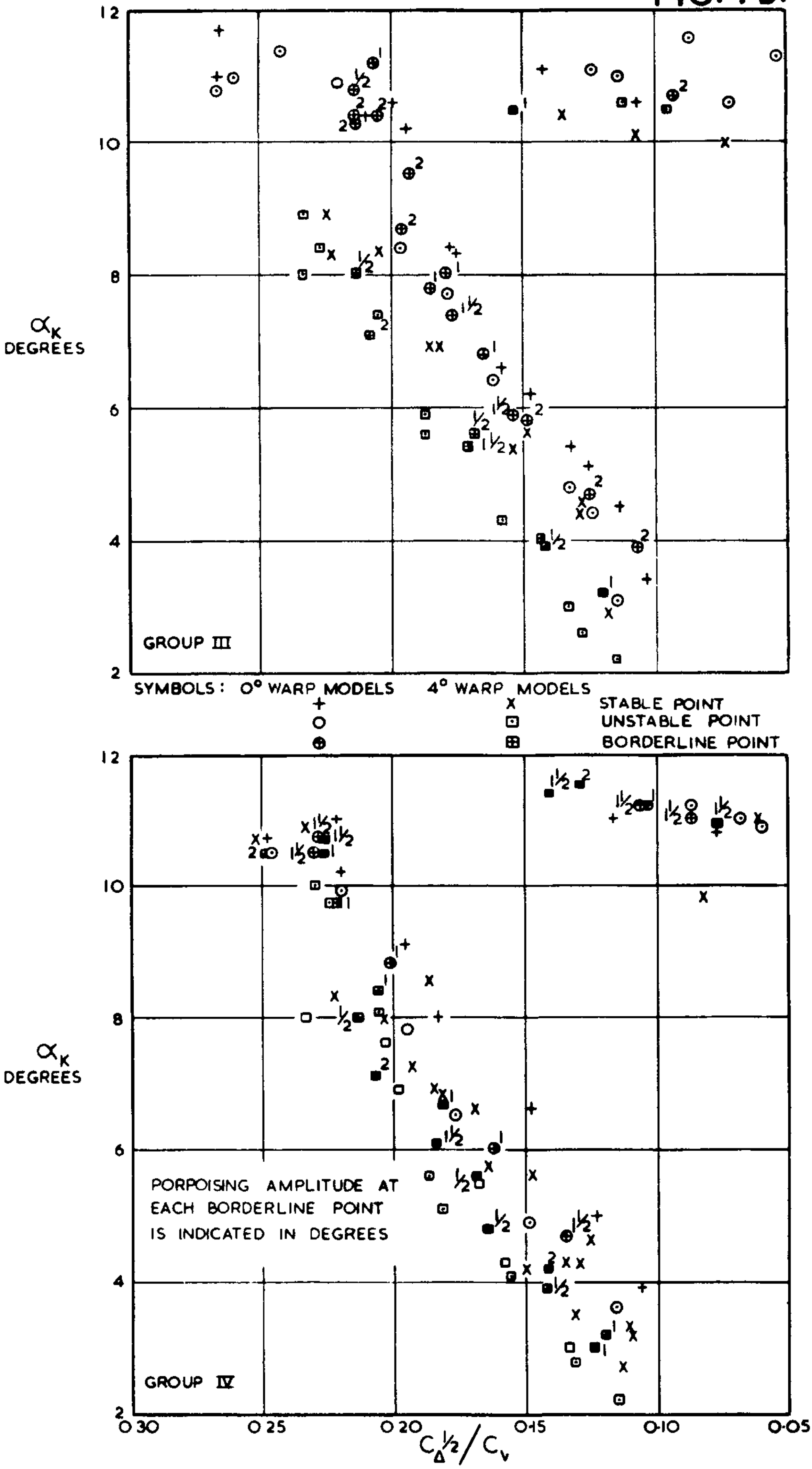


LONGITUDINAL STABILITY LIMITS ON A $C_\Delta^{1/2} / C_V$ BASE, DISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.



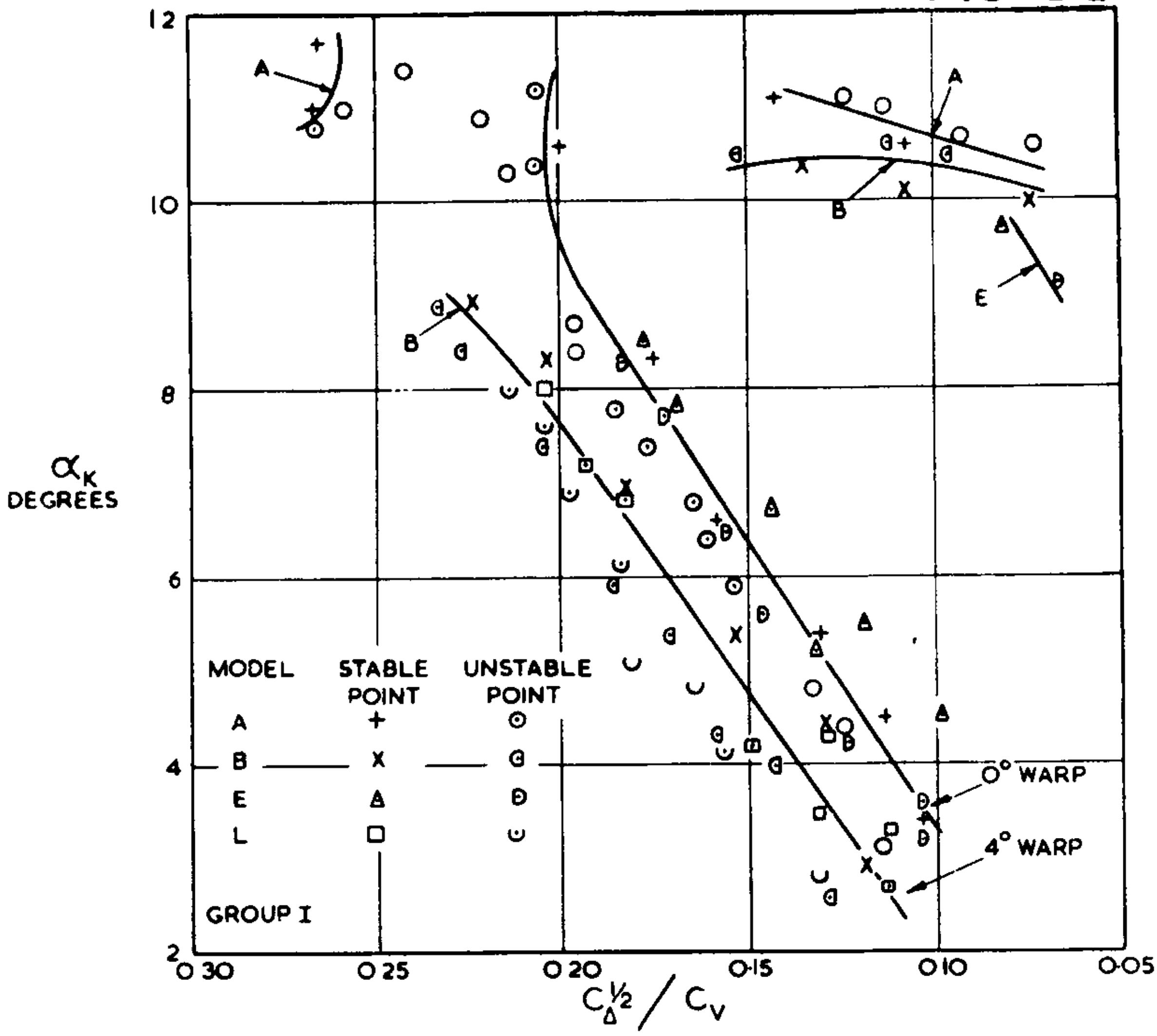
POINTS DEFINING LONGITUDINAL STABILITY LIMITS ON A $C_\Delta^{1/2}/C_V$ BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

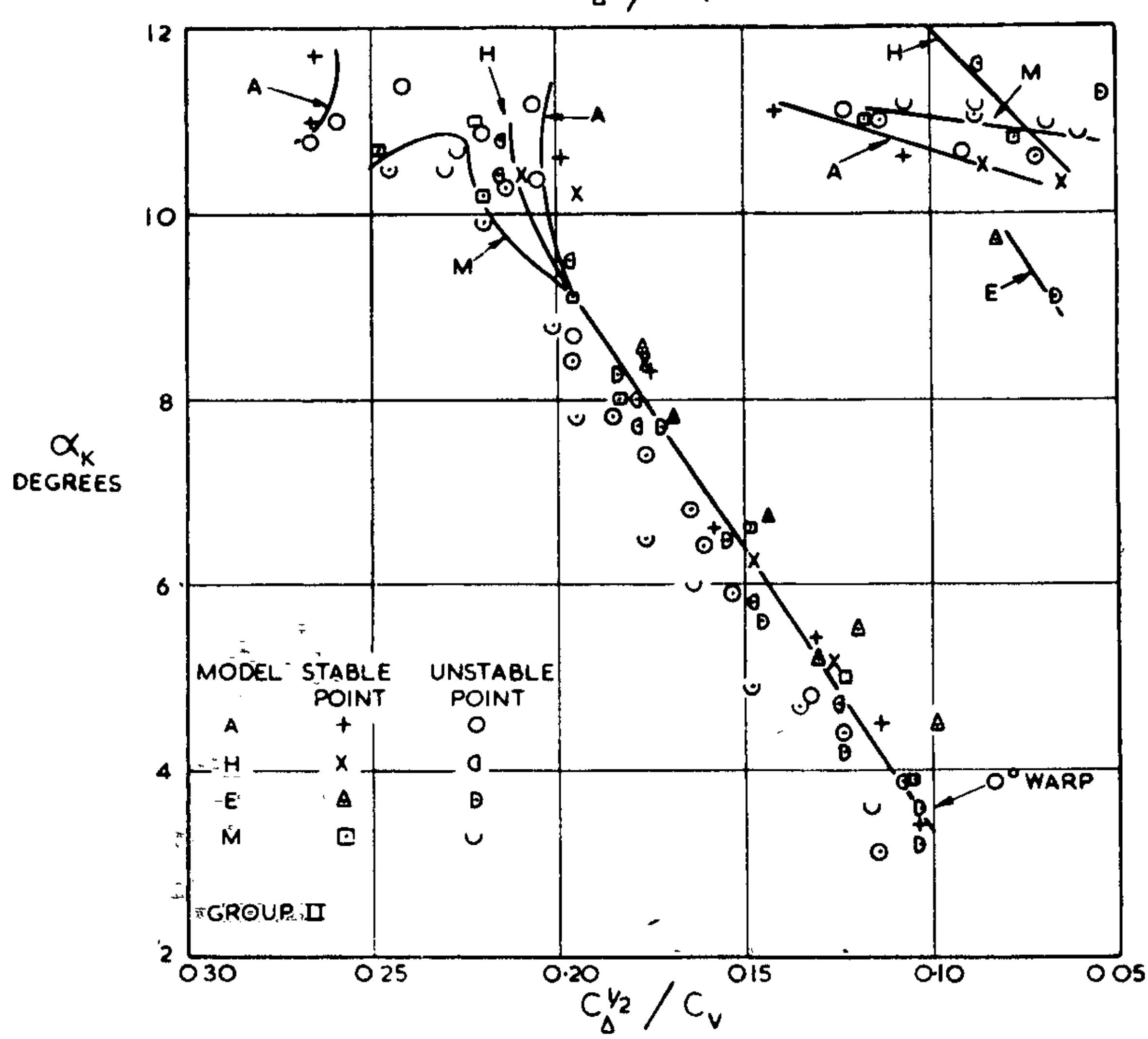
FIG. 7b.



POINTS DEFINING LONGITUDINAL STABILITY LIMITS ON A $C_\Delta^{1/2}/C_V$ BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2\cdot75$.

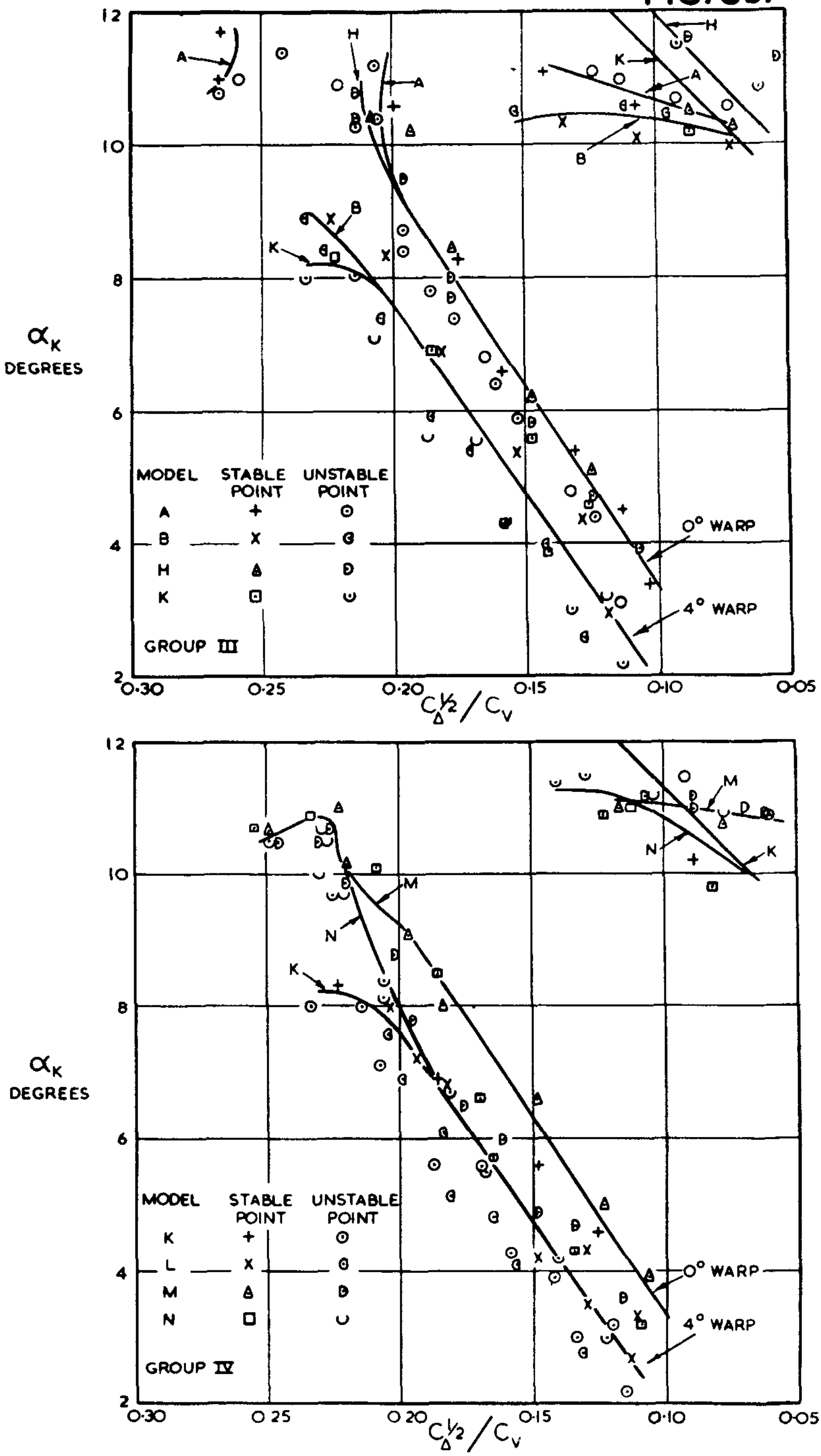
FIG. 8a.





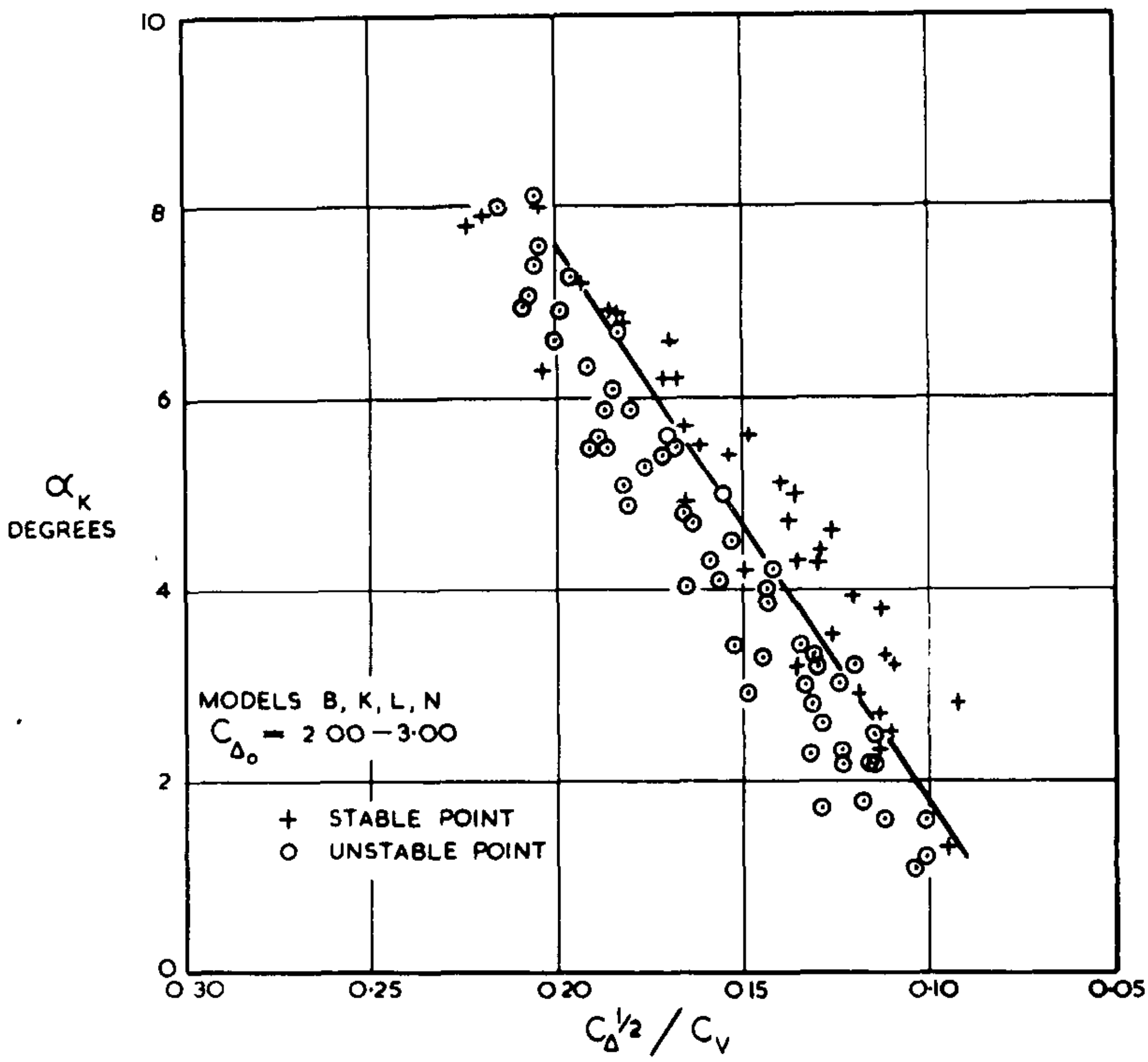
REDEFINED STABILITY LIMITS ON A $C_\Delta^{1/2} / C_V$ BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$

FIG. 8b.



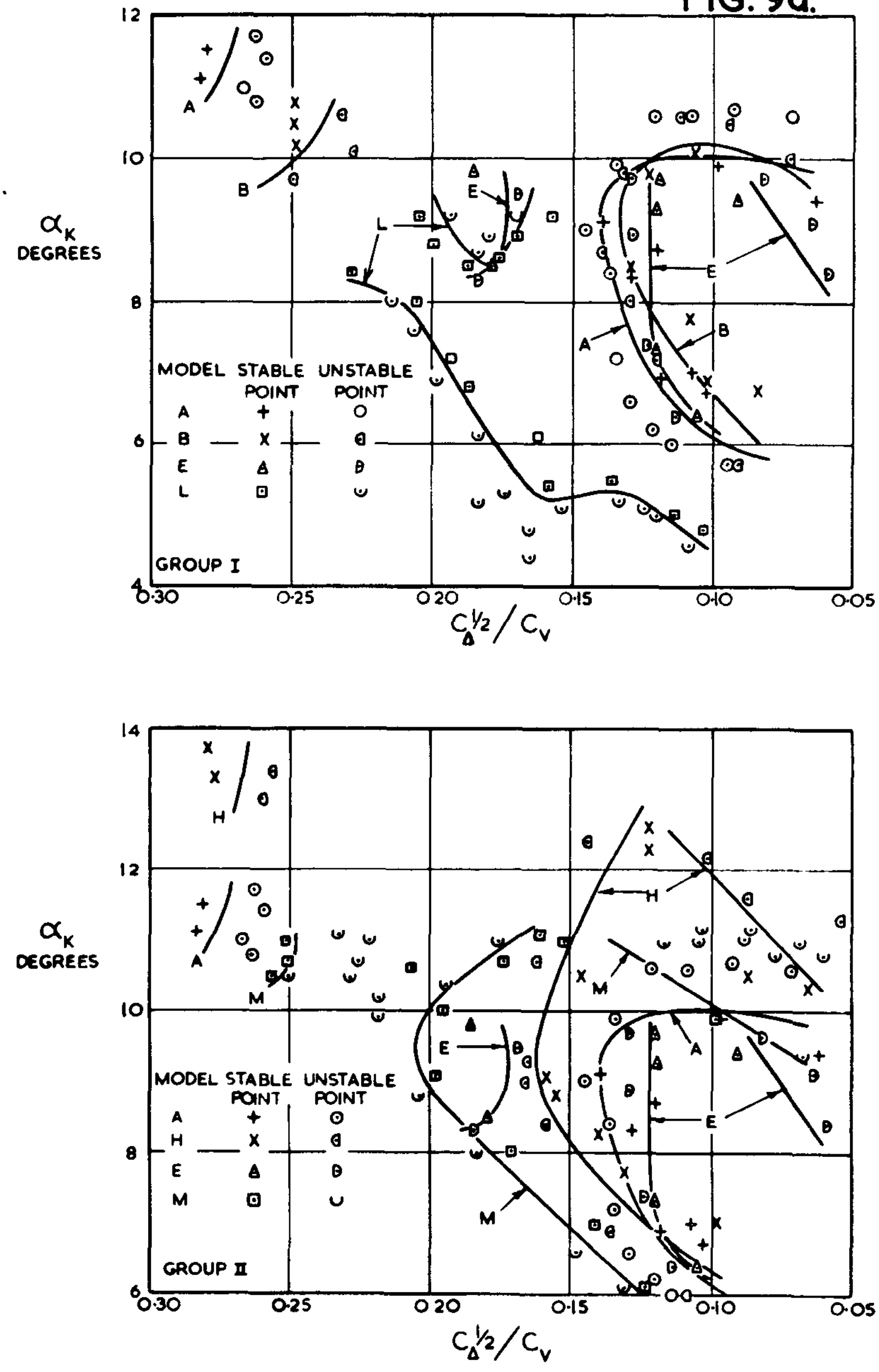
REDEFINED STABILITY LIMITS ON A $C_{\Delta}^{1/2}/C_V$ BASE, UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$

FIG. 8c.



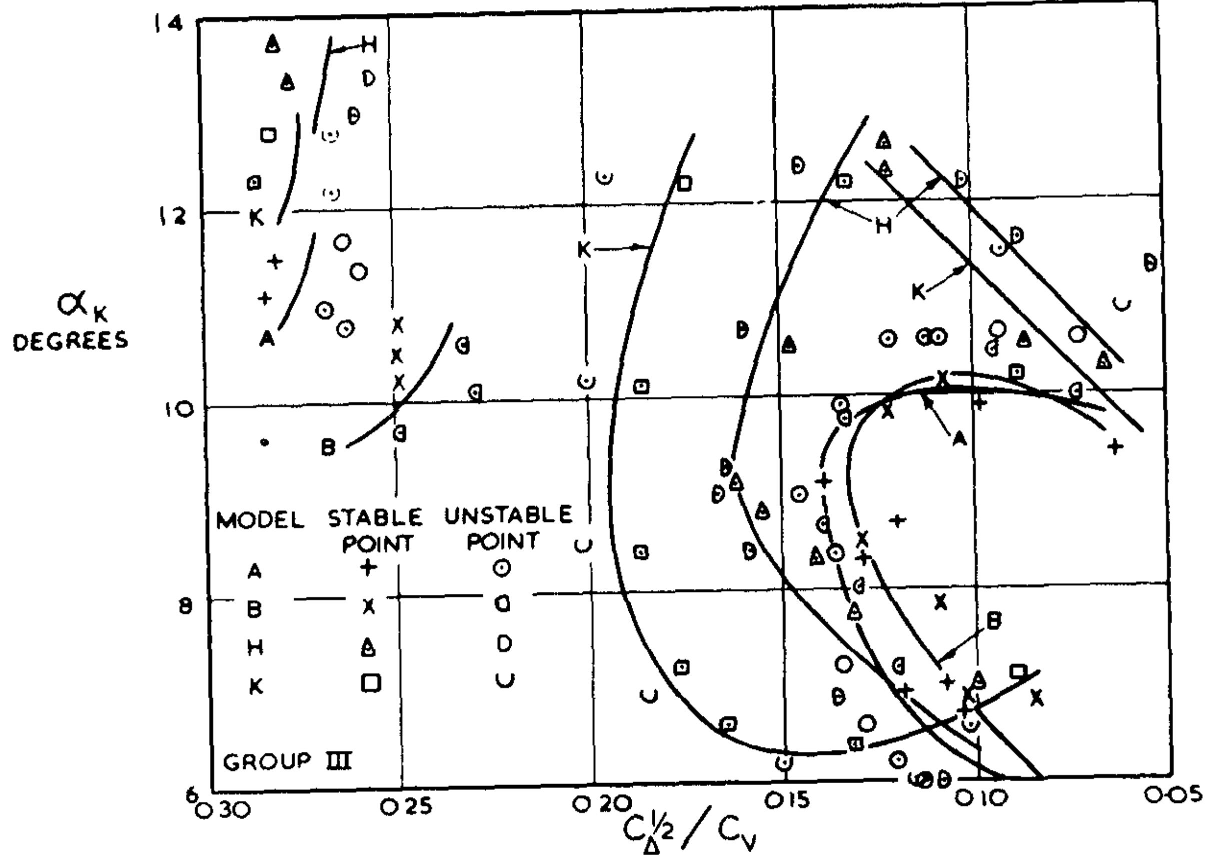
REDEFINED LOWER STABILITY LIMIT ON A $C_\Delta^{1/2}/C_V$ BASE FOR WARPED FOREBODY MODELS, OVER A RANGE OF C_{Δ_0}, UNDISTURBED CASE.

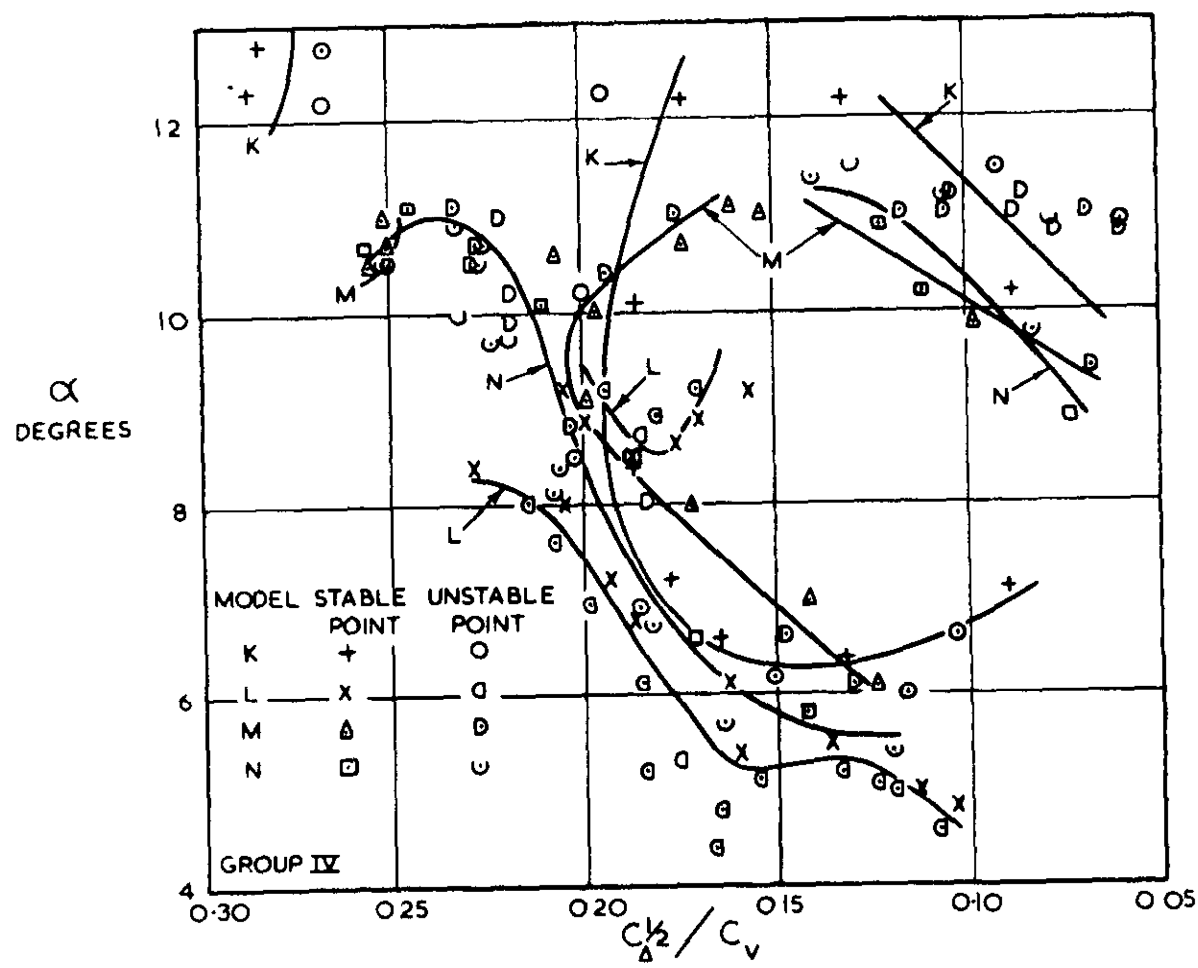
FIG. 9a.



REDEFINED STABILITY LIMITS ON A $C_\Delta^{1/2}/C_V$ BASE, DISTURBED CASE, $C_{\Delta_o} = 2{\cdot}75$.

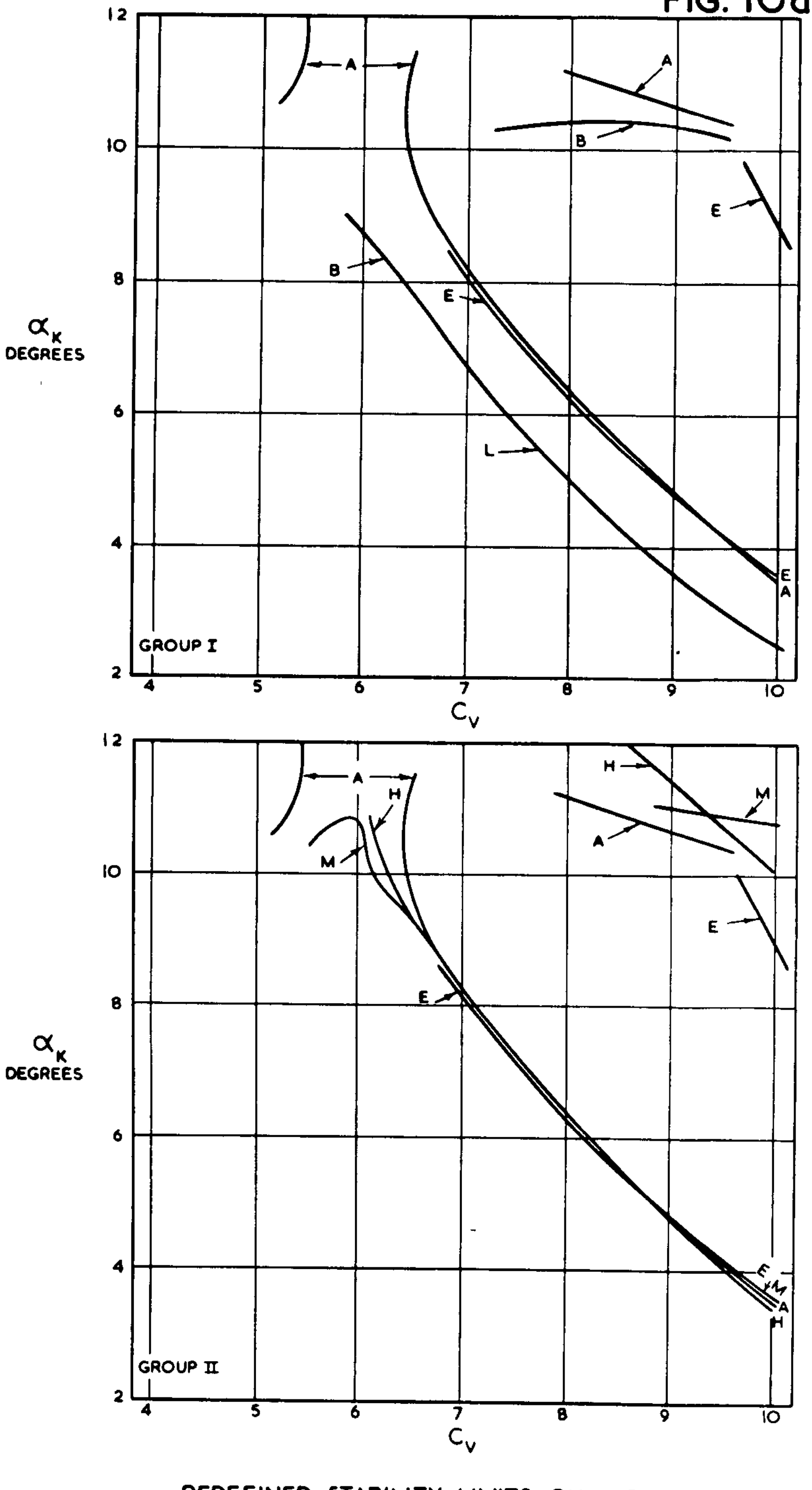
FIG. 9b.





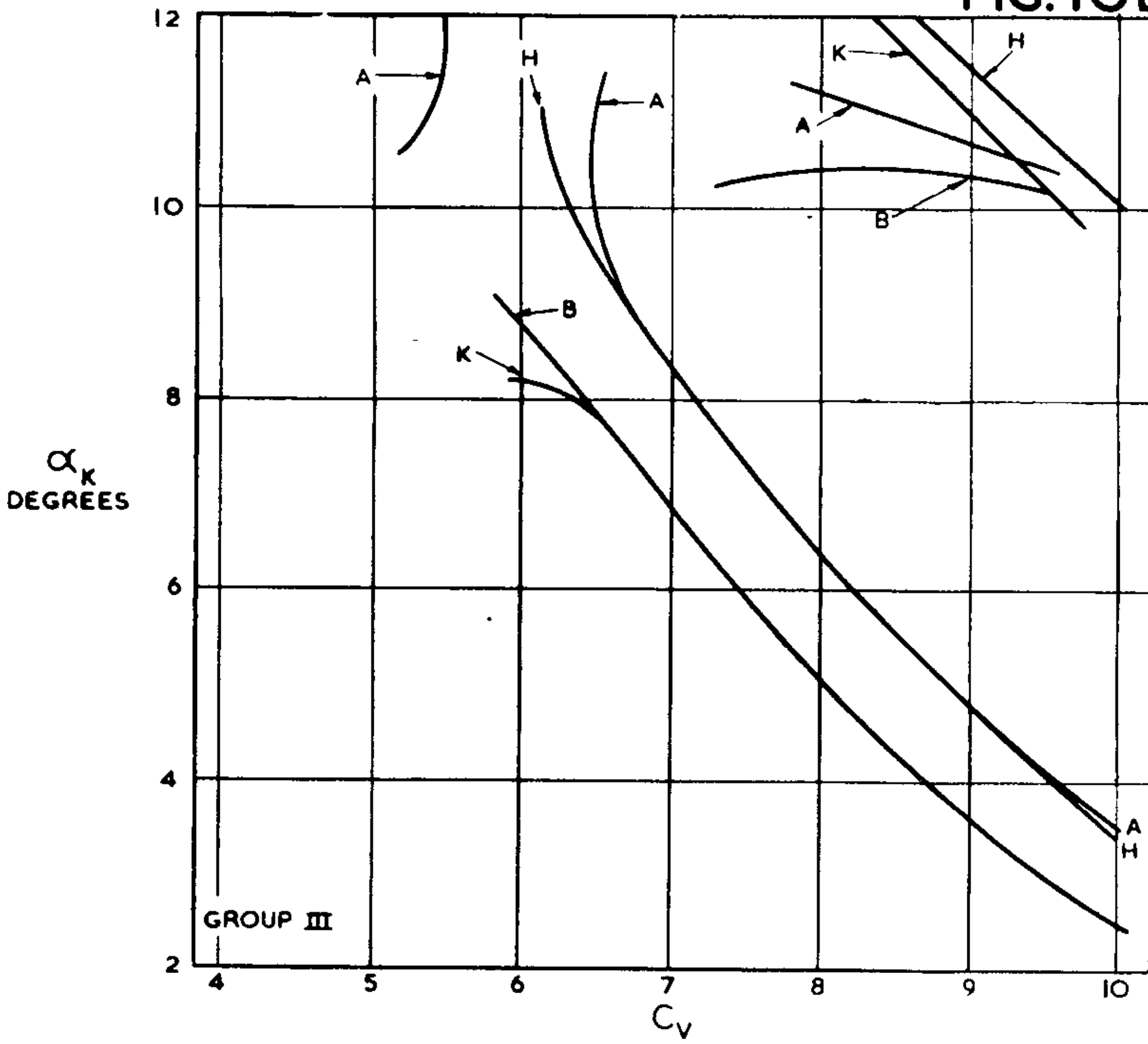
REDEFINED STABILITY LIMITS ON A $C_{\Delta}^{1/2}/C_V$ BASE, DISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

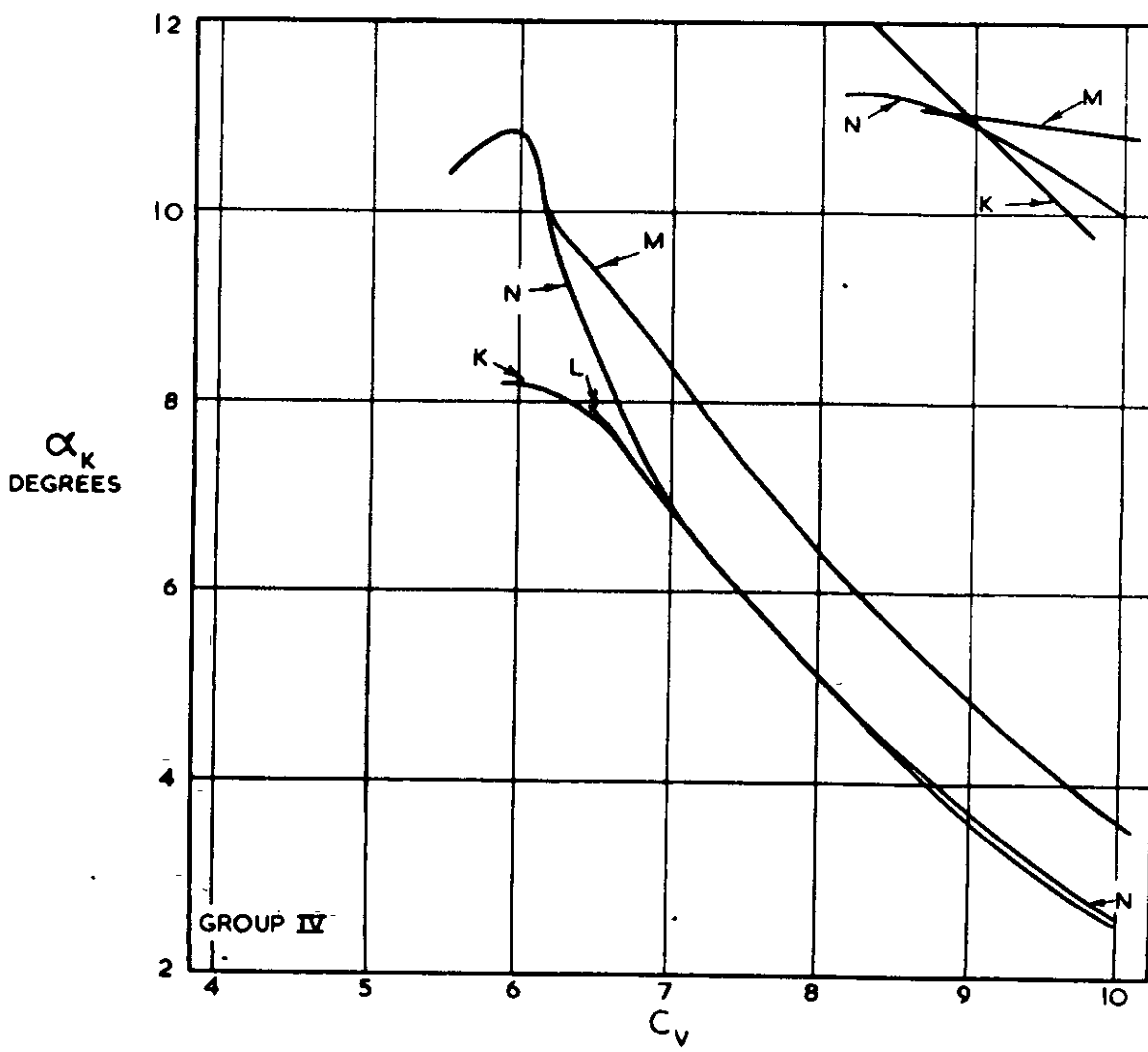
FIG. 10a.



REDEFINED STABILITY LIMITS ON A C_V BASE,
UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

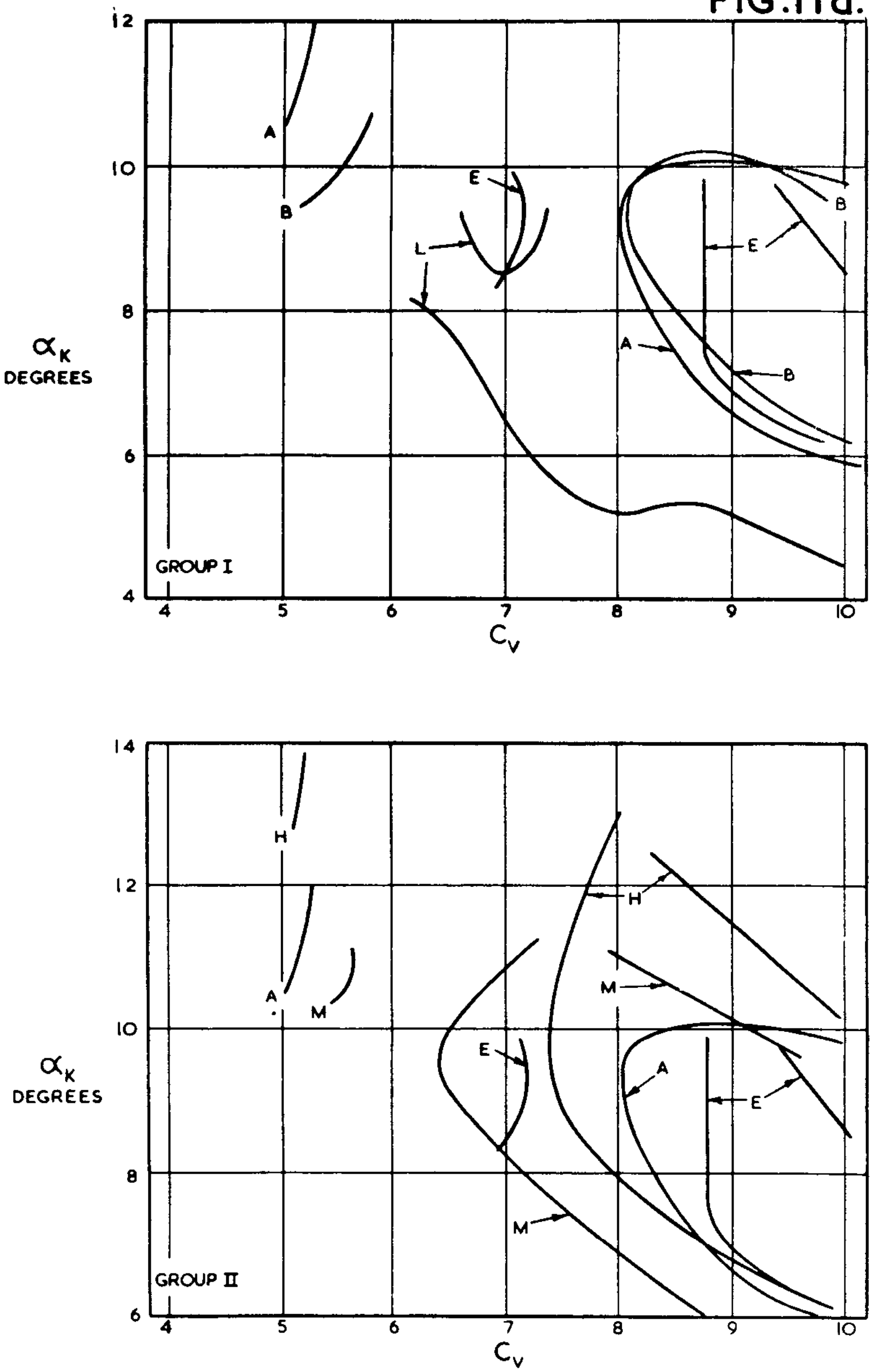
FIG. 10b.





REDEFINED STABILITY LIMITS ON A C_V BASE,
UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

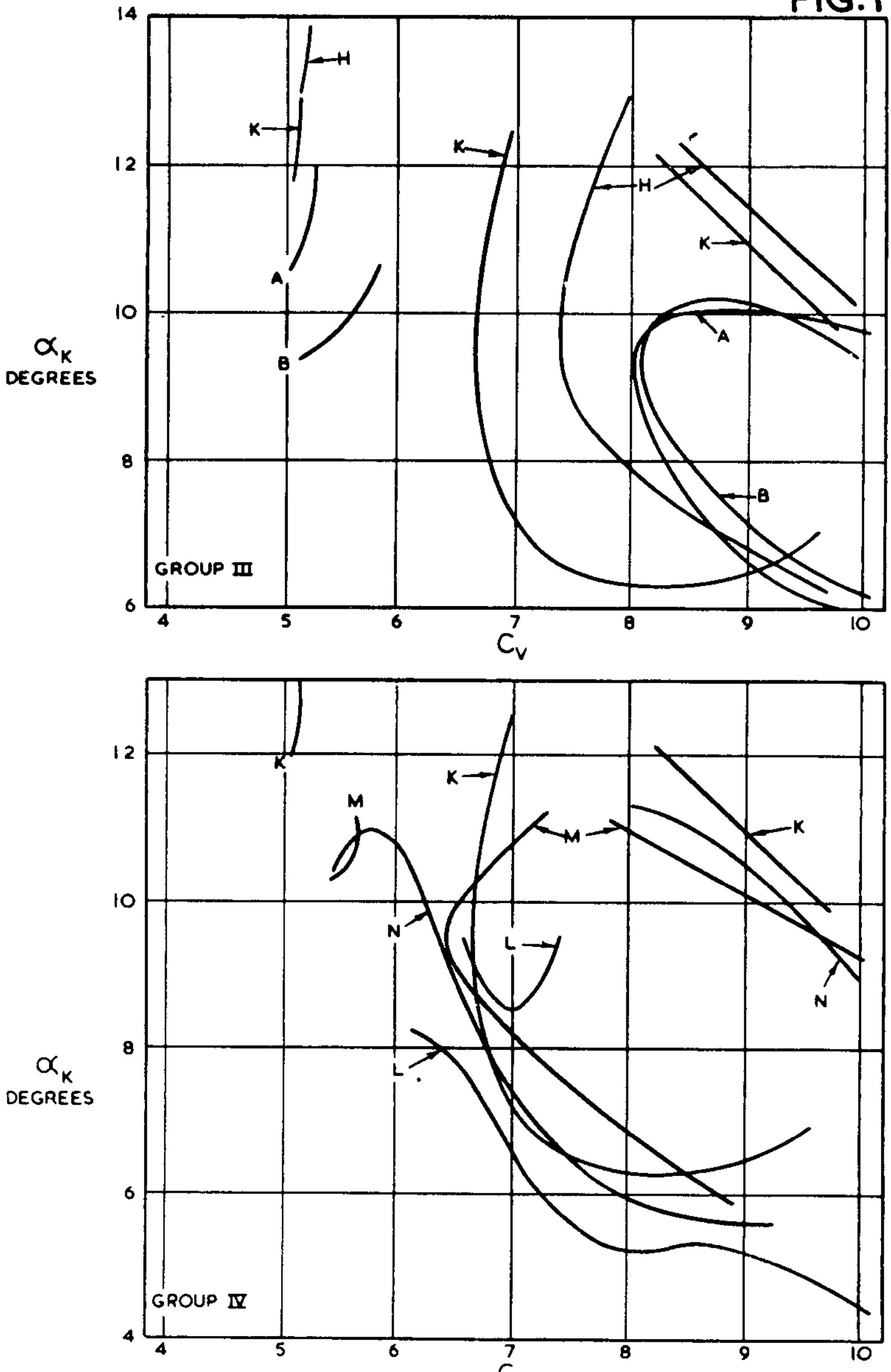
FIG. 11a.



REDEFINED STABILITY LIMITS ON A C_V BASE,

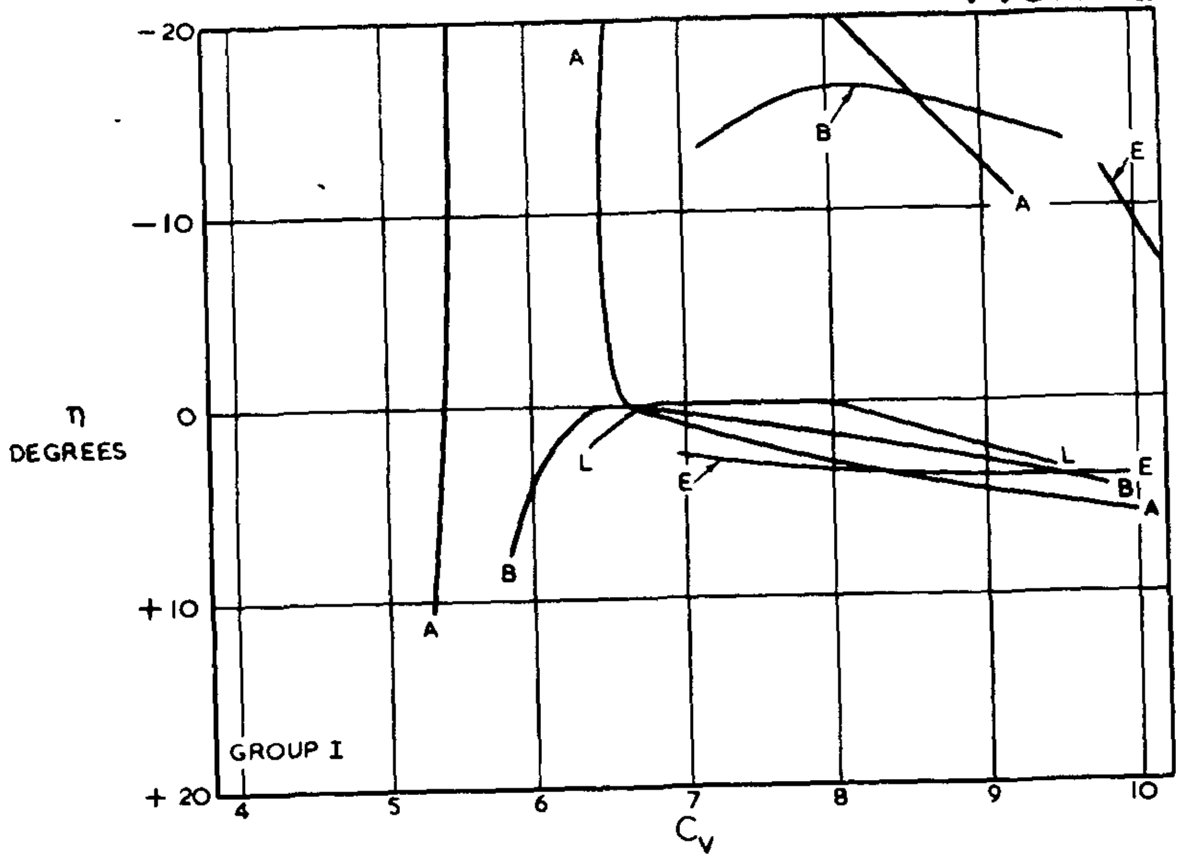
DISTURBED CASE, $C_{\Delta_o} = 2{\cdot}75$.

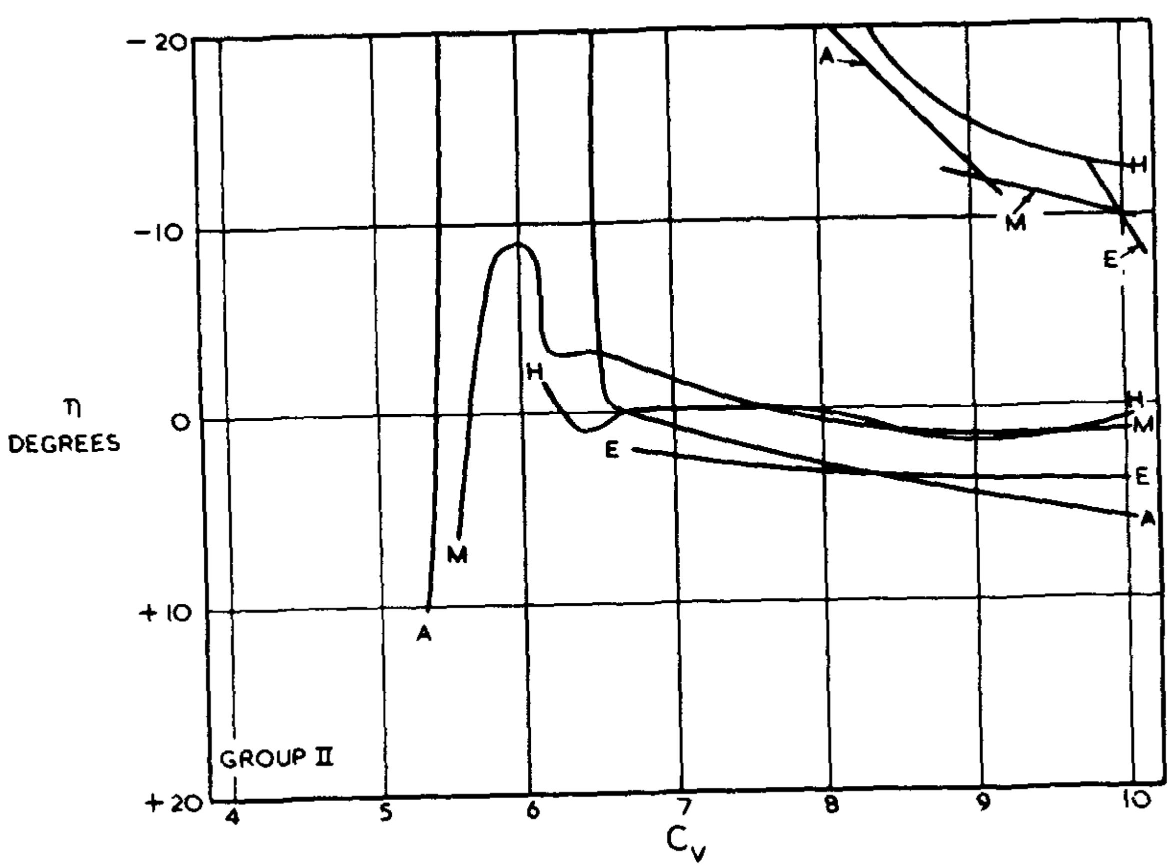
FIG. 11b.



REDEFINED STABILITY LIMITS ON A C_V BASE,
DISTURBED CASE, $C_{\Delta_o} = 2\ 75$.

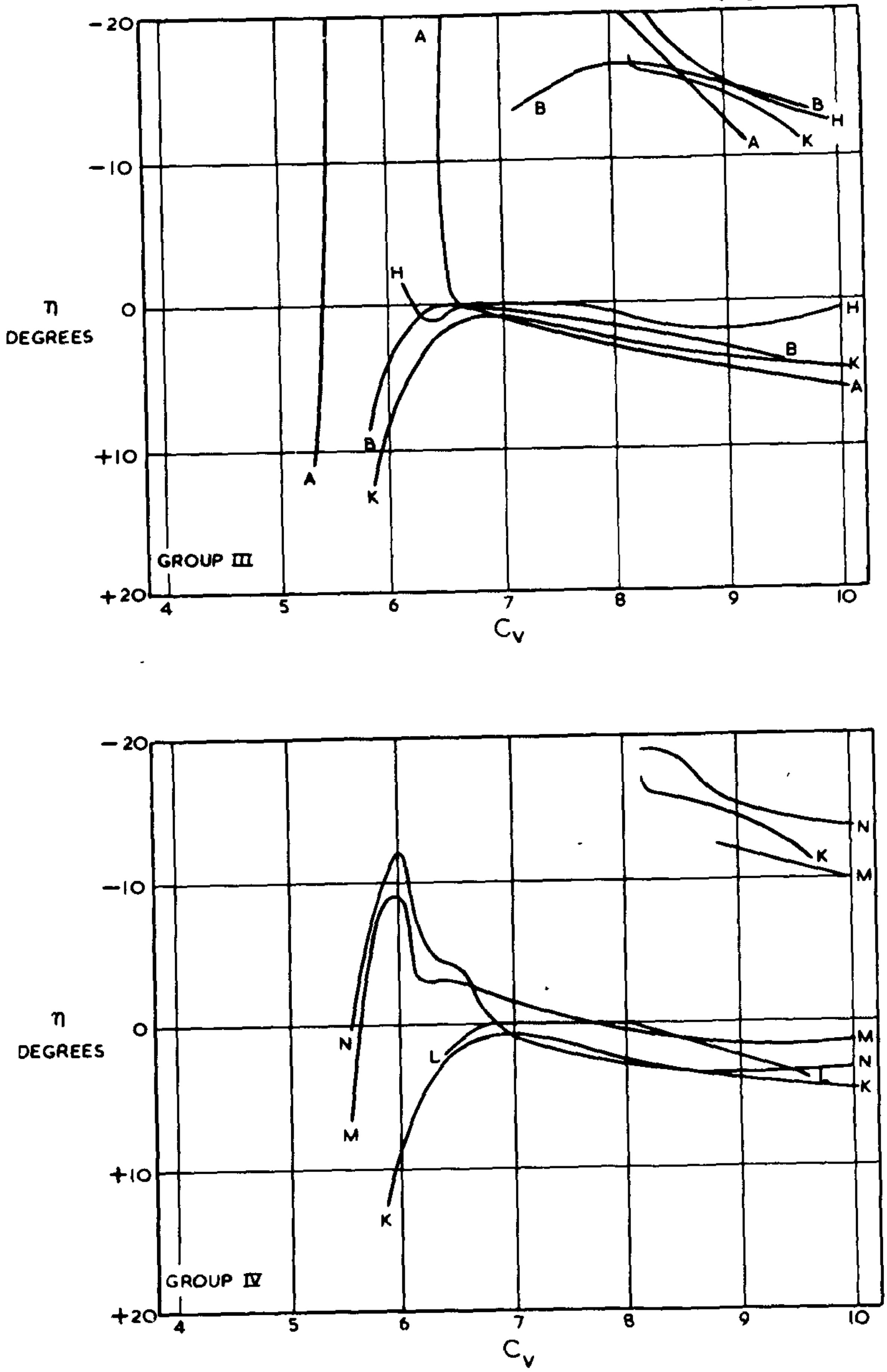
FIG. 12a





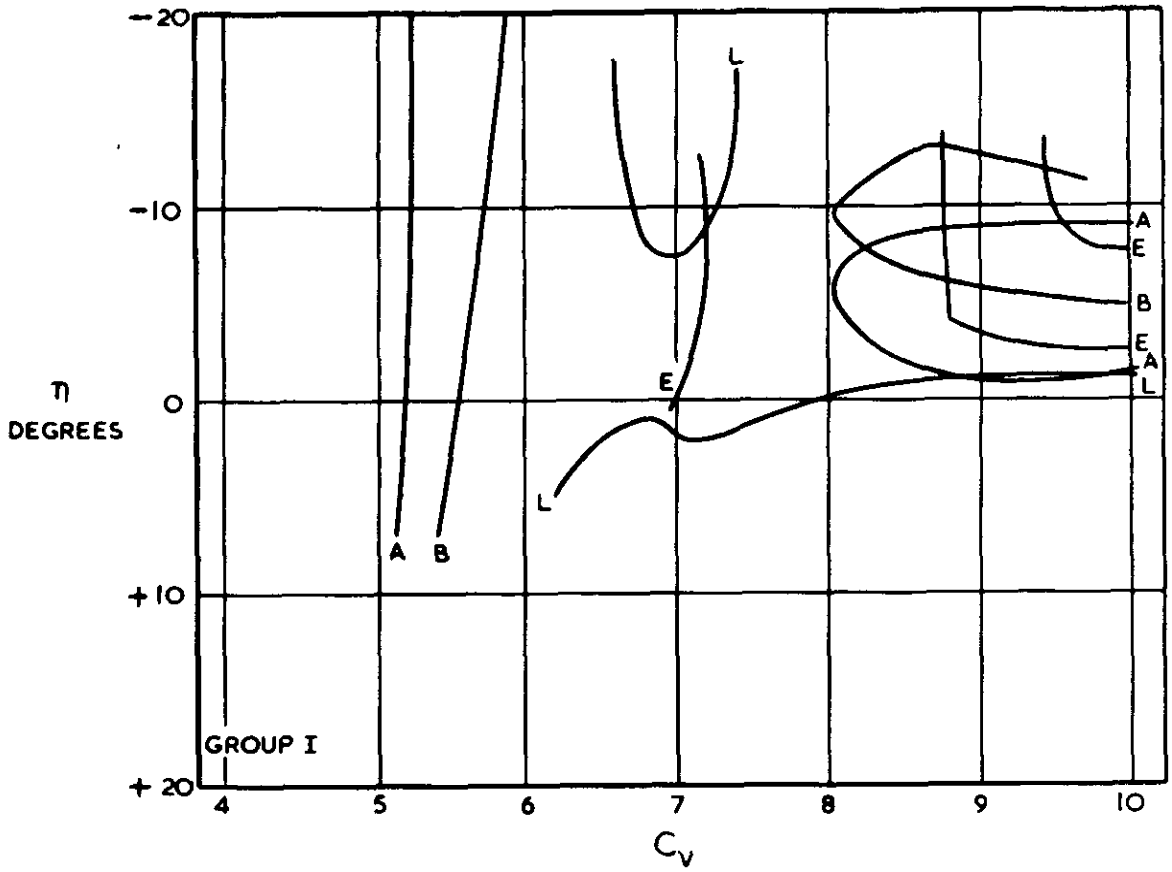
RELATION BETWEEN ELEVATOR SETTINGS AND REDEFINED STABILITY LIMITS, UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

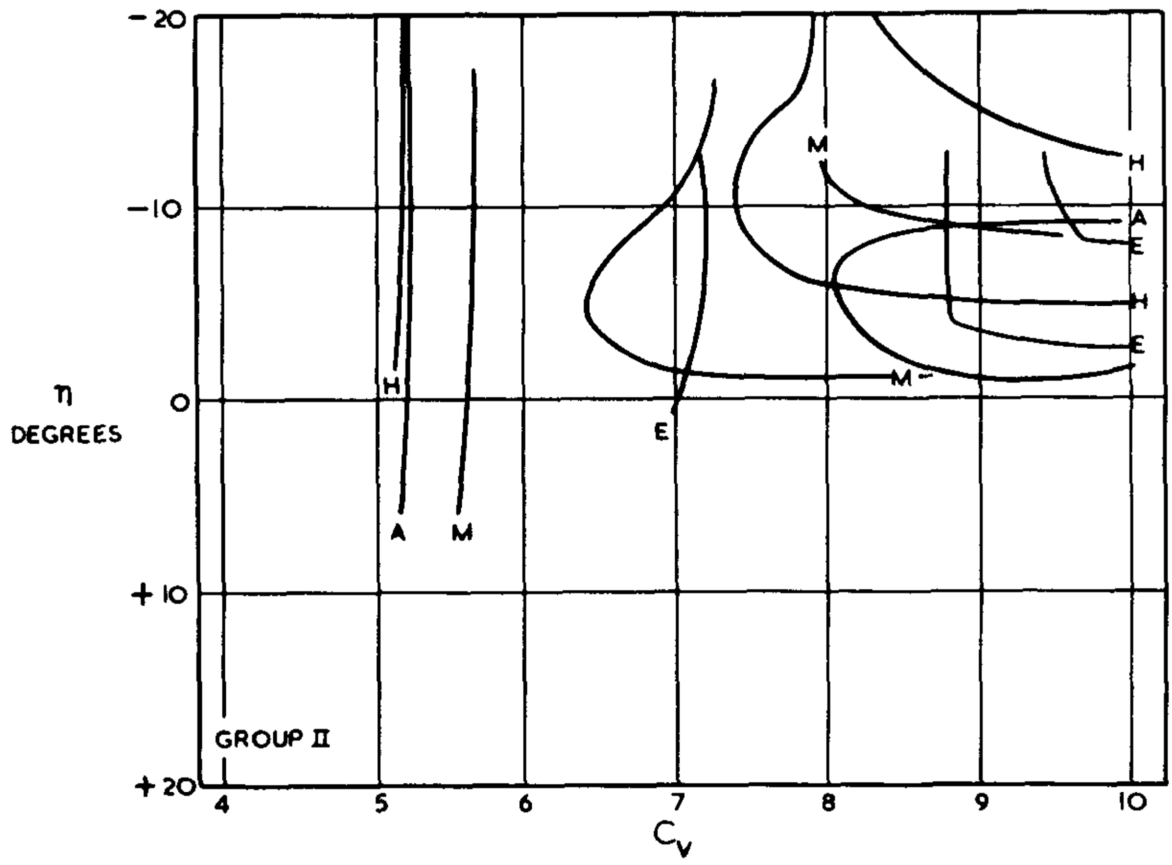
FIG. 12b.



RELATION BETWEEN ELEVATOR SETTINGS AND REDEFINED STABILITY LIMITS, UNDISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

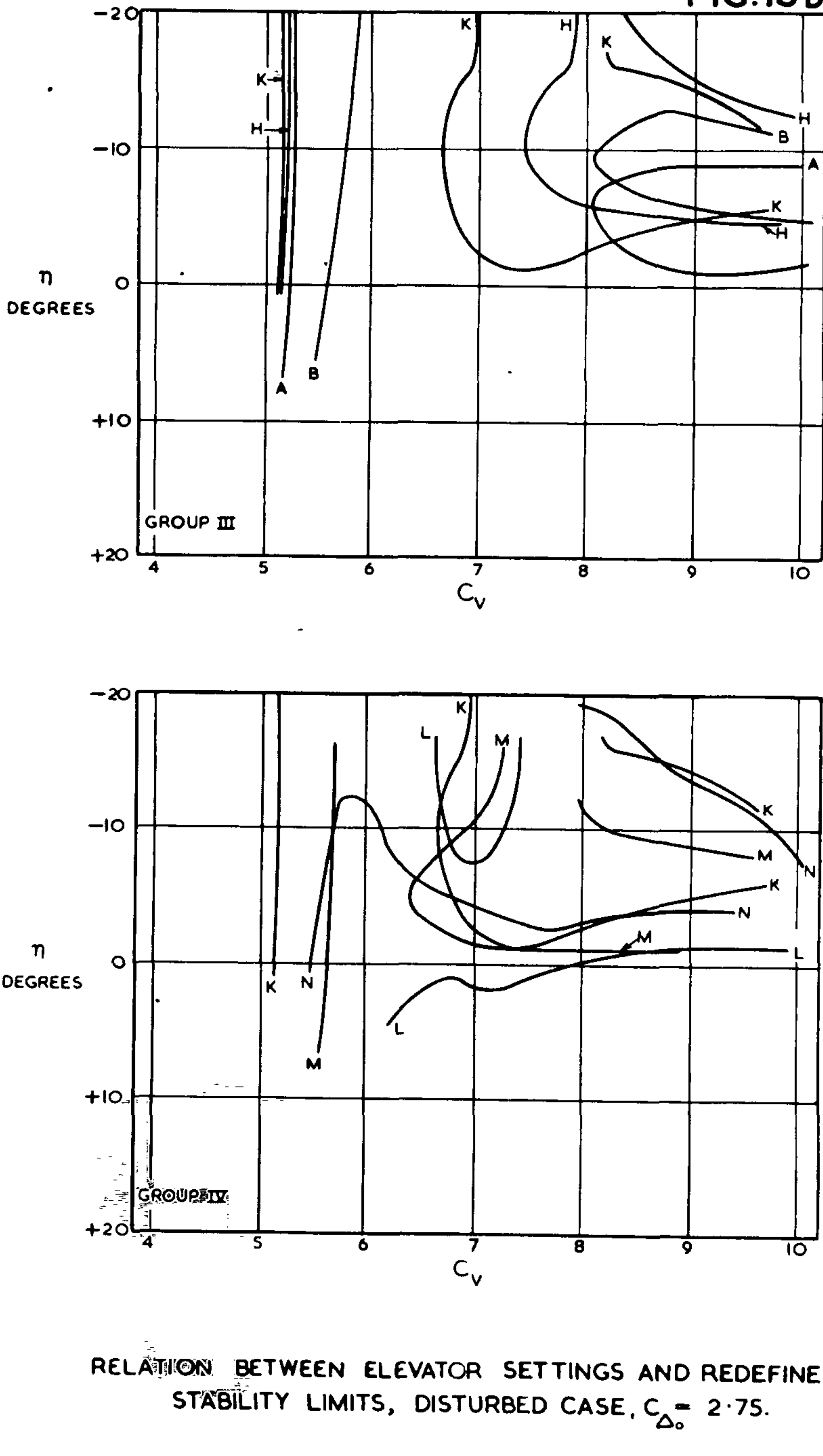
FIG. 13a.





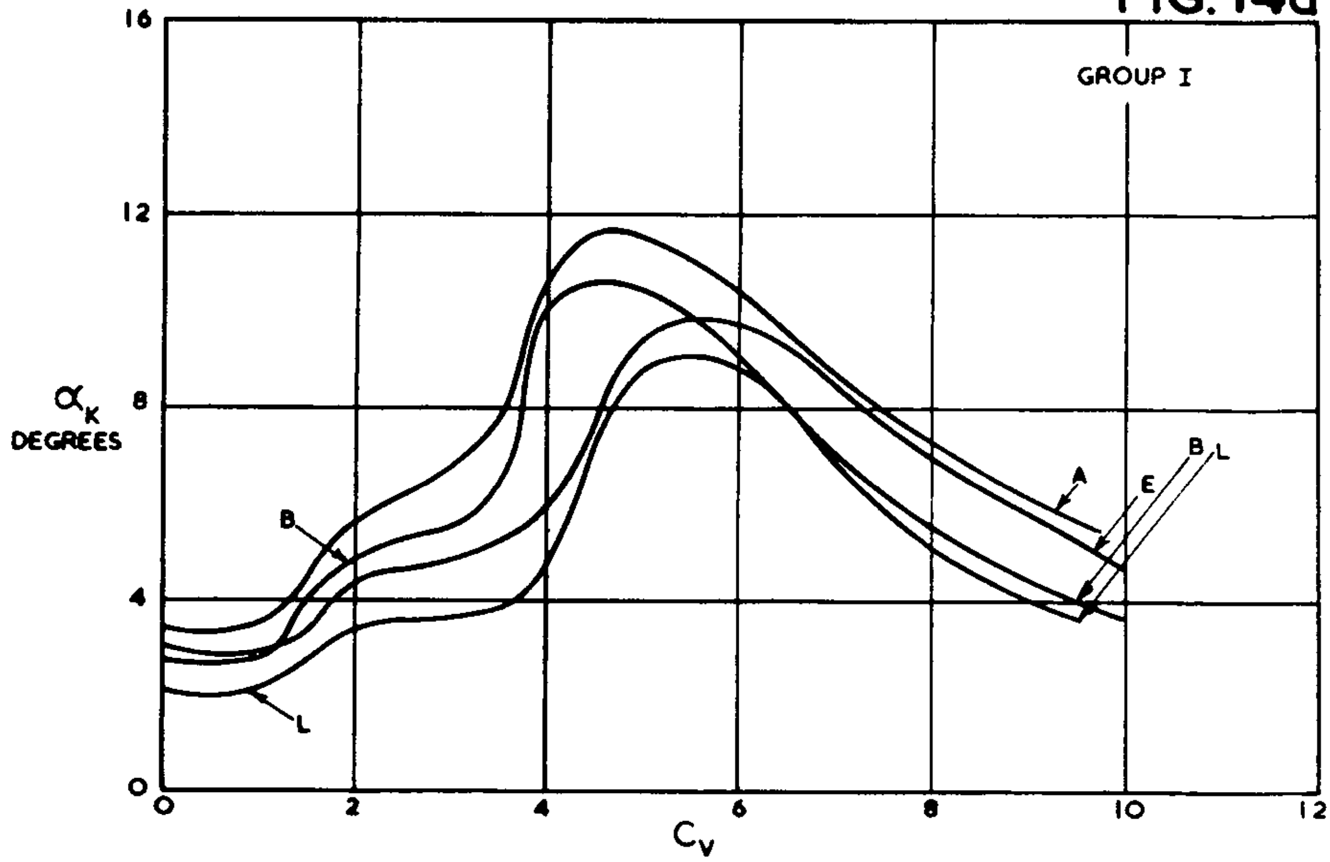
RELATION BETWEEN ELEVATOR SETTINGS AND REDEFINED STABILITY LIMITS, DISTURBED CASE, $C_{\Delta_0} = 2 \cdot 75$.

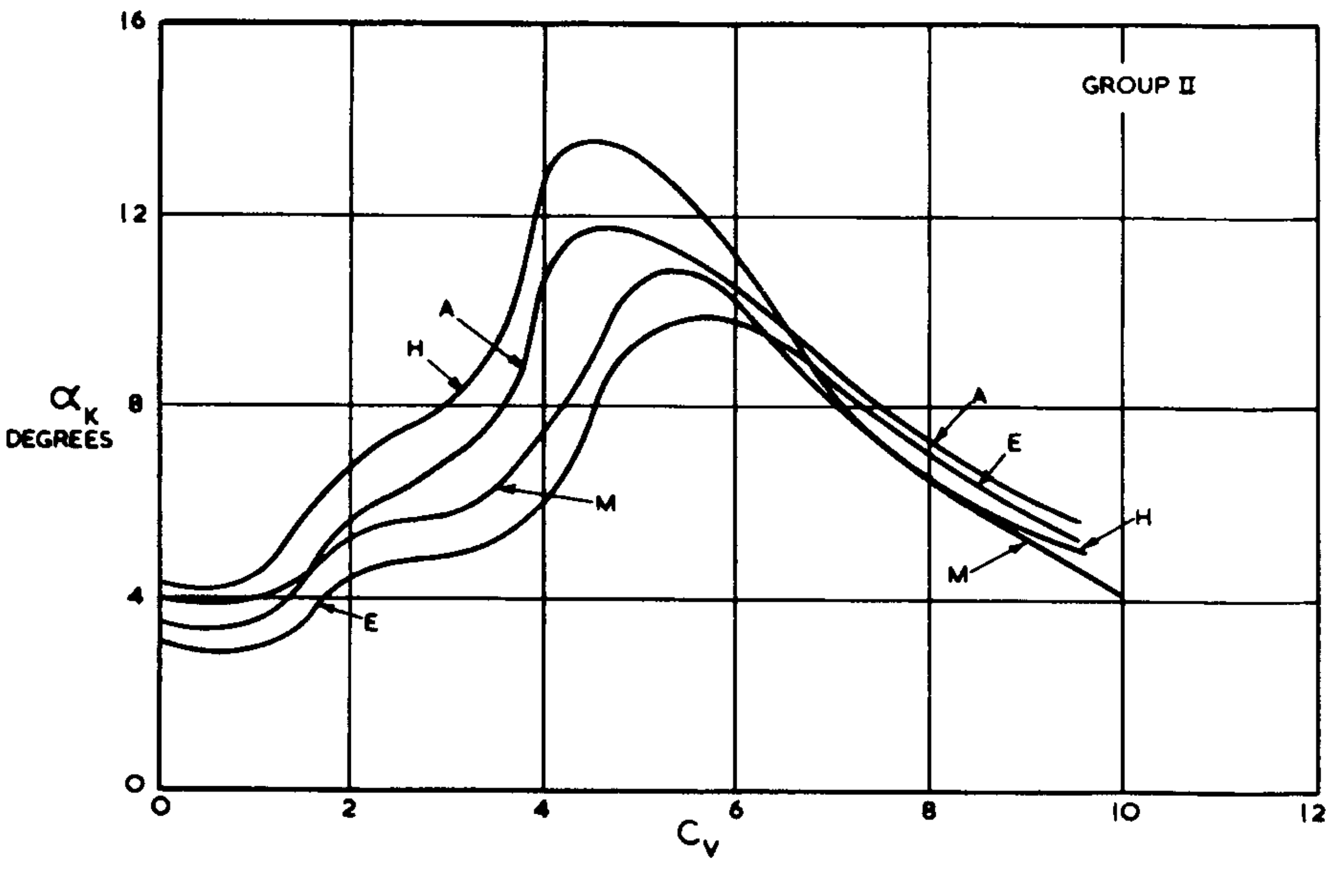
FIG. 13 b.



RELATION BETWEEN ELEVATOR SETTINGS AND REDEFINED STABILITY LIMITS, DISTURBED CASE, $C_{\Delta_0} = 2{\cdot}75$.

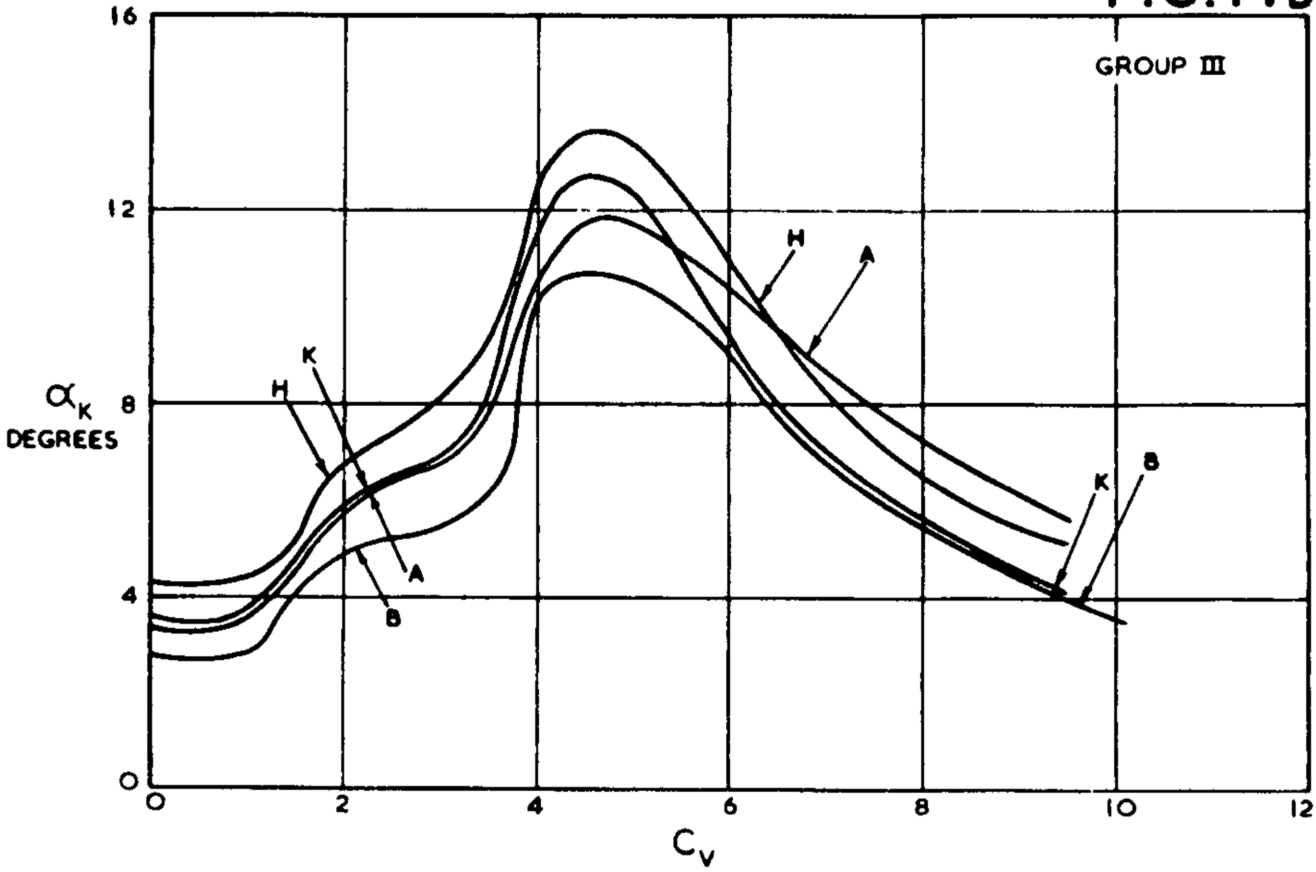
FIG. 14a.

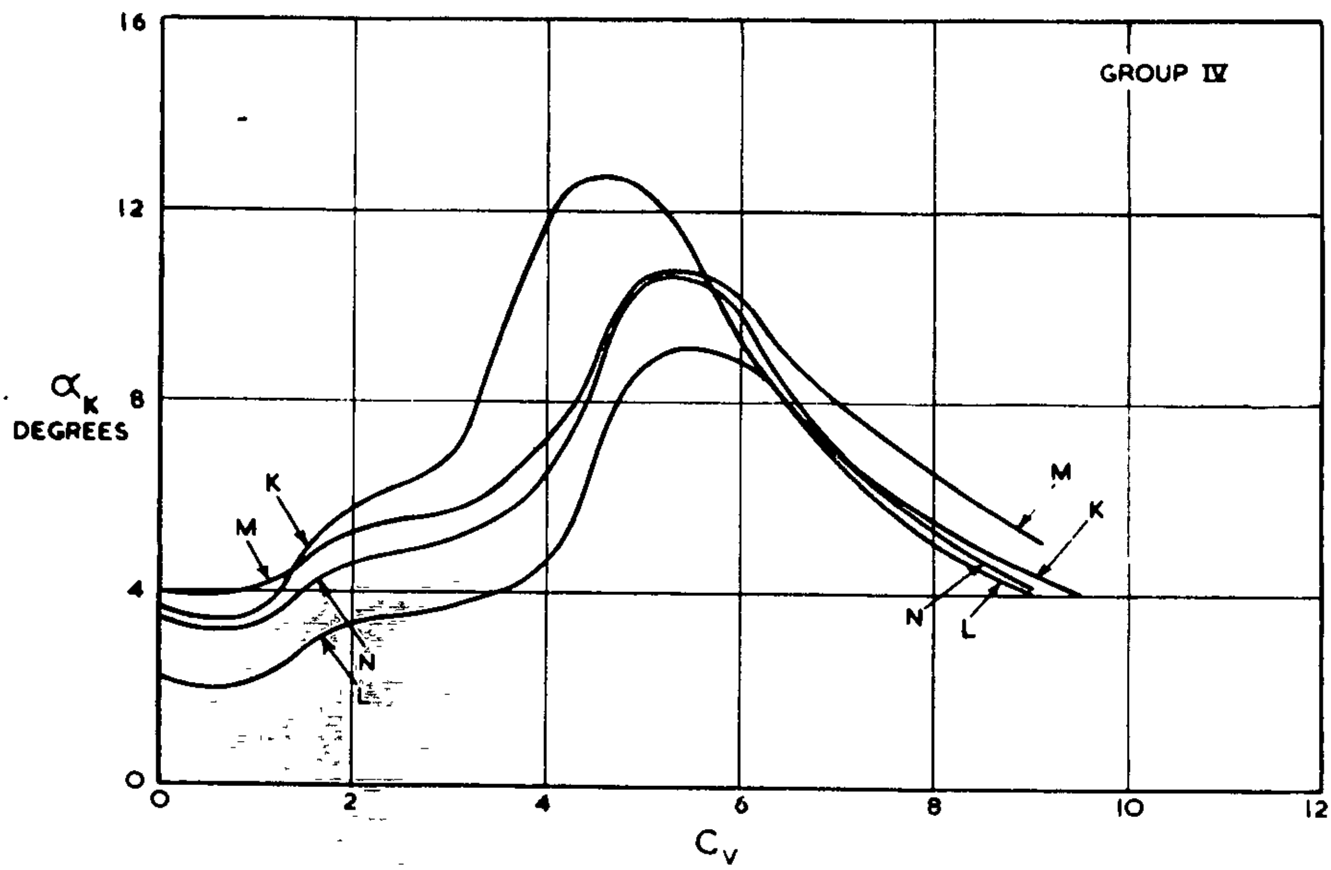




COMPARISON OF TRIM CURVES, $\eta = 0°$, $C_{\Delta_0} = 2\cdot75$.

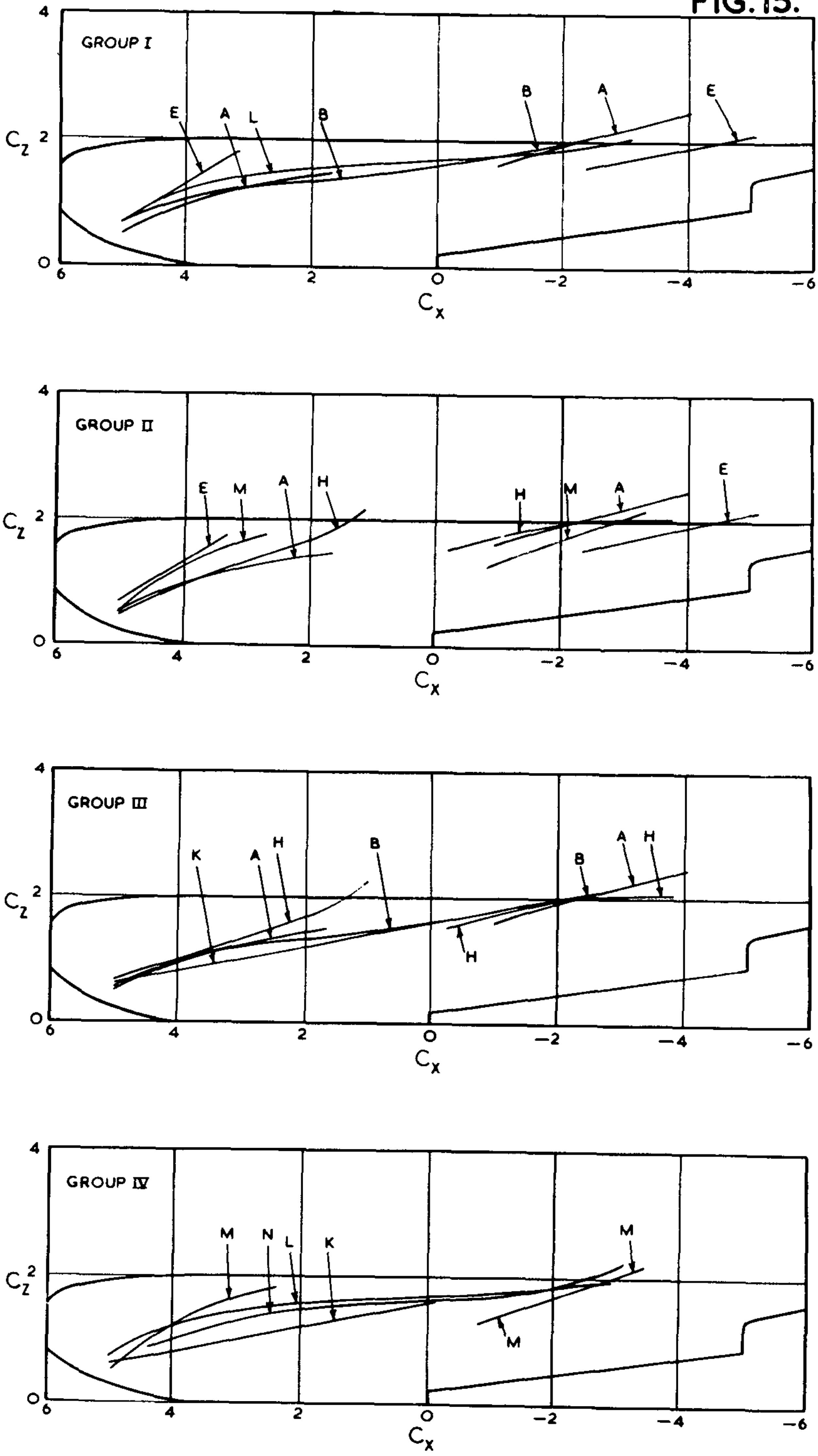
FIG. 14b.





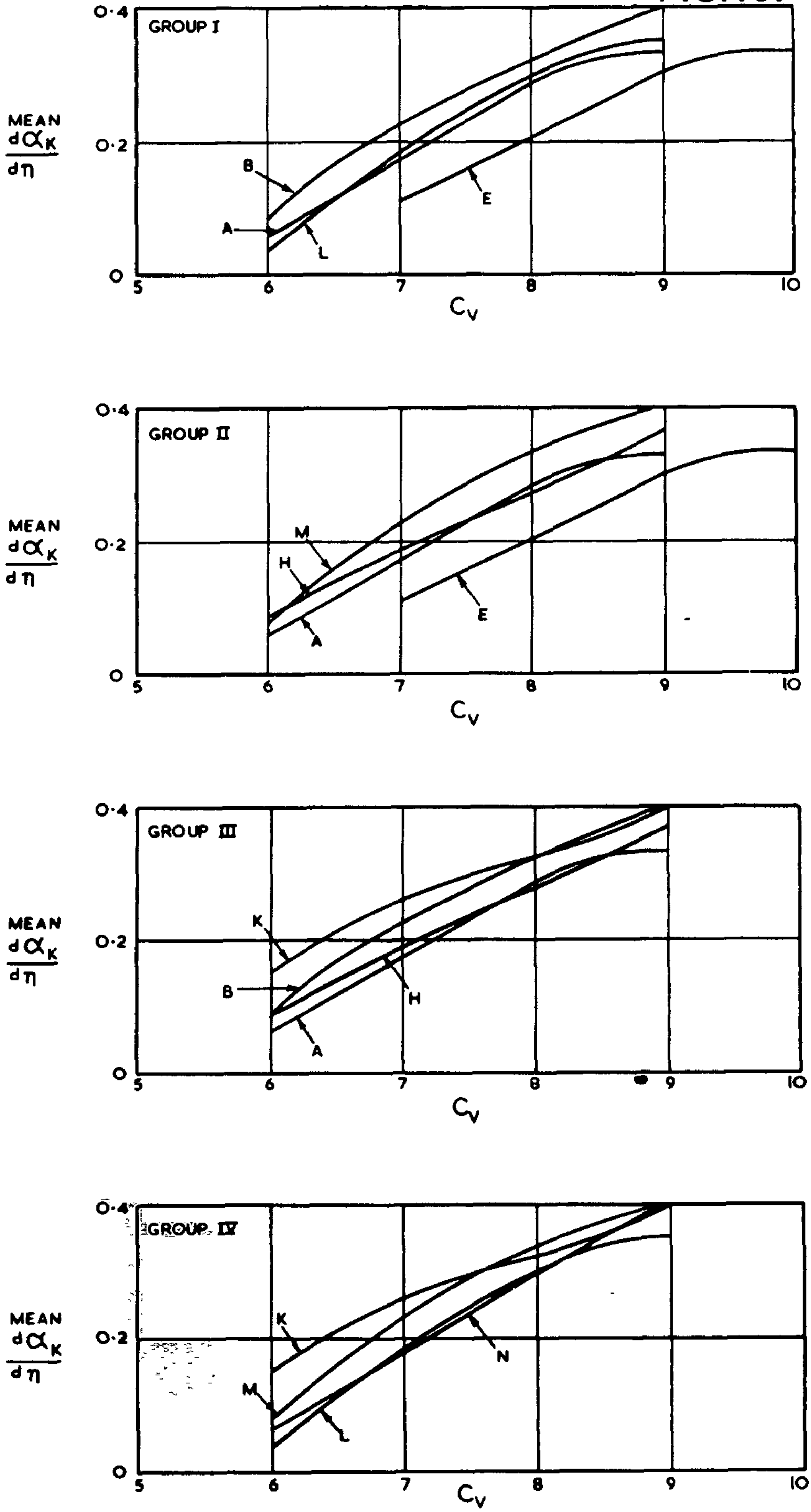
COMPARISON OF TRIM CURVES, $\eta = 0°$, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 15.



COMPARISON OF SPRAY PROFILES, $C_{\Delta_0} = 2 \cdot 75$.

FIG. 16.



COMPARISON OF ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 2{\cdot}75$.

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