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A GRAPHICAL METHOD FOR INTERPOLATION OF HYDRODYNAMIC CHARACTERISTICS OF SPECIFIC FLYING BOATS FROM COLLAPSED RESULTS OF GENERAL TESTS OF FLYING-BOAT-HULL MODELS

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SUMMARY

This report presents a simple and rapid method for interpolating the hydrodynamic characteristics of specific flying boats from a chart presenting test results in collapsed form. The method is graphical and will allow interpolation of the hydrodynamic characteristics for any combination of load or aerodynamic characteristics. To obtain the water resistance and porpoising characteristics of one specific case requires about 20 or 30 minutes' work. It is believed that the rapidity with which interpolations may be made will open up the way for comprehensive design studies of the influence of various factors on flying-boat performance.

INTRODUCTION

The general type of test to determine the hydrodynamic characteristics of flying-boat-hull models has been in use for some time. It has proved to be an exceedingly powerful tool for comparing the hydrodynamic characteristics of various hulls independently of any assumed air structure. However, the general test has several important disadvantages, which are:

1. A large amount of time is involved in accumulating the necessarily large amount of data.

2. A large number of charts are required to present the results of tests of one model; this makes comparison between different hulls awkward and time consuming.

3. The interpolation of the characteristics of specific designs is so time consuming as to make the cost of thorough design studies of the effect of various factors almost prohibitive.

A large amount of effort has been spent in overcoming the first two objections. Methods have been developed (references 1 to 3) so that general tests of resistance, porpoising, and the main spray characteristics can be made almost as quickly as a specific test. The reduced number of results of all three types of tests are presented in collapsed form on a single chart (see fig. 1, for an example) which covers all practicable combinations of load and get-away speed and thus retains the advantages of the general test for comparisons independent of aerodynamic characteristics. A large number of these hydrodynamic summary charts may be found in reference 4.

The third criticism mentioned may well be the most important. A short survey of the literature reveals that only four design studies of the effect of various hydrodynamic factors on the performance of flying boats have been published (references 5 to 8). There are a number of others which give little or no attention to the influence of the hull on performance. Of the four design studies mentioned, only the last, by Olson and Allison, may be considered to be at all comprehensive. This paucity of design studies may be taken as a clear indication of the excessive time required to determine analytically the characteristics of individual hulls as applied to specific aircraft. It is the purpose of the present report to attempt to overcome this difficulty by presenting a simple and rapid method for the interpolation of the hydrodynamic characteristics of any specific flying-boat design from the type of chart previously developed showing the results of general tests in collapsed form.

The proposed method might be considered as an adaptation of slide-rule technique. It consists essentially of plots of constant-speed contours for various aerodynamic characteristics (given in terms of the hull beam) plotted on a chart of trim against the appropriate load-speed relation for the displacement or planing ranges. These plots are scribed on transparent sheets which may be superimposed on charts showing the hydrodynamic characteristics of hulls. The location of the transparent sheet relative to the chart of the hydrodynamic characteristics is controlled only by the setting of the wing relative to the hull. The transparent sheets were designed to cover all practical combinations of gross load and wing design.

The most important disadvantage of the chart (fig. 1) showing the results of general resistance, porpoising, and spray tests of one hull is that the curves are unfamiliar to the designer in both shape and magnitude. This fact will, of course, seriously impede attempted comparisons between hulls. It is believed, however, that the interpolation system presented in this report should aid in overcoming this obstacle. In the past year and a half a fairly large number of complete interpolations have been made, and the time required to get the water resistance and porpoising characteristics of any specific case appears to be about 20 or 30 minutes. In addition to being a rapid method of interpolation, the significance of the shape of the curves and their magnitudes in collapsed form will assume more meaning to the designer through use of the method. In time the collapsed curves will undoubtedly be almost as easy to interpret as the more conventional types of plotting.

SYMBOLS

The following symbols are used throughout this report:

C_Δ load coefficient (Δ/wb^3)

C_{Δ_o} initial-load coefficient (Δ_o/wb^3)

C_R resistance coefficient (R/wb^3)

C_V speed coefficient $(V/\sqrt{gb})$

C_M trimming-moment coefficient (M/wb^4)

C_X longitudinal-spray coefficient (X/b)

C_Y lateral-spray coefficient (Y/b)

C_Z vertical-spray coefficient (Z/b)

C_L aerodynamic-lift coefficient $\left(L/S \dfrac{\rho_a}{2} V^2\right)$

where

Δ load on water, pounds

Δ_o initial load on water (gross weight), pounds

w specific weight of water, pounds per cubic foot

b beam at main step, feet

R water resistance, pounds

V water speed, feet per second

g acceleration of gravity (32.2 ft/sec^2)

M trimming moment, pound-feet

X longitudinal position of main-spray point of tangency with reference to step (positive forward and negative aft of step), feet

Y lateral position of main-spray point of tangency, measured from hull center line, feet

Z vertical position of main-spray point of tangency, measured from tangent to forebody keel at main step, feet

L total aerodynamic lift, pounds

S wing area, square feet

ρ_w mass density of water, pound-seconds^2 per foot^4

ρ_a mass density of air, pound-seconds^2 per foot^4

α_o absolute angle of attack of wing-flap combination when trim is zero (measured from zero lift), degrees

$\alpha_{L=0}$ angle of zero lift of wing with respect to its own reference line, degrees

i_w angle of attack of wing reference line with respect to tangent to forebody keel at main step, degrees

$i_w = \alpha_o - \alpha_{L=0}$

τ trim angle (angle between tangent to forebody keel at main step and free-water surface), degrees

DEVELOPMENT OF CHARTS

As already explained, the interpolation process is based on the graphical use of special charts. The development of these charts is based on the fact that at any speed and trim angle during take-off, the water-borne load of a flying boat is given by the relation:

$$\Delta = \Delta_o - L \tag{1}$$

The lift component of this relation can be put into terms of the aerodynamic characteristics,

$$\Delta = \Delta_o - \frac{dC_L}{d\alpha}(\tau + \alpha_o)\frac{\rho_a}{2} SV^2 \tag{2}$$

and if both sides are divided by wb^3 to obtain the usual NACA seaplane coefficients, equation (2) will reduce to:

$$C_\Delta = C_{\Delta_o} - \frac{1}{2}\frac{\rho_a}{\rho_w}\frac{dC_L}{d\alpha}\frac{S}{b^2}(\tau + \alpha_o)C_V{}^2 \tag{3}$$

This equation is not an approximation, but will give the true load on the water if the true values of the various terms are substituted into it. Thus, the propeller slipstream and ground effect can be accounted for by the proper adjustment to $dC_L/d\alpha$ and α_o and the effect of the elevators by alteration to α_o. Other changes of the aerodynamic characteristics can be similarly taken into account.

Displacement Range

In the displacement range, by following the reasoning of reference 2, equation (3) may be transformed to

$$\frac{C_V{}^2}{C_\Delta{}^{1/3}} = \frac{C_V{}^2}{\sqrt[3]{C_{\Delta_o} - \frac{1}{2}\frac{\rho_a}{\rho_w}\frac{dC_L}{d\alpha}\frac{S}{b^2}(\tau + \alpha_o)C_V{}^2}} \tag{4}$$

From this relation, contours of constant velocity on a chart of absolute angle of attack against $C_V{}^2/C_\Delta{}^{1/3}$ can be constructed for specific values of the product $\frac{dC_L}{d\alpha}\frac{S}{b^2}$ for any given value of C_{Δ_o}. Such a chart is shown in figure 2, which was constructed for C_{Δ_o}

equal to unity for simplicity in converting it for use with other values of C_{Δ_o}.

It will be noted that when the absolute angle of attack $(\tau + \alpha_o)$ is zero there is no wing lift, and hence at any speed the load on the water must then be the static displacement. The values of C_V corresponding to any value of C_{Δ_o} other than that for which figure 2 was constructed can be determined by multiplying the values of C_V shown by the sixth root of the particular C_{Δ_o} under consideration.

Further, it will be seen that if the definitions of the coefficients are substituted in equation (4) the beam will drop out completely. Thus, for the chart in figure 2, it becomes necessary to use $\frac{S}{b^2}$ also on the basis of $C_{\Delta_o} = 1.00$. This may be done by calculating the beam which would give a value of C_{Δ_o} of unity for the weight under consideration. A simpler step is to remove the beam and substitute $S/(\Delta_o/w)^{2/3}$ for use in the parameter; this has been done in figure 2.

A study of reference 9 showed that $\frac{S}{b^2}$ was usually between 15 and 25 for most flying boats, with a few as low as 10 and as high as 40. Since $dC_L/d\alpha$ will be somewhere near 0.100 for most modern designs, the charts were constructed for a range of the product $\frac{dC_L}{d\alpha} \frac{S}{(\Delta_o/w)^{2/3}}$ of from 1.0 to 4.0.

Planing Range

In the planing range, again by following reference 2, equation (3) becomes

$$\frac{\sqrt{C_\Delta}}{C_V} - \frac{\sqrt{C_{\Delta_o} = \frac{1}{2}\frac{\rho_a}{\rho_w}\frac{dC_L}{d\alpha}\frac{S}{b^2}(\tau + \alpha_o)C_V^2}}{C_V} \tag{5}$$

Again, contours of constant velocity on a chart of absolute angle of attack against $\sqrt{C_\Delta}/C_V$ may be prepared for specific values of the product $\frac{dC_L}{d\alpha}\frac{S}{b^2}$ and C_{Δ_o}. Figures 3 to 5 show such charts constructed for $C_{\Delta_o} = 1.00$. The reason more than one chart was prepared for the planing range was to prevent too much overlapping of the various contours. If the definitions of the coefficients are substituted into equation (5), it will be found that the beam will not drop out as it did from equation (4). Hence, the values of S/b^2 used in reading the charts will be the specific ones under consideration.

If a value of C_{Δ_o} other than unity is under consideration, it is again necessary to convert the scale of C_V at the bottom of each of these charts by multiplying by the square root of the particular C_{Δ_o}. This accomplishes conversion because at zero absolute angle of attack the water-borne load is the static gross weight, and is, of course, known.

Before either of the charts for the displacement of planing ranges may be conveniently used for interpolation, transparent copies should be prepared. This is most simple to do by making a photographic film positive.

USE OF CHARTS

The charts just described can be used to interpolate the hydrodynamic characteristics of any proposed seaplane or flying boat from a chart showing the collapsed results of general tests of a particular model. Each type of interpolation will be described separately, but certain steps apply to all types.

In the displacement range, the trim track is fixed by the assumption that the sum of the available moments is not large enough to allow deviation from the free-to-trim track. Hence, the first step will always be to find the trim intersection with the constant-speed contour, at which point the value of ${C_V}^2/{C_\Delta}^{1/3}$ may be found. Since C_V is known, C_Δ can be found.

In the planing range, the available moments are usually large enough so that any trim track within reason may be assumed. However, it is necessary to assume some trim track. Whenever stability limits are given, it will naturally be desirable to keep the assumed trim track within the range of stable trim. Basically, there are four different applications in which these charts may be used, and each application will be described individually in detail.

Effect of Wing and Flap Setting

Suppose the hull beam, gross weight, and wing characteristics have been selected by the designer from other considerations. The effect of the setting of the wing relative to the hull and the flap relative to the wing can be determined as follows:

In equation (3) the only term that will be affected if the angle of the wing or the flap setting is altered is $(\tau + \alpha_o)$. Changing the flap setting only will change the angle of zero lift of the wing-flap combination and the value of $C_{L_{max}}$ but will not affect the lift rate $dC_L/d\alpha$, at least to a very good first approximation. Hence the first step is to determine the value of α_o for the assumed aerodynamic characteristics.

In the displacement range, the speed scale at the bottom of the chart must be converted by multiplying the values of C_V shown by the particular values of $C_{\Delta_o}^{1/6}$. Next, the value of $(dC_L/d\alpha)(S/\Delta_o/w)^{2/3}$ must be calculated. The transparent displacement-range chart is now laid on top of the chart of the hull characteristics so that the value of α_o corresponds to zero trim. Start with the lowest speed and find the value of $C_V^2/C_\Delta^{1/3}$ at the intersection of the appropriate constant-speed curve on the transparent chart with the free-to-trim track having the same load coefficient as the chosen C_{Δ_o}. Next, calculate the value of C_Δ; it should be very slightly less than C_{Δ_o} but close enough to it so that a second trial will not be worth while. Use the next speed, and determine the value of $C_V^2/C_\Delta^{1/3}$ at the intersection of the constant-speed contour with the free-to-trim track for the value of C_Δ found at the previous speed. Again, the new value of C_Δ should be slightly lower than the assumed value. Repeat at increasing speeds by using at each speed the value of C_Δ found at the preceding speed for interpolation purposes. It will only rarely be necessary to make a second trial at any speed. Finally, for the various values of $C_V^2/C_\Delta^{1/3}$ find the values of $C_R/C_V^2C_\Delta^{2/3}$ at the proper value of C_Δ. Since both C_V and C_Δ are known, C_R can be found.

In the planing range, multiply the values of C_V shown at the bottom of the appropriate chart by the specific $C_{\Delta_o}{}^{1/2}$. After using the specific value of S/b^2 to find the parameter $\frac{dC_L}{d\alpha}\frac{S}{b^2}$, lay the transparent chart on top of the chart of the hull characteristics in the planing range so that the chosen value of α_o corresponds with the zero-trim angle. Find the intersection of the appropriate constant-speed contour with the trim track under consideration and read the value of $\sqrt{C_R}/C_V$ occurring at the intersection. Since C_V is known, the value of C_R can be found, and it should especially be noted that it is not necessary to find C_Δ. If general stability limits are given, the intersection of the constant-speed contours will allow the construction of the specific limits.

The entire process may be repeated for other values of the wing or flap setting by merely shifting the relation of the transparent chart having the constant-speed contours to the chart of the collapsed results of general tests. At any given value of α_o, the curve of C_R against C_V represents a large number of wing-flap-setting combinations. However, the total air-plus-water resistance will depend to a large extent on the flap setting. Thus, if the water resistance is calculated for several values of α_o, it may be used in conjunction with quite a large variety of flap settings, provided, of course, that the stall is not exceeded in any case.

Effect of Hull Size

If the weight, the wing area, and the wing setting are assumed, then the effect of various over-all hull sizes (that is, with constant length-beam ratio) can be found in the following manner:

In the displacement range, find $S/(\Delta_o/w)^{2/3}$ and retain this value for all hull sizes under investigation. Each value of C_{Δ_o}

will alter the values of C_V appearing at the bottom of the transparent sheet of constant-speed contours, since they must be multiplied by the particular values of $C_{\Delta_o}^{1/6}$. However, the actual speed in feet per second for a given nominal value of C_V will not be altered by this process. In the planing range, on the other hand, the specific values of S/b^2 must be calculated for each hull size. The nominal values of C_V should be multiplied by the specific $C_{\Delta_o}^{1/2}$ for each hull size, as previously explained, and the actual speed at each nominal value of C_V will be altered.

Place the appropriate transparent chart of constant-speed contours on top of the chart of collapsed hydrodynamic characteristics so that the assumed value of α_o coincides with zero-trim angle. From there on, the interpolation is just the same as under Effect of Wing and Flap Setting.

Effect of Wing Size

If the weight, beam, and wing setting are known, the effect of the wing size (that is, wing loading) can be determined as follows:

In the displacement range, find the value of $(\Delta_o/w)^{2/3}$. Use this value in each particular $S/(\Delta_o/w)^{2/3}$ to be investigated. Since the value of C_{Δ_o} will not change from case to case, the speed scale on the transparent chart need be altered only once by multiplying by the particular value of $C_{\Delta_o}^{1/6}$.

In the planing range each specific value of S/b^2 must be calculated for each wing. The speed scale, however, requires only one conversion, depending on the initial choice of hull beam. Otherwise, the interpolation procedure in both the displacement and the planing ranges is the same as before.

The effect of wing aspect ratio alone may be investigated by altering $dC_L/d\alpha$ alone. All the other constants remain unchanged.

Effect of Weight

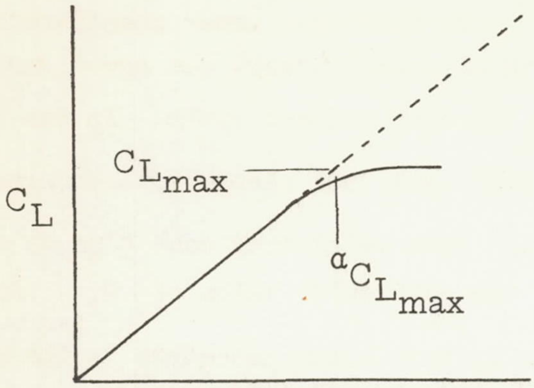
With hull size, wing area, and wing setting fixed, the designer can investigate the effect of changes of gross weight in the following manner:

Find $S/(\Delta_o/w)^{2/3}$ for each case under consideration, and each time the weight is altered, convert the speed scale by multiplying by $C_{\Delta_o}{}^{1/6}$ in the displacement range. In the planing range, the value of S/b^2 will not change with changes of C_{Δ_o}, though the scale of C_V must be altered each time by multiplying by the square root of the particular value of C_{Δ_o}. Except for these differences. the interpolation procedure is the same as previously under Effect of Wing and Flap Setting.

Miscellaneous

Each of the important items was considered as being altered independently of the others. There is, of course, no reason any desired combinations of these items may not be used. Further, if it is desired to assume that the flap angle changes with speed, as apparently has been found desirable in some previous calculations, it may be accomplished quite simply by shifting the relation between the transparent constant-speed-contour chart and the chart showing the collapsed results of the general tests as the speed changes.

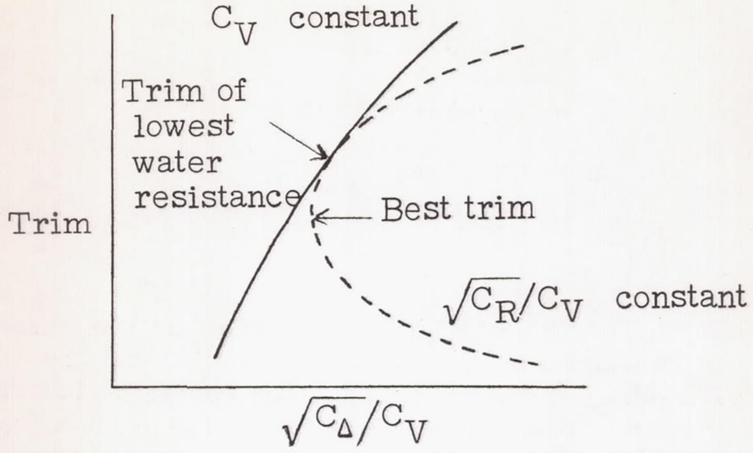
The constant-speed-contour charts have been drawn with the assumption that the wing does not stall. Naturally, this is never the case, though usually the wing setting will be chosen so that the stall does not occur at possible trim angles while the flying boat is on the water. If it should become necessary to consider the effect of a stalled wing. one rather simple type of stall can be easily considered. The following sketch shows the lift curve having a "flat-top" stall. The charts were constructed with the assumption that the lift continued along the dashed line. The apparent value of α at $C_{L_{max}}$ can be determined



in the manner indicated. At absolute angles of attack greater than this value, the constant-speed contours will be vertical straight lines, since the load on the water does not change with increasing trim. It seems possible that a good many types of stall can at least be approximated in this manner.

The effect of power and the propeller slipstream can also be included if their influence on the aerodynamic lift characteristics is known. From the results presented in reference 10, power has quite a large effect on $C_{L_{max}}$, $dC_L/d\alpha$, and the angle of attack for zero lift. If at all possible, an effort should be made to allow for its influence on the aerodynamic characteristics.

In the planing range, it is possible to perceive readily the "best" trim on the charts showing the collapsed results of general tests. The point of tangency of a vertical straight line (constant load at constant speed) to a $\sqrt{C_R/C_V}$ contour will be the best trim as commonly used in NACA publications. The trim of lowest water resistance of a hull and airplane combination will be higher than the best trim of the hull alone because of the decreasing load on the water with increasing trim due to the wing lift. It should be noted that the trim of lowest water resistance for a specific design will be found at the tangency of the appropriate specific constant-speed contour. The "optimum" trim, at which the sum of



the air and water resistance of a specific design is minimum, will be somewhere between these two. It seems likely that for most cases the optimum trim will be close to the best trim. This will, of course, depend on both the assumed aerodynamic characteristics and on the shape of the constant $\sqrt{C_R}/C_V$ contours.

Finally, in the displacement range, extrapolation to loads outside the ranges tested can lead into serious errors unless done very carefully. It is likely to be more critical to extrapolate to loads greater than to loads less than those investigated. Because of this danger, the curves in the displacement range are labeled for the values of the load coefficients at which the tests were made. In the planing range, the values of C_Δ investigated are not shown because extrapolation is much less likely to introduce discrepancies.

SAMPLE CALCULATIONS

In order to aid in understanding the interpolation process, two sample calculations of the water resistance have been prepared. They have not been carried through to find take-off times and distances since this report is not concerned with a design study.

Flying Boat A

It is assumed that the designer has specified, for one reason or another, the following information:

$$\Delta_o = 15{,}000 \text{ pounds}$$

$$S = 906 \text{ square feet}$$

$$b = 7.77 \text{ feet}$$

$$dC_L/d\alpha = 0.068$$

and wishes to know the effect of the wing setting on the take-off performance of the flying boat when using a hull having the lines of NACA Model No. 84-EF-3 (reference 11). The aerodynamic characteristics of the assumed wing are shown in figure 6. This flying boat has characteristics similar to seaplane "A" in reference 5.

In order to avoid confusion, specific interpolation charts were prepared for this flying boat and are shown in figure 7. They may be used only when all the characteristics are as given in the preceding paragraph. The use of the general interpolation charts will be described in the next calculation.

For the beam and load specified, the static load coefficient is 0.500. For $\alpha_o = 10^\circ$, the calculations shown in table I were made as follows:

Displacement range.-

1. A transparent copy of figure 7(a) is laid on top of the displacement-range curves for NACA Model No. 84-EF-3 in figure 8 (in order that the process can be more easily followed, the constant-speed contours were traced off and appear as dashed lines), so that the absolute angle of attack of the wing-flap combination is 10° when the hull trim is zero.

2. At zero speed the trim angle is found to be 2.4° for $C_\Delta = 0.500$.

3. At the intersection of the constant-speed contour at 10 feet per second with the free-to-trim track for $C_\Delta = 0.5$, the trim is found to be 2.5° and $C_V{}^2/C_\Delta{}^{1/3} = 0.50$.

4. Since C_V is known, solving for C_Δ gives 0.496.

5. At the intersection of the constant-speed contour at 20 feet per second with the free-to-trim curve for $C_\Delta = 0.496$, the trim is found to be 6.0° and $C_V^2/C_\Delta^{1/3} = 2.04$.

6. Since C_V is known, solving for C_Δ yields 0.481.

7. Repeat this process at each speed, finding the load coefficient and the trim angle. The trim curve shown in figure 9 was found by the interpolation process just described.

8. At 10 feet per second, $C_V^2/C_\Delta^{1/3} = 0.50$ and at that value the unique value of $C_R/C_V^2 C_\Delta^{2/3}$ is found to be 0.0345.

9. Since both C_V and C_Δ are known, C_R may be found to be 0.008.

10. At 20 feet per second, $C_V^2/C_\Delta^{1/3} = 2.04$ and $C_R/C_V^2 C_\Delta^{2/3} = 0.062$.

11. As both C_V and C_Δ are known, solving for C_R gives 0.062.

12. At 35 feet per second and higher, $C_R/C_V^2 C_\Delta^{2/3}$ must be interpolated for use of the previously found value of the load coefficient.

Planing range.-

1. A transparent copy of figure 7(b) is laid on top of the collapsed planing-range curves for NACA Model No. 84-EF-3 of figure 8, so that the absolute angle of attack of the wing-flap combination is 10° when the hull trim is zero. (Again, the speed contours were traced off and appear as dashed lines.)

2. Before proceeding, some arbitrary trim track must be assumed. The one shown in figure 8 was selected on the basis of the following considerations:

(a) Even though stability limits are not available, it would probably lie in the range of stable trims.

(b) It is at trims which are within the range of available control moments.

3. At the intersection of the constant-speed contour at 35 feet per second with the assumed trim curve, read $\sqrt{C_R}/C_V$ equal to 0.148.

4. Since C_V is known, solving for C_R yields 0.106.

5. Repeat at as many speeds as desired.

Finally, a plot of the interpolated values of trim and resistance coefficients is shown in figure 9. The values of trim and C_R below 50 feet per second, which were interpolated from the planing range, are considerably higher than those interpolated from the displacement range. The former should be abandoned, and the reason for this lies in the manner in which the collapsed curves in planing-range charts were prepared. The two charts in figure 10 are auxiliary charts used in preparing the final chart. It will be seen that at large values of $\sqrt{C_\Delta}/C_V$ (that is, low speeds and high loads) the curves used in preparing the final chart are really envelopes. It will further be noted that there is a small region in which neither type of collapsing criterion works well. The extent and the location of this region depend to a very large degree on both the hull lines and the trim angle. However, the difficulty it introduces may be overcome by ignoring the interpolation from the planing range when it gives a higher trim or resistance than the interpolation from the displacement range at the same speed.

The interpolations just described were repeated for α_o equal to 8° and 12° by first shifting the transparent chart downward 2° relative to the chart of collapsed hydrodynamic characteristics and then raising it 2°. The results are also shown in table I. The planing range was not interpolated from 35 to 45 feet per second for these two additional wing settings because of the reasoning given in the preceding paragraph. From table I it will be seen that α_o has its largest effect at high planing speeds. However, without adding in the air drag, it is impossible to predict the value of α_o that will give the best take-off time. The chart in figure 6 showing the aerodynamic characteristics of this flying boat indicates that a flap angle of 15° is likely to give the best take-off time because of the high $C_{L_{max}}$ in combination with low drag. It would probably be sufficient to calculate the take-off time for three flap angles at one value of α_o and the best for the other values. These steps were not taken because the designer is already quite familiar with them.

Flying Boat B

A flying-boat-hull designer is given the following specifications (which are similar to those of the XPB2M-1):

$$\Delta_o = 140{,}000 \text{ pounds}$$

$$S = 3{,}500 \text{ square feet}$$

$$\alpha_o = 8^\circ$$

$$dC_L/d\alpha = 0.100$$

and wishes to find the effect of hull size, when using SIT Model No. 339-1, on the resistance, porpoising, and main spray blister characteristics, with the aid of the general interpolation charts.

Displacement range.-

1. The first step is to calculate $S/(\Delta_o/w)^{2/3}$, which for the assumed particulars will be 20.75. Multiplying by the lift rate, $dC_L/d\alpha = 0.100$, gives 2.08, and this value will be used for the interpolation of all hull sizes in the displacement range. The entire calculation may be found in table II.

2. Assume that the beam equals 11.83 feet, which will make $C_{\Delta_o} = 1.331$ and $C_{\Delta_o}{}^{1/6} = 1.050$.

3. Tabulate C_V for $C_{\Delta_o} = 1.00$ from the bottom of the chart in figure 2 and multiply each value by 1.050 to obtain the second column in table II. The second column represents the true value of C_V for the selected beam.

4. Set a transparent copy of the general chart of constant-speed contours in the displacement range (fig. 2) on top of the collapsed displacement-range curves for SIT Model No. 339-1 in figure 1 so that the absolute angle of attack of the wing-flap combination is 8° when the hull trim is zero.

5. The interpolation of the trim and resistance is then just the same as for Flying Boat A described under SAMPLE CALCULATIONS - care being emphasized to interpolate for a constant-speed contour of $\left(dC_L/d\alpha\right)\left[S/(\Delta_o/w)^{2/3}\right] = 2.08$.

6. Since $C_V^2/C_\Delta^{1/3}$ is known, from the collapsed spray curves read $C_X/C_\Delta^{1/3}$ and C_Z/C_Δ. Because it is probably of less interest $C_Y/C_\Delta^{1/3}$ has been omitted in the present instance.

7. Since C_Δ is known for each speed, C_X and C_Z may be determined.

Planing range.-

1. Calculate S/b^2 and multiply it by $dC_L/d\alpha$. The result is 2.50 for the assumed beam of 11.83.

2. Tabulate C_V for $C_{\Delta_o} = 1.00$ and multiply each value by $C_{\Delta_o}^{1/2}$, which is 1.155, to get the specific values of C_V for the selected beam.

3. Take a transparent copy of the appropriate general chart of constant-speed contours in the planing range (fig. 4) and set it on top of the collapsed planing-range curves for SIT Model No. 339-1 so that α_o is 8°.

4. After selecting the trim track for zero applied moment, since it lies between the stability limits, read the value of $\sqrt{C_R}/C_V$ and the trim at the intersection of the assumed trim curve with the constant-speed contour $(dC_L/d\alpha)(S/b^2) = 2.50$. At the same time, the intersection of the general stability limits with the same constant-speed contour will give the trims for the specific upper and lower limits.

5. Proceed as for Flying Boat A.

Tables III and IV show the calculations for two increased hull sizes. In the displacement range $S/(\Delta_o/w)^{2/3}$ was not changed with changes of hull size. However, C_{Δ_o} does change and hence the specific values of C_V also change. In the planing range, the value of S/b^2 must be calculated for each hull size investigated. The specific values of C_V must be altered because of the changes of C_{Δ_o}. Otherwise, the interpolation procedure in both the displacement and the planing ranges is just the same as previously outlined. To find the beam which will give the best take-off time will require the addition of the aerodynamic drag and then a conventional take-off-time calculation. The spray information may be used to find the necessary hull height to allow proper clearance of the wing and the propellers. After the height has been found, the aerodynamic drag of the hull may be calculated. In order to find optimums, it may be necessary to investigate additional sizes between those shown.

Sample calculations to show the effect of alterations of wing size or the effect of changes of gross weight have not been prepared. It is hoped that the notes under USE OF CHARTS, in combination with the two calculations already shown, will be sufficient to make the process of these other interpolations clear.

CONCLUDING REMARKS

A simple and rapid method for the interpolation of the characteristics of specific flying boats from the collapsed results of general tests has been developed. The method should aid considerably in making detailed design studies to determine the influence of the hull on flying-boat performance. Through use of the interpolation method, the shapes and the magnitudes of the collapsed curves of general tests should acquire more meaning to the designer.

Design Research Division
Bureau of Aeronautics, Navy Department
Washington, D. C., September 25, 1946

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TABLE I.- EFFECT OF α_o ON FLYING BOAT A

Displacement range

			$\alpha_o = 8^\circ$						$\alpha_o = 10^\circ$						$\alpha_o = 12^\circ$					
V (ft/sec)	C_V	C_V^2	τ (deg)	$\frac{C_V^2}{C_\Delta^{1/3}}$	C_Δ	$\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	C_R	R (lb)	τ (deg)	$\frac{C_V^2}{C_\Delta^{1/3}}$	C_Δ	$\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	C_R	R (lb)	τ (deg)	$\frac{C_V^2}{C_\Delta^{1/3}}$	C_Δ	$\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	C_R	R (lb)
0	0	0	2.4	0	0.500	------	0	0	2.4	0	0.500	----	0	0	2.4	0	0.500	----	0	0
10	.63	.40	2.5	.50	.496	0.0345	.008	240	2.5	.50	.496	0.0345	.008	240	2.5	.50	.496	0.0345	.008	240
20	1.26	1.60	6.0	2.04	.481	.0625	.062	1845	6.0	2.04	.481	.0625	.062	1845	6.0	2.04	.481	.0625	.062	1845
25	1.58	2.49	6.6	3.20	.474	.0470	.071	2130	6.5	3.20	.474	.0470	.071	2130	6.5	3.20	.474	.0470	.071	2130
30	1.89	3.59	8.7	4.62	.467	.0396	.086	2565	8.8	4.64	.463	.0394	.084	2540	8.9	4.65	.462	.0393	.084	2520
35	2.21	4.90	10.4	6.42	.444	.0320	.091	2730	10.4	6.45	.439	.0318	.090	2690	10.4	6.48	.432	.0315	.088	2640
40	2.53	6.40	10.3	8.49	.429	.0244	.089	2670	10.2	8.54	.421	.0243	.088	2640	10.2	8.59	.414	.0241	.086	2580
45	2.84	8.06	9.6	10.80	.415	.0186	.084	2505	9.5	10.87	.405	.0181	.080	2375	9.4	10.99	.395	.0179	.078	2340

Planing range

V (ft/sec)	C_V	τ (deg)	$\frac{\sqrt{C_R}}{C_V}$	C_R	R (lb)	τ (deg)	$\frac{\sqrt{C_R}}{C_V}$	C_R	R (lb)	τ (deg)	$\frac{\sqrt{C_R}}{C_V}$	C_R	R (lb)
35	2.21					12.8	0.148	0.106					
40	2.53					11.4	.122	.094					
45	2.84					9.9	.100	.082					
50	3.16	8.6	0.086	0.074	2235	8.5	.084	.070	2115	8.3	0.082	0.068	2040
55	3.48	7.7	.074	.066	1995	7.6	.072	.064	1905	7.5	.072	.063	1890
60	3.79	7.3	.066	.064	1905	7.2	.065	.060	1815	7.1	.063	.057	1710
70	4.42	6.8	.054	.057	1710	6.8	.052	.054	1620	6.7	.052	.052	1560
80	5.06	6.6	.047	.056	1695	6.6	.046	.053	1590	6.6	.044	.050	1485
90	5.69	6.6	.042	.057	1710	6.6	.040	.052	1545	6.5	.038	.048	1440
100	6.32	6.5	.038	.058	1725	6.5	.037	.054	1635	6.5	.034	.045	1350
110	6.95	6.5	.034	.058	1725	6.5	.032	.050	1485				

TABLE II - FLYING BOAT B

[b = 11.83 ft]

Displacement range

C_V (C_{Δ_o} = 1.0)	C_V	Resistance						Spray				X (ft)	Z (ft)	R (lb)	V (ft/sec)
		τ (deg)	$\frac{C_V^2}{C_\Delta^{1/3}}$	C_V^2	C_Δ	$\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	C_R	$\frac{C_X}{C_\Delta^{1/3}}$	$\frac{C_Z}{C_\Delta}$	C_X	C_Z				
0	0	1.9	0	0	1.331	- - - - -	0							0	0
1.00	1.05	3.6	1.00	1.10	1.33	0.0488	.065	+2.75	0.50	+3.03	0.66	+35.8	8.0	6,850	20.5
1.25	1.31	5.4	1.57	1.72	1.32	.0660	.136	2.30	.50	2.52	.66	29.8	7.9	14,300	25.5
1.50	1.58	6.2	2.27	2.48	1.30	.0543	.160	1.75	.58	1.91	.75	22.6	8.9	16,850	30.8
1.75	1.84	6.6	3.12	3.38	1.27	.0462	.183	1.17	.70	1.27	.89	15.0	10.5	19,250	35.9
2.00	2.10	8.4	4.11	4.41	1.23	.0425	.215	+ .50	.84	+ .54	1.03	+ 6.4	12.3	22,600	41.0
2.25	2.36	10.0	5.30	5.57	1.16	.0450	.277	-.27	1.01	-.28	1.17	-3.3	13.8	29,150	46.0
2.50	2.62	11.3	6.60	6.90	1.14	.0325	.244	1.07	1.20	1.12	1.37	13.2	16.2	25,700	51.2
2.75	2.89	11.7	8.11	8.35	1.09	.0270	.238	1.96	1.41	2.02	1.54	23.9	18.2	25,000	56.4
3.00	3.15	11.8	9.79	9.94	1.04	.0225	.229	2.90	1.65	2.94	1.71	34.8	20.2	24,100	61.4
3.25	3.41	11.7	11.65	11.62	1.00	.0196	.227	-3.92	1.92	-3.91	1.91	-46.3	22.5	23,900	66.5

Planing range

C_V (C_{Δ_o} = 1.0)	C_V	Resistance			Upper limit trim	Lower limit trim	R (lb)	V (ft/sec)
		τ (deg)	$\sqrt{C_R}/C_V$	C_R				
3.00	3.47	11.3	0.138	0.228	Stable	Stable	24,000	67.7
3.50	4.05	11.0	.109	.195	11.2	10.4	20,500	79.0
4.00	4.62	9.0	.086	.158	11.0	9.0	16,600	90.1
4.50	5.20	7.5	.068	.127	10.7	6.8	13,350	101.5
5.00	5.78	6.9	.058	.110	10.0	5.0	11,600	112.7
5.50	6.35	6.6	.050	.103	8.9	3.9	10,850	123.8
6.00	6.93	6.4	.044	.095	7.9	3.2	10,000	135.1
6.50	7.51	6.2	.038	.081	7.3	2.8	8,500	146.5

Constants

Δ_o = 140,000 lb
S = 3,500 sq ft
$\alpha_o = 8^\circ$
$dC_L/d\alpha$ = 0.100

$S/(\Delta/w)^{2/3}$ = 20.75
b = 11.83 ft

S/b^2 = 25.0
C_{Δ_o} = 1.331

$C_{\Delta_o}{}^{1/2}$ = 1.155
$C_{\Delta_o}{}^{1/6}$ = 1.050
wb^3 = 105,200
$\sqrt{gb}$ = 19.50

Hull: SIT Model No. 339-1

\+ forward of step
\- aft of step

TABLE III.- FLYING BOAT B

[b = 13.23 ft]

Displacement range

C_V ($C_{\Delta_o} = 1.0$)	C_V	Resistance: τ (deg)	Resistance: $\frac{C_V^2}{C_\Delta^{1/3}}$	Resistance: C_V^2	Resistance: C_Δ	Resistance: $\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	Resistance: C_R	Spray: $\frac{C_X}{C_\Delta^{1/3}}$	Spray: $\frac{C_Z}{C_\Delta}$	Spray: C_X	Spray: C_Z	X (ft)	Z (ft)	R (lb)	V (ft/sec)
0	0	2.0	0	0	0.916	- - - - -	0							0	0
1.00	.98	3.1	1.00	.97	.913	0.0488	.044	+2.75	0.50	+2.67	0.46	+35.3	5.9	6,800	20.4
1.25	1.23	4.4	1.57	1.52	.908	.0660	.093	2.30	.50	2.23	.46	29.5	5.9	14,200	25.4
1.50	1.48	5.2	2.27	2.18	.875	.0543	.108	1.75	.58	1.68	.51	22.2	6.8	16,500	30.5
1.75	1.72	5.5	3.12	2.96	.854	.0462	.123	1.17	.70	1.11	.60	14.7	7.9	18,800	35.5
2.00	1.97	6.0	4.11	3.89	.848	.0425	.148	+ .50	.84	+ .47	.71	+ 6.2	9.4	22,600	40.6
2.25	2.22	8.1	5.28	4.92	.810	.0394	.168	-.28	1.01	-.26	.82	-3.4	10.8	25,800	45.8
2.50	2.47	8.0	6.60	6.08	.791	.0285	.147	1.07	1.20	.99	.94	13.1	12.4	22,500	51.0
2.75	2.71	10.0	8.07	7.35	.755	.0250	.152	1.94	1.41	1.77	1.06	23.4	14.1	23,250	55.9
3.00	2.96	10.5	9.75	8.75	.723	.0220	.155	2.88	1.65	2.59	1.19	34.3	15.7	23,700	61.1
3.25	3.20	10.5	11.60	10.28	.694	.0188	.152	-3.89	1.91	-3.45	1.32	-45.6	17.4	23,200	66.1

Planing range

C_V ($C_{\Delta_o} = 1.0$)	C_V	Resistance: τ (deg)	Resistance: $\sqrt{C_R}/C_V$	Resistance: C_R	Upper limit trim	Lower limit trim	R (lb)	V (ft/sec)
3.00	2.87	11.4	0.143	0.168	Stable	Stable	25,700	59.2
3.50	3.35	10.9	.116	.150	11.0	10.4	22,900	69.1
4.00	3.83	9.7	.093	.127	10.9	9.6	19,400	79.0
4.50	4.30	8.1	.074	.103	10.8	7.7	15,750	89.7
5.00	4.78	7.2	.063	.091	10.5	5.8	13,900	98.6
6.00	5.74	6.7	.050	.081	8.8	3.5	12,400	118.5
7.00	6.70	6.2	.040	.070	7.7	2.8	10,700	138.3
7.50	7.18	6.0	.034	.060	- - - -	2.6	9,200	148.0

Constants

Δ_o = 140,000 lb

S = 3,500 sq ft

$\alpha_o = 8^\circ$

$dC_L/d\alpha = 0.100$

$S/(\Delta/w)^{2/3} = 20.75$

b = 13.23 ft

$S/b^2 = 20.0$

$C_{\Delta_o} = 0.916$

$C_{\Delta_o}^{1/2} = 0.957$

$C_{\Delta_o}^{1/6} = 0.986$

$wb^3 = 152,900$

$\sqrt{gb} = 20.62$

Hull: SIT Model No. 339-1

\+ forward of step

− aft of step

TABLE IV.– FLYING BOAT B

[$b = 15.28$ ft]

Displacement range																
		Resistance					Spray									
C_V ($C_{\Delta_o} = 1.0$)	C_V	τ (deg)	$\frac{C_V^2}{C_\Delta^{1/3}}$	C_V^2	C_Δ	$\frac{C_R}{C_V^2 C_\Delta^{2/3}}$	C_R	$\frac{C_X}{C_\Delta^{1/3}}$	$\frac{C_Z}{C_\Delta}$	C_X	C_Z	X (ft)	Z (ft)	R (lb)	V (ft/sec)
0	0	2.5	0	0	0.614	- - - - -	0							0	0
1.00	.92	2.6	1.00	.85	.613	0.0488	.030	+2.75	0.50	+2.34	0.30	+35.8	4.6	6,850	20.4
1.25	1.15	3.5	1.57	1.33	.608	.0660	.063	2.30	.50	1.95	.30	29.8	4.6	14,350	25.5
1.50	1.38	4.4	2.27	1.91	.596	.0543	.074	1.75	.58	1.48	.34	22.5	5.3	16,750	30.6
1.75	1.61	4.7	3.11	2.60	.585	.0463	.084	1.47	.69	.98	.40	15.0	6.2	19,150	35.7
2.00	1.84	5.1	4.10	3.40	.570	.0425	.099	+ .51	.84	+ .42	.48	+ 6.4	7.3	22,600	40.8
2.25	2.08	5.7	5.25	4.30	.549	.0320	.092	-.25	1.00	-.20	.55	-3.1	8.4	21,000	46.1
2.50	2.30	5.5	6.51	5.31	.544	.0255	.090	1.03	1.19	.84	.65	12.8	10.0	20,650	51.0
2.75	2.53	7.8	7.99	6.42	.519	.0238	.099	1.89	1.39	1.52	.72	23.2	11.0	27,600	56.2
3.00	2.77	9.2	9.65	7.65	.498	.0217	.104	2.83	1.63	2.24	.81	34.3	12.4	23,700	61.5
3.25	3.00	9.7	11.54	8.98	.473	.0188	.102	-3.86	1.90	-3.01	.90	-46.0	13.8	23,400	66.6

Planing range								
		Resistance						
C_V ($C_{\Delta_o} = 1.0$)	C_V	τ (deg)	$\sqrt{C_R}/C_V$	C_R	Upper limit trim	Lower limit trim	R (lb)	V (ft/sec)
3.00	2.35	11.4	0.148	0.120	Stable	Stable	27,350	52.2
3.50	2.74	11.2	.122	.111	11.3	10.2	25,300	60.8
4.00	3.13	10.4	.100	.098	11.2	10.1	22,350	69.5
5.00	3.92	7.7	.069	.073	10.9	6.7	16,650	87.0
6.00	4.70	6.7	.054	.064	9.8	4.2	14,700	104.2
7.00	5.48	6.4	.046	.064	8.6	3.1	14,500	121.5
8.00	6.26	6.2	.038	.056	7.6	2.8	12,900	139.0
8.50	6.66	6.1	.034	.051	- - -	2.6	11,650	147.8

Constants

$\Delta_o = 140{,}000$ lb

$S = 3{,}500$ sq ft

$\alpha_o = 8^\circ$

$dC_L/d\alpha = 0.100$

$S/(\Delta/w)^{2/3} = 20.75$

$b = 15.28$ ft

$S/b^2 = 15.0$

$C_{\Delta_o} = 0.614$

$C_{\Delta_o}^{1/2} = 0.784$

$C_{\Delta_o}^{1/6} = 0.922$

$wb^3 = 228{,}000$

$\sqrt{gb} = 22.20$

Hull: SIT Model No. 339-1

+ forward of step

– aft of step

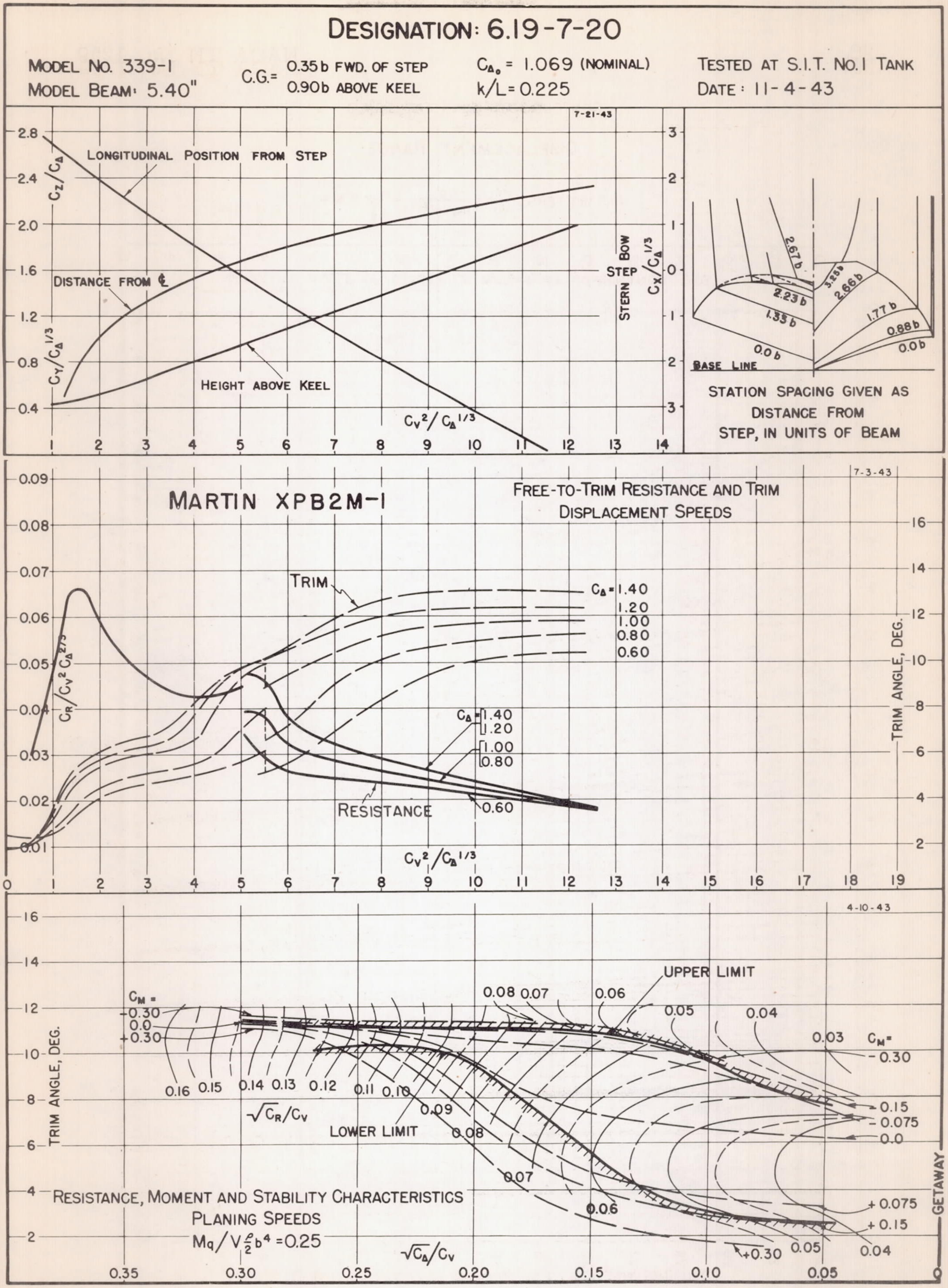
DESIGNATION: 6.19-7-20
MODEL NO. 339-1
MODEL BEAM: 5.40"
C.G.= 0.35b FWD. OF STEP
0.90b ABOVE KEEL
C_{Δ_0} = 1.069 (NOMINAL)
k/L = 0.225
TESTED AT S.I.T. NO. 1 TANK
DATE: 11-4-43
7-21-43
LONGITUDINAL POSITION FROM STEP
DISTANCE FROM ℄
HEIGHT ABOVE KEEL
C_Z/C_Δ
$C_Y/C_\Delta^{1/3}$
$C_X/C_\Delta^{1/3}$
STERN BOW
STEP
$C_V^2/C_\Delta^{1/3}$
STATION SPACING GIVEN AS DISTANCE FROM STEP, IN UNITS OF BEAM
BASE LINE
2.67b
2.23b
1.35b
0.0b
3.28b
2.66b
1.77b
0.88b
0.0b
7-3-43
MARTIN XPB2M-1
FREE-TO-TRIM RESISTANCE AND TRIM
DISPLACEMENT SPEEDS
TRIM
C_Δ = 1.40
1.20
1.00
0.80
0.60
RESISTANCE
$C_R/C_V^2 C_\Delta^{2/3}$
TRIM ANGLE, DEG.
4-10-43
UPPER LIMIT
LOWER LIMIT
C_M =
-0.30
0.0
+0.30
0.16 0.15 0.14 0.13 0.12 0.11 0.10 0.09 0.08 0.07 0.06 0.05 0.04 0.03
$\sqrt{C_R}/C_V$
+0.15
-0.075
0.0
+0.075
+0.15
+0.30
GETAWAY
RESISTANCE, MOMENT AND STABILITY CHARACTERISTICS
PLANING SPEEDS
$M_q/V\frac{\rho}{2}b^4$ = 0.25
$\sqrt{C_\Delta}/C_V$

Figure 1

CONTOURS OF CONSTANT SPEED
IN THE
DISPLACEMENT RANGE

PARAMETERS, $\frac{dC_L}{d\alpha} \times \frac{S}{(\Delta_o/w)^{2/3}}$ = 1,2,3 & 4

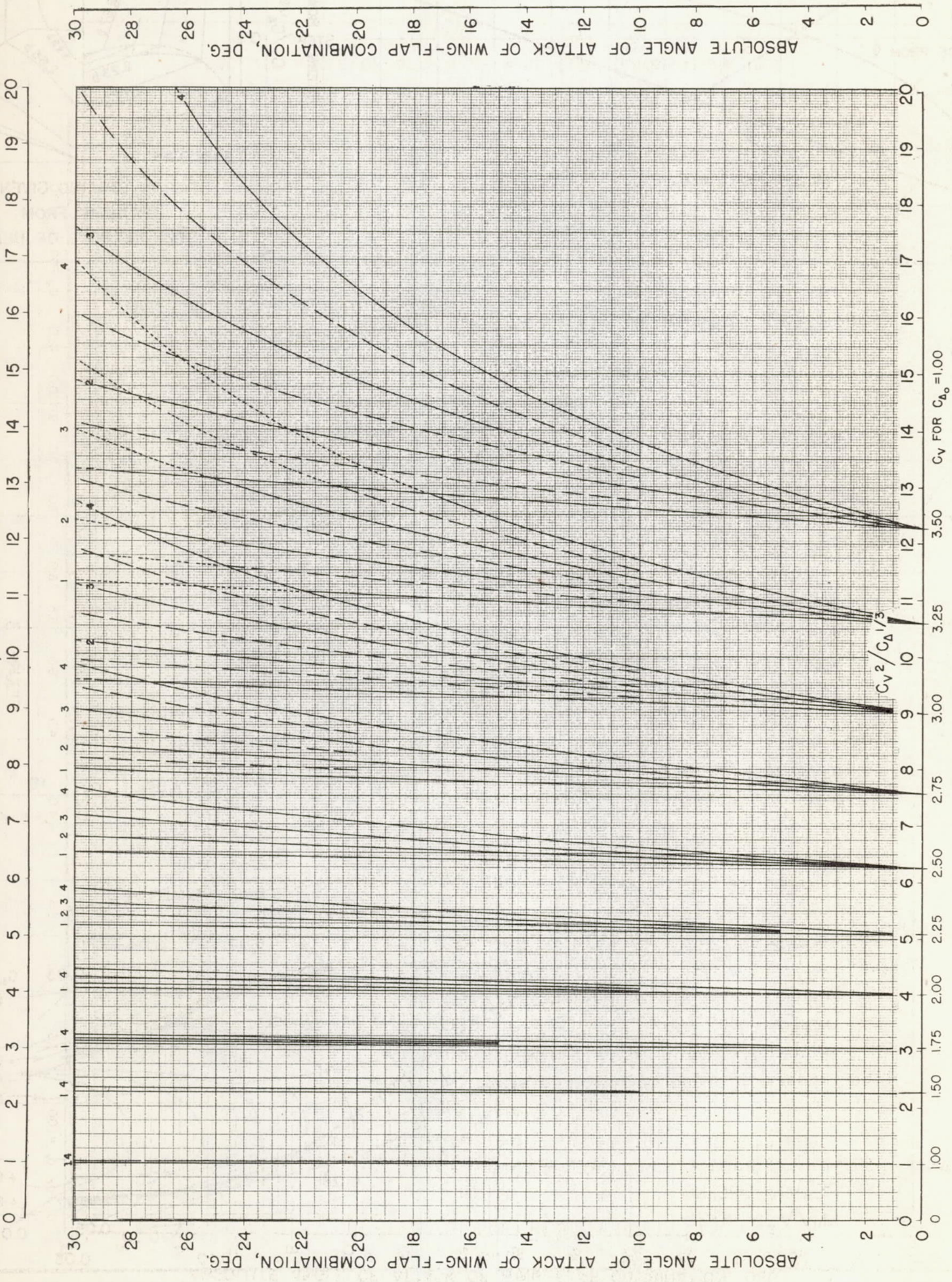

FIGURE 2

CONTOURS OF CONSTANT SPEED
IN THE
PLANING RANGE

PARAMETERS, $\frac{dC_L}{d\alpha} \times \frac{S}{b^2}$ = 1.0, 1.5 & 2.0

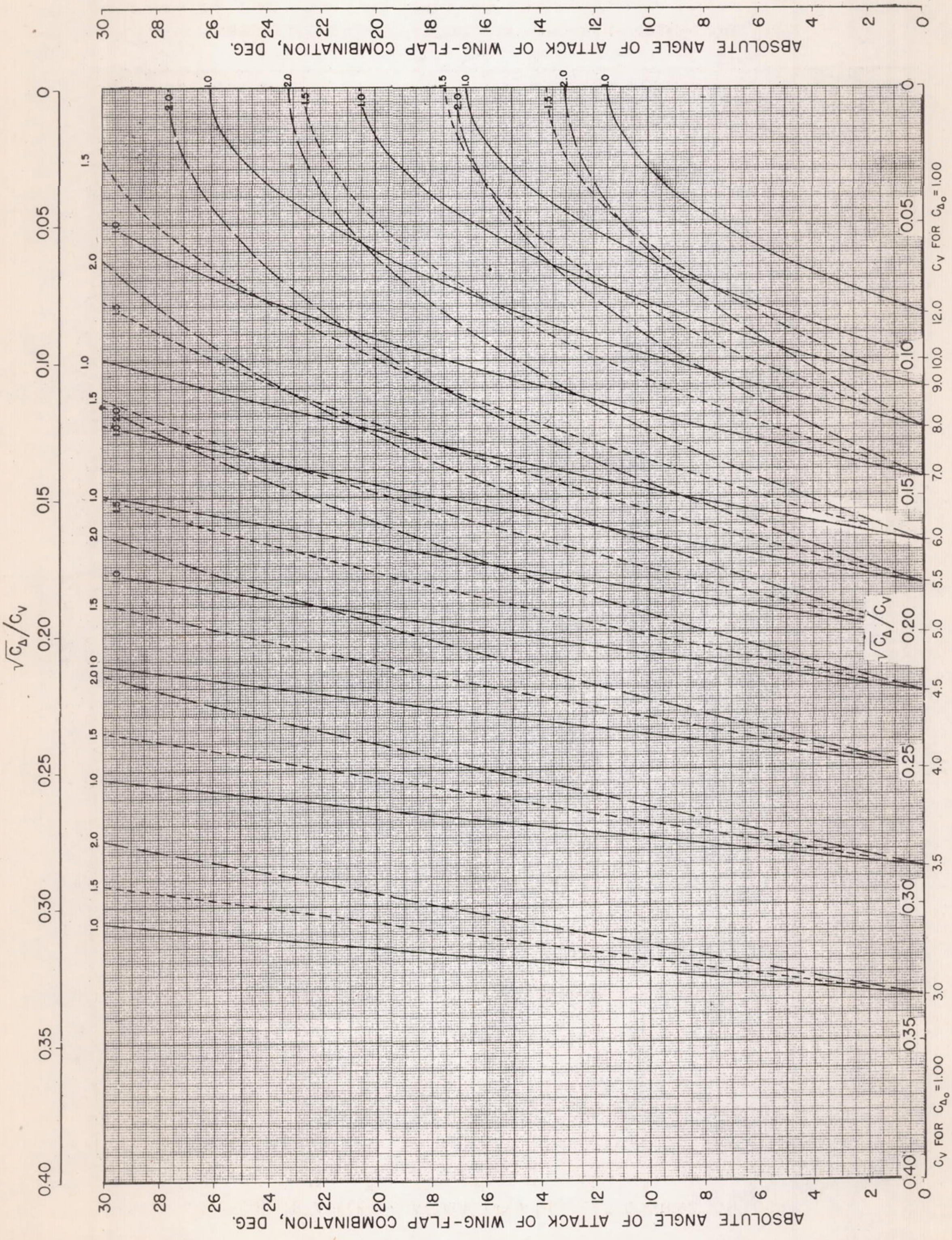

FIGURE 3

CONTOURS OF CONSTANT SPEED IN THE PLANING RANGE

PARAMETERS, $\frac{dC_L}{d\alpha} \times \frac{S}{b^2}$ = 2.0, 2.5 & 3.0

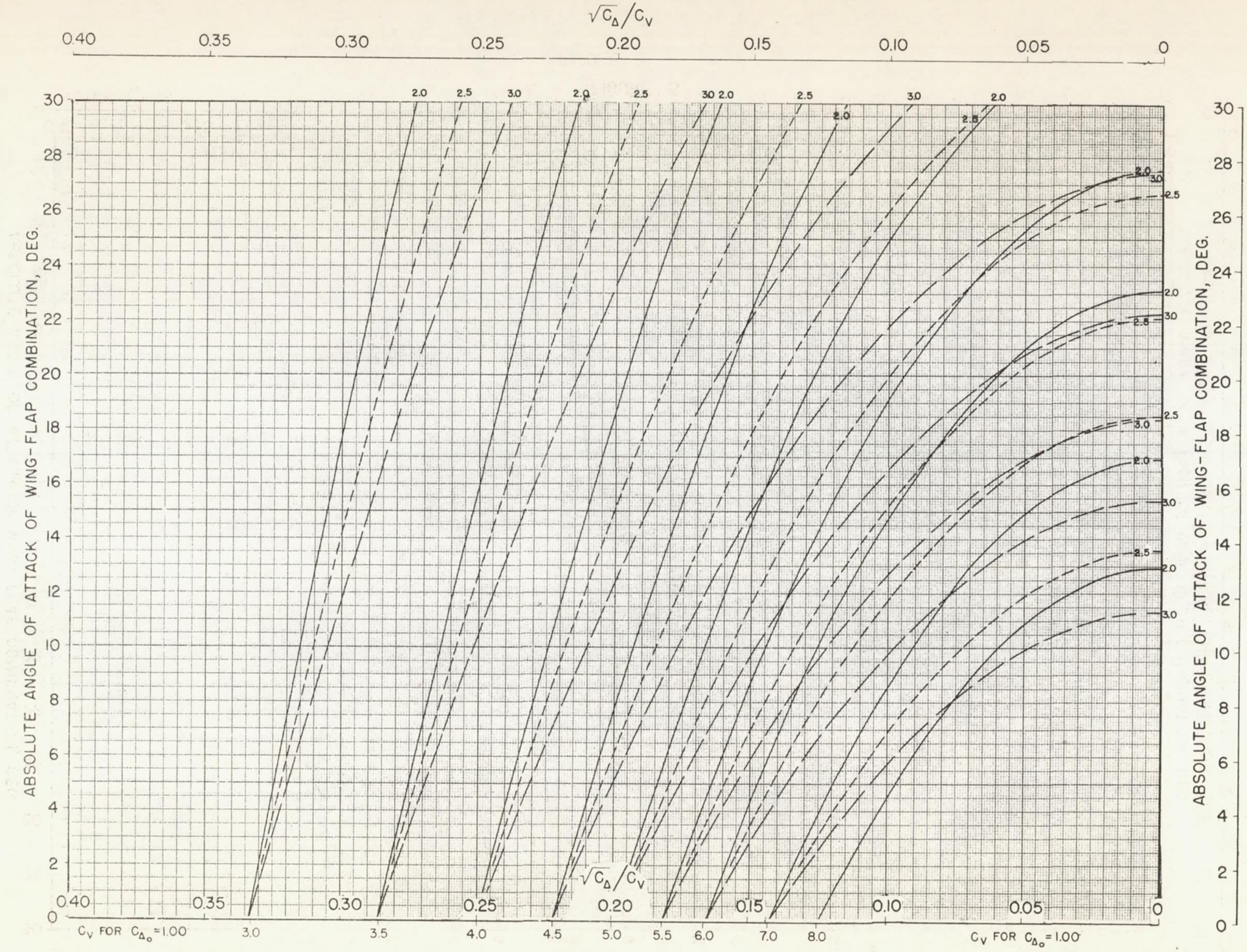

FIGURE 4

CONTOURS OF CONSTANT SPEED
IN THE
PLANING RANGE

PARAMETERS, $\frac{dC_L}{d\alpha} \times \frac{S}{b^2}$ = 3.0, 3.5 & 4.0

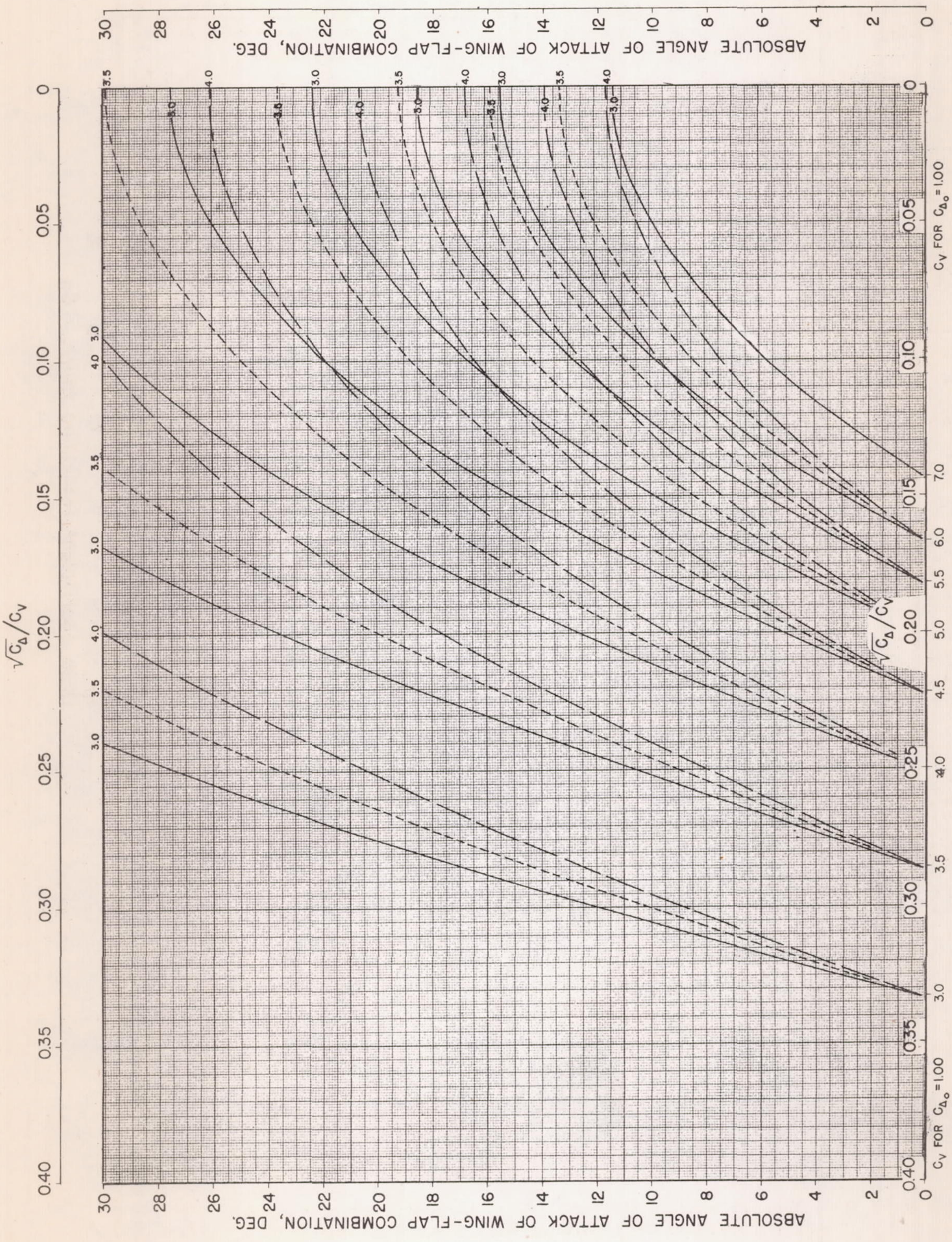

FIGURE 5

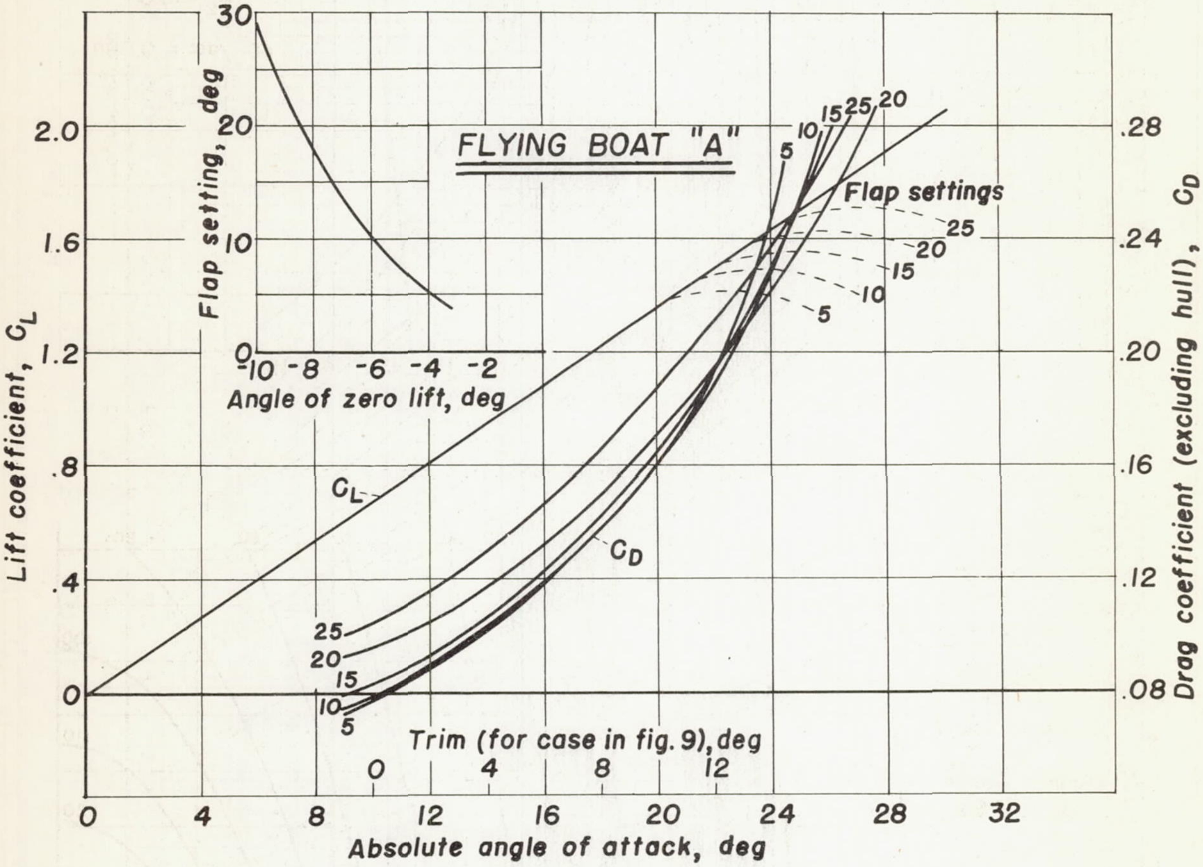
FLYING BOAT "A"
Flap setting, deg
30
20
10
0
-10 -8 -6 -4 -2
Angle of zero lift, deg
Lift coefficient, C_L
2.0
1.6
1.2
.8
.4
0
Drag coefficient (excluding hull), C_D
.28
.24
.20
.16
.12
.08
Flap settings
25
20
15
10
5
C_L
C_D
Trim (for case in fig. 9), deg
0 4 8 12
0 4 8 12 16 20 24 28 32
Absolute angle of attack, deg

Figure 6

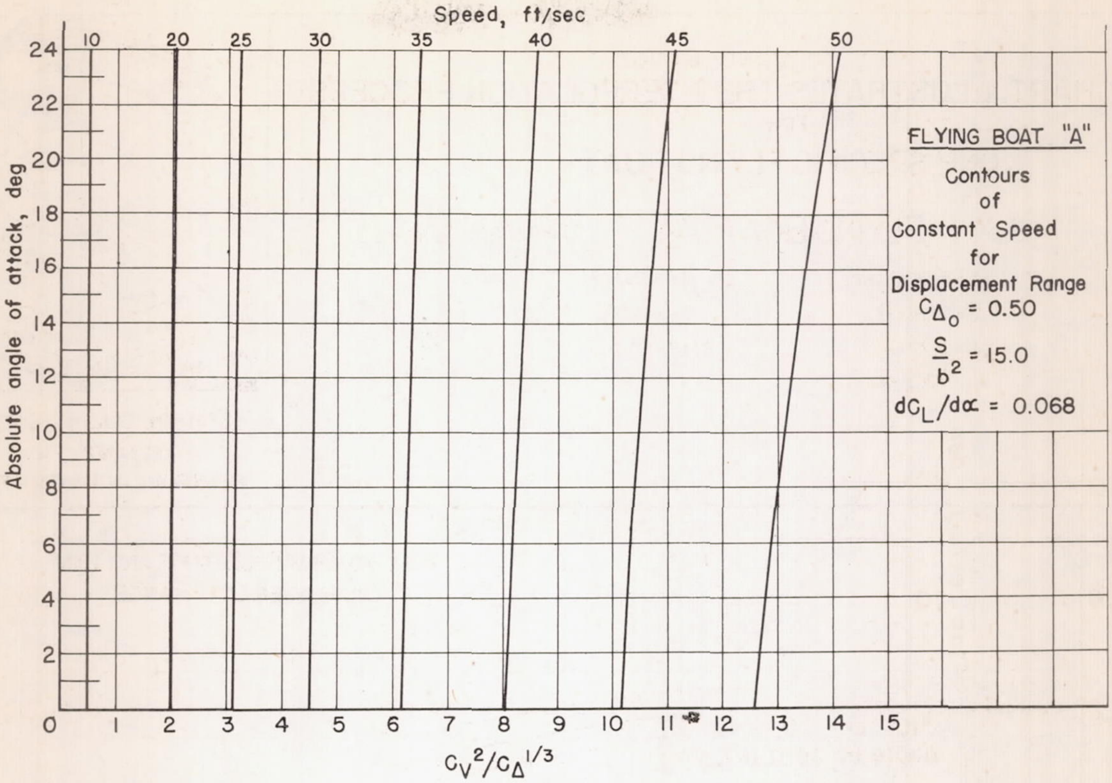

Figure 7(a)

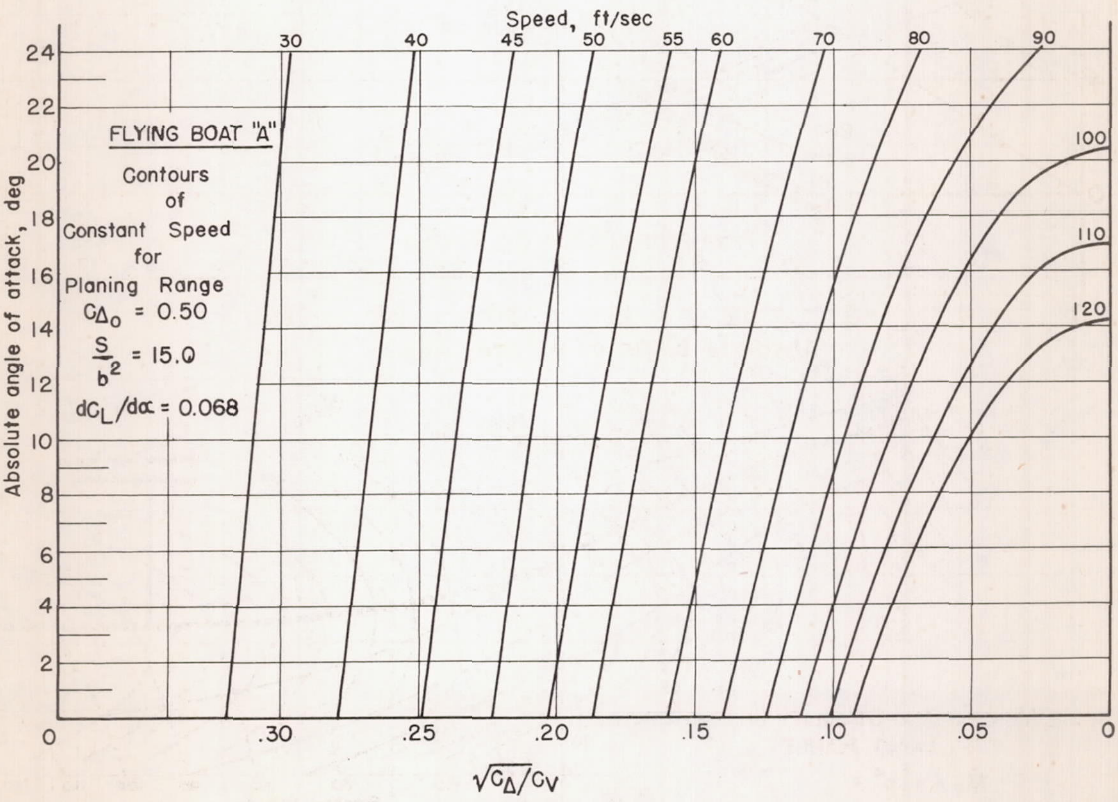

Figure 7(b)

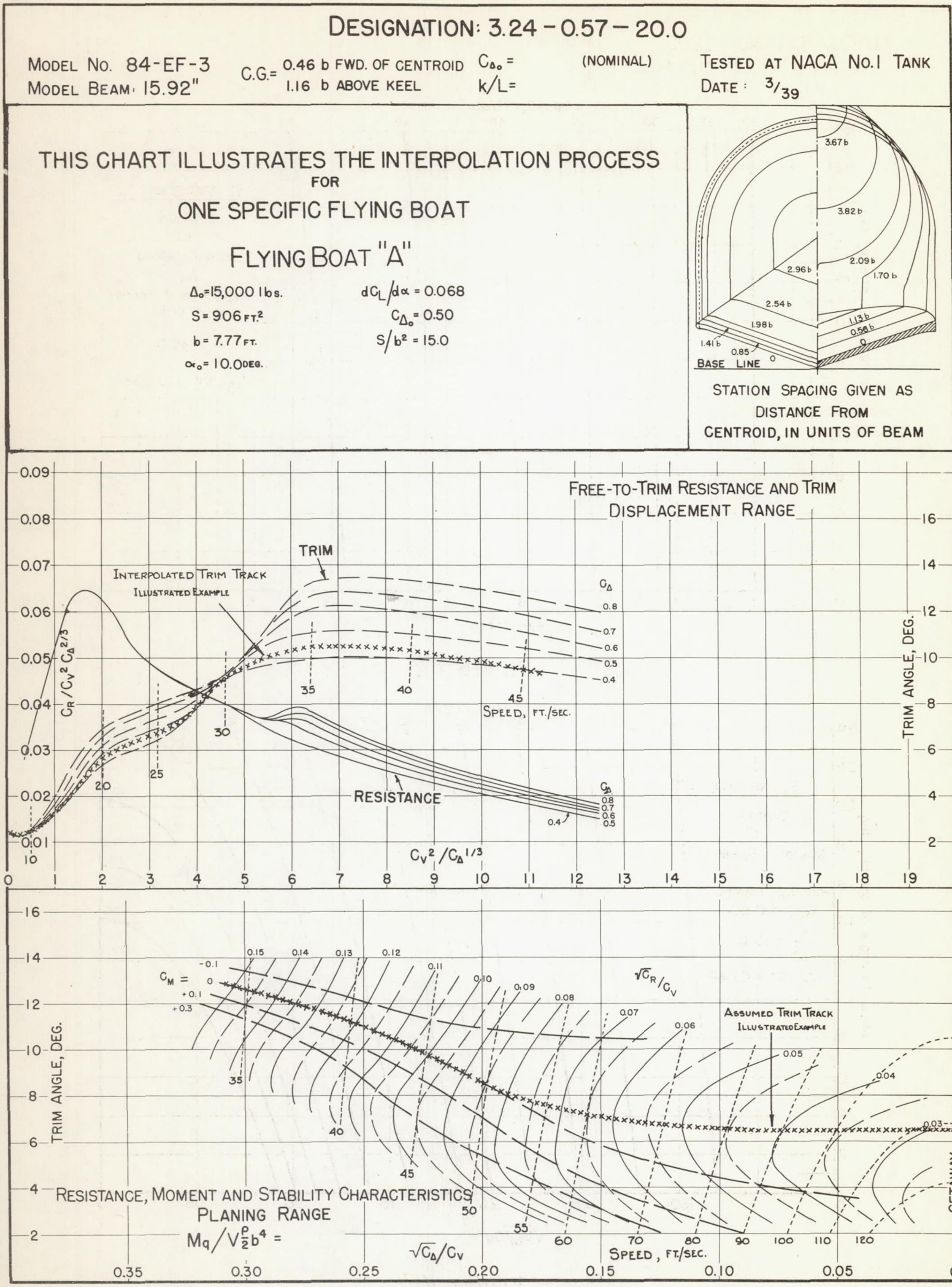
DESIGNATION: 3.24 - 0.57 - 20.0
MODEL NO. 84-EF-3
MODEL BEAM: 15.92"
C.G.= 0.46 b FWD. OF CENTROID
1.16 b ABOVE KEEL
C_{Δ_0} = (NOMINAL)
k/L=
TESTED AT NACA NO. 1 TANK
DATE: 3/39
THIS CHART ILLUSTRATES THE INTERPOLATION PROCESS
FOR
ONE SPECIFIC FLYING BOAT
FLYING BOAT "A"
Δ_0=15,000 lbs.
S = 906 FT.²
b = 7.77 FT.
α_0 = 10.0 DEG.
$dC_L/d\alpha$ = 0.068
C_{Δ_0} = 0.50
S/b^2 = 15.0
3.67b
3.82b
2.96b
2.09b
1.70b
2.54b
1.98b
1.13b
0.56b
1.41b
0.85
0
BASE LINE
STATION SPACING GIVEN AS
DISTANCE FROM
CENTROID, IN UNITS OF BEAM
FREE-TO-TRIM RESISTANCE AND TRIM
DISPLACEMENT RANGE
TRIM
INTERPOLATED TRIM TRACK
ILLUSTRATED EXAMPLE
C_Δ
0.8
0.7
0.6
0.5
0.4
SPEED, FT./SEC.
RESISTANCE
$C_R/C_V^2 C_\Delta^{2/3}$
TRIM ANGLE, DEG.
$C_V^2/C_\Delta^{1/3}$
C_M =
$\sqrt{C_R}/C_V$
ASSUMED TRIM TRACK
ILLUSTRATED EXAMPLE
RESISTANCE, MOMENT AND STABILITY CHARACTERISTICS
PLANING RANGE
$M_q/V\frac{\rho}{2}b^4$ =
$\sqrt{C_\Delta}/C_V$
SPEED, FT./SEC.
GETAWAY

FIGURE 8

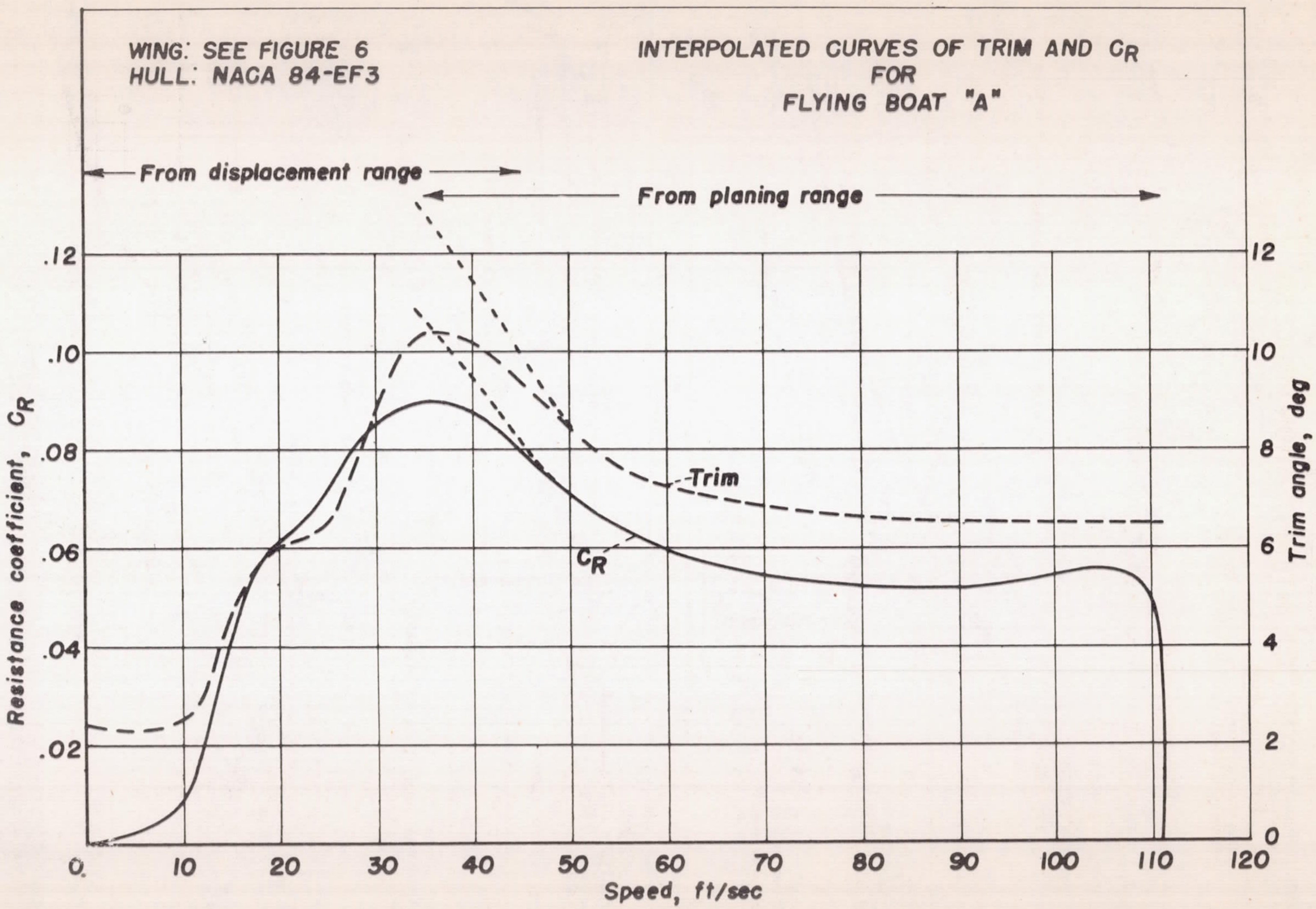
WING: SEE FIGURE 6
HULL: NACA 84-EF3
INTERPOLATED CURVES OF TRIM AND C_R
FOR
FLYING BOAT "A"
From displacement range
From planing range
Trim
C_R
Resistance coefficient, C_R
Trim angle, deg
Speed, ft/sec
.12
.10
.08
.06
.04
.02
0
10
20
30
40
50
60
70
80
90
100
110
120
12
10
8
6
4
2
0

Figure 9

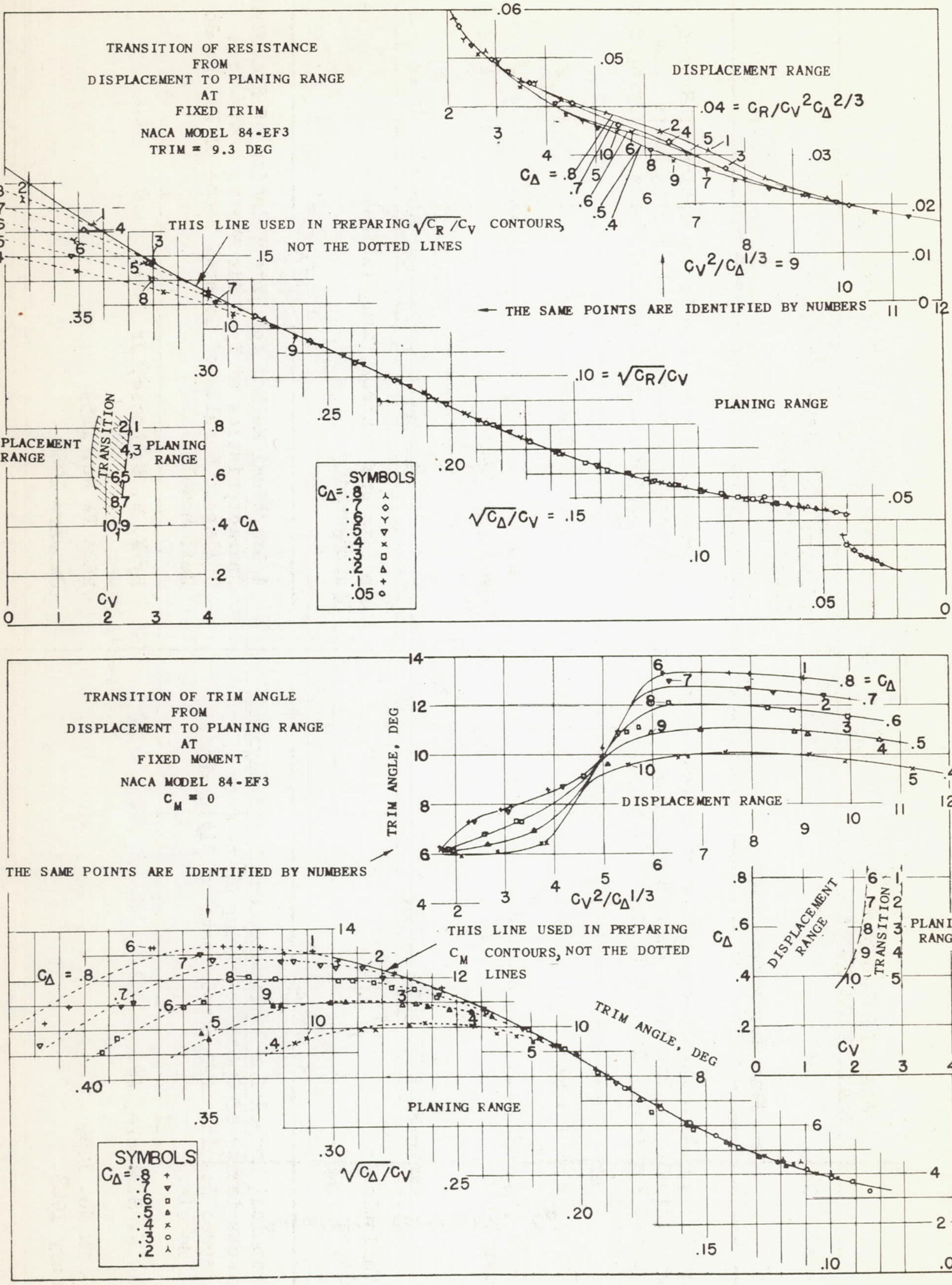
TRANSITION OF RESISTANCE FROM DISPLACEMENT TO PLANING RANGE AT FIXED TRIM
NACA MODEL 84-EF3
TRIM = 9.3 DEG
DISPLACEMENT RANGE
.04 = $C_R/C_V{}^2C_\Delta{}^{2/3}$
$C_V{}^2/C_\Delta{}^{1/3}$ = 9
THE SAME POINTS ARE IDENTIFIED BY NUMBERS
THIS LINE USED IN PREPARING $\sqrt{C_R}/C_V$ CONTOURS, NOT THE DOTTED LINES
.10 = $\sqrt{C_R}/C_V$
PLANING RANGE
TRANSITION
DISPLACEMENT RANGE
PLANING RANGE
SYMBOLS
$\sqrt{C_\Delta}/C_V$ = .15
TRANSITION OF TRIM ANGLE FROM DISPLACEMENT TO PLANING RANGE AT FIXED MOMENT
NACA MODEL 84-EF3
C_M = 0
TRIM ANGLE, DEG
DISPLACEMENT RANGE
$C_V{}^2/C_\Delta{}^{1/3}$
THE SAME POINTS ARE IDENTIFIED BY NUMBERS
THIS LINE USED IN PREPARING C_M CONTOURS, NOT THE DOTTED LINES
TRIM ANGLE, DEG
PLANING RANGE
SYMBOLS
$\sqrt{C_\Delta}/C_V$

Figure 10