WRW 96

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

96

WARTIME REPORT

ORIGINALLY ISSUED

September 1943 as
Advance Restricted Report 3I17

GENERAL PORPOISING TESTS OF FLYING-BOAT-HULL MODELS

By F. W. S. Locke, Jr.
Stevens Institute of Technology

NACA

WASHINGTON

34

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

GENERAL PORPOISING TESTS OF FLYING-BOAT-HULL MODELS

By F. W. S. Locke, Jr.

SUMMARY

This report gives evidence in support of the propriety of substituting, for many practical purposes, a "general" porpoising test of flying-boat-hull models in place of the usual "specific" test. The results of a general test of a particular model are presented and compared with the results of a specific test of the same model. The comparison is shown in charts (figs. 4 and 5).

The report also discusses appropriate average values of the variables necessarily considered for ordinary use in general testing. These variables are:

M_q aerodynamic pitch damping rate

I_p pitching moment of inertia

position of center of gravity

The terms "general" and "specific" are used in the sense in which they have been used for some time by the NACA in connection with resistance tests. (See NACA T.N. No. 464.)

INTRODUCTION

It was concluded in reference 1, from analyses of the results of systematic tests at this tank, that the porpoising characteristics of a given flying-boat hull are determined mainly by only three variables:

Δ load on water

V speed

M_q aerodynamic pitch damping rate

and that the limit curves of stability could be expressed as functions of the planing lift coefficient $\Delta/\frac{\rho_w}{2} V^2 b^2$ (actually the equivalent criterion $\sqrt{C_\Delta}/C_V$ has been found more convenient), with the aerodynamic pitch damping coefficient $\dfrac{M_q}{V \frac{\rho_w}{2} b^4}$ as a parameter.

This evidence strongly suggested that some general porpoising test might properly be substituted for the usual specific test. In a general porpoising test, as in a general resistance test, the controlling variable or variables would be altered in systematic steps to produce results applicable to any flying boat; in the specific test, the loadings and the aerodynamic characteristics of a particular flying boat are reproduced in the model test in their entirety.

The advantages of a general porpoising test are obvious; it would

(1) Provide a basis for predicting the porpoising characteristics of proposed complete airplanes prior to specific testing. The porpoising tests for a contemplated design could be run even prior to the fixing of final specifications for the aerodynamic structure and thus valuable time could be saved in the early stages of designing, when decisions for major changes are still possible.

(2) Facilitate direct comparison of the porpoising characteristics of different hull forms and thus enormously simplify any problem involving the hydrodynamic development of hull form.

A satisfactory general test would appear to be practically a prerequisite to the successful carrying out of any extensive exploration of the porpoising characteristics of systematically varied hull forms within a reasonable period of time.

The usual method of determining the longitudinal dynamic stability of a flying boat is to test a dynamically similar model, complete with wings and tail surfaces (sometimes even motor-driven propellers) reproduced in exact detail. This method, however useful for specific testing, has the difficulties that the aerodynamic characteristics are not easily determined nor readily altered. The method now employed at this tank, described in reference 3, differs in that the equivalent of the aerodynamic structure is supplied by a calibrated hydrofoil for lift forces and by mechanical means for pitching moments and damping. The aerodynamic characteristics are therefore under direct control at all times and may be varied at will. This feature made possible the strict system by which the specific tests analyzed in reference 1 were carried out and which has led in turn to the idea of general testing.

It is the purpose of this report to present the results of a general porpoising test of a particular model and to show the comparison between these and the results of a specific test of the same model. The agreement between the two tests is considered sufficiently good to constitute evidence of the practicability of general testing - at least for many purposes.

The important question of the choice of suitable average values of certain variables, for use under ordinary circumstances in general porpoising tests, is also discussed.

This investigation, conducted at Stevens Institute of Technology, was sponsored by, and conducted with financial assistance from, the National Advisory Committee for Aeronautics.

GENERAL PORPOISING TEST OF A PARTICULAR MODEL

Procedure Used for General Test

The same apparatus was used as is ordinarily employed at this tank for specific porpoising tests; this apparatus is described in detail in reference 3. For the present general tests, the hydrofoil which supplies the lift force and its derivatives in specific tests was removed from the apparatus, with its entire mechanism. This was the only change made.

The model and the parts of the apparatus moving vertically with it had a weight corresponding to $C_\Delta = 0.80$. In order to get other values of the load on the water, the model was loaded or unloaded without altering the moment of inertia in pitch. The following tabulation gives, in terms of load coefficient, the weight equivalent of the mass moving vertically (including unloading) for the various values of load on the water covered by the tests. This weight equivalent of the mass may be considered to be, so far as porpoising is concerned, the gross load.

Load on water, C_Δ	Weight equivalent of mass in vertical oscillation, C_{Δ_0}
0.10	1.50
.20	1.40
.40	1.20
.60	1.00
.80	.80
1.00	1.00

The design gross-load coefficient of the model was about 0.90, so that even at the very low values of C_Δ the weight in vertical oscillation during porpoising was never much more than 50 percent too high. From the evidence presented in the first section of Evidence Concerning Variables, this amount of excess weight would not be expected to have an appreciable influence on the limits of stability.

The recommended pitching moment of inertia calculated from the dimensions of the model, in accordance with the proposal in the second section of Selection of Values of Influential Variables, is 358 pound-inches^2. In this first trial of the general test method, it was convenient to stick to the value of pitching moment of inertia used in previous specific tests of the model, namely, 260 pound-inches^2. The recommended value is seen to be about 40 percent higher than the actual value used. From the evidence in the second section of Evidence Concerning Variables, this discrepancy would not be expected to affect appreciably the stability limits.

The aerodynamic pitch damping rate used was limited to one value of the coefficient $\dfrac{M_q}{V \frac{\rho_w}{2} b^4}$, to avoid stretching out the test program. The value used was 0.25, which is the middle of the three values proposed in the first section of Selection of Values of Influential Variables.

All tests were made at constant speed, in substantially still water, and otherwise in accordance with the detailed procedure ordinarily used for specific porpoising tests at this tank, as described in reference 3.

The tests for each load coefficient followed the same basic program, namely:

(1) Tests were made at each of a number of fixed speeds, the choice of speeds depending upon the load coefficient.

(2) At each speed, tests were made with various values of the applied moment to cover a range of steady-motion trims sufficient to embrace the upper and the lower stability limits.

(3) At each speed and applied moment, a test was made with a pitch damping rate corresponding to $\dfrac{M_q}{V \frac{\rho_w}{2} b^4} = 0.25$ as previously described.

When this rate failed to cause stability, an additional test was made with a large excess of pitch damping to define the steady-motion attitude.

(4) Graphical records were made of the steady-state, fully developed porpoising cycle for all tests in which porpoising occurred.

(5) The stability limit was arbitrarily defined as the trim at which the total sweep in trim angle during porpoising (that is, the double amplitude) is 2°. This definition is of greatest significance in connection with lower-limit porpoising, where the amplitude tends to increase progressively; in the case of upper-limit porpoising, which tends to start suddenly and may often consist principally of vertical motion, an arbitrary definition of the stability limit is largely unnecessary. In the experience of this tank, porpoising cycles in which a substantial amplitude in heave occurred without at least 2° sweep in trim have been exceedingly rare (the model being, of course, free to trim).

General-Test Results and Comparison with Specific-Test Results

The general-test results are shown in detail in figures 1 to 3 in large charts, each of which gives complete data for one value of C_Δ. These figures are the usual wall-paper charts of trim against speed, as used at this tank; details of their form and preparation will be found in reference 3. Cross plots of the trim sweep in porpoising against the steady-motion trim were prepared from the porpoising cycles shown on these charts - from which, in turn, the arbitrarily defined stability limit (20° sweep) was read. The stability limits, obtained in this way, are shown in figure 4, plotted against the criterion $\sqrt{C_\Delta}/C_V$. This chart shows also, for direct comparison, the limits for a specific test of the same hull. The specific test was made under the particulars and specifications of the XPB2M-1 airplane, as used in reference 3. It is clear that the agreement between the results from the two types of test is very good and that only one curve is needed for either the lower-limit or the upper-limit points from both tests.

Figure 4 shows a chart for the specific test and, for comparison, a chart for the same particulars and specifications built up from the general-test charts of figures 1 to 3. Again, the results from the two types of test are seen to be in good agreement. The actual porpoising cycles are not everywhere identical but they are reasonably alike, and it is apparent that both charts define the same limit curves without abusing either set of data.

The fading out of the upper-limit curve at high speeds was not very thoroughly investigated in the general tests herein reported. At $C_\Delta = 0.20$, the upper limit is in the process of dying out at the highest speed tested. At $C_\Delta = 0.10$, tests were made at only three very high speeds and at none of these was any upper-limit porpoising found - though it seems probable that it would have occurred at lower speeds. The presence or absence of the high-speed end of the upper-limit curve is important in practice; attention should therefore be given to exploring this region in the course of future general tests.

The lowest speeds for inception of both upper-limit and lower-limit porpoising are given in the following table, which is reproduced from figure 4.

C_Δ	C_V		$\sqrt{C_\Delta}/C_V$	
	Lower limit	Upper limit	Lower limit	Upper limit
General test				
0.10	-----	-----	-----	-----
.20	-----	4.48	-----	0.100
.40	2.87	4.28	0.220	.148
.60	3.10	4.28	.250	.181
.80	3.33	4.47	.268	.200
1.00	3.80	5.18	.263	.193
Specific test				
----------	3.15	4.15	0.257	0.166

It will be seen from this table that, for all practical purposes, lower-limit porpoising may be considered to start when the value of $\sqrt{C_\Delta}/C_V$ becomes less than about 0.260. The starting of upper-limit porpoising, on the other hand, is governed by two conditions: (1) the value of C_V must be greater than 4.35, which is the average of the values of C_V for all C_Δ values except 1.00; and (2) the value of $\sqrt{C_\Delta}/C_V$ must be less than 0.200.

If sufficient test information were available, conditions for the ending of upper-limit porpoising, at high speeds, could presumably have been similarly codified.

At the time figure 5 was prepared, there was some discussion of the indication that upper-limit porpoising did not start at a constant value of $\sqrt{C_\Delta}/C_V$. The suggestion was made that there might be some discontinuities in the moment curves in the region. In order to investigate this possibility, figure 6 was prepared. This chart shows a plot of $\sqrt{C_\Delta}/C_V$ against trim, with the trimming moment coefficient $C_M = M/wb^4$ as a parameter. The points shown are from auxiliary cross plots of moment against trim. The values of the trimming moment for the curves are close to the actual test moments, so that undue cross fairing is not involved. The points scatter about as much as the limit points in figure 5 so that it is difficult to tell whether or not there is a discontinuity in the moment curves in the upper-limit region; if there is a discontinuity, it is evidently very small. By far the most significant point brought out by this chart is that the trimming moment, like the stability limits, is primarily a function of the trim angle and of $\sqrt{C_\Delta}/C_V$ only.

Figure 7 is a final summary chart of the dynamic stability and moment characteristics of the hull under consideration, prepared by tracing the curves of figures 5 and 6. This chart may be used to calculate the stability limits of the hull in combination with any desired gross weight, aerodynamic characteristics of the wing, inclination of the thrust axis, and similar factors. The moment characteristics permit calculating the free-to-trim track and the available trim range with any desired longitudinal position of the center of gravity, elevator moments, and so on.

INFLUENTIAL VARIABLES IN GENERAL TESTING

Before general porpoising tests can be run, it is necessary to decide which of the variables can safely be neglected and to determine suitable values for those that cannot be neglected. A study was made in reference 1 of the effect of various variables on the porpoising characteristics of the XPB2M-1, as indicated by systematic specific tests. This part of the report considers that study as well as the results of other investigators and gives recommended values for the variables which have to be considered.

Evidence Concerning Variables

Mass in vertical oscillation.- Figure 8 shows the results of specific tests of the XPB2M-1 at various gross loads, from references 1 and 3. The limit of stability is plotted against the criterion $\sqrt{C_\Delta}/C_V$. Changes of the gross load C_{Δ_0} are, on this basis, changes of the mass in vertical oscillation only and, in the tests shown, the moment of inertia was kept constant.

The NACA has recently made some experiments on the lower-limit porpoising characteristics of a forebody alone (reference 2) with a model having only horizontal tail surfaces and loaded or unloaded to get desired values of C_Δ. It will be seen that the method used was not unlike that employed in the general porpoising tests considered in this report. These experiments have been analyzed by plotting the critical trim against the ratio $\sqrt{C_\Delta}/C_V$. (A similar form of plotting has recently been used by the NACA in references 11 and 12.) The results, shown in figure 9, are for two different values of the mass in vertical oscillation, each tested at four different values of C_Δ. Figure 10 is similar to figure 9 except that the longitudinal position of the center of gravity is different from that for the data of figure 9. For all these tests the radius of gyration was kept constant.

Study of the three charts in figures 8 to 10 indicates that, within the ranges covered, the magnitude of the mass in vertical oscillation has no definable influence on the limits of stability. Additional confirmation of this conclusion has been found recently in the unpublished specific tests at this tank of another model where the gross load was varied.

In an actual airplane, the mass in vertical oscillation must always correspond, of course, to the actual gross weight. In general porpoising tests, therefore, the mass in vertical oscillation probably should not be allowed to depart too far from the design gross weight of the hull, if this is known; but, since the data of figures 8 to 10 indicate that doubling the mass has no appreciable influence on the stability limits, it is apparent that no great emphasis need be placed on using a very exact value.

Pitching moment of inertia.- The data of figure 8, from reference 3, are for tests of the XPB2M-1 made at several different gross weights but with only one moment of inertia. Additional experiments, from the same reference, showed that increasing the pitching moment of inertia by 50 percent at one gross weight lowered the lower limit by only a very slight amount at low speeds and had practically no other effect on the limits. These experiments indicate, therefore, that neither the moment of inertia nor the radius of gyration has any appreciable influence on the stability limits.

British experiments (references 6 and 7) have shown that increasing the moment of inertia by as much as 100 percent without altering the mass has only very minor effects on both the lower limit and the upper limit.

The NACA tests of a forebody alone (reference 2) covered this point indirectly. The results, plotted in figure 11, are not in full agreement with the afore-mentioned tests because a similar change of mass at constant moment of inertia - that is, an alteration in the radius of gyration - had a moderate effect on the stability limit.

All sources are in agreement that the main effects of increasing the moment of inertia are to decrease the frequency of oscillation and to increase somewhat the amplitudes of the fully developed porpoising oscillations.

The fact that the pitching moment of inertia may have a small influence on the stability limits is not an important objection to the use of general porpoising tests because, as discussed later, the pitching moment of inertia of actual flying boats is primarily a function of the hull length, so that a reasonably reliable value is readily deduced for any hull.

Center-of-gravity position.- The specific tests of the XPB2M-1 (reference 3) show that altering the longitudinal position of the center of gravity causes certain minor changes in the lower-limit curve at low speeds but has no other effect on the stability limits.

Figure 12 shows the results of the NACA tests in reference 2. The same data are included as in figures 9 and 10, but they are differentiated on the plot only when the longitudinal position of the center of gravity differs. It is clear that the longitudinal position of the center of gravity has no distinguishable influence on the stability limit.

British tests (references 6, 7, and 9) are in agreement in that the lower limit at low speeds is slightly affected. In one case, an effect was found on the upper limit. The same British tests showed the vertical position of the center of gravity to have no distinguishable effect.

The NACA results in figure 13, also from reference 2, are the only ones available which permit isolating the effect of varying the height of the center of gravity above the keel. The results are somewhat scattered, but there is no clear indication that the vertical position of the center of gravity has any appreciable influence on the lower limit.

The longitudinal position of the center of gravity, though unimportant in fixing the stability limits, is very important in an actual flying boat because of its major effect on the free-to-trim track and the available trim range. General porpoising tests should ordinarily be run, therefore, with a center-of-gravity position which will result in a desirable trim track. The effect on trim of altering the gravity position is easily computed after the tests are completed.

Aerodynamic derivatives.- The analyses in reference 1 indicate that the only aerodynamic derivative not affecting the net load on the water in steady motion and which has any influence on the stability limits is the aerodynamic pitch damping rate M_q.

It has been found at this tank (references 3, 5, and 10), and also in British experiments (references 7 and 8), that the pitch damping rate has an appreciable effect on the lower limit at high planing speeds. However, if M_q has a value within the range ordinarily found in modern practice, further increase is found to have comparatively little effect. Therefore, while it is desirable that a good average value of tail damping be used in general porpoising tests, the precise value selected is not particularly important. This is especially true in view of the fact that the principal effect is on the lower limit at high planing speeds, which is a region of comparatively little practical importance.

The influence of pitch damping rate on the upper limit of stability appears to be confined to affecting, to a small extent, the speeds at which upper-limit porpoising begins and ends; it has no measurable effect on the location of the upper-limit curve.

Résumé.- To sum up, only two of the possible 11 variables which might conceivably influence the stability limits have any noticeable effect, provided that

(1) None of the others have absurdly impractical values.

(2) The limit curves are considered in terms of the criterion $\sqrt{C_\Delta}/C_V$

Variable	Influence
Speed, Load on water } when combined to $\sqrt{C_\Delta}/C_V$	Negligible
Mass in vertical oscillation	Do.
Pitching moment of inertia	Slight
Center-of-gravity position	Negligible
Aerodynamic Z_θ	Do.
Aerodynamic Z_w	Do.
Aerodynamic Z_q	Do.
Aerodynamic M_θ	Do.
Aerodynamic M_w	Do.
Aerodynamic M_q (pitch damping rate)	Appreciable

For purposes of general testing, it remains, therefore, to select appropriate values of the aerodynamic pitch damping rate and of the pitching moment of inertia. These are discussed hereinafter, where some consideration is given also to convenient positions of the center of gravity. All three are necessarily decided upon before testing can proceed.

Selection of Values of Influential Variables

<u>Aerodynamic pitch damping rate M_q</u>.- As pointed out in the discussion the precise values of the pitch damping coefficient, $\dfrac{M_q}{V\,\frac{\rho_w}{2}\,b^4}$ selected for general porpoising tests can be more or less arbitrary. Figure 14 shows calculated values of this coefficient for a number of representative flying boats. The American and British hulls

shown, having been constructed during the last decade, are all fairly modern. All of the values of M_q were calculated by the same method, for the horizontal tail alone, from the equation:

$$M_q = K \frac{\rho_a}{2} S_t \, l_t^2 \, V \left(\frac{dC_L}{d\alpha}\right)_t \qquad (1)$$

The value of K was taken as 1.00. The values of S_t and l_t were taken from reference 4. The ratio $\left(\frac{dC_L}{d\alpha}\right)_t$ was calculated for each case from unpublished curves of coordinated wind-tunnel tests furnished by one of the aircraft manufacturers.

The practice at this tank for an extensive series of specific porpoising tests of modifications of the XPB2M-1 (reference 3) has been to use three values of the coefficient $\frac{M_q}{V \frac{\rho_w}{2} b^4}$ - namely, 0.125, 0.250, and 0.500 - when occasion demands but to emphasize the middle value for most testing. Figure 14 indicates that these three values satisfactorily cover the range of tail damping rates which have been used in actual practice. It therefore appears that the same values, with emphasis on the middle value, should be reasonably satisfactory for general porpoising tests of most hulls.

<u>Pitching moment of inertia</u>.- The pitching moment of inertia has little influence on the limits of stability but affects the time scale of the motion; and, in any case, a value is necessarily predetermined before porpoising tests can proceed. It is possible to show that, in practice, the pitching moment of inertia is chiefly a function of the hull length.

Benson (reference 2) plotted the pitching radius of gyration against the gross load, on a coefficient basis. It was found that k/b increased fairly rapidly with C_{Δ_0}. The data of reference 3 have been replotted in figure 15, together with various values accumulated at this tank. This chart indicates a lower rate of increase than Benson's and clearly does not abuse Benson's data. The mean line shown is given by

$$\frac{k}{b} = 1.38 \left(C_{\Delta_o}\right)^{1/3} \tag{2}$$

Benson did not give a statement of lengths with the data. In reference 4, page 5, it is suggested that the length-beam ratio may be represented by

$$\frac{L}{b} = 6.05 \left(C_{\Delta_o}\right)^{1/3} \tag{3}$$

so that combining equations (2) and (3) gives

$$k = 0.227\ L \tag{4}$$

which indicates that k/L is independent of L.

Other information collected at this tank, shown in figure 16, indicates that a slow decrease of k/L with increasing L is probably more nearly correct. In any case, it is obvious that an assumption that k is primarily a function of hull length L is close to the facts.

For the purposes of general testing, the curve of figure 16 appears to be a satisfactory guide to fixing the value of k. Equation (3) may then be used (since L will be known) to deduce a value of mass for computation of the pitching moment of inertia by throwing it into the form

$$L = 6.05 \left(\frac{m}{\rho_w}\right)^{1/3} \tag{3a}$$

from which

$$m = \rho_w \left(\frac{L}{6.05}\right)^3$$

Center-of-gravity position.- It is desirable, for reasons of convenience, that the position of the center of gravity be such that the free-to-trim track misses the lower limit of stability just past the hump and lies between the two limits at high speeds. This will ordinarily be accomplished, with reasonably conventional hulls, if a line joining the tip of the main step with the center of gravity slopes forward, with respect to a perpendicular to the forebody keel, by 20° to 25°.

Another, and possibly better, rule is to locate the center of gravity between 0.35b and 0.40b forward of the step. The vertical location is less important but may well be between 0.80b and 1.00b above the forebody keel for flying boats and perhaps 2.00b above the forebody keel for float seaplanes. (See reference 4.)

CONCLUSIONS AND RECOMMENDATIONS

The porpoising characteristics of a flying-boat hull may be determined by a general porpoising test, in which all of the aerodynamic characteristics - with the exception of the pitch damping rate M_q - are neglected. The stability limits, determined at various loads, can be reduced to a single set of curves, with $\dfrac{M_q}{V \frac{\rho_w}{2} b^4}$ as a parameter, by plotting against the criterion $\sqrt{C_\Delta}/C_V$.

Appropriate mean values can be deduced for the variables necessarily decided upon before general porpoising tests can be made. These are discussed in the section Selection of Values of Influential Variables, where the following values are recommended:

Aerodynamic tail-damping rate, M_q

$$\frac{M_q}{V \frac{\rho_w}{2} b^4} = 0.125,\ 0.250,\ 0.500$$ with emphasis on the middle value

Pitching moment of inertia

$$\frac{k}{L} = 0.225$$

$$m = \rho_w \left(\frac{L}{6.05}\right)^3$$

Center-of-gravity position

0.35b to 0.40b ahead of main step

0.80b to 1.00b above the forebody keel for flying boats and
2.00b above the forebody keel for float seaplanes

A final chart of the type of figure 7 shows both the porpoising and the moment characteristics of a given hull. Such a chart can be used to predict the porpoising characteristics of proposed complete flying boats or to compare hull designs. Work now in progress aims to present information on resistance, spray-throwing, and directional-stability characteristics in parallel simple form.

Experimental Towing Tank,
Stevens Institute of Technology,
Hoboken, N.J., July 10, 1943.

REFERENCES

1. Davidson, K. S. M., and Locke, F. W. S., Jr.: Some Analyses of Systematic Experiments on the Resistance and Porpoising Characteristics of Flying-Boat Hulls. NACA A.R.R., Sept. 1943.

2. Benson, James M.: The Porpoising Characteristics of a Planing Surface Representing the Forebody of a Flying-Boat Hull. NACA A.R.R., May 1942.

3. Davidson, Kenneth S. M., and Locke, F. W. S., Jr.: Some Systematic Model Experiments on the Porpoising Characteristics of Flying-Boat Hulls. NACA A.R.R., June 1943.

4. Locke, Fred W. S., Jr.: A Correlation of the Dimensions, Proportions, and Loadings of Existing Seaplane Floats and Flying-Boat Hulls. NACA A.R.R., March 1943.

5. Anon.: Porpoising Investigation. Experiments with Model No. 294-9 (Progress Report No. 1 on Research Project R-35). T.M. No. 46, Stevens Inst. Tech., 1941.

6. Coombes, L. P., Perring, W. G. A., and Johnston, L.: The Use of Dynamically Similar Models for Determining the Porpoising Characteristics of Seaplanes. R. & M. No. 1718, British A.R.C., 1936.

7. Perring, W. G. A., Coombes, L. P., and Johnston, L.: Tank Tests on a Dynamic Model of the Singapore IIa. Rep. No. B.A. 1050, R.A.E. (British), 1933.

8. Garner, H. M.: Porpoising Tests on a Model of a Flying Boat Hull. R. & M. No. 1492, British A.R.C., 1932.

9. Perring, W. G. A., and Hutchinson, J. L.: Full Scale and Model Porpoising Tests of the Singapore IIC. R. & M. No. 1712, British A.R.C., 1936.

10. Davidson, Kenneth S. M., Locke, F. W. S., Jr., and Suarez, A.: Porpoising - A Comparison of Theory with Experiment. NACA A.R.R., July 1943.

11. Benson, James M., and Lina, Lindsay J.: The Effect of Dead Rise upon the Low-Angle Type of Porpoising. NACA A.R.R., Oct. 1942.

12. Benson, James M., and Klein, Milton M.: The Effect of Dead Rise upon the High-Angle Porpoising Characteristics of Two Planing Surfaces in Tandem. NACA A.R.R., June 1943.

BIBLIOGRAPHY

Parkinson, John B., and Olson, Roland E.: Tank Tests of a 1/5 Full-Size Dynamically Similar Model of the Army OA-9 Amphibian with Motor-Driven Propellers - NACA Model 117. NACA A.R.R., Dec. 1941.

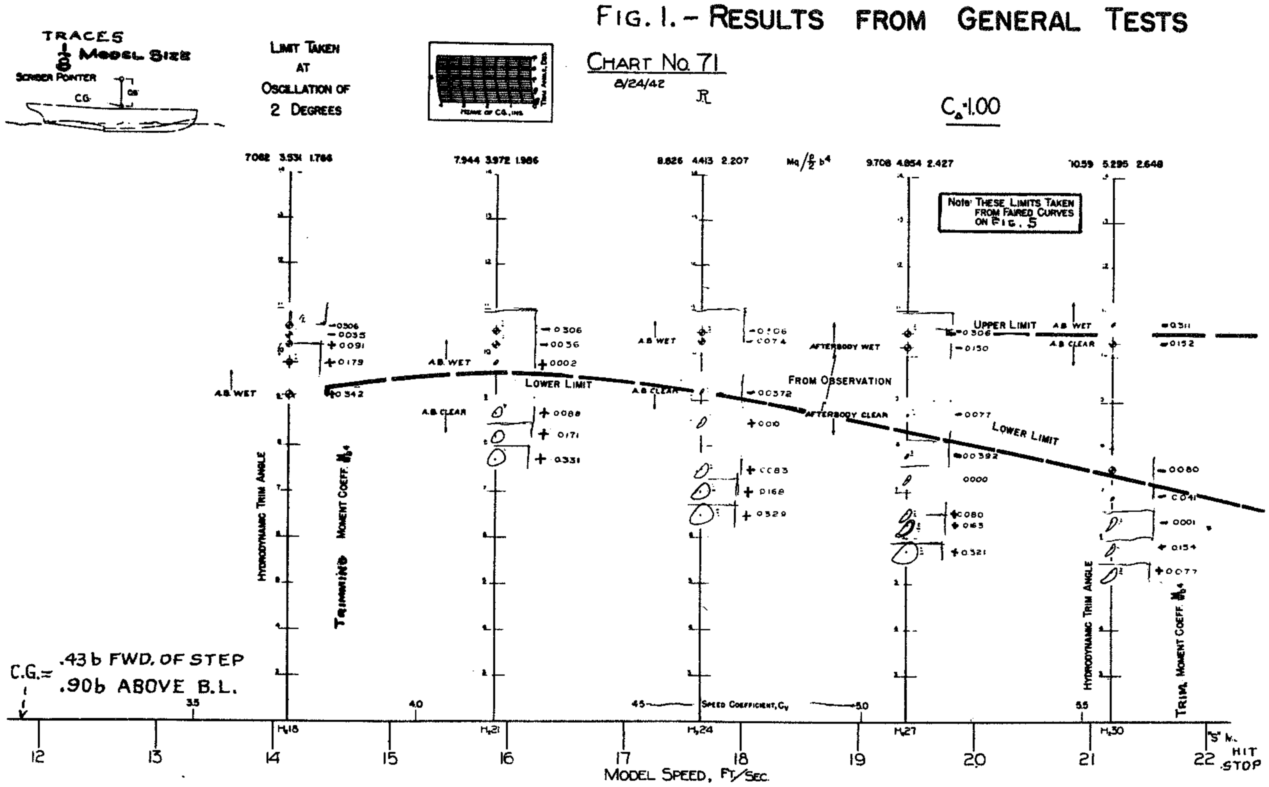
Perring, W. G. A., and Glauert, H.: The Stability on the Water of a Seaplane in the Planing Condition. R. & M. No. 1493, British A.R.C., 1933.

Perring, W. G. A., and Johnston, L.: The Hydrodynamic Forces and Moments on Simple Planing Surfaces, and an Analysis of the Hydrodynamic Forces and Moments on a Flying Boat Hull. R. & M. No. 1646, British A.R.C., 1935.

Schröder, Paul: The Take-Off of Seaplanes, Based on a New Hydrodynamic Reduction Theory. T.M. No. 621, NACA, 1931.

Shoemaker, James M., and Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - NACA Model No. 11. T.N. No. 464, NACA, 1933.

FIG. 1.- RESULTS FROM GENERAL TESTS



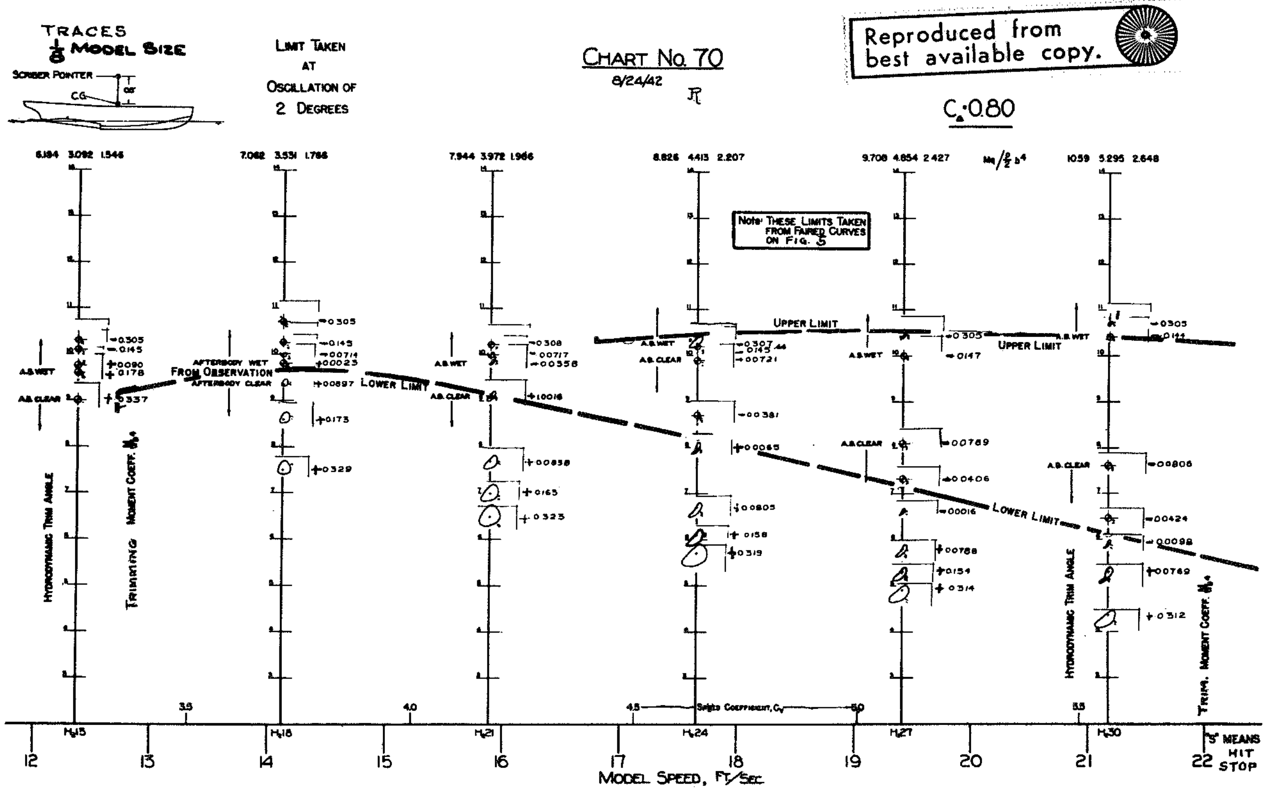
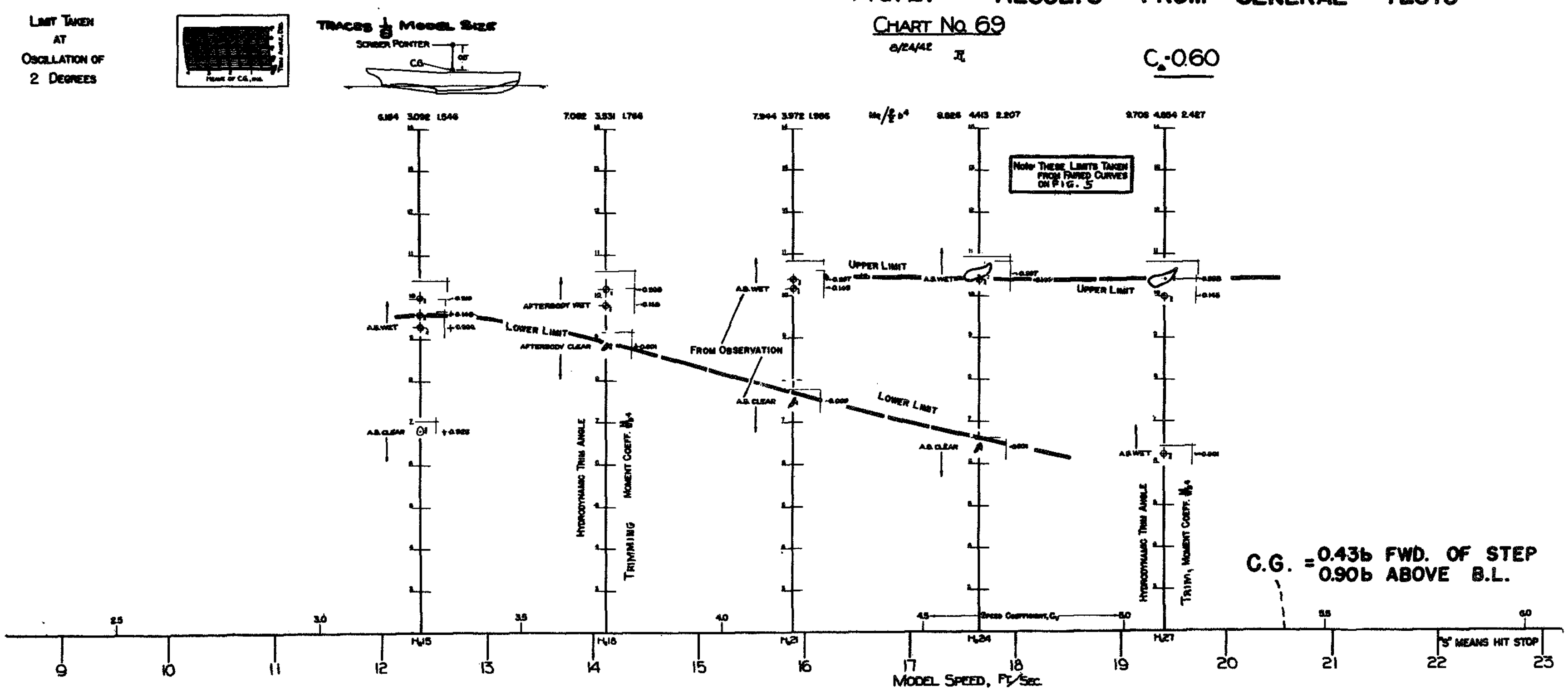


FIG. 2. - RESULTS FROM GENERAL TESTS



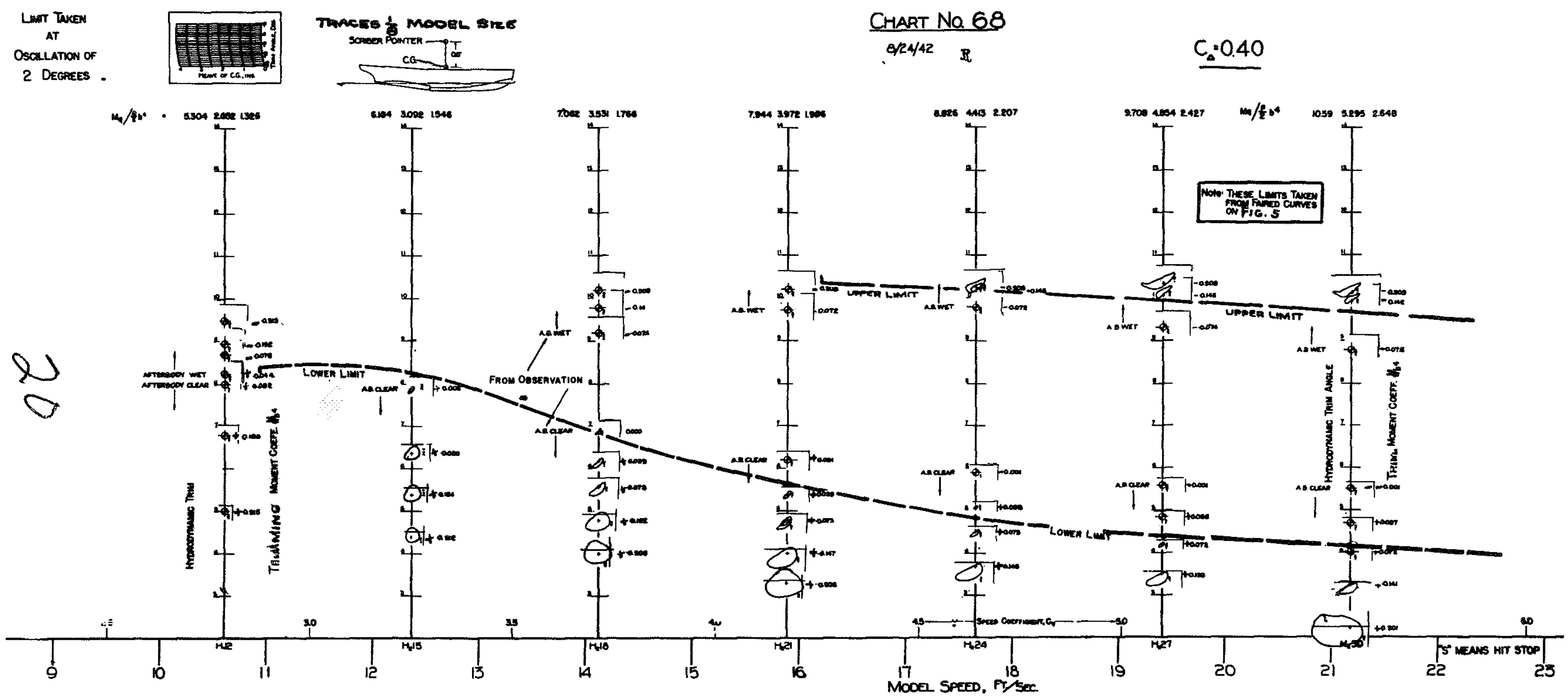


FIG. 2 CONTINUED.

FIG. 3. – RESULTS FROM GENERAL TESTS

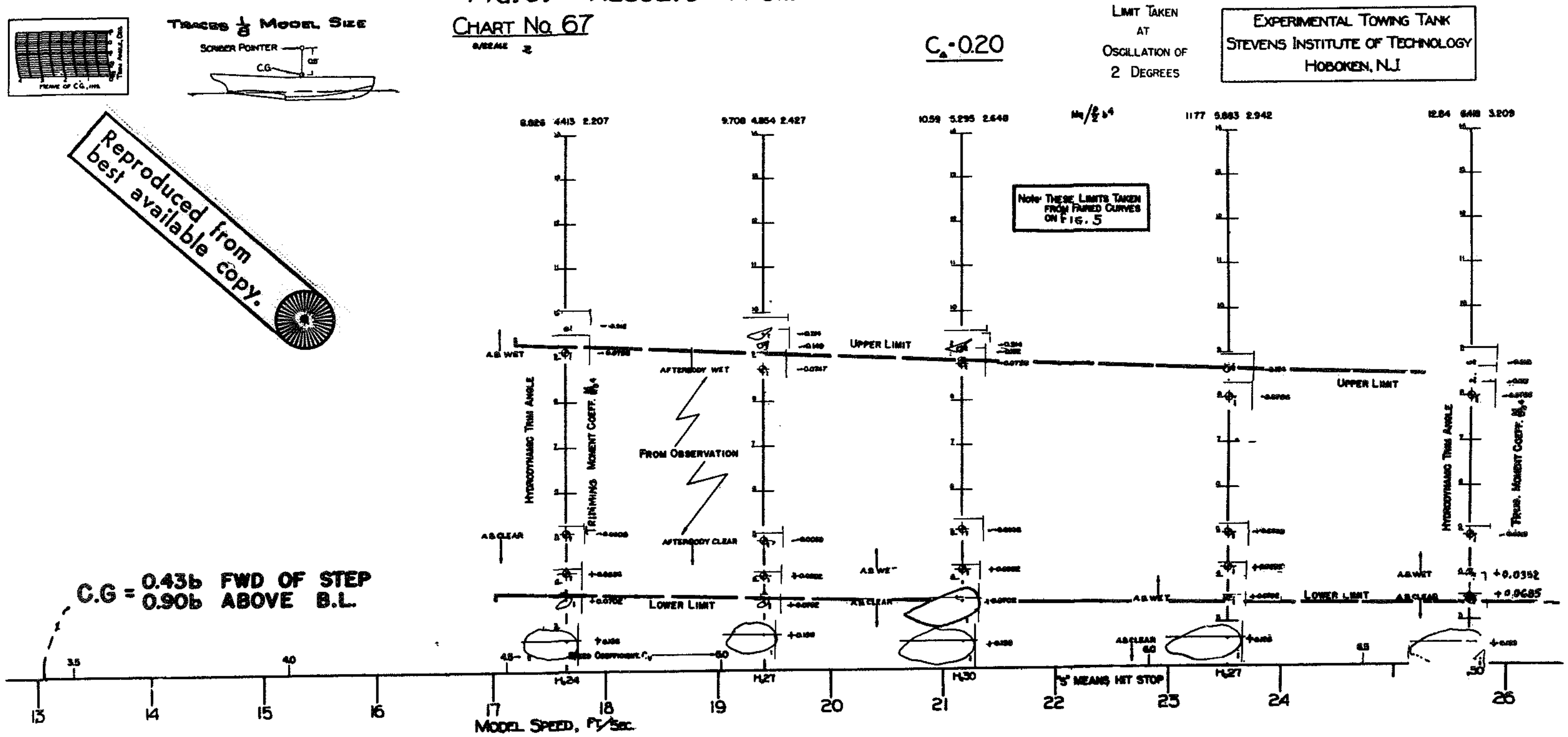
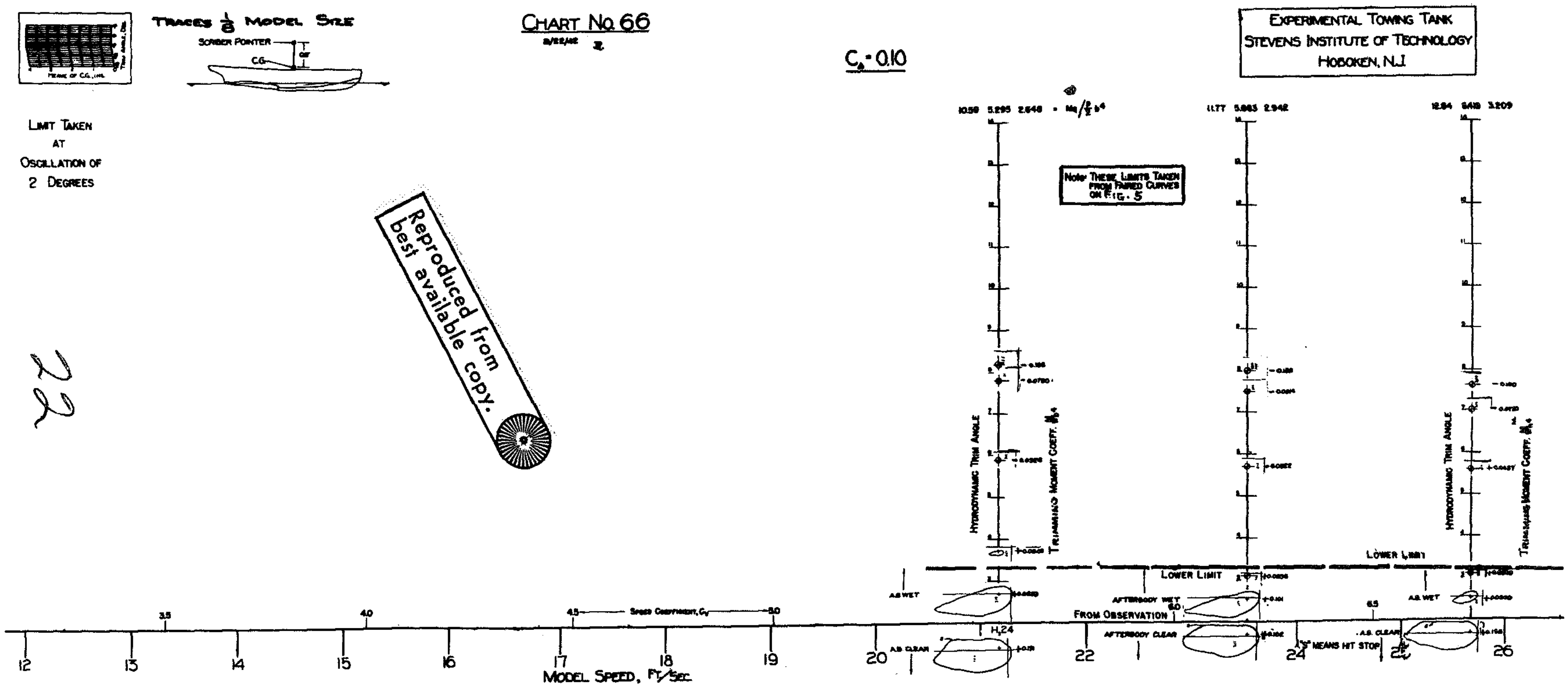


Fig. 3

NACA



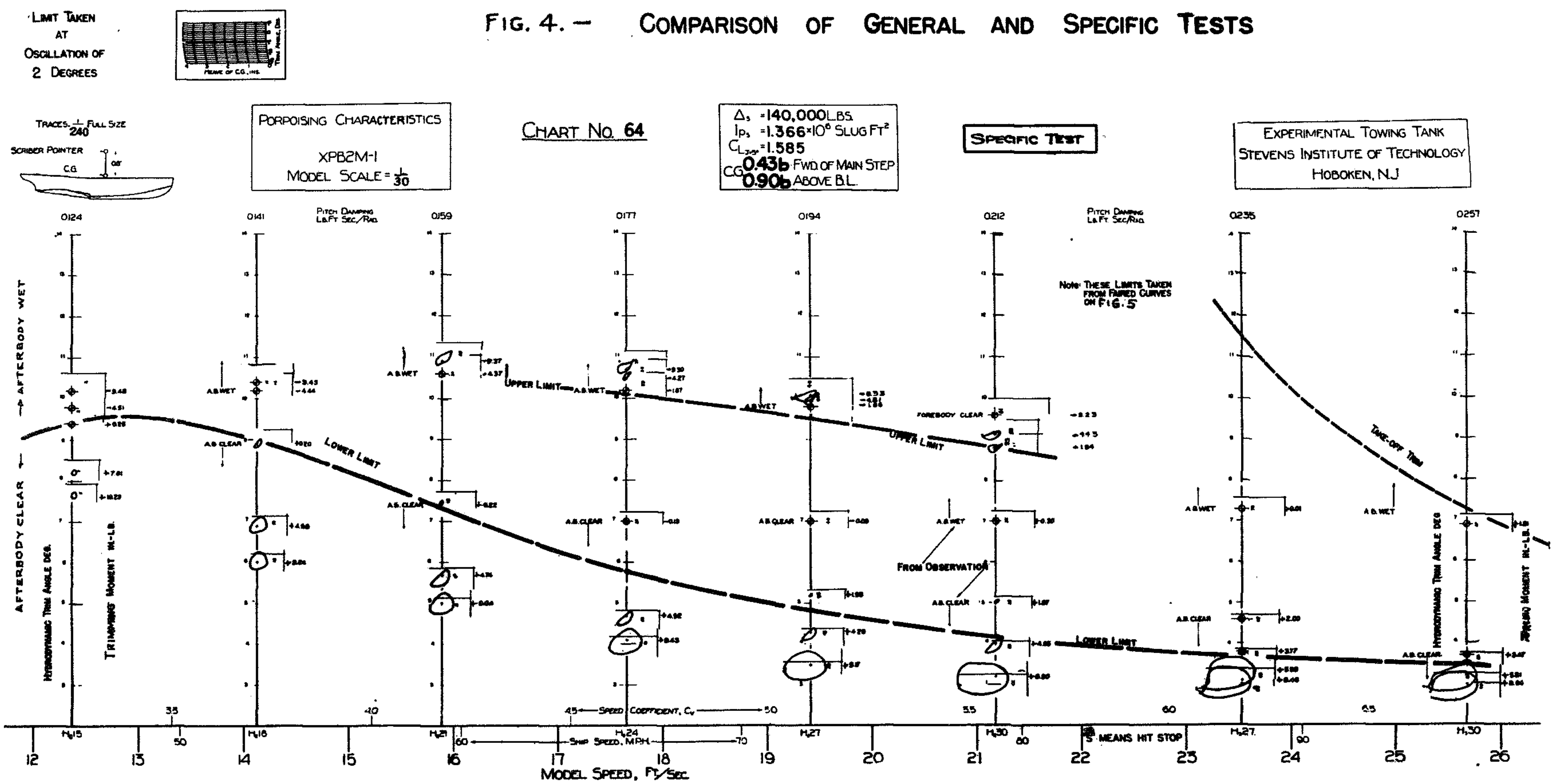
22

FIG. 3 CONTINUED.

Fig. 3cont.

Fig. 4

Fig. 4. — Comparison of General and Specific Tests



NACA

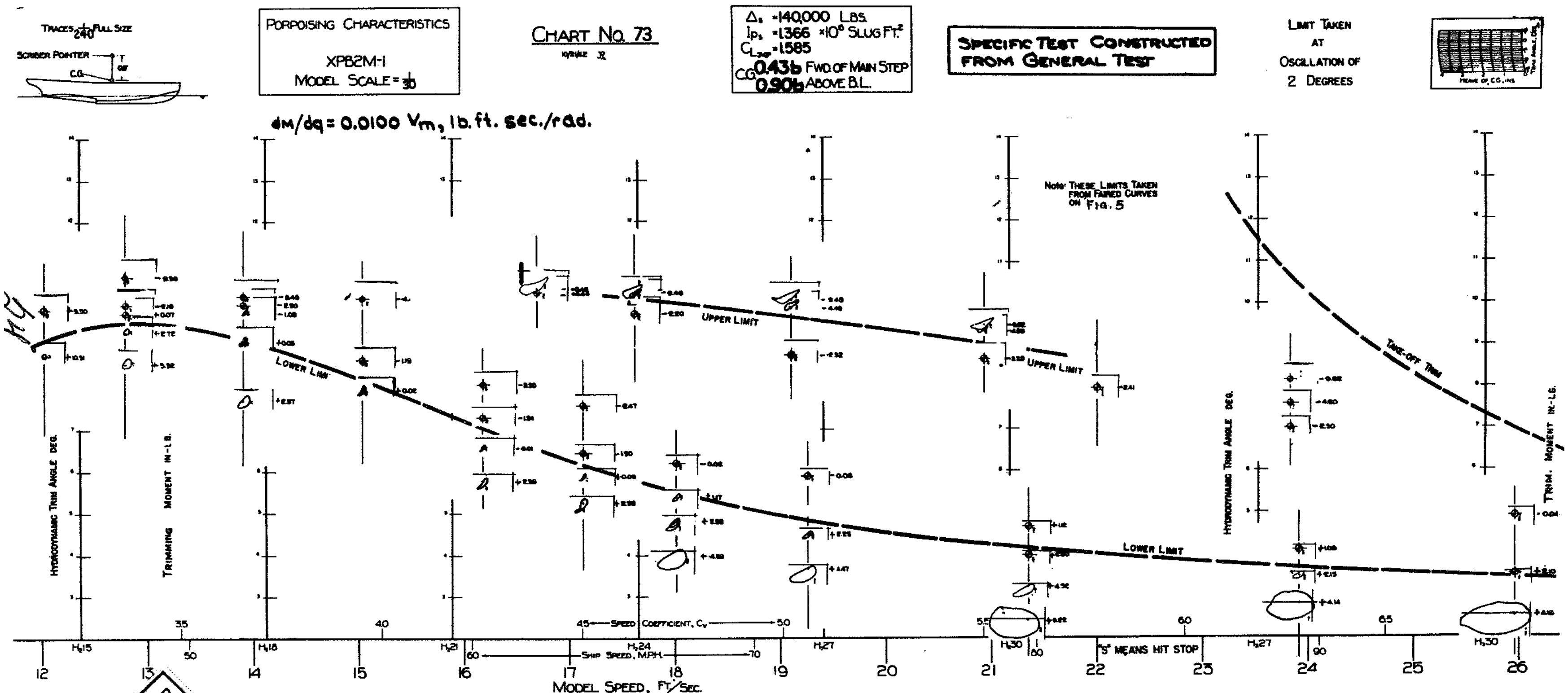


FIG. 4 CONTINUED.

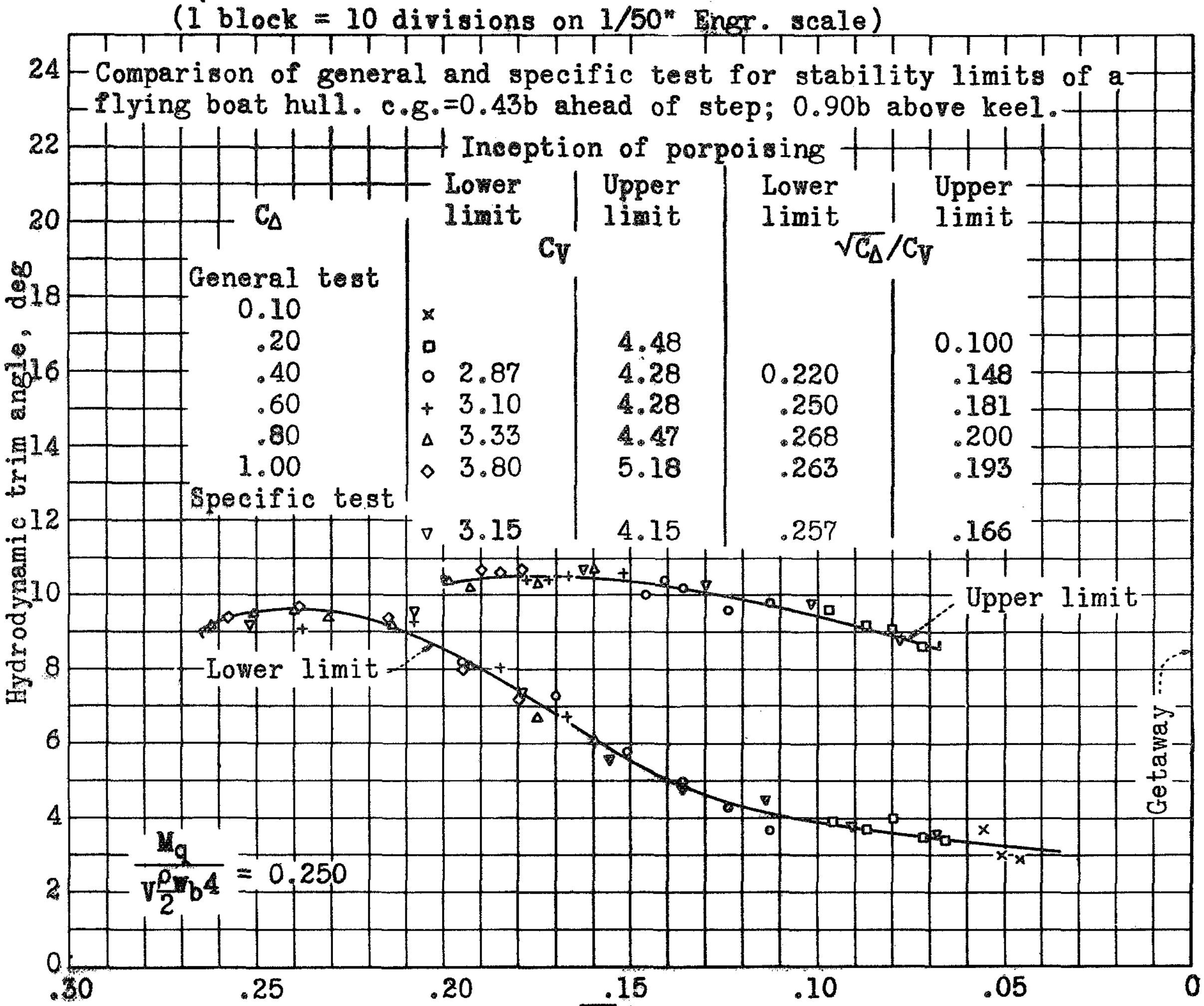


Figure 5.(Note-Limit taken at an oscillation of 2.0 deg)

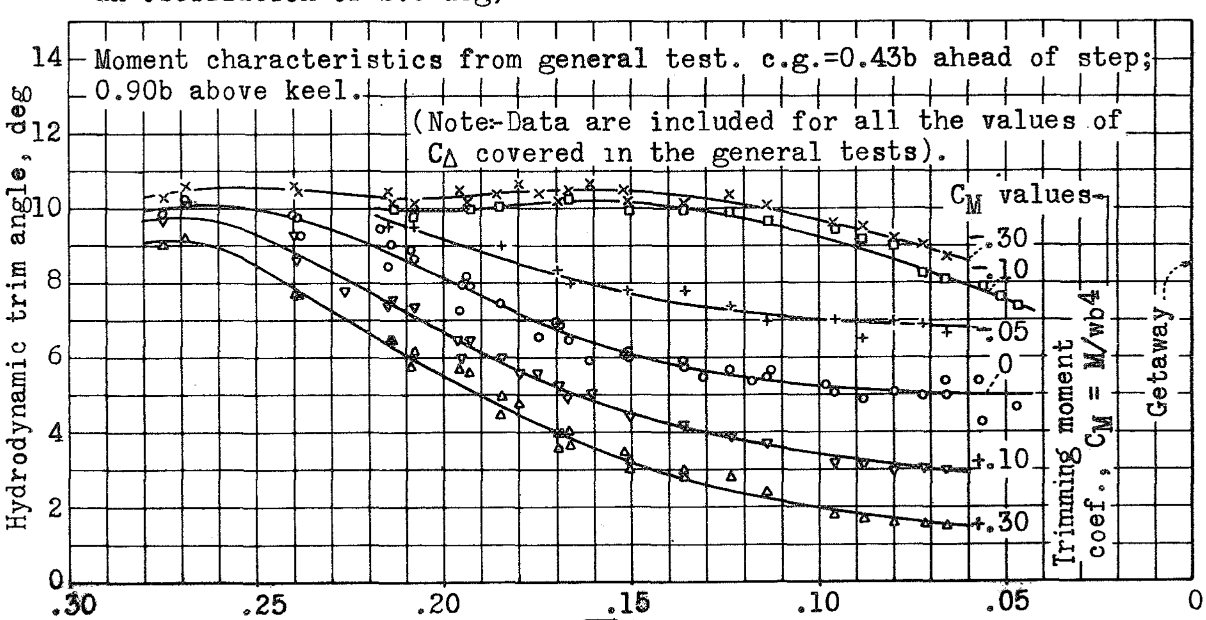


Figure 6.

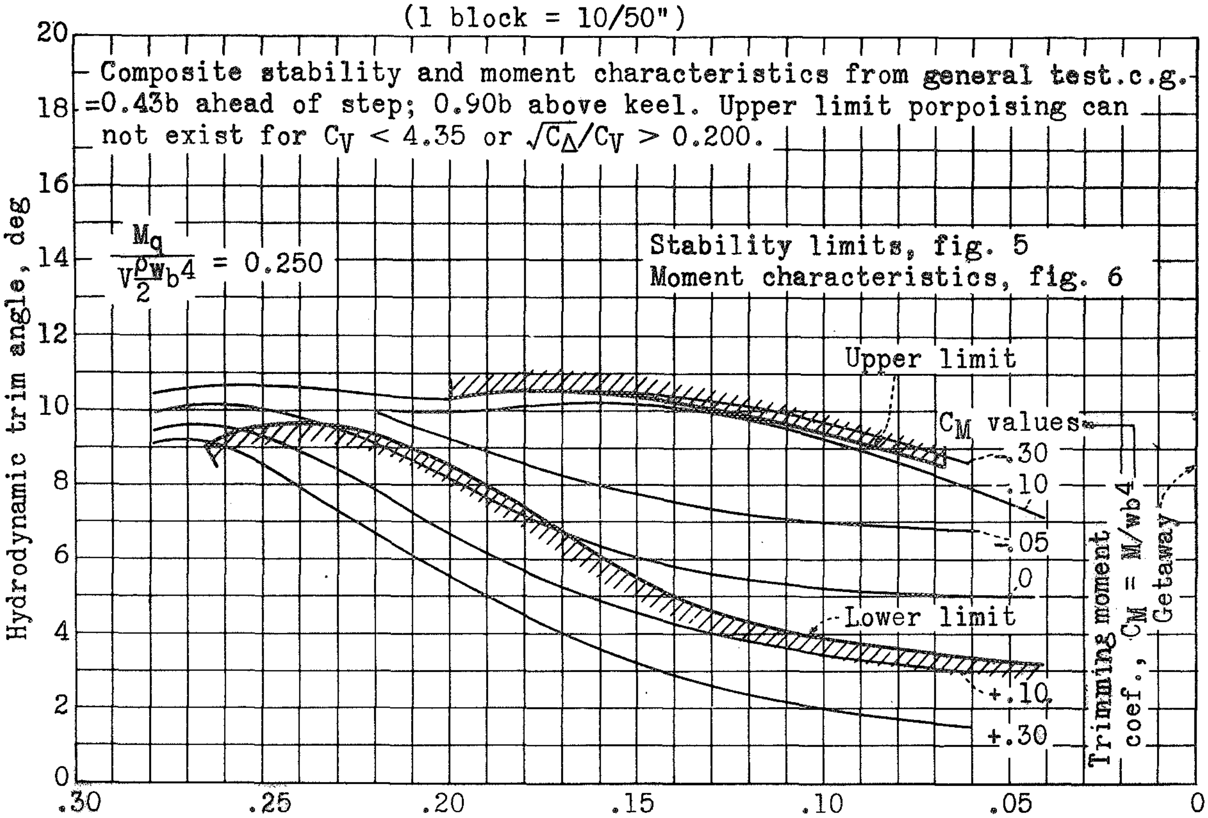


Figure 7.

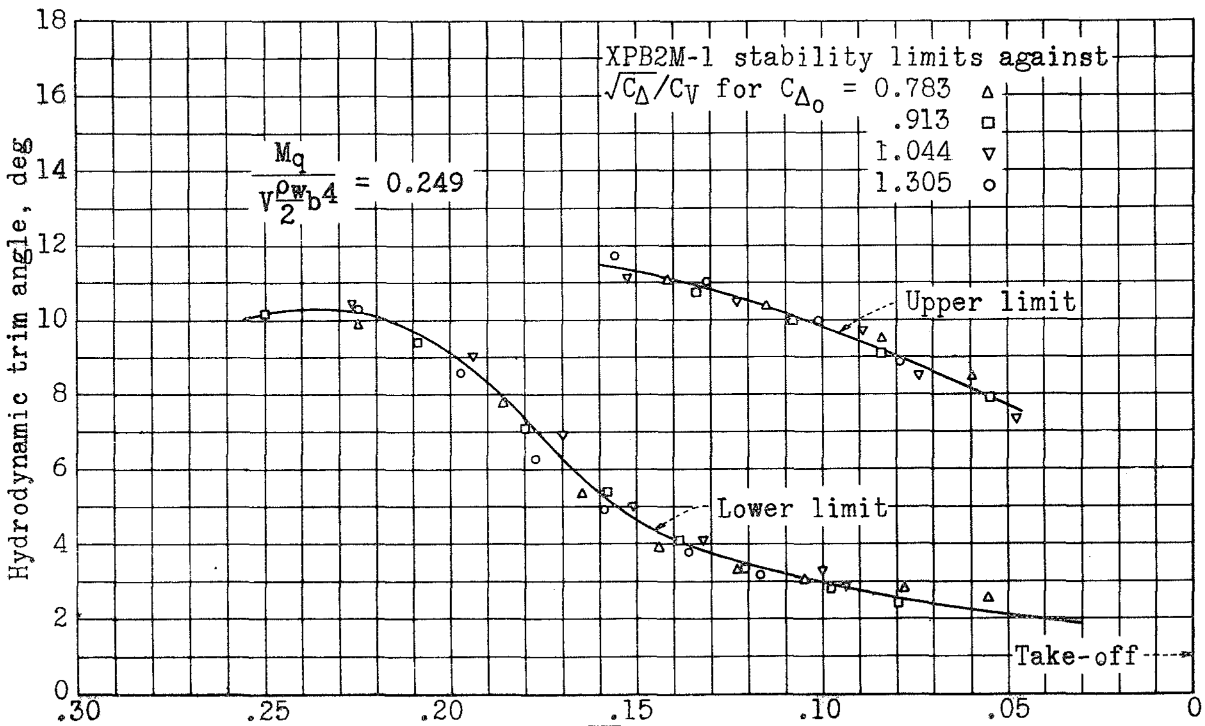


Figure 8.

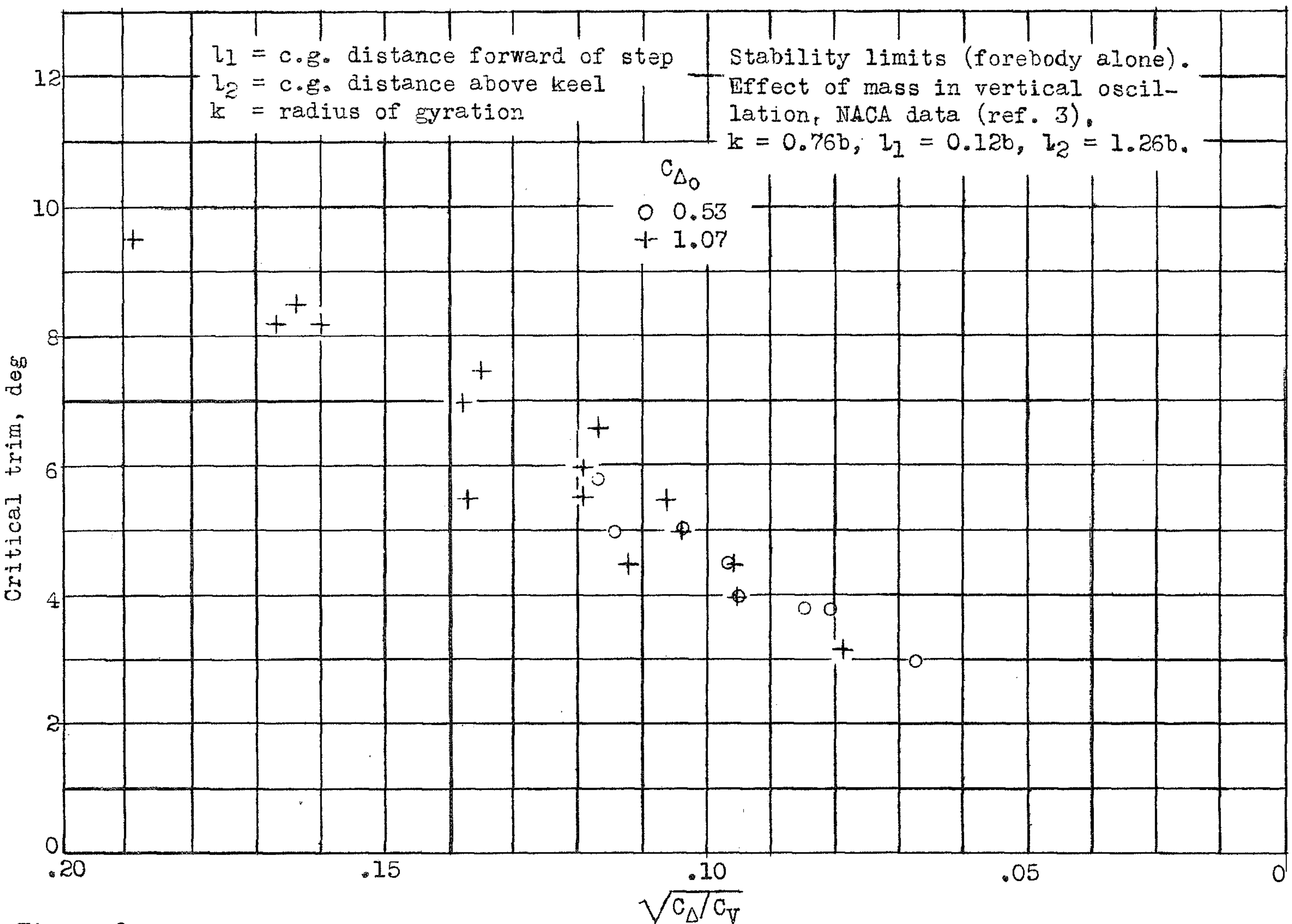

l_1 = c.g. distance forward of step
l_2 = c.g. distance above keel
k = radius of gyration
Stability limits (forebody alone).
Effect of mass in vertical oscillation, NACA data (ref. 3).
k = 0.76b, l_1 = 0.12b, l_2 = 1.26b.
C_{Δ_0}
0.53
1.07
Critical trim, deg
0
2
4
6
8
10
12
.20
.15
.10
.05
0
$\sqrt{C_\Delta / C_V}$

Figure 9.

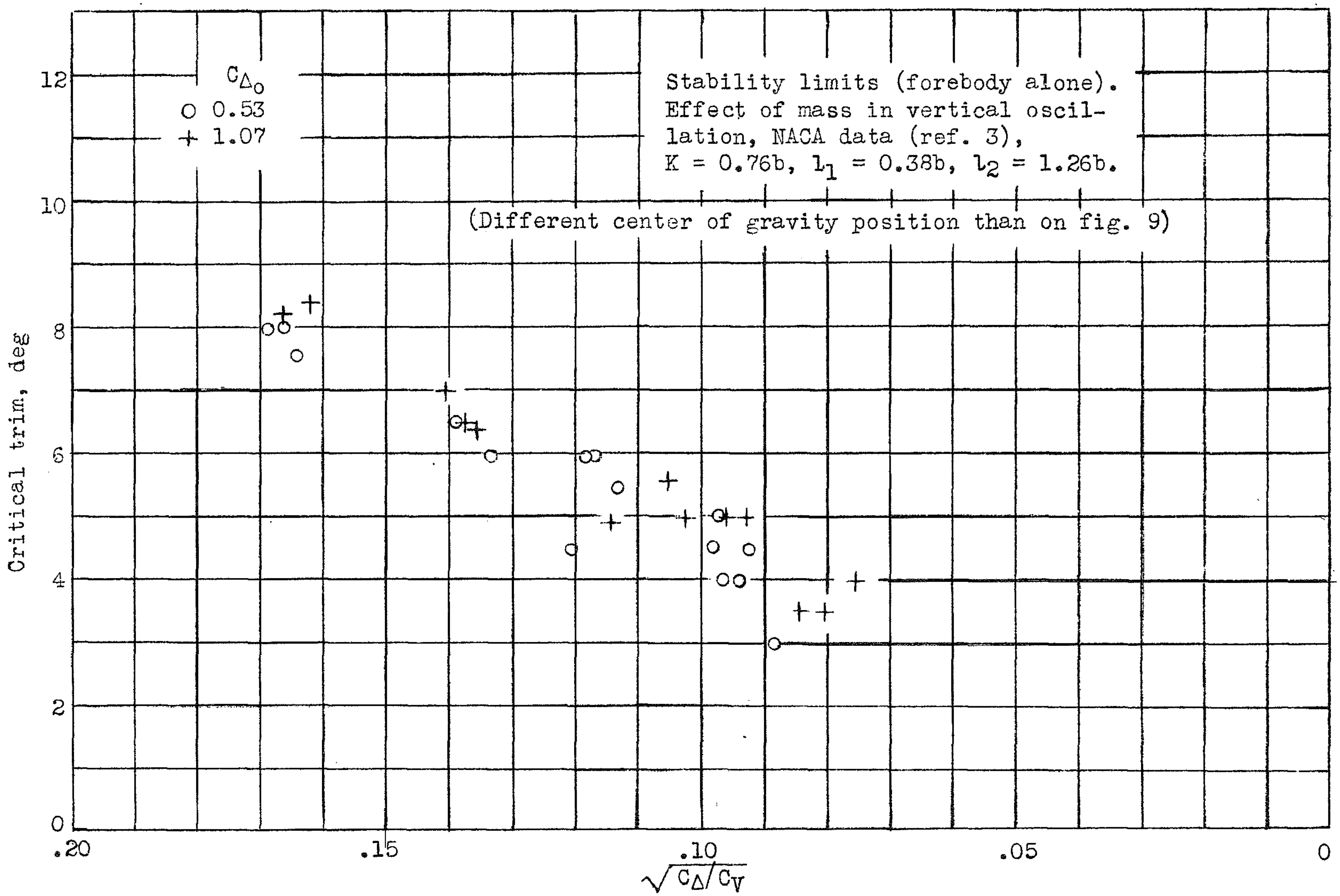

C_{Δ_0}
○ 0.53
+ 1.07
Stability limits (forebody alone).
Effect of mass in vertical oscil-
lation, NACA data (ref. 3),
K = 0.76b, l_1 = 0.38b, l_2 = 1.26b.
(Different center of gravity position than on fig. 9)
Critical trim, deg
12
10
8
6
4
2
0
.20
.15
.10
.05
0
$\sqrt{C_\Delta/C_V}$

Figure 10.

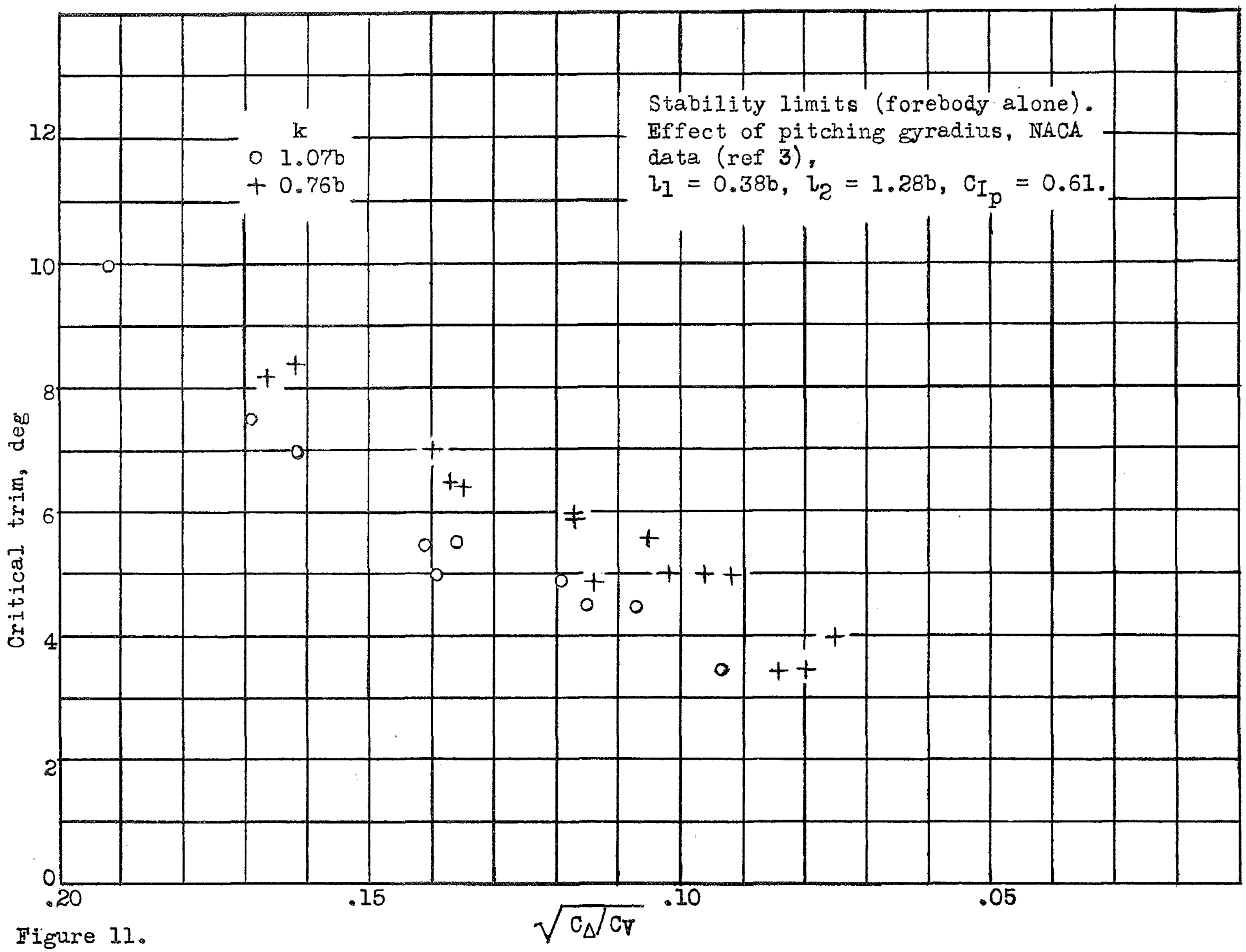

Stability limits (forebody alone).
Effect of pitching gyradius, NACA data (ref 3),
$l_1 = 0.38b$, $l_2 = 1.28b$, $C_{I_p} = 0.61$.
k
o 1.07b
+ 0.76b
Critical trim, deg
$\sqrt{C_\Delta / C_V}$
12
10
8
6
4
2
0
.20
.15
.10
.05

Figure 11.

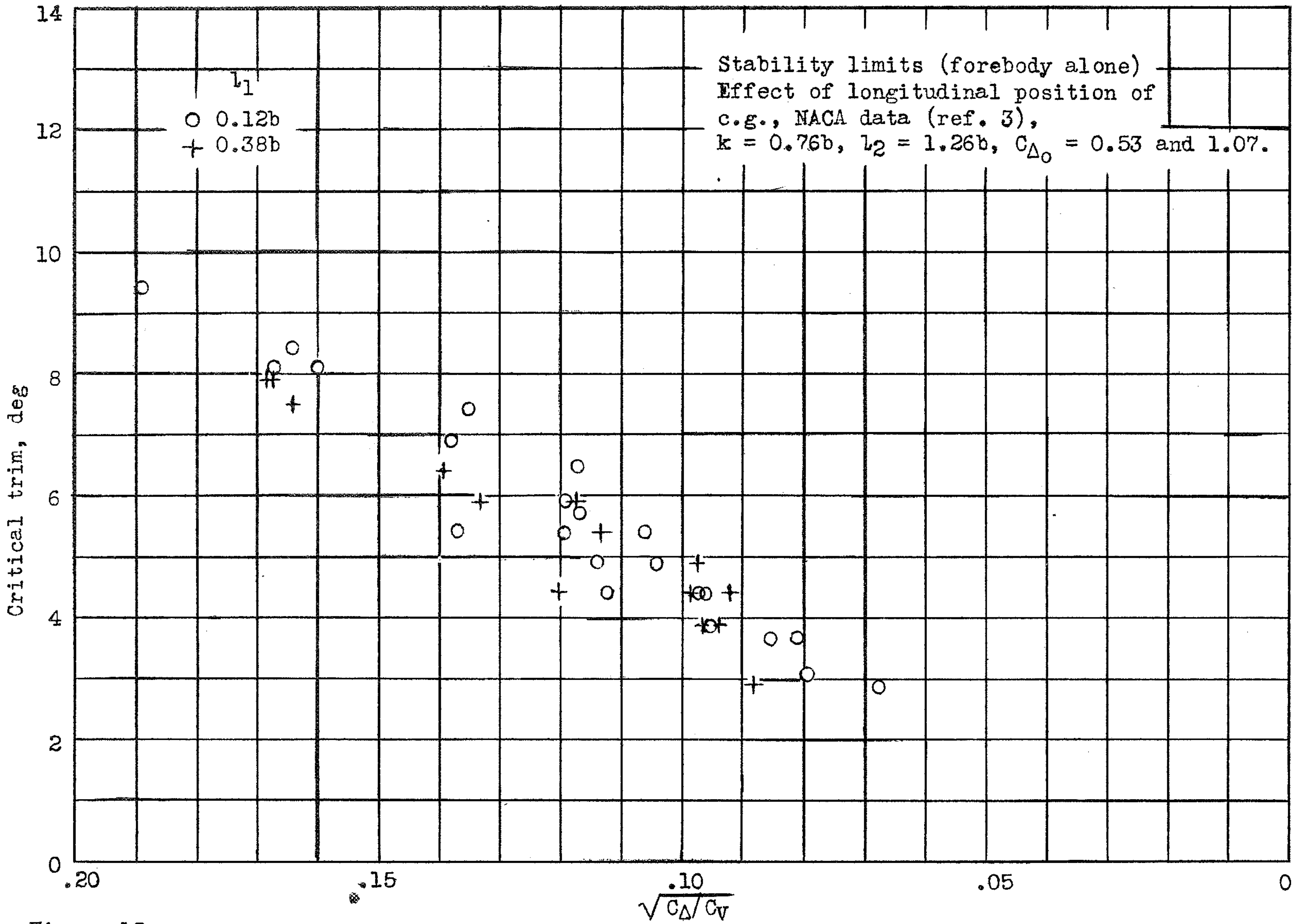
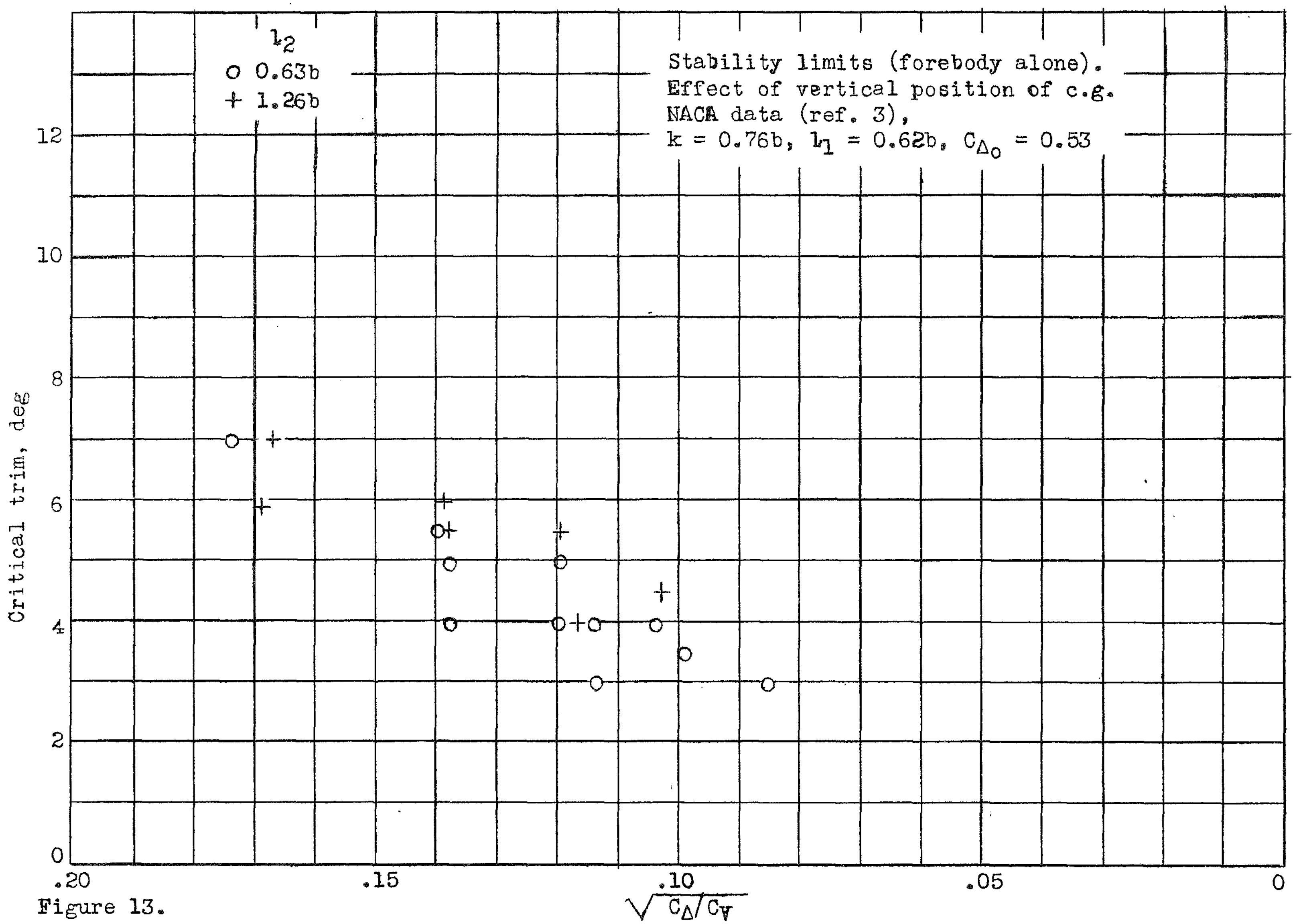


Figure 12.

NACA

30

Fig. 12



l_2
o 0.63b
+ 1.26b
Stability limits (forebody alone).
Effect of vertical position of c.g.
NACA data (ref. 3),
$k = 0.76b$, $l_1 = 0.62b$, $C_{\Delta_0} = 0.53$
Critical trim, deg
0
2
4
6
8
10
12
.20
.15
.10
.05
0
$\sqrt{C_\Delta / C_V}$

Figure 13.

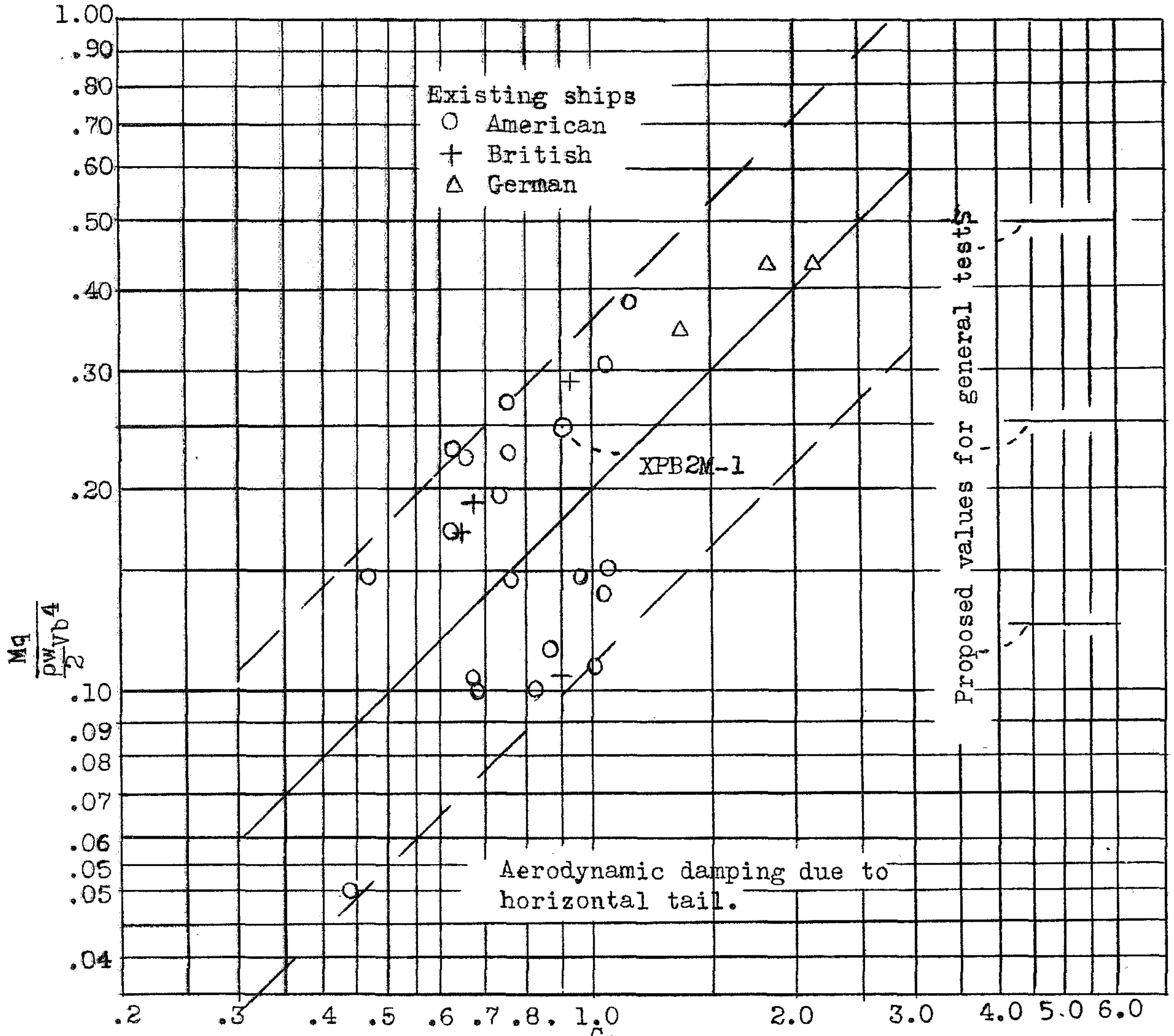


Figure 14.

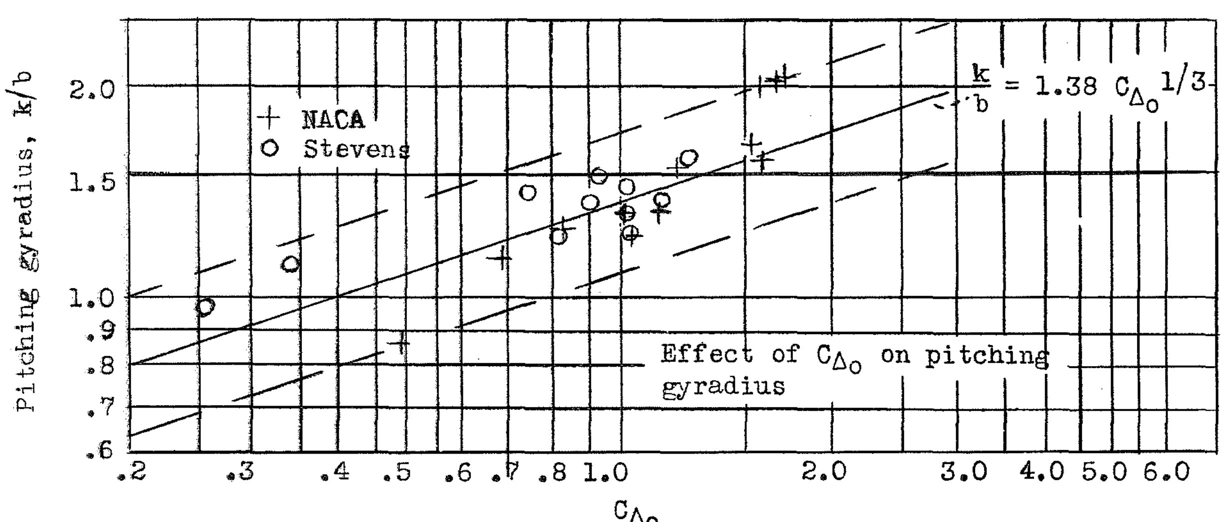


Figure 15.

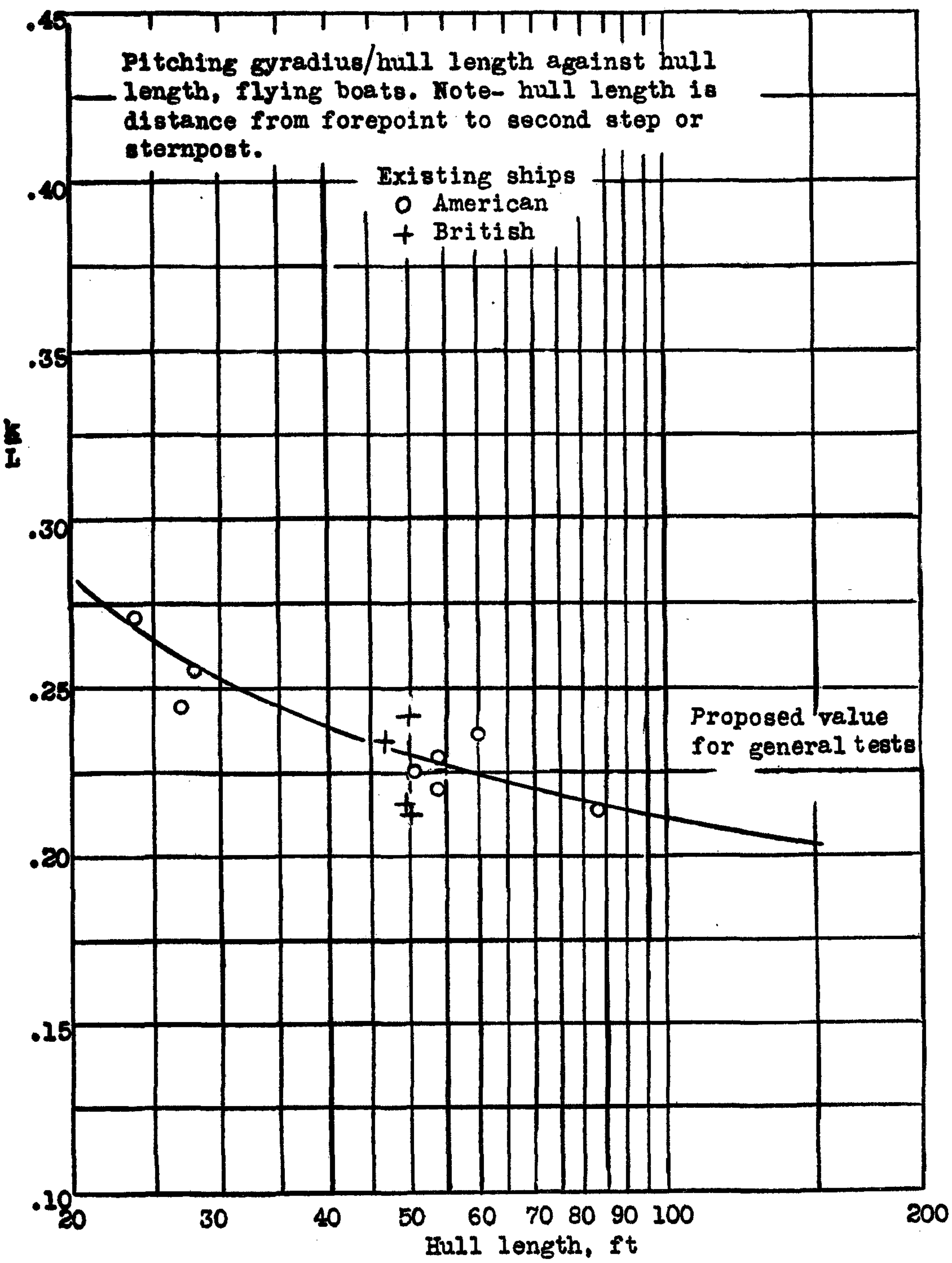

Pitching gyradius/hull length against hull length, flying boats. Note- hull length is distance from forepoint to second step or sternpost.
Existing ships
O American
+ British
Proposed value for general tests
k/L
.45
.40
.35
.30
.25
.20
.15
.10
20
30
40
50
60
70
80
90
100
200
Hull length, ft

Figure 16.