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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

By F. W. S. Locke, Jr.

Bureau of Aeronautics, Navy Department

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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:

- $C_\Delta$: load coefficient ($\Delta/\omega b^3$)
- $C_{\Delta o}$: initial-load coefficient ($\Delta_o/\omega b^3$)
- $C_R$: resistance coefficient ($R/\omega b^3$)
- $C_V$: speed coefficient ($V/\sqrt{\omega b}$)
- $C_M$: trimming-moment coefficient ($M/\omega b^4$)
- $C_X$: longitudinal-spray coefficient ($X/b$)
- $C_Y$: lateral-spray coefficient ($Y/b$)
- $C_Z$: vertical-spray coefficient ($Z/b$)
- $C_L$: aerodynamic-lift coefficient ($L/S \frac{\rho a}{2} \frac{V^2}{\omega}$)

where

- $\Delta$: load on water, pounds
- $\Delta_o$: initial load on water (gross weight), pounds
- $\omega$: specific weight of water, pounds per cubic foot
- $b$: beam at main step, feet
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:
\[ \Delta = \Delta_o - L \] (1)

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

\[ \Delta = \Delta_o - \frac{dC_L}{\partial \alpha} (\tau + \alpha_o) \frac{\rho a}{2} SV^2 \] (2)

and if both sides are divided by \( \omega b \) to obtain the usual NACA seaplane coefficients, equation (2) will reduce to:

\[ C_\Delta = C_{\Delta_0} - \frac{1}{2} \frac{\rho a}{\omega_v} \frac{dC_L}{\partial \alpha} \frac{S}{b^2} (\tau + \alpha_o) C_v^2 \] (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 \( \frac{dC_L}{\partial \alpha} \) and \( \alpha_o \) and the effect of the elevators by alteration to \( \alpha_o \). 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

\[ \frac{C_v^2}{C_{\Delta_0}^{1/3}} = \frac{C_v^2}{\sqrt[3]{C_{\Delta_0} - \frac{1}{2} \frac{\rho a}{\omega_v} \frac{dC_L}{\partial \alpha} \frac{S}{b^2} (\tau + \alpha_o) C_v^2}} \] (4)

From this relation, contours of constant velocity on a chart of absolute angle of attack against \( \frac{C_v^2}{C_{\Delta_0}^{1/3}} \) can be constructed for specific values of the product \( \frac{dC_L}{\partial \alpha} \frac{S}{b^2} \) for any given value of \( C_{\Delta_0} \). Such a chart is shown in figure 2, which was constructed for \( C_{\Delta_0} \).
equal to unity for simplicity in converting it for use with other values of \( C_{\Delta_o} \).

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 \( C_{\Delta_o} \) 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 \( C_{\Delta_o} \) 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 \( C_{\Delta_o} \) of unity for the weight under consideration. A simpler step is to remove the beam and substitute \( \frac{S}{(\Delta_o/w)^{2/3}} \) 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 \( \frac{dC_L}{d\alpha} \) 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

\[
\sqrt{C_{\triangle}} = \sqrt{C_{\Delta_o}} \frac{1}{2} \frac{S}{\rho_v \alpha \frac{dC_L}{d\alpha} b^2} \frac{1}{(\tau + \alpha_o)C_V^2}
\]

(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 $\frac{\frac{1}{2} S}{b^2}$ and $C_\Delta$. Figures 3 to 5 show such charts constructed
for $C_\Delta = 1.00$. 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 (6), 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 $C_\Delta$ 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 $C_\Delta$. 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, $C_\Delta$ 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 \(C_{L_{\text{max}}}\) but will not affect the lift rate \(\frac{dC_L}{d\alpha}\), at least to a very good first approximation. Hence the first step is to determine the value of \(\alpha_o\) 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 \(\frac{dC_L}{d\alpha}(S/\Delta_o/w)^{2/3}\) 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 \(\alpha_o\) corresponds to zero trim. Start with the lowest speed and find the value of \(C_{\text{v}}^{2/3}C_{\Delta}^{1/3}\) 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 \(C_{\Delta_o}\). Next, calculate the value of \(C_{\Delta}\); it should be very slightly less than \(C_{\Delta_o}\) but close enough to it so that a second trial will not be worth while. Use the next speed, and determine the value of \(C_{\text{v}}^{2/3}C_{\Delta}^{1/3}\) at the intersection of the constant-speed contour with the free-to-trim track for the value of \(C_{\Delta}\) found at the previous speed. Again, the new value of \(C_{\Delta}\) should be slightly lower than the assumed value. Repeat at increasing speeds by using at each speed the value of \(C_{\Delta}\) 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 \( CV^2 / C_\Delta^{1/3} \) find the values of \( CR / CV^{2/3} C_\Delta^{2/3} \) at the proper value

of \( C_\Delta \). Since both \( CV \) and \( C_\Delta \) are known, \( CR \) can be found.

In the planing range, multiply the values of \( CV \) shown at the

different values shown in the appropriate chart by the specific \( C_\Delta^{1/2} \). After using

the specific value of \( S/b^2 \) to find the parameter \( \frac{dC_L S}{d\alpha} b^2 \), lay

the transparent chart on top of the chart of the hull characteristics

in the planing range so that the chosen value of \( \alpha_o \) 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 \( \sqrt{CR / CV} \) occurring at the intersection. Since \( CV \) is known,

the value of \( CR \) can be found, and it should especially be noted that

it is not necessary to find \( C_\Delta \). If general stability limits are given,

the intersection of the constant-speed contours will allow the construc-

tion 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

general tests. At any given value of \( \alpha_o \), the curve of \( CR \)

against \( CV \) 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 \( \alpha_o \), 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 \( \Delta_o \)
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 $\alpha_o$ 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 $(\Delta_o/\omega)^{2/3}$. Use this value in each particular $S/(\Delta_o/\omega)^{2/3}$ to be investigated. Since the value of $C_{\Delta_o}$ 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 $S/\left(\Delta_0/w\right)^{2/3}$ for each case under consideration, and each time the weight is altered, convert the speed scale by multiplying by $C_{\Delta_0}^{1/6}$ in the displacement range. In the planing range, the value of $S/b^2$ will not change with changes of $C_{\Delta_0}$, though the scale of $C_V$ must be altered each time by multiplying by the square root of the particular value of $C_{\Delta_0}$. 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 $\alpha$ at $C_{L_{\text{max}}}$ 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 $C_{L_{\text{max}}}$, $dC_L/da$, 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 $\sqrt{C_P/C_V}$ 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

![Diagram showing CV constant and SQRT(CR/CV) constant]

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 $\sqrt{\frac{C_R}{C_V}}$ 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 $C_\Delta$ 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:

\[ \Delta_0 = 15,000 \text{ pounds} \]

\[ S = 906 \text{ square feet} \]

\[ b = 7.77 \text{ feet} \]

\[ \frac{dC_L}{d\alpha} = 0.068 \]

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 \( \alpha_0 = 10^\circ \), 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 \( 10^\circ \) when the hull trim is zero.

2. At zero speed the trim angle is found to be \( 2.4^\circ \) 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 \( 2.5^\circ \) and \( C_L^2/C_\Delta^{1/3} = 0.50 \).
4. Since \( C_V \) is known, solving for \( C_\Delta \) 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 \( \frac{C_V^2}{C_\Delta^{1/3}} = 2.04 \).

6. Since \( C_V \) is known, solving for \( C_\Delta \) 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, \( \frac{C_V^2}{C_\Delta^{1/3}} = 0.50 \) and at that value the unique value of \( \frac{C_R}{C_V^2 C_\Delta^{2/3}} \) is found to be 0.0345.

9. Since both \( C_V \) and \( C_\Delta \) are known, \( C_R \) may be found to be 0.008.

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

11. As both \( C_V \) and \( C_\Delta \) are known, solving for \( C_R \) gives 0.062.

12. At 35 feet per second and higher, \( \frac{C_R}{C_V^2 C_\Delta^{2/3}} \) 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. 64-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 $\sqrt{C_A/C_V}$ (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 $\alpha_o$ equal to $8^\circ$ and $12^\circ$ by first shifting the transparent chart downward $2^\circ$ relative to the chart of collapsed hydrodynamic characteristics and then raising it $2^\circ$. 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 $\alpha_o$ has its largest effect at high planing speeds. However, without adding in the air drag, it is impossible to predict the value of $\alpha_o$ 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 $15^\circ$ is likely to give the best take-off time because of the high $C_{l_{\text{max}}}$ in combination with low drag. It would probably be sufficient to calculate the take-off time for three flap angles at one value of $\alpha_o$ 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 XPB-4-M-1):

\[ \Delta_0 = 140,000 \text{ pounds} \]
\[ S = 3,500 \text{ square feet} \]
\[ \alpha_0 = 8^\circ \]
\[ \frac{dC_L}{d\alpha} = 0.100 \]

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 \( S/(\Delta_0/w)^{2/3} \), which for the assumed particulars will be 20.75. Multiplying by the lift rate, \( \frac{dC_L}{d\alpha} = 0.100 \), 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 \( C_{\Delta_0} = 1.331 \) and \( C_{\Delta_0}^{1/6} = 1.050 \).

3. Tabulate \( C_V \) for \( C_{\Delta_0} = 1.00 \) 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 \[ \left( \frac{dC_L}{d\alpha} \right)[S/(\Delta_0/w)^{2/3}] = 2.08. \]
6. Since $C_V/C_D^{1/3}$ is known, from the collapsed spray
curves read $C_X/C_D^{1/3}$ and $C_Z/C_D$. Because it is probably of
less interest $C_V/C_D^{1/3}$ has been omitted in the present instance.

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

Planing range.

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

2. Tabulate $C_V$ for $C_D = 1.00$ and multiply each value by
$C_D^{1/2}$, 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 $\alpha_o$ 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, $C_D$ 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 $C_{\Delta o}$. Otherwise, the interpolation procedure in both the

displacement and the planing ranges is just the same as previously

calculated. 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

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 characteris-
tics 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
REFERENCES


TABLE I.- EFFECT OF \( \alpha_0 \) ON FLYING BOAT A

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<th>( \alpha_0 = 12^\circ )</th>
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<td><strong>Displacement range</strong></td>
<td><strong>Displacement range</strong></td>
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<td>( C_Y^2 )</td>
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<td><strong>Planing range</strong></td>
<td><strong>Planing range</strong></td>
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<td>( C_Y )</td>
<td>( \gamma_\Delta )</td>
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### TABLE II - FLYING BOAT B

\[ b = 11.83 \text{ ft} \]

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<th>( C_R )</th>
<th>( X ) (ft)</th>
<th>( Z ) (ft)</th>
<th>( B ) (lb)</th>
<th>( V ) (ft/sec)</th>
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### Planing range

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<th>( C_V )</th>
<th>( C_D )</th>
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<th>( C_R )</th>
<th>( X ) (deg)</th>
<th>( Y ) (deg)</th>
<th>( Z ) (deg)</th>
<th>( B ) (lb)</th>
<th>( V ) (ft/sec)</th>
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### Constants

- \( A_o = 140,000 \) lb
- \( S = 3,500 \) sq ft
- \( \alpha_o = 0^\circ \)
- \( dC_f/da = 0.100 \)

\[
S/(A/o)^{2/3} = 20.75
\]

\[
b = 11.83 \text{ ft}
\]

\[
C_{o,1/6} = 1.195
\]

\[
C_{o,b/2} = 1.075
\]

\[
\sqrt{\phi^2} = 105,200
\]

\[
\sqrt{\phi^2} = 19.50
\]

Hull: S&T Model No. 339-1
- forward of step
- aft of step
### TABLE III - FLYING BOAT B

\[ b = 13.23 \text{ ft} \]

**Displacement Range**

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<th>( C_D ) (( C_D = 1.0 )</th>
<th>( C_V )</th>
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<th>( C_V^2 )</th>
<th>( C_D^2 )</th>
<th>( C_R )</th>
<th>( C_X )</th>
<th>( C_Z )</th>
<th>( X ) (ft)</th>
<th>( Z ) (ft)</th>
<th>( R ) (lb)</th>
<th>( V ) (ft/sec)</th>
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**Flaring Range**

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<th>( C_V )</th>
<th>( \tau ) (deg)</th>
<th>( \sqrt{C_D/C_V} )</th>
<th>( C_R )</th>
<th>Upper limit&lt;br&gt;trim</th>
<th>Lower limit&lt;br&gt;trim</th>
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<th>( V ) (ft/sec)</th>
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**Constants**

- \( \Delta = 140,000 \text{ lb} \)
- \( S = 3,500 \text{ sq ft} \)
- \( a_0 = 8^1 \)
- \( dC_T/da = 0.100 \)
- \( S/(\tau V)^{3/4} = 30.75 \)
- \( b = 13.23 \text{ ft} \)
- \( S/\tau^2 = 20.0 \)
- \( \tau = 0.915 \)
- \( \tau^{1/4} = 0.957 \)
- \( C_D_{1/5} = 0.966 \)
- \( \omega-b^3 = 152,900 \)
- \( \sqrt{\omega} = 30.62 \)

Hull: SIT Model No. 339-1
- Forward of step
- Aft of step
### Table IV. Flying Boat B

\[ b = 15.28 \text{ ft} \]

#### Displacement Range

<table>
<thead>
<tr>
<th>( C_Y )</th>
<th>( \tau )</th>
<th>( C_Y^2 )</th>
<th>( C_Y )</th>
<th>( C_R )</th>
<th>( C_X )</th>
<th>( C_Z )</th>
<th>( I ) (ft)</th>
<th>( Z ) (ft)</th>
<th>( R ) (lb)</th>
<th>( V ) (ft/sec)</th>
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</thead>
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</table>

#### Planing Range

<table>
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<tr>
<th>( C_Y )</th>
<th>( \tau )</th>
<th>( \sqrt{C_R/C_Y} )</th>
<th>( C_R )</th>
<th>( \text{Upper limit trim} )</th>
<th>( \text{Lower limit trim} )</th>
<th>( R ) (lb)</th>
<th>( V ) (ft/sec)</th>
</tr>
</thead>
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</table>

**Constants**

\[
\Delta_0 = 140,000 \text{ lb} \quad S/\Delta_0^{1/3} = 20.75 \quad C_{\Delta} = 0.764
\]

\[
b = 15.28 \text{ ft} \quad S/\Delta_0 = 60 \quad C_{\Delta} = 0.922
\]

\[
\Delta_0 = 140,000 \text{ lb} \quad S/\Delta_0 = 228,000 \quad \sqrt{\Delta_0} = 22.99
\]

\[
C_{\Delta} = 0.764 \quad \text{forward of step}
\]

\[
C_{\Delta} = 0.922 \quad \text{aft of step}
\]

**Note:** SIT Model No. 339-1
### Designation: 6.19-7-20

**Model No. 339-I**
- C.G. = 0.35b FWD. OF STEP
- C.G. = 0.90b ABOVE KEEL
- C_a = 1.069 (Nominal)
- k/L = 0.225

**Tested at S.I.T. No.1 Tank**
- Date: 11-4-43

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**Martin XPB2M-1**

**Free-to-Trim Resistance and Trim Displacement Speeds**

**Planing Speeds**
- $M_0/V^2_{1/6} = 0.25$
- $\sqrt{C_m/C_V}$

---

Figure 1
CONTOURS OF CONSTANT SPEED IN THE DISPLACEMENT RANGE

PARAMETERS, \( \frac{dc_L}{dc_x} = \frac{5}{(2u/\omega)^{3/2}} = 1, 2, 3 & 4 \)

Figure 2
CONTOURS OF CONSTANT SPEED IN THE PLANING RANGE

PARAMETERS, \( \frac{dC_L}{dx} \), \( \frac{C}{b^2} = 1.0, 1.5, 2.0 \)

FIGURE 3
CONTOURS OF CONSTANT SPEED
IN THE
PLANING RANGE
PARAMETERS, $d_{CL} \times \frac{s}{bT} = 20, 25, 30$
Contours of Constant Speed In the Planing Range

Parameters, \( \frac{dCL}{d\alpha} \) = 3.0, 3.5 & 4.0

Figure 5

Absolute Angle of Attack of Wing-Flap Combination Deg.
Figure 6

FLYING BOAT "A"

Lift coefficient, $C_L$

Drag coefficient (excluding hull), $C_D$

Absolute angle of attack, deg

Flap settings

Trim (for case in fig. 9), deg

Angle of zero lift, deg
Figure 7(a)

Figure 7(b)
DESIGNATION: 3.24 - 0.57 - 20.0
MODEL NO. 84-EF-3
MODEL BEAM: 15.92"
CG = 0.46 b FWD. OF CENTROID (NOMINAL)
CG = 1.16 b ABOVE KEEL

TESTED AT NACA NO.1 TANK
DATE: 3/39

THIS CHART ILLUSTRATES THE INTERPOLATION PROCESS
FOR ONE SPECIFIC FLYING BOAT

FLYING BOAT "A"

Δa = 15,000 lbs.
S = 906 ft²
b = 7.77 ft.
α = 10.0°

S/b = 120
S/ft = 15.0

FREE-TO-TRIM RESISTANCE AND TRIM
DISPLACEMENT RANGE

INTERPOLATED TRIM TRACK
ILLUSTRATED EXAMPLE

TRIM

RESISTANCE

STATION SPACING GIVEN AS
DISTANCE FROM
CENTROID, IN UNITS OF BEAM

FIGURE 8
Figure 10

TRANITION OF RESISTANCE FROM DISPLACEMENT TO PLANING RANGE AT FIXED TRIM
NACA MODEL 84-EF3 TRIM = 9.3 DEG

THIS LINE USED IN PREPARING $\frac{C_D}{C_V}$ CONTOURS, NOT THE DOTTED LINES

THE SAME POINTS ARE IDENTIFIED BY NUMBERS

C_D = 0.8

C_D = 0.6

C_D = 0.4

C_D = 0.2

C_D = 0.0

$\frac{C_D}{C_V}$ CONTOURS

$\frac{C_D}{C_V} = 0.15$

$\frac{C_D}{C_V} = 0.10$

$\frac{C_D}{C_V} = 0.05$

$\frac{C_D}{C_V} = 0.08$

$\frac{C_D}{C_V} = 0.03$

$\frac{C_D}{C_V} = 0.01$

$\frac{C_D}{C_V} = 0.00$

Figure 10

TRANITION OF TRIM ANGLE FROM DISPLACEMENT TO PLANING RANGE AT FIXED MOMENT
NACA MODEL 84-EF3

$C_m = 0$

THE SAME POINTS ARE IDENTIFIED BY NUMBERS

$\frac{C_D}{C_V} = 0.15$

$\frac{C_D}{C_V} = 0.10$

$\frac{C_D}{C_V} = 0.05$

$\frac{C_D}{C_V} = 0.08$

$\frac{C_D}{C_V} = 0.03$

$\frac{C_D}{C_V} = 0.01$

$\frac{C_D}{C_V} = 0.00$

Figure 10
A simple and rapid method is presented for interpolating the hydrodynamic characteristics of specific flying boats from a chart showing test results in a collapsed form. Water resistance and porpoising characteristics of one specific case may be determined in about 20 to 30 minutes. Through the use of the interpolation method the shapes and magnitudes of collapsed curves of general tests will be of great aid to the designers.
Flying Boats
Hydrodynamic Characteristics
A simple and rapid method is presented for interpolating the hydrodynamic characteristics of specific flying boats from a chart showing test results in a collapsed form. Water resistance and porpoising characteristics of one specific case may be determined in about 20 to 30 minutes. Through the use of the interpolation method the shapes and magnitudes of collapsed curves of general tests will be of great aid to the designers.