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CASDAC 231011 • MCSA

SHIP DESIGN

COMPUTER PROGRAM

Hydrofoil Ship Longitudinal, Static, Trim Load Program

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NAVY DEPARTMENT
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CONTENTS

I - IDENTIFICATION

I 1 Title: Hydrofoil Ship Longitudinal, Static:, Trim-Load Program (CASDAC 231011-MCSA NAVSHIPS 0900-006-5390)

I 2 Brief Description: This program computes the foil control surface deflection angles necessary to produce static equilibrium for a hydrofoil ship operating at a specified hull clearance, pitch angle, and velocity. Assuming the hull can be represented by a prismatic planing hull, the conditions through a quasi-static (i.e. ignoring accelerations and rates) take-off can also be determined. The program computes and tabulates the individual forces acting on the ship and outputs them for ready reference.

There are two subroutines and one non-standard function.

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Date: July 1968

I 4 Language: FORTRAN IV, IBSYS

I 5 Machine: IBM 7090

I 6 Security Classification: UNCLASSIFIED

I 7 Estimated Running Time: Execution time is approximately 2 minutes per set of data. Time will vary according to the number of iterations required to converge to a solution.

II - PURPOSE, METHOD AND THEORY.

II 1 Purpose

During the past several years as hydrofoil ship design has developed its own special working tools for the rational prediction of ship performance, the area of synthesizing these theoretical and experimental methods of the several arts into tools, to be used in concept formulation or preliminary design studies of 'basic trade-offs, has generally been ignored. Admittedly, the primary concern of first generation ships is to get them working smoothly. However, second generation ship designs should benefit from some optimizations studies of the working designs.

The variations of forces and moments acting on a hydrofoil ship are strongly influenced by the conditions at which it is operating. It would seem natural to study the combinations of hull and foil-strut-nacelle arrays to minimize the forces and moments. In addition, at least the longitudinal mode, stability in the presence of small perturbations should be evaluated about the equilibrium flight condition, which must be foreknown. If the hull can be represented by a prismatic planing hull, then the effects of beam and deadrise angle can be included in the optimization study.

This program is specifically tailored to balance the ship in static equilibrium and then list out the details. It is left to the designer's art to gain insight from the details and produce a workable design. The longitudinal stability calculations are deferred to a planned revision when the hull stability derivatives are firmly established.

II 2 Method and Theory

2.1 Method

A moving body will be in static equilibrium if the sum of its external forces and moments is zero. For the longitudinal motion of a hydrofoil ship, an equilibrium condition can be obtained by trimming the foil control surfaces so that for a specified operating depth and velocity, the drag of the ship is equal to the horizontal component of the thrust vector and the sum of the vertical forces and pitching moments are within specified tolerances. The hydrofoil configuration analyzed in the worked example is shown in Figure 1. The particular development of the total lift and drag from the contributions of their various components will be detailed in the following sectlons.

An iteration technique is used to determine the control surface deflection angles necessary for equilibrium. The input data contains the initial estimated control surface deflection angles, on which the Initial summations of lift and pitching moment are calculated. A control surface deflection increment is then applied to the forward foil (s) and the change in summations of lift and moment are determined. The forward foil control surface is reset to Its former position, a control surface deflection increment is then applied to the aft foil(s), and the summations of lift and pitching moment are recalculated. As a result, the summations of lift and moment errors due to incrementing the forward and aft control surfaces are obtained and used to generate new, Initial control surface deflection angles that will reduce the lift and pitching moment errors. If at the end of the input number of iteration sequences, the control surface deflection limits have been exceeded, the flying height of the craft will be adjusted so as to bring the control surface deflection angles within the input limits. In the hullborne mode, the percent of load carried by the hull is adjusted, which In turn adjusts the foil submergence. When the lift and pitching moment errors are less than the arbitrarily established input limits, then the ship is said to be in equilibrlum and the details are output.

II 2.2 Theory

2.2.1 Coordinate Systems

The three coordinate systems commonly used In studying hydrofoil ship dynamics are: the body axes, the earth axes and the water or "wind" axes coordinate systems, each of which are "right-hand" orthogonal systems. The body axes coordinate system generally used In the study of ship motions has the origin at the ship's center of gravity and is fixed relative to the ship. Its X axis runs forward longitudinally through the craft and the Z axis is down through the keel.. The weight engineer will locate the ship's center of gravity either from the mid-ship section or from the fore perpendicular and the baseline. On the other hand the planing hull analyst will prefer the body axes origin at the aft perpendicular and the baseline. All three can be called "body axes fixed relative to the ship". For the purpose of this program the lift, drag and pitching moment equilibrium equations are written with respect to the center of gravity. However, the ship's center of gravity and foil components are located with respect to the origin at the aft perpendicular and the baseline. The justification for this is that the designer can change the location of the ship's center of gravity or relocate a foil-strut-nacelle array or even consider water-jet propulsion rather that water propellers, with minimum changes to the input data. Let the computer calculate lever arms. The aft perpendicular is preferred in consideration of the equations developed for the prismatic planing hull.

The earth axes coordinate system fixed relative to the earth's surface is typically used In a full dynamic analysis of the ship's motion. This program assumes the quasi-dynamic situation of the ship's motion being without acceleration and therefore independent of the flight history. Thus the earth axes are always centered on the ship's center of gravity and serves as a measure of craft pitch attitude. The program user may specify a ship pitch angle as part of the input.

The water axes coordinate system is the basis for lift and drag force directions. Clearly lift and weight or thrust and drag are opposing forces all normally thought of as positive. Typical hydrodynamic model test data is taken and presented as plots of non-dimensional coefficients In terms of the water axes coordinate system. The simultaneous equations this program solves are written in terms of thrust, drag, lift, weight, center of gravity above the baseline, foils located below the baseline, etc. all being positive where historical designs have clearly established an orientation.,

The result is that the "Coordinate System" is a conglomeration of all three axes where past usage dictates a particular preference. Hopefully, the naval architect will find the various axes rational rather than whimsical.

II 2.2.2 Lift of Hydrofoils

The lift characteristics of hydrofoils operating well submerged are directly equivalent to the airfoil in an infinite fluid, assuming all-wetted flow and allowing for the change in fluid density. There are several theories currently available for reliably estimating the all-wetted lift curve slope as a function of foil gemetry. However, the effects of the free surface on the hydrodynamic characteristics of operating hydrofoils, remains a prime concern to the hydrofoil ship designer. The presence of a free surface (a) leads to an increase in the drag of the foil as represented by a visable loss in energy through the trailing wave train and (b) leads to a loss in lift through a change in the pressure field as the flying draft is reduced.

The total foil lift is developedby contributions from camber, craft pitch angle and control surface deflection. For the present time, we assume the effects of the free surface are felt on the total lift coefficient rather than on just one component:

$$C_L = \left[C_{L_d} + C_{L_\alpha}\alpha + C_{L_\delta}\delta\right] \frac{dC_{L_h}}{dC_{L_\infty}} \qquad (2.1)$$

where: C_L total lift coefficient (L/qA)

C_{L_d} design lift coefficient, infinite depth

C_{L_α} change in lift coefficient with pitch angle, infinite depth

C_{L_δ} change in lift coefficient with control surface deflection angle, infinite depth

dC_{L_h}/dC_{L_∞} change in lift coefficient with submergence, Figure 2

α craft pitch angle,+ bow up

δ control surface deflection angle, + trailing edge down

Note that the graphical function of dC_{L_h}/dC_{L_∞} versus depth/chord ration (h/E) as shown in Figure 2 is Input for subsequent interpolation at the depth/chord ratio of Interest. There is some controversial evidence that the angle of zero lift changes with depth and that the CL, change with depth is not equal to the C_{L_δ} change. However, these changes are, typically, quite small and outside the program's intended use in concept formulation and preliminary design. The lift is presumed to act at 1/4 chord point of the mean hydrodynamic chord.

II 2.2.3 Drag of Hydrofoils

The total drag of the hydrofoil-strut-nacelle array is assumed to be composed of five parts: (a) foil drag,

(b) strut drag, (c) nacelle drag, (d) ventral fin drag and (e) strut spray drag. The strut drag is based on only the wetted area from the flying waterline to the top of the nacelle. Two dimensional flow is assumed based on the nacelle and free-surface acting as "end plates" to eliminate any spanwise flow. The foil drag is based on total planform area Including the area covered by the nacelle. It has thus been assumed that the inclusion of this extra foil drag and the exclusion of the extra strut drag results in a realistic allowance for anycomponent, mutual interference drag.

2.2.3.1 Foil Drag: The general expression for the total drag coefficient of subcavitating foils is (ref (1)):

$$C_D = 2(C_{D_f} + \Delta C_f) + C_{D_{pmin}} + \Delta C_{D_p} + C_{D_i} + C_{D_W} \qquad (3.1)$$

where:

	C_D	total drag coefficient (D/qA)
	C_{D_f}	Schoenherr skin friction drag coefficient
	ΔC_f	roughness allowance for foils
	$C_{D_{Pmin}}$	minimum profile drag coefficient
	ΔC_{D_P}	change in profile drag coefficient due to control surface deflection
	C_{D_i}	induced drag coefficient, due to lift
	C_{D_w}	wave drag coefficient

The Schoenherr skin friction drag coefficient is used throughout the entire program. A special library function is used since C_{D_f} only depends on the Reynolds number, Rn. The characteristic length for calculating Rn for the hydrofoil is the mean hydrodynamic chord. A single roughness allowance is input for all hydrofoil-strut-nacelle arrays.

The minimum profile drag may be input or, if it is unkown and the appropriate input field is left blank, the program estimates a value based on Reference 2:

$$C_{D_{pmin}} = 2\, C_{D_f} \left(1.2 \frac{t}{c} + 60.0 \frac{t}{c}^{4}\right) \quad (3.2)$$

Note that when the emperical formulation is used, the roughness allowance is not included, but 60.0 $(t/c)^4$ is included.

The lift coeffident changes from the design value as the flaps are deflected or as the foil Incidence is changed, with a corresponding increase in the foil profile drag. The change in profile drag coefficient ΔC_{D_P} due to control surface deflection must be determined from model test results as it cannot be calculated theoretically. Figure 3 is a typical plot of graphical functions ready for inputing. When the foils will be operating well submerged at a high pitch angle, as during take-off, the corresponding, control surface deflection induced profile drag coefficient taken about that high pitch angle should be input as shown.

The induced drag due to lift and the induced drag due to wave generation are both Internally generated from the formulas, (ref (1) & (3)):

$$C_{D_i} = C_L^2 \left[\frac{1}{\pi AR} + \frac{K_1 c}{8\pi} \right] \quad (3.3)$$

$$C_{D_W} = C_L^2 \left[\frac{\gamma g c}{4U^2} \right] \quad (3.4)$$

where: AR = foil aspect ratio (b^2/A)

$\gamma = 1/e^{2gh/U^2}$

$$K_1 c = \frac{4\, AR}{AR^2 + 16(h/c)^2} \left[\frac{1}{\sqrt{AR^2 + 16(h/c)^2 + 1}} + 1 \right]$$

2.2.3.2 Strut Drag

The minimum profile drag of a strut is treated in the same manner as for the hydrofoil. Since the program is written for straight ahead flight only, the other drag components are not applicable. The program estimates a strut minimum profile drag coefficient based on Reference 4:

$$C_{D_{P\ strut}} = 2\, C_{D_f} \left[1 + 10(t/c)^2 \right] \quad (3.5)$$

Then the total profile drag coefficient of the strut is found as:

$$C_{D_{strut}} = 2(C_{D_f} + \Delta C_f) + C_{D_{Pstrut}} \quad (3.6)$$

2.2.3.3 Nacelle Drag

Nacelle drag is based on wetted surface, rather than a projected area, in keeping with the presentations of the popular DTMB Series 58 bodies of revolution, (References 5 and 6). Any nacelle applied to a hydrofoil ship design must be carefully evaluated for a high cavitation inception speed. Model 4162 of the DTMB Series 58 has shown the most promise for pure applications (Reference 7) with Model 4156 another possibility where some parallel middle-body must be inserted (Reference 8). Specifically, the nacelle drag is calculated by:

$$D_{nacelle} = (C_{D_p} + C_{D_f} + \Delta C_f)\, q\, S_{nacelle} \qquad (3.7)$$

where $S_{nacelle}$ = wetted surface of nacelle ($C_{ws} \pi l_n D_n$)

The user must input the nacelle length (l_n), length/diameter ratio (l_n/D_n), and wetted surface coefficient (C_{ws}). Whenever a Series 58 nacelle is used, the wetted surface coefficient is readily obtained from Reference 6. The user may input the nacelle profile drag coefficient of his choice or if the appropriate data field is left blank the program will make an estimate based on Reference 2:

$$C_{D_p} = C_{D_f} \left[1.5 \left(\frac{D_n}{l_n}\right)^{1.5} + 7.0 \left(\frac{D_n}{l_n}\right)^{3} \right] \qquad (3.8)$$

2.2.3.4 Ventral Fin Drag

Certain problems in the area of dynamic lateral stability arise when the steering hydrofoil-strut-nacelle array either vents as in a tight turn or broaches in short high waves. As a result of some rather dramatic experiences, ventral fins may be installed for directional control below the nacelles. The ventral fins can be mounted on either the forward or aft arrays, or both. This program assumes that if they are mounted, It is one per array following the common practice. The ventral fin drag is calculated as:

$$D_{v.fin} = (2C_{D_f} + 2\Delta C_f + C_{D_p})\, qA_{v.fin} \qquad (3.9)$$

where $A_{v.fin}$ = projected area of ventral fin

The user must input the ventral fin length, thickness/chord ratio and projected area. If no ventral fin length is input, then the program rightly assumes no ventral fin is to beincluded. Whenever used, the ventral fin profile drag coefficient is estimated from Reference 2 as:

$$C_{D_{p_{v.fin}}} = 2\,C_{D_f}\left[1.2\left(\frac{t}{c}\right) + 60\left(\frac{t}{c}\right)^4\right] \qquad (3.10)$$

fhere are some indications that a negative, squared term should be included in Equation 3.10 for tip effects. However, substatiating data would also provide the correct profile drag coefficient, which should be used rather than the estimated value.

2.2.3.5 Strut Spray Drag

Wherever a strut pierces the surface, additional energy is carried away in the form of spray. This drag is primarily a function of the thickness and the sharpness of the leading edge. At the relatively high speeds of hydrofoil ships, the spray drag coefficient apparently does not vary appreciably with either Reynolds number or Froude number. For the present, the computer program calculates spray drag from:

$$D_{spray} = C_{D_{spray}}\; q\, t^2 \qquad (3.11)$$

For typical hydrofoil strut sections, Reference 2 suggests using $C_{D_{spray}} = 0.24$. Additional strut studies were reported in reference 9 and an alternate emperical relationship for the spray drag presented. Certainly more effort in this area is desirable to settle on a 'best' formulation.

II 2.2.4 Wetted Area of Prismatic Planing Hulls (ref 10)

Generally speaking, for planing hulls there are three wetted areas, 1) the wetted pressure or load carrying area, 2) the spray wetted area and 3) the side wetted area. At the pre-take-off condition, hydrofoil ship hulls are predominatly supported by dynamic pressure over the wetted pressure area. The spray wetted area is typically small and is assumed to contribute only to the drag. Since the present program is based on hard chine, planing hulls there is no side wetting on the hull.

The wetted pressure area needs to be clearly defined as it is the cornerstone of the subsequent calculations. The wetted pressure area is defined as that portion of the wetted area over which water pressure is exerted, excluding the forward thrown spray sheet but including all the hull bottom area aft of a line drawn normal to the planing surface and tangent to the spray root curve.

For the Vee-shaped planing hulls, aft of the initial point of contact 0, the rise of the water surface is along the two oblique spray root lines (O-B, see Figure 4) which are ahead of the line of calm water intersection (O-C). Thus the mean wetted length of a deadrise planing surface is defined as the average of the wetted keel and the wetted chine lengths measured from the transom to the Intersection with the spray root line.

The mean wetted length to beam ratio, which defines the length of the wetted pressure area, is then:

$$\frac{L_k + L_c}{2B} = \frac{T_k}{\sin\tau \; B} - \frac{1}{2\pi}\left[\frac{\tan\beta}{\tan\tau}\right] = \lambda \qquad (4.1)$$

where B average wetted beam, ft.

T_k draft of keel at transom, ft.

β deadrise angle, deg.

τ trim angle, deg.

If we define a speed coefficient, as the Froude number based on beam:

$$C_v = \frac{U}{\sqrt{gB}} \qquad (4.2)$$

where U = velocity of ship, ft/sec.

g = acceleration due to gravity, ft/sec^2

then the experimental evidence collected by Davidson Laboratory indicates that equation (4.1) is applicable for all deadrise angle and trim angle combinations such that the speed coefficient, C_v, is greater than two. For lower speed coefficients, the user should consult Reference 10 or model test results. The product λB^2 thus sizes the wetted pressure area.

The spray wetted surface area is forward of the spray root line and the total spray area, both sides of the keel, is given by:

$$S_{h_{sp}} = \frac{B^2}{2\cos\beta}\left[\frac{\tan\beta}{\pi\tan\tau} - \frac{1}{2\tan\Phi\cos\beta}\right] \qquad (4.3)$$

where Φ = angle between the keel and the spray edge measured in the plane of the bottom

$\tan g = (a + k_1)/(1 - A k_1)$

$$A = \frac{\sqrt{\sin^2\tau\,(1-2K) + K^2 \tan^2\tau\,[(1/\sin^2\beta) - \sin^2\tau]}}{\cos\tau + K \tan\tau \sin\tau}$$

$$k_1 = K \tan\tau / \sin\beta$$

$$K = \frac{\pi}{2}\left[1 - \frac{3\tan^2\beta\cos\beta}{1.7\pi^2} - \frac{\tan\beta\sin^2\beta}{3.3\pi}\right]$$

An average wetted length for the Reynolds number and Schoenherr skin friction drag coefficient is:

$$L_{spray} = \frac{B}{2}\left[\frac{\tan\beta}{\pi\tan\tau} - \frac{1}{2\tan\beta\cos\beta}\right] \qquad (4,4)$$

Recall the assumption of a hard chine, planing hull so there is no side wetting! As this computer program finds wider acceptance and use in developing preliminary hydrofoil ship designs, then (in cooperation with the users) perhaps a later revision will allow for rounded chines or wetted sides.

2.2.5 Lift of Prismatic Planing Hulls (Ref. 10)

The lift of a planing surface at fixed trim and draft can be attributed to two separate effects; the dynamic reaction of the fluid against the moving surface and the buoyant contribution. Taking both effects into consideration, the emperical planing lift equation for a zero deadrise surface was given in Reference 10 as:

$$C_{L_{\beta=0}} = C_{L_d} + C_{L_b} = \tau^{1.1}\left[0.012\,\lambda^{1/2} + \frac{.0055\,\lambda^{5/2}}{C_V^2}\right] \qquad (5.1)$$

where $C_{L_{\beta=0}}$ = total lift coefficient of a zero deadrise planing surface

C_{L_d} = dynamic lift coefficient of a zero deadrise planing sruface

C_{L_b} = buoyancy lift coefficient of a zero deadrise planing surface

For a given trim and mean wetted length to beam ratio, the effect of Increasing the deadrise angle is to reduce the planing lift due to the reduction in stagnation pressure at the leading edge of the wetted area. The lift coefficient of a Vee surface was compared with that of a flat plate at the identical values of τ, λ and C_v by the staff of Davidson Laboratory. Based on that comparision, an emperical equation for the planing lift of a deadrlse surface was found:

$$C_{L_\beta} = C_{L_{\beta=0}} - 0.0065\beta\, C_{L_{\beta=0}}^{0.6} \qquad (5.2)$$

where C_{L_β} = total lift coefficient of a deadrise planing surface.

The total lift coefficient required of a deadrise planing surface is fixed by the hull design:

$$C_{L_\beta} = \frac{W}{\frac{1}{2}\rho U^2 B^2} \qquad (5.3)$$

where W = weight on hull, pounds

ρ = mass density of water, slugs/ft^3

Recall that in Section II 2.2.4, the cornerstone of these calculations is determining the wetted pressure area λB which provides the hydrodynamic lift. With C_{L_β} known by equation (5.3), we find $C_{L_{\beta=0}}$ from equation (5.2) by iterating. The iteration formula used, by applying the Newton-Raphson method and consolidating terms, is:

$$\left[C_{L_{\beta=0}}\right]_{n+1} = \frac{C_{L_\beta}\left[C_{L_{\beta=0}}\right]_n^{0.4} + 0.0026\beta\left[C_{L_{\beta=0}}\right]_n}{\left[C_{L_{\beta=0}}\right]_n^{0.4} - 0.0039\beta} \qquad (5.4)$$

where the iteration is repeated until $\left|\left[C_{L_{\beta=0}}\right]_{n+1} - \left[C_{L_{\beta=0}}\right]_n\right|$

< 0.0001. Now with an assumed planing surface trim angle, which is the ships pitch angle, the only unknown in equation (5.1) is the desired mean wetted length to beam ratio. After applying the Newton-Raphson iteration formula and consolidating terms again, we have:

$$\lambda_{n+1} = \frac{0.6\,\lambda_n^3 - 0.4363\,C_v^2\lambda_n + 72.7272\,(C_{L_{\beta=0}}/\tau^{1.1})\,C_v^2\sqrt{\lambda_n}}{\lambda_n^2 + 0.4363\,C_v^2} \qquad (5.5)$$

where here again the iteration is repeated until $/\lambda_{n+1} - \lambda_n/$ < 0.0001. With the mean wetted length to beam ratio known, then the drag of the planing surface, the wetted keel and chine lengths, the spray drag and the skeg drag are all quickly calculated.

It should be mentioned that the manipulations and consolidations leading to equations (5.4) and (5.5) were accomplished to speed up the computations. With the IBM 1620, FORTRAN II version of Reference 10 (Reference il), the time required to balance the hull at an Input speed was HALTED. Another item that should be mentioned here is that for certain combinations of high deadrise and high speed, the computer will find a very low (or even negative) value of mean wetted length to beam ratio will satisfy equation (5.5). In those cases the output would show $L_c < 0$ which means that the intersection of the spray root line with the chine is aft of the transom. This chines dry condition is quite possible for a hydrofoil ship hull just prior to take-off but it is outside the range of applicability of these emperlcal planing equations. Such cases should be rerun using a reduced beam such that $L_c \geq 0$. The hull subroutine is set up to return to the main program and increase the weight fraction carried by the hull whenever $L_c < 0$, which is to say the program is self correcting of this situation.

II 2.2.6 Drag of Prismatic Planing Hulls

The total hydrodynamic drag of prismatic planing hulls as evaluated by this program is composed of three parts: (a) pressure drag developed by forces acting normal to the inclined hull, (b) viscous drag acting along the hull bottom parallel to the keel in the pressure area, and (c) viscous drag acting along the hull bottom parallel to the keel in the spray area, (see Figure 5). Since this analysis is restricted to hard chine hulls there is no additional component of viscous drag due to side wetting.

(a) The hull pressure drag force is taken in the horizontal direction:

$$D_{h_p} = \Delta \tan ?' \qquad (6.1)$$

It is assumed to act at the ship's center of gravity and so produces no moment.

(b) The viscous drag in the wetted pressure area is computed by:

$$D_{h_f} = \frac{1}{2} \rho U_m^2 \quad (C_{D_f} + \Delta C_f) \; S_{h_f} \qquad (6.2)$$

where U_m = mean or average hull bottom velocity

ΔC_f = roughness allowance for hull

S_{h_f} = wetted pressure surface of hull, $\lambda B^2/\cos\beta$

The mean velocity over the bottom of the hull in the wetted pressure area is less than the planing velocity due to the increase in pressure. The mean hull bottom velocity corrected for deadrise angle in the wetted pressure area is:

$$U_m = u \sqrt{1 - \frac{0.012 \lambda^{.5} \tau^{1.1} - 0.0065 \beta (0.012 \lambda^{.5} \tau^{1.1})^{0.6}}{\lambda \cos\tau}} \quad (6.3)$$

Note that U_m is used to calculate the Reynold 's Number on which the Schoenherr skin friction drag coefficient is based. The viscous drag-is assumed to act parallel to the keel at a point 1/2 the chine height, measured from the keel. The lever arm as shown in Figure 5 is then:

$$l_{h_f} = VCG - \frac{B}{4} \tan\beta \quad (6.4)$$

(c) The viscous drag of the spray is computed by:

$$D_{h_{sp}} = \frac{1}{2} \rho U^2 \, (C_{D_f} + \Delta C_f) \; S_{h_{sp}} \quad (6.5)$$

where $S_{h_{sp}}$ = surface of hull wetted by spray (Equation 4.3). Note that the reflection of the spray about the spray root line means that the ship velocity must be used. The spray drag is assumed to act parallel to the keel at a point 2/3 of the chine height measured from the keel. The lever arm as shown in Figure 5 is then:

$$l_{h_{sp}} = VCG - \frac{B}{3} \tan\beta \quad (6.6)$$

It should be polnted out that the spray does <u>not</u> act parallel to the keel and Savitsky does not advocate its inclusion in the performance prediction when the keel trim angle is less than 4°. Therefore, this program does not include spray drag when the keel trim angle is less then 4°. Since the spray drag vector direction is debateable, so is the lever arm and average wetted length. However, the justification for refining this portion of the prediction method must rest in an evaluation of the correlation with full scale trials data. The validity of restricting the inclusion of the spray drag to trim conditions greater than or equai to 4° will then also become apparent.

II 2.2.7 Hull Air Drag

Hull air drag of hydrofoil ships is nearly impossible to estimate from scratch what with the unknown Interference effects of the superstrucutre and "appendages", such as antennas, ordnance items, cowlings, etc. In some cases, parametric studies for example, the designer may justifiably ignore the air drag. The alternate is to resort to wind tunnel test results. Non-dimenslonallzlng the wind tunnel data leads to defining a projected area, which continually and radically changes with wind azmiuth angle. Certainly the "best" reference area should Include the length of the ship. To-date, the problem has no uniformly accepted solution. For the purposes of this program, the hull air drag side-steps the issue by defining this drag:

$$D_{air} = C'_{D_{air}} V^2 \qquad (7.1)$$

where $C'_{D_{air}} = \frac{1}{2} \rho_{air} C_D A_{hull} 1.6889^2$

ρ_{air} = density of air

C_D = drag coefficient from model tests

A_{hull} = hull projected area used on model tests

V = ship velocity, knots

II 2.2.8 Center of Pressure and Thrust Moment

The center of pressure of planing surfaces can be evaluated by considering the buoyant and dynamic forces separately. Take the dynamic component at $33\frac{1}{3}\%$ forward of the transom. With the two forces as given in equation (5.1) then Savitsky (Reference 10) found that the hull center of nressure lever arm would be:

$$l_{c.p.} = LCG - \lambda B \left[.75 - \frac{1}{5.21(C_V/\lambda)^2 + 2.39} \right] \qquad (8.1)$$

With the advent of waterjets as candidate propulsion systems, greater flexibility is required in locating the thrust vector. However, rather than distract the designer with laying out the geometry every time the center of gravity shifts or the propulsor is moved, the program calculates the thrust lever arm. Referring to Figure 6, the thrust lever arm is:

$$l_T = \left[(VCG \quad D2T)^2 + (LCG - XL1T)^2 \right]^{1/2} \sin\xi \qquad (8.2)$$

where $\xi = \tan^{-1} \frac{(VCG + D2T)}{(LCG - XL1T)} - \epsilon$

ϵ = "shaft" angle to keel

II. 2.2.9 Static Equilibrium Condition

Static equilibrium is satisfied by setting the **thrust** equal to the drag and then adjusting the fore and **aft** lift distribution such that the summation of vertical **forces** and longitudinal moments are within the Input error limits. If the control surfaces do not provide a sufficient range of deflection angles to balance the ship statically, the program automatically adjusts the height of the ship's center of gravity relative to the water surface so as to alleviate the imbalance. No provisions are made for adjusting the ship's pitch angle nor speed to **hasten** the balancing. The user does **exercise** control over the number of Iterations per depth as **well** as the overall job time. Specifically, the static equilibrium equations are:

$$\Sigma F_{xx} = T \cos(\tau+\xi) = D_{air} + D_{strut}\ (spray) + D_{v.\ fins} + D_{nacelles} + D_{struts}\ (profile + friction) + D_{foils} + D_{hull}\ (pressure) + D_{hull}\ (friction) + D_{hull}\ spray \quad (9.1)$$

$$\Sigma F_{zz} = L_{foils} - A + T \sin(\tau+\xi) + L_{hull} \quad (9.2)$$

$$\Sigma M_{yy} = -D_{strut}\ (spray)\, d_{c.g.}\ D_{v.\ fin}\ (VCG + d_{v.\ fin}) - D_{nacelle}(VCG + d_{nacelle}) - D_{struts}\ (profile + friction)(d_{c.g.} + \tfrac{1}{2} d_{strut}) - D_{foils}(d_{c.g.} + d_{foils})\ T\ l_{thrust} + L_{foils}\ l_{foils} - D_{hull}\ (pressure)\ l_{c.p.} - D_{hull}\ (friction)\ l_{hull}\ (friction) - D_{hull}\ (spray)\ l_{hull(spray)} \quad (9.3)$$

It should be mentioned that in equations 9.1 through 9.3 the separate contributions from the fore and aft foils have been omitted for brevity. Of course they appear in the program, along with an occasional lever arm sign change to reflect the physical location of the aft hydrofoil being aft of the center of gravity. When equations 9.2 and 9.3 are satisfied within the input error limits, the hydrofoil ship is said to be in equilibrium and the results are output.

II. **3** General Remarks

This program was developed from the one reported in General Dynamics/Convair Report GDC **66-075-2,** Reference 12, which was written under Navy contract NOBS-90430. The program and documentation have been throughly revised from the special needs of that contract to the more general design requirements of the Naval hydrofoil ship design program. Some effort has been made to minimize the proliferation of diverse mathematical models by incorporating much of the excellent material reported in Reference 1, which was written under Navy contract N61339-1630. It is not intended that this program will remain static but rather will be revised and updated as new material, including the hullborne mode, becomes available. Some expansion into the foilborne stability area could be incorporated immediatly, however the hullborne stability problem definition 'is immenient.

II. 4 References

1) Jamieson, J.J., "Hydrofoil Simulation Equations Study: Mathematical Model Report, Vol. I. Foilborne Equations of Motion" Tech. Rpt NAVTRADEVCEN 1630-2-1, Naval Training Device Center, Orlando, Fla., Dec. 1966.

2) Hoerner, S. F. Fluid Dynamic Drag, published by the author, 1958

3) Wadlin, K. et al, "A Theoretical and Experimental Investigation of the Lift and Drag Characteristics of Hydrofoils at Subcritical and Supercritical Speeds," NACA Report 1232, 1955.

4) Michel, W.H., Editor "Hydrofoil Handbook, Vol. II., Hydrodynamic Characteristics of Components' Gibbs & Cox, Nonr-507(00), 1954.

5) Clement, E.P. and Moore, W.L., "Resistance Data and Potential Velocity Distributions for a Systematic Series of Streamlined Bodies of Revolution (Series 58) for Application to the Design of Hydrofoil Boat Nacelles", DTMB Report C-1382, April 1962.

6) Gertler, M., "Resistance Experiments on a Systematic Series of Streamlined Bodies of Revolution - For Application to the Design of High Speed Submarines," DTMB Report C-297, April 1950.

7) Moore, W.L. "Bodies of Revolution with High Cavitation Inception Speeds - For Application to the Design of Hydrofoil Boat Nacelles' DTMB Report 1669.

8) Price, E.V. "The Subcavitating Hydrofoil (HYSTAD) Program Phase I Final Technical Report" General Dynamics/Convair Report GDC-66-075-1, June 1966.

9) Savitsky, D. and Breslin, J.P., "Experimental Study of Spray Drag of Some Surface Piercing Struts" Davidson Laboratory Report 1192, Dec 1966.

10) Savitsky, D. "Hydrodynamic Design of Planing Hulls" Marine Technology, Vol. 1, No. 1, Oct. 1964

11) Bauman, W. D., "Hydrodynamic Design of Prismatic Planing Hulls", Ship Design Computer Program, NAVSHIPS 0900-006-5310, June 1966.

12) Price E.V., "Addendum to the Subcavitating Hydrofoil (HYSTAD) Program Phase 1 Final Technical Report General Dynamics/Convair Report GDC 66-075-2, Contract Nobs 90430, June 1966.

III - INPUT OUTPUT REQUIREMENTS

III 1. General Restrictions

The input data format is set up to facilitate running multiple trim-load problems on each job. After the foil geometry, foil characteristics and initial hull data have been read In, only the hull data is necessary for subsequent problems on the same job.

The following numerical values are assumed:

g	=	32.17	acceleration due to gravity
e	=	2.7182818	Naperian log. base
π	=	3.1415927	pi
deg/rad.	=	57.29578	change of angular unit
V/V_k	=	1.6889	conversion from kts. to fps
δ_{max}	=	$\pm 10^{\circ}$	maximum foil control surface deflection angle, fwd and aft foils
log/ln	=	0.43429448	conversion of base

No special tapes are required.

No non-standard hardware is required. However, page turn control is provided by a 1 in output card column 1. Each output page is numbered for comparison with the input number of problems per job.

Ten one-column arrays are used with the largest having 20 elements. All four graphical Inputs must utilize monotone Increasing numerical values on the abscissa.

There are no special operating instructions; however, the user and the machine operator are not without responsibility. During the development of this program, several potential calculation flow fumbles were spotted and suitable self-correction features provided. Typical CONFORM parametric studies range from the absurd to the ludicrous as regards ship configurations. Naturally at either extreme some inexplicable difficulty in obtaining a static trim-load solution may be expected. The user is therefore cautioned to input extreme hull-foil-propulsion configurations by steps from working designs. An alerted machine operator can abort the program if the total time becomes excessive.

III 2. Input Data Preparations

III 2.1 Control Card

Program control is accomplished by the five numbers: Kinematic Viscosity of Water (VS2), No. of Problems/This Job (XJOBS), Lift Error Bound (ZL), Moment Error Bound (ZM), and No. of Iterations/Each Problem (XNTRYS). The kinematic viscosity of water is checked numerically to see if a job follows. XJOBS Indicates how many problems are to be run with the input foil configuration; i.e., how many pairs of hull data cards are to be read. Both the lift and moment error bounds influence the accuracy of the final force and moment trim; indirectly they influence the computation time. Finally, XNTRYS specifies the number of times the control surface deflection angles are adjusted prior to re-evaluating the foil submergence.

III 2.2 Hydrofoil Data Cards

The first set of hydrofoil data cards applies to the forward foil(s) while the second set applies to the aft foil(s).

The three initial cards in each set identify configuration constants such as area, thickness to chord ratios, number of foil-strut-nacelle arrays fwd or aft, drag coefficients, etc. The last four cards in each hydrofoil data set are used to input graphical information typified by Figures 2 and 3. These figures are derived from model test results.

III 2.3 Hull Data Cards

Cards 17 and 18 describe the hull, how much of the total load it carries and how fast the ship is moving. These latter two cards are input XJOBS times, with the desired changes.

Input data specifications are presented with sample numerical values in Table 1.

TABLE 1 INPUT DATA LAYOUT FORM

Card Column	Input Format	Program Symbol	Definition	Typical Value
Card Number 1				
1-12	~12.4	vs2	Kinematic viscosity	0.0000128
13-21	F9.0	DE1W	Density of water	2.000
22-27	F6.0	DL1CF1	Roughness allowance, hull	.0004
28-32	F5.0	XJOBS	Number of problems	5.0
33-37	F5.0	DL1CF2	Roughness allowance, foils	.0001
38-42	F5.0	ZL	Lift error bound	200.0
43-47	F5.0	ZM	Moment error bound	50.0
48-52	F5.0	XNTRYS	Number of control surface angle iterations	13.0
Card Number 2				
1-80	20A4	DATAID	Title (centered)	
Card Number 3 (fwd foil-nacelle-strut array)				
1-10	F10.3	D2F	Depth below B.L., foil	9.00
11-20	F10.3	D2N	Depth below B.L., nacelle	9.00
21-30	F10.3	D2V	Depth below B.L., ventral fin	0.00
31-40	F10.3	XL1LT	Length to center of lift	88.30
41-50	F10.3	XL1CM	Mean foil chord length	3.68
51-60	F10.3	XL1CS	Mean strut chord length	4.25
61-70	F10.3	XL1V	Mean ventral fin chord length	0.00
71-80	F10.3	XL1N	Nacelle length	6.12

Card Column	Input Format	Program Symbol	Definition	Typical Value

Card Number 3 (fwd foil-nacelle-strut array)

Card Column	Input Format	Program Symbol	Definition	Typical Value
1-10	F10.3	A1P	Planform area, foil	65.63
11-20	F10.3	A1PV	Planform area, ventral fin	0.00
21-30	F10.3	R1TCM	Thickness/chord, foil	0.09
31-40	F10.3	R1TCS	Thickness/chord, strut	0.12
41-50	F10.3	R1TCV	Thickness/chord, ventral fin	0.00
51-60	F10.3	R1LDN	Length/diameter, nacelle	7.00
61-70	F10.3	A3DD	Initial control surface deflection angle	2.00
71-80	F10.3	XN2SN	Number of arrays, fwd	1.00

Card Number 4 (fwd foil-nacelle-strut array)

Card Column	Input Format	Program Symbol	Definition	Typical Value
1-10	F10.3	C1LD	Design lift coeff. ∞ depth	0.22
11-20	F10.3	DR1PT	C_{L_γ}, ∞ depth	4.302
21-30	F10.3	DR1PD	C_{l_a}, ∞ depth	2.109
31-40	F10.3	C1DSP	Strut spray drag coeff.	0.24
41-50	F10.3	C1DFP	Foil pressure drag coeff.	0.00
51-60	F10.3	C1DNP	Nacelle pressure drag coeff.	0.00
61-70	F10.3	C1WSN	Nacelle wetted surface coeff.	0.7742
71-80	F10.3	R1AS	Poll aspect ratio	6.60

Card Number 5 (fwd foil-nacelle-strut array)

Card Column	Input Format	Program Symbol	Definition	Typical Value
1-8 . . . 65-72	9F8.2	R1HCT	Foil depth/chord ratio (from Figure 2)	

Card Column	Input Format	Program Symbol	Definition	Typical Value

Card Number 6 (fwd foil-nacelle-strut array)

1-8 . . .	9FU.2	R1CLT	$\frac{C_{L_h}}{C_{L_\infty}}$ at each $\frac{h}{c}$ of Card 5 (from Figure 2)	
65-72				

Card Number 7 (fwd foil-nacelle-strut array)

1-8 . . .	9F8.2	C1LEA	3-D C_L by control surface deflection [from Figure 3)	
65-72				

Card Number 8 (fwd foil-nacelle-strut array)

1-8 . . .	9FU.2	C1DICA	C_{D_i} at each C_L of Card 7 (from Figure 3)	
65-72				

Card Number 9-15 (aft foil-nacelle-strut array)

These cards duplicate the input data layout format of cards 3 through 8; the data is applicable to the aft array however.

Card Number 16 (first hull data card)

1-10	F10.3	D	Height of C.G. above W.L.	12.96
11-20	F10.3	C1DAIR	Hull Air drag coeff.	0.772
21-30	FlW.3	XL1T	Length to thrust, fwd of	22.00
31-40	F10.3	PC1H	% of Δ carried by hull1	0.0

Card Column	Input Format	Program Symbol	Definition	Typical Value
Card Number 17	(second hull data card)			
1-12	F12.4	DP1P	Weight of ship, pounds	256,000.0
13-21	F9.0	CG1LT	Long. C. of Gravity, from transom	46.00
22-27	F6.0	CG1VB	Vert. C. of Gravity, from baseline	8.00
28-32	F5.0	B1A	Beam, average	22.00
33-37	F5.0	A3BD	Deadrlse angle, degrees	8.00
38-42	F5.0	U1SK	Speed, knots	45.00
43-47	F5.0	D2T	Depth to thrust, below baseline	11.25
48-52	F5.0	A3SHD	Shaft angle	0.00
53-57	F5.0	A3TAD	Trim (pitch) angle	0.00
Card Number 18				
1-12	~12.4		End of Jobs Card	9999.0

III 3 Output Data Editing

Program output is presented as three tables of data. The first table Itemizes the equilibrium conditions. These numbers should be carefully reviewed, for Internally generated, required changes to the Input Initial conditions. The enclosed sample data shows five problems using the "flying" data from Figure 3 followed by ten problems using the "takeoff" data of Figure 3.

Sampling the first table for the 50 kts, foilborne problem note the following: (a) a 2^{o} flaps down was Input for both the forward and aft foil whereas -0.9^{o} fwd and -0.6^{o} aft are required, reducing the pitch angle or slowing to approximately 47.5 kts would eliminate the necessity for any flaps, and (b) the keel draft aft (on centerline at the transom) is a -4.6', which is Indicative of an ample keel clearance. Later on, when the hull carries some of the load, the keel draft aft goes positive In accordance with expectations.

The second or middle table presents the drag breakdown into lever arms, characteristic lengths, drag coefficients of the elements, areas and finally the net drag of the various elements. This middle table is Invaluable for discerning the causes for wide variations In total drag. Note, for example, that in slowing to 30 knots (page 5, foilborne data) that the increment In profile drag due to control surface deflection has increased from $\Delta C_{D_P} = 0.00502$ to $\Delta C_{D_P} = 0.05948$ for the forward foil and the variation is even greater for the aft foil. Clearly, an Increase in pitch angle at lower speeds should be investigated to relieve the requirement for flaps with their associated, induced profile drag.

The third and last table presents the drag and lift summary. Recall that hull drag is omitted unless the pitch angle is greater than 0° and spray drag is omitted unless the trim angle is greater than 4°. The summation of the lift and drag components equals their respective totals within the Input error bounds.

Some familiarization with the program, Its Input and output is to be expected. NAVSEC will work with the program's users and try to accommodate suggested revisions, additions or deletions. This program is particularly intended for CONFORM and Preliminary Design Studies to quickly predict credible propulsion requirements considering the sensitivity to such hull parameters as beam, deadrise angle, center of gravity and location of the thrust vector.

III 4 Validation

Program validation was certified by hand calculation of the 30 knot hullborne case with 10% of the weight carried by the hull at a 2.5° bow up attitude. Input data as listed was used and the results compared with page 2 of the hullborne output. No significant differences were found.

III 4.1 Sample Input

The sample input shown is for the two situations of low trim angle for full foilborne operations and moderate trim angles for low foilborne and takeoff operations. The basic difference is in the choice of data from Figure 3, which must be established from model or full scale test data. Refer to Table 1 for the definition of the various data.

DATA

0.00001280 2.0000 .0004 5.0 .0001 200. 50 10. 13.

HYDROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

9.00	9.00	0.00	88.	30 3.680	4.250	0.00	6.12	
65.63	0.05	0.09	3.12	0.000	7.00	2.00	1.00	
0.220	4.302	2.109	0.240	0.000	0.000	.7742	6.60	
.0000	.5000	1.0000	1.5000	2.0000	3.0000	5.0000	7.5000	10.0000	R1HCT
.5000	.7680	.8600	.9020	.9280	.9550	.9810	.9940	9980	R1CLTR1CL
.0000	.750	.1500	.2000	.2500	.3000	.4000	.4750	.5250	C1LE
.0090	.0025	.0002	.0000	.0005	.0019	.0091	.0230	.0508	C1DIE
11.25	11.25	0.00	22.00	4.75	4.25	0.00	12.33	
74.82	0.00	0.09	CJ.12	0.00	4.82	2.00	2.00	
.1500	4.914	1.352	0.240	0.00	0.00001	.9588	6.60	
.0000	.5000	1.0000	1.5000	2.0000	3.0000	5.0000	7.5000	10.0000	R1HCTA
.5000	.7790	.8690	.9080	.9310	.9550	.9810	.9940	.9980	R1CLTA
.0000	.0750	.1500	.2000	.2500	.3000	.4000	.4750	.5250	C1LEA
.0063	.0022	.0002	.0000	.0005	.0019	.0089	.0220	.0420	C1DIEA

12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 50. 11.25 0.0 0.5
12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 45. 11.25 0.0 0.5
12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 40. 11.25 0.0 0.5
12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 35. 11.23 0.0 0.5
12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 30. 11.25 0.0 0.5

0.00001280 2.0000 .0004 10. .0001 200. 53. 13.

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

9.00	9.00	0.00	88.30	3.680	4.250	0.00	6.12	
65.63	0.00	3.09	0.12	0.003	7.00	2.03	1.00	
0.220	4.302	2.109	0.240	0.000	0.000	.7742	6.60	
.0000	.5000	1.0000	1.5000	2.0000	3.0000	5.0000	7.5000	10.0000	R1HCT
.5000	.7680	.8600	.9020	.9280	[illegible]	.9810	.9940	.9980	R1CLT
.0000	.0750	.1500	.2000	.3000	.4000	.5250	.6500	.8000	C1LE
.0040	.0014	.0002	.0000	.0000	.0010	.0048	.0135	.0500	C1DIE
11.25	11.25	0.00	22.00	4.75	4.25	3.03	12.33	
74.82	0.00	0.09	0.12	0.00	4.82	2.00	2.00	
.1500	4.914	1.952	0.240	0.00	0.00001	.9588	6.60	
.0000	.5000	1.0000	1.5000	2.0000	3.0000	5.0000	7.5000	10.0000	R1HCTA
.5000	.7790	.8690	.9080	.9310	.9550	.9810	.9940	.9980	R1CLTA
.0000	.1000	.2000	.3000	.4000	.5000	.6000	.7000	.8000	C1LEA
.0101	.0053	.0018	.0002	.0000	.0022	.0073	.0162	.0305	C1DIEA

12.96 0.772 22.00 0.0
256000.0 46.00 8.00 22.0 8.0 30. 11.25 0.0 2.5
12.96 0.772 22.00 0.1
256000.0 46.00 8.00 22.0 8.0 30. 11.25 0.0 2.5
12.96 0.772 22.00 0.2
256000.0 46.00 8.00 22.0 8.0 30. 11.25 0.0 2.5
12.06 0.772 22.00 1.2
256000.0 46.00 8.00 22.0 8.0 30. 11.25 0.0 3.0
12.96 0.772 22.00 0.2
256000.0 46.00 8.00 22.0 8.0 27. 11.25 0.0 2.5
12.96 2.772 22.00 0.2
256000.0 46.00 8.00 22.0 8.0 27. 11.25 0.0 3.0

```
   12.96      0.712      22.03              0.2
256000.0     46.00    8.00 22.1,  8.0 27.11.25    0.0    3.5
   12.96      0.772      22.00              32
256000.0     46.00    8.0022.0 8.02   4   .  11.23    0.0    2.5
   12.96      0.772      22.00              u2
256000.0     46.00    8.00 22."    8.02   4   .   11.250.0.0
   12.96      0.772      22      .00        0.2
256000.0     46.00    8.0022.08.0   24.  11.25    0.0    3.5
9999.0
$EOF
```

III 4.2 **Sample Output**

The sample output enclosed is for the sample Input and may be used to validate proper operation on other machines. Figure 7 is a graphical presentation of the salient data. For design purposes, many more data runs would be made, varying speed, trim angle and percent load carried by the hull. Considering those three variables-as most strongly Influencing total resistance, and the net results being a four dimensional "saddle," then this program finds application In defining the path of minimum total resistance through takeoff to full flying speed.

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

RESULTS FOR V= 50.D KTS, Q= 7131. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.7 FT
VCG FROM KEEL= 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 23.0 FT
CG ABOVE FWL = 13.0 FT	TRIM ANGLE = 0.5 DEG	F DRAFT FWD. 3.7 FT
MEAN BEAM = 27.0 FT	CONT DEFL FWD= -0.9 DEG	F DRAFT AFT. 6.5 FT
WETTED KEEL. = 0. FT	CONT DEFL AFT = -0.6 DEG	K DRAFT AFT. -4.6 FT
WETTED CHINE = 0. FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL.	9.o		9.0	0.	11.2		11.7	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.1%	0.	4.75	4.2'5	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00057	0.00571	0.00024	-0.00000	0.00055	0.00571	0.00001	-0.00000
FRICTION (2)	0.00255	0.00250	0.00236	0.	0.00245	0.00250	0.00213	0.
ROUGHNESS (2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.00257				0.00153			
D PROFILE	0.00002				0.00018			
WAVE OR SPRAY	0.00015	0.24000			0.00012	0.24000		
TOTAL COEFF	0.00862				0.00749			
AREA-PROFILE	65.63	13.74	13.01	0.	74.82	72.113	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	4032.7	1067.9	250.7	0.	7Y93.R	3448.1	3039.8	0.
DRAG-STRUT SPRAY		445.1				890.3		

HULL AIR DRAG	1930.o	FWD FOIL LIFT	90878.8
HULL SPRAY DRAG	0.	AFT FOIL LIFT	164919.7
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS * DRAG, LBS 23098.4 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

RESULTS FGR V= 45.0 KTS, CI= 5776. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEFL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 72.0 FT
CG ABOVE FWL = 13.0 FT	TRIM ANGLE = 0.5 DEG	F DRAFT FWD. 3.7 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 0.6 DEG	F DRAFT AFT. 6.5 FT
WETTED KEEL = 0. FT	CONT DEFL AFT= 0.6 DEG	K DRAFT AFT. -4.6 FT
WETTED CHINE = 0. FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30	`			22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L -REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COE FF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00057	0.00580	0.00024	-0.00000	0.00055	0.00580	0.00001	-0.00000
FRICTION (2)	0.00259	0.00254	0.00240	0.	0.00749	0.00254	0.00117	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.00393				0.00233			
D PROFILE	0.00040				0.00004			
WAVE OR SPRAY	0.00028	0.24000			Q.00022	0.24000		
TOTAL COEFF	0.01057				0.00833			
AREA-PROFILE	65.63	13.74	13.01	0.	74.82	22.18	95.01	n.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	4008.8	878.7	205.9	0.	7197.5,	2R37.4	2497.7	0.
DRAG-STRUT SPRAY		360.6				721.1		

HULL AIR DRAG	1563.3	FWD FOIL. LIFT	'91065.4
HULL SPRAY DRAG	0.,	AFT FOIL LIFT	164757.6
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS * DRAG, LBS 20271.4 * * * * 4 * 4 * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDR-061, REF. NAVSHIPS 0900-006-5390

HYUROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

RESULTS FOR V= 40.0 KTS, Q= 4564. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
C G ABOVE FWL= 13.0 FT	TRIM ANGLE = 0.5 DEG	F DRAFT FWD. 3.7 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 7.6 DEG	F DRAFT AFT. 6.5 FT
WETTED KEEL = 0. FT	CONT DEFL AFT= 2.2 DEG	K DRAFT AFT. -4.6 FT
WETTED CHINE = 0. FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
I/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.

TYPE OF CRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COFFF	COEFF
PROFILE	0.00057	0.00591	0.00024	-0.00000	0.00055	0.00591	0.00001	-0.00000
FRICTION(2)	0.00264	0.00258	0.00244	0.	0.00254	0.00258	0.00220	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.00632				0.00373			
D PROFILE	0.00223				0.00041.			
WAVE OR SPRAY	0.00057	0.24000			0.00044	0.24000		
TOTAL COEFF	0.01517				0.01041			

AREA-PROFILE	65.63	13.74	13.01	0.	74.82	22.18	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	4543.1	706.8	165.2	0.	7108.4	2282.1	2005.5	0.
DRAG-STRUT SPRAY		264.9				569.8		

HULL AIR DRAG	1235.2	FWD FOIL LIFT	91209.5
HULL SPRAY DRAG	0.	AFT FOIL LIFT	164625.5
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS *@RAG, LBS 18901.0 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

RESULTS FOR V= 35.0 KTS, Q= 3494. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 13.0 FT	TRIM ANGLE = 0.5 DEG	F DRAFT FWD. 3.7 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 5.6 DEG	F DRAFT AFT. 6.5 FT
WETTED KEEL = 0. FT	CONT DEFL AFT= 4.6 DEG	K DRAFT AFT. -4.6 FT
WETTED CHINE = 0. FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.17	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00057	0.00603	0.00024	-0.00000	0.00055	0.00603	0.00001	-0.00000
FRICTION (2)	0.00270	0.00264	0.00249	0.	0.00259	0.00264	0.00225	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.01080				0.00635			
D PROFILE	0.00896				0.00297			
WAVE OR SPRAY	0.00125	0.24000			0.00096	0.24000		
TOTAL COEFF	0.02718				0.01617			
AREA-PROFILE	65.63	13.74	13.01	0.	74.82	22.18	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	6232.6	552.2	128.8	0.	8456.7	1783.1	1564.0	0.
DRAG-STRUT SPRAY		218.1				436.2		

HULL AIR DRAG	945.7	FWD FOIL LIFT	91285.A
HULL SPRAY DRAG	0.	AFT FOIL LIFT	164536.9
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS * DRAG, LBS 20317.4 * * 4 * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061 , KEF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, FOILBORNE 9/30/68

RESULTS FUR V= 30.0 KTS, Q= 2567. PSF

LCG FROM TRANS= 46.0 F-i	DEADRISE ANG.= 8.0 DEG	T BELOW KFEL 11.7 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 12.8 FT	TRIM ANGLE = 0.5 DEG	F DRAFT FWD. 3.9 FT
ME4N BEAM = 22.0 FT	CONT DEFL FWD= 10.0 DEG	F DRAFT AFT. 6.7 FT
WETTED KEEL = 0. FT	CONT DEFL AFT= 8.3 DEG	K DRAFT AFT. -4.4 FT
WETTED CHINE = 0. FT		

	FORWARD	ARRAY			AFT	ARRAY		
	FOIL	STRUT	POD	V-F IN	FOIL	STKUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.?	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.1%	0.	4.75	4.25	17.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00057	0.00618	0.00024	-0.00000	0.00055	0.00618	0.0nnn1	-n.n0000
FRICTION (2)	0.00276	0.00270	0.00255	0.	0.00265	0.00270	0.00230	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.01972				0.01172			
D PROFILE	0.05932				0.01391			
WAVE OR SPRAY	0.00305	0.24000			0.00231	0.24000		
TOTAL COEFF	0.08840				0.03400			
AREA-PROFILE	65.63	14.59	13.01.	0.	74.82	23.03	95.01	0.
AREA-SPRAY		0.26				0.76		
DRAG-ELEMENT	14893.1	441.1	96.6	0.	13060.3	1392.8	1174.0	0.
DRAG-STRUT SPRAY		160.3				320.5		

HULL AIR DRAG	694.8	FWD FOIL LIFT	91035.9
HULL SPRAY ORAG	0.	AFT FOIL LIFT	164682.8
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS * DRAG, LBS 32233.5 * * * * * * * * * LIFT, LBS 256000.0

HYDRDDYNAWIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, RFF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 30.0 KTS, Q= 2567. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE= 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 13.0 FT	TRIM ANGLE = 2.5 DEG	F DRAFT FWD. 2.2 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 7.1 DEG	F DRAFT AFT. 7.3 FT
WETTED KEEL = 0. FT	CONT DEFL AFT = 3.3 DEG	K DRAFT AFT. -3.0 FT
WETTED CHINE = 0. FT		

	FORWARD	ARRAY			AFT	ARRAY		
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00062	0.00618	0.00026	-0.00000	0.00059	0.00618	0.00001	-0.00000
FRICTION (2)	0.00276	0.00270	0.00255	0.	0.00765	0.00270	0.00230	0.
ROUGHNESS(Z)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.02012				0.01175			
D PROFILE	0.00490				0.00074			
WAVE OR SPRAY	0.00303	0.24000			0.00233	0.24000		
TOTAL COEFF	0.03439				0.07091			
AREA-PROFILE	65.63	7.40	13.01	0.	74.82.	25.67	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	5794.1	223.8	97.2	0.	8033.9	1552.1	1174.0	0.
DRAG-STRUT SPRAY		160.3				320.5		

HULL AIR DRAG	694.8	FWD FOIL LIFT	88694.8
HULL SPRAY DRAG	0.	AFT FOIL LIFT	166517.1
HULL FRICTION DRAG	0.	HULL LIFT	0.
HULL PRESSURE DRAG	0.		

TOTALS * DRAG, LBS 18050.8 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESIJLTS FOR V= 30.0 KTS, Q= 2567. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KFEL 11.7 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRAMS. 22.0 FT
C G ABOVE FWL = 8.5 FT	TRIM ANGLE = 2.5 DEG	F DRAFT FWD. 6.2 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 5.3 DEG	F DRAFT AFT. 11.3 FT
WETTED KEEL = 24.4 FT	CONT DEFL AFT= 0.4 DEG	K DRAFT AFT. 1.1 FT
WETTED CHINE = 1.8 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.83	0.
L -REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF @RAG	CDEFF	COEFF	COEFF	COEFF	CDEFF	COEFF	COEFF	CDEFF
PROFILE	0.00062	0.00618	0.00026	-0.00000	0.00059	0.00618	0.00001	-0.00000
FRICTION (2)	0.00276	0.00270	0.00255	0.	0.00265	0.00270	0.00230	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.01861				0.00717			
D PROFILE	0.00662				0.00009			
WAVE OR SPRkY	0.00300	0.24000			0.00142	0.24000		
TOTAL COE FF	0.03457				0.01478			
AREA-PROFILE	65.63	24.50	13.01	0.	74.82	42.77	95.01	0.
AREA-SPRAY		0.26				0.26		
DXAG-ELEMENT	5825.2	740.8	97.2	0.	5677.9	2586.2	1174.0	0.
DRAG-STRUT SPRAY		160.3				320.5		

HULL AIR DRAG	694.8	FWD FOIL LIFT	92860.2
HULL SPRAY DRAG	0.	AFT FOIL LIFT	136653.6
HULL FRICTION DRAG	1936.1	HULL LIFT	25600.0
HULL PRESSURE DRAG	1117.7		

TOTALS * DRAG, LBS 20330.8 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDH-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V = 30.0 KTS, Q = 2567. PSF

LCG FROM TRANS = 46.0 FT	DEADRISE ANG. = 6.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = A.1 FT	TRIM ANGLE = 2." DEG	F DRAFT FWD. 7.0 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 4.4 DEG	F DRAFT AFT. 17.7 FT
WETTED KEEL = 43.0 FT	CONT DEFL AFT= - 1.4 DEG	K DRAFT AFT. 1.9 FT
WETTED CHINE = 20.4 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-F IN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.1.2	4.82	0.
L-REY N.N0	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	CUEFF	COEFF	COEFF	COEFF	CGEFF
PROFILE	0.00062	0.00618	0.00026	-0.00000	0.00059	0.00618	0.00001	-0.00000
FRICTION (2)	0.00276	0.00270	0.00255	0.	0.00265	0.00270	0.00230	0.
ROUGHNESS (2)	0.000 10	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.01638				0.00505			
D PROFILE	0.00478				0.00020			
HAVE OR SPRAY	0.00266	0.24000			0.00099	0.24000		
TOTAL COEFF	0.03016				0.01234			
AREA-PROFILE	65.63	27.95	13.01	0.	74.82	46.72	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	5082.1	845.1	97.2	0.	4741.0	2794.8	1174.0	0.
DRAG-STRUT SPRAY		100.3				320.5		

HULL AIR DRAG	654.8	FWD FOIL LIFT	$38346.5
HULL SPRAY DRAG	0.	AFT FOIL LIFT	115476.3
HULL FRICTION DRAG	42 60. 4	HULL LIFT	151200.0
FULL PRESSURE DRAG	2235.4		

TOTALS * DRAG, LBS 22405.6 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061 , REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 30.0 KTS, Q= 2567. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 8.6 FT	TRIM ANGLE =3.0 DEG	F DRAFT FWD. 6.2 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 4.0 DEG	F DRAFT AFT. 11.9 FT
WETTED KEEL = 34.4 FT	CONT DEFL AFT= -2.8 DEG	K DRAFT AFT. 1.8 FT
WETTED CHINE = 15.6 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	CDEFF	CDEFF	COEFF	COEFF	CDEFF	COEFF
PROFILE	0.00062	0.00618	0.00026	-0.00000	0.00059	0.00618	0.00001	-0.00000
FRICTION (2)	0.00276	0.00770	0.00755	0.	0.00265	0.00270	0.00230	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.01770				0.00485			
D PROFILE	0.00573				0.00030			
WAVE OR SPRAY	0.00286	0.24000			0.00095	0.24000		
TOTAL COEFF	0.03272				0.01220			
AREA-PRUFILE	65.63	24.35	13.01	0.	74.82	45.05	95.01	0.
AKEA-SPRAY		0.26				0.26		
DRAG-ELEMENT	5512.1	736.1	97.2	0.	4688.4	2725.1	1174.0	0.
DRAG-STRUT SPRAY		160.3				320.5		

HULL AIR DRAG	694.8	FWD FOIL LIFT	90701.2
HULL SPRAY DRAG	0.	AFT FOIL LIFT	112934.5
HULL FRICTION DRAG	3425.7	HULL LIFT	51200.0
HULL PRESSURE DRAG	2683.3		

TOTALS * DRAG, LBS 22217.4 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATJON DATA, HULLBORNE 9/30/68

RESULTS FOR V= 27.0 KTS, Q= 2079. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 1.1.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 7.9 FT	TRIM ANGLE = 2.5 DEG	F DRAFT FWD. 7.2 FT
WEAN BEAM = 22.0 FT	CONT DEFL FWD= 7.6 DEG	F DRAFT AFT. 12.4 FT
WETTED KEEL = 47.8 FT	CONT DEFL AFT= 1.0 DEG	K DRAFT AFT. 2.1 FT
WETTED CHINE = 25.2 FT		

	FORWARD	ARRAY			AFT	ARRAY		
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.7		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/O	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00062	0.00628	0.00026	-0.00000	0.00059	0.00628	0.00001	-0.00000
FRICTION (2)	0.00281	0.00275	0.00259	0.	0.00270	0.00275	0.00233	0.
ROUGHNESS(Z)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.02407				0.00784			
D PROFILE	0.01265				0.00005			
WAVE OR SPRAY	0.00463	0.24000			0.00176	0.24000		
TOTAL COEFF	0.04779				0.01585			
AREA-PROFILE	65.63	28.84	13.01	0.	74.87	47.11	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	6521.6	718.0	79.9	0.	4931.2	2345.5	965.1	0.
DRAG-STRUT SPRAY		129.8				259.6		

HULL AIR DRAG	562.8	FWD FOIL LIFT	97037.7
HULL SPRAY DRAG	0.	AFT FOIL LIFT	116770.9
HULL FRICTION DRAG	3963.7	HULL LIFT	51200.0
HULL PRESSURE DRAG	2235.4		

TOTALS * DRAG, LBS 22712.7 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 27.0 KTS, Q= 2079. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL = 6.3 FT	TRIM ANGLE = 3.0 DEG	F DRAFT FWD. 6.4 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 7.2 DEG	F DRAFT AFT. 12.1 FT
WETTED KEEL = 39.4 FT	CONT DEFL AFT= -0.5 DEG	K DRAFT AFT. 2.1 FT
WETTED CHINE = 20.6 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	5.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.05	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00062	0.00628	0.00026	-0.00000	0.00059	0.00628	0.00001	-0.00000
FRICTION (2)	0.00281	0.00275	0.00259	0.	0.00270	0.00275	0.00233	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.02576				0.0076.0			
D PROFILE	0.01376				0.00006			
WAVE OR SPRAY	0.00495	0.24000			0.00172	0.24000		
TOTAL COEFF	0.05090				0.01557			
AREA-PROFILE	65.63	25.46	13.01	0.	74.82	46.18	55.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	6946.6	633.5	79.9	0.	4845.1	2299.2	965.1	n .
DRAG-STRUT SPRAY		129.8				759.h		

HULL AIR DRAG	562.8	FWD FOIL LIFT	Htjh50.9
HULL SPRAY DRAG	0.	AFT FOIL LIFT	114759.2
HULL FRICTION DRAG	3309.2	HULL LIFT	51200.0
HULL PRESSURE DRAG	2683.3		

TOTALS * DRAG, LBS 22714.5 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 27.0 KTS, Q= 2079. PSF

LCG FROM TRANS	= 46.0 FT	DEADRISE ANG.	= 8.0 DEG	T BELOW KEEL	11.2 FT
VCG FROM KEEL	= 8.0 FT	SHAFT ANGLE	= 0. DEG	T FWD TRANS.	22.0 FT
CG ABOVE FWL	= 8.8 FT	TRIM ANGLE	= 3.5 DEG	F DRAFT FWD.	5.6 FT
MEAN BEAM	= 22.0 FT	CONT DEFL FWD	= 6.8 DEG	F DRAFT AFT.	11.9 FT
WETTED KEEL	= 32.8 FT	CONT DEFL AFT	= -1.9 DEG	K DRAFT AFT.	2.0 FT
WETTED CHINE	= 16.7 FT				

	FORWARD FOIL	FORWARD ARRAY STRUT	FORWARD ARRAY POD	FORWARD V-FIN	AFT FOIL	AFT ARRAY STRUT	AFT ARRAY POD	AFT V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L -REYN.NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF
PROFILE	0.00062	0.00628	0.00026	-0.00000	0.00059	0.00628	0.00001	-0.00000
FRICTION(2)	0.00281	0.00775	0.00259	0.	0.00270	0.00275	0.00233	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.02751				0.00740			
D PROFILE	0.01649				0.00007			
WAVE OR SPRAY	0.00525	0.24000			0.00168	0.24000		
TOTAL COEFF	0.05568				0.01534			
AREA-PROFILE	65.63	21.93	13.01	0.	74.82	45.10	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	7598.9	545.9	79.9	0.	4774.7	7745.4	965.1	0.
DRAG-STRUT SPRAY		129.8				259.6		

HULL AIR DRAG	562.8	FWD FOIL LIFT	90382.4
HULL SPRAY DRAG	0.	AFT FOIL LIFT	113007.4
HULL FRICTION DRAG	2772.4	HULL LIFT	51200.0
HULL PRESSURE DRAG	3131.5		

TOTALS *DRAG,LBS 23066.0 ********* LIFT, LBS 25hnnn.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WD6-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 24.0 KTS, Q= 1643. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 27.0 FT
CG ABOVE FWL = 6.9 FT	TRIM ANGLE = 2.5 DEG	F DRAFT FWD. 8.2 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 9.7 DEG	F DRAFT AFT. 13.3 FT
WETTED KEEL = 70.0 FT	CONT DEFL AFT= 0.3 DEG	K DRAFT AFT. 3.1. FT
WETTED CHINE = 47.5 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-F IN	FOIL	STRUT	POD	V-F IN
L BELOW KEEL	9.0		9.0	0.	11.7		11.2	0.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.17	4.82	0.
L -KEYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	COEFF	COEFF	CDEFF	COEFF
PROFILE	0.00062	0.00640	0.00026	-0.00000	0.00059	0.00640	0.00001	-0.00000
FRICTION (2)	0.00286	0.00280	0.00264	0.	0.00275	0.00280	0.00237	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.02927				0.00693			
D PROFILE	0.02888				0.00009			
WAVE OR SPRAY	0.00665	0.24000			0.00174	0.74000		
TOTAL COEFF	0.07134				0.01505			
AREA-PROFILE	65.63	32.96	13.01	0.	74.82	51.23	95.01	0.
AREA-SPRAY		0.26				0.26		
DRAG-ELEMENT	7693.0	660.4	64.1	0.	3698.9	2052.7	775.4	0.
DRAG-STRUT SPRAY		102.6				705.1		

HULL AIR DRAG	444.7	FWD FOIL LIFT	76904.5
HULL SPRAY DRAG	0.	AFT FOIL LIFT	87372.3
HULL FRICTION DRAG	4857.0	HULL LIFT	90703.9
HULL PRESSURE DRAG	3960.2		

TOTALS * DRAG, LBS 24514.3 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FDR V= 24.0 KTS, Q= 1643. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.7 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 72.0 FT
C G ABOVE FWL = 7.3 FT	TRIM ANGLE = 3.0 DEG	F DRAFT FWD. 7.4 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 9.9 DEG	F DRAFT AFT. 13.1 FT
WETTED KEEL = 58.2 FT	CONT DEFL AFT= -0.5 DEG	K DRAFT AFT. 3.0 FT
WETTED CHINE = 39.5 FT		

	FORWARD ARRAY				AFT ARRAY			
	FOIL	STRUT	POD	V-FIN	FOIL	STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.2	0.
L FWD TKANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.82	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	CDE FF	COEFF	COEFF	COEFF	COEFF	COEFF	COFFF	COEFF
PROFILE	0.00062	0.00640	0.00026	-0.00000	0.00059	0.00640	0.00001	-0.00000
FRICTION (2)	0.00386	0.00280	0.00264	0.	0.00275	0.00280	0.00237	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.001310	0.00010	0.00010
INDUCED	0.03326				0.00756			
D PROFILE	0.03828				0.00006			
WAVE OR SPRAY	0.00762	0.24000			0.00191	0.24000		
TOTAL COEFF	0.08570				'0.01582			
AREA-PROFILE	65.63	29.65	13.01	0.	74.82	50.37	95.01	0.
AKEA-SPRAY		0.26				0.26		
DRAG-ELEMENT	9241.0	594.1	64.1	0.	3889.8	2018.3	775.4	0.
DRAG-STRUT SPRAY		102.6				205.1		

HULL AIR DRAG	444.7	FWD **FOIL LIFT**	81070.5
HULL SPRAY DRAG	0.	**AFT FOIL LIFT**	91121.5
HULL FRICTION DRAG	**4100.9**	HULL LIFT	82458.1
HULL PRESSURE DRAG	4321.4		

TOTALS * DRAG, LBS 25757.4 * * * * * * * * * LIFT, LBS 256000.0

HYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS'
NAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-5390

HYDROFOIL PATROL CRAFT VALIDATION DATA, HULLBORNE 9/30/68

RESULTS FOR V= 24.0 KTS, Q= 1643. PSF

LCG FROM TRANS= 46.0 FT	DEADRISE ANG.= 8.0 DEG	T BELOW KEEL 11.2 FT
VCG FROM KEEL = 8.0 FT	SHAFT ANGLE = 0. DEG	T FWD TRANS. 22.0 FT
CG ABOVE FWL= 7.7 FT	TRIM ANGLE = 3.5 DEG	F DRAFT FWD. 6.7 FT
MEAN BEAM = 22.0 FT	CONT DEFL FWD= 9.6 DEG	F DRAFT AFT. 13.0 FT
WETTED KEEL = 51.4 FT	CONT DEFL AFT= -2.0 DEG	K DRAFT AFT. 3.1 FT
WETTED CHINE = 35.3 FT		

	FORWARD FOIL	ARRAY STRUT	POD	V-F IN	AFT FOIL	ARRAY STRUT	POD	V-FIN
L BELOW KEEL	9.0		9.0	0.	11.2		11.7	6.
L FWD TRANS	88.30				22.00			
T/C OR L/D	0.09	0.12	7.00	0.	0.09	0.12	4.87	0.
L - REYN. NO	3.68	4.25	6.12	0.	4.75	4.25	12.33	0.
TYPE OF DRAG	COEFF	COEFF	COEFF	COEFF	CCIEFF	COEFF	COEFF	COEFF
PROFILE	0.00062	0.00640	0.00026	-0.00000	0.00059	0.00640	0.00001	-0.00000
FRICTION(2)	0.00286	0.00280	0.00264	0.	0.00275	0.00280	0.00237	0.
ROUGHNESS(2)	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
INDUCED	0.03541				0.00726			
D PROFILE	0.04204				0.00007			
WAVE OR SPRAY	0.00815	0.24000			0.00184	0.24000		
TOTAL COEFF	0.09214				0.01546			
AREA-PROFILE	65.63	26.75	13.01	0.	74.82	49.97	95.01	0.
AHFA-SPRAY		0.76				0.26		
DRAG-ELEMENT	9935.0	536.0	64.1	0.	3800.3	2000.3	775.4	0.
DRAG-STRUT SPRAY		102.6				705.1		

HULL AIR DRAG	444.7	FWD FOIL LIFT	X2735.5
HULL SPRAY DRAG	0.	AFT FOIL LIFT	89184.2
HULL FRICTION DRAG	3669.6	HULL LIFT	82458.1
HULL PRESSURE DRAG	5043.4		

TOTALS* DRAG, LBS 26576.4 * * * * * * * * * LIFT, LBS 256000.0

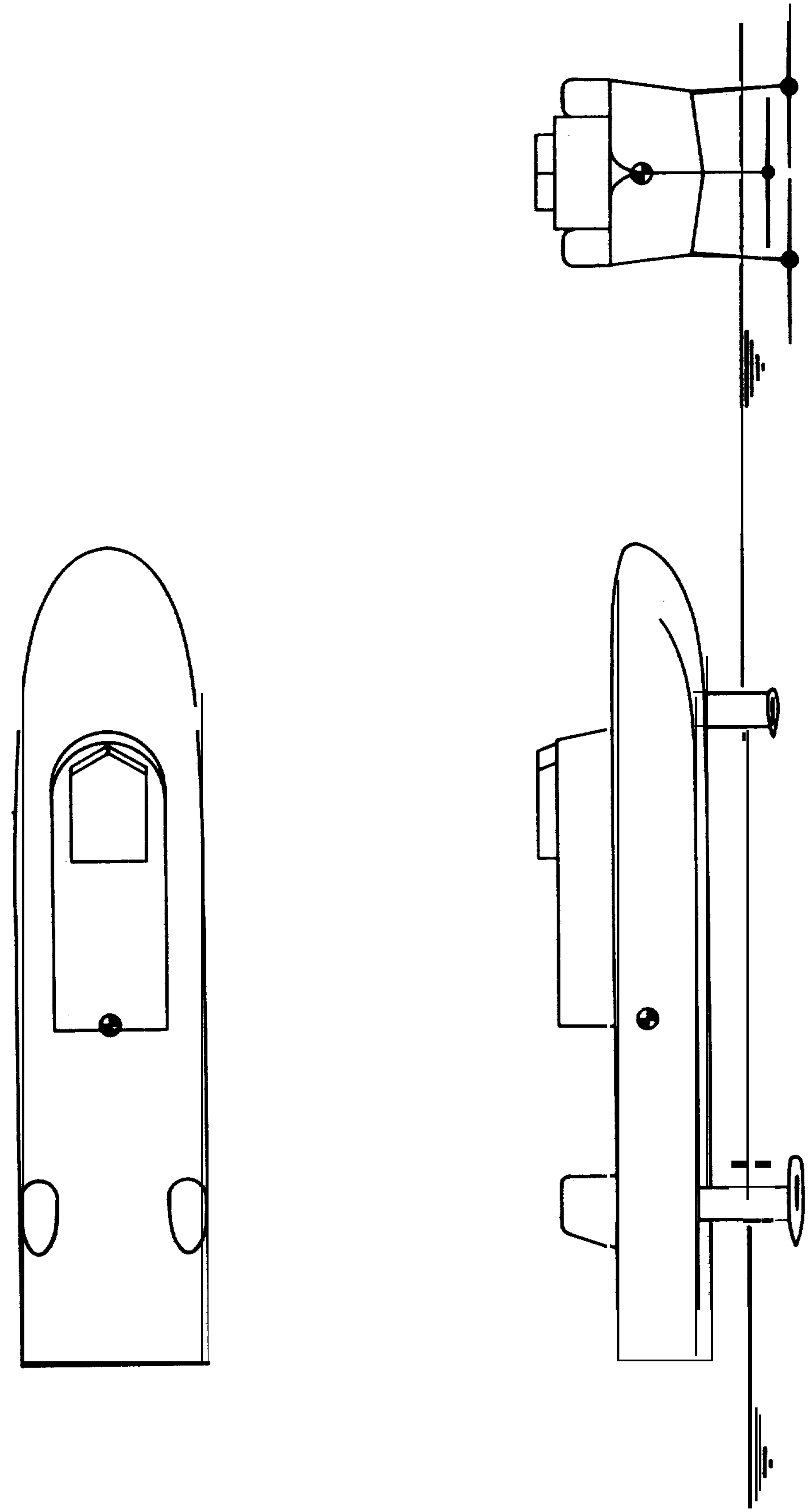


FIGURE IDEALIZED HYDROFOIL SHIP

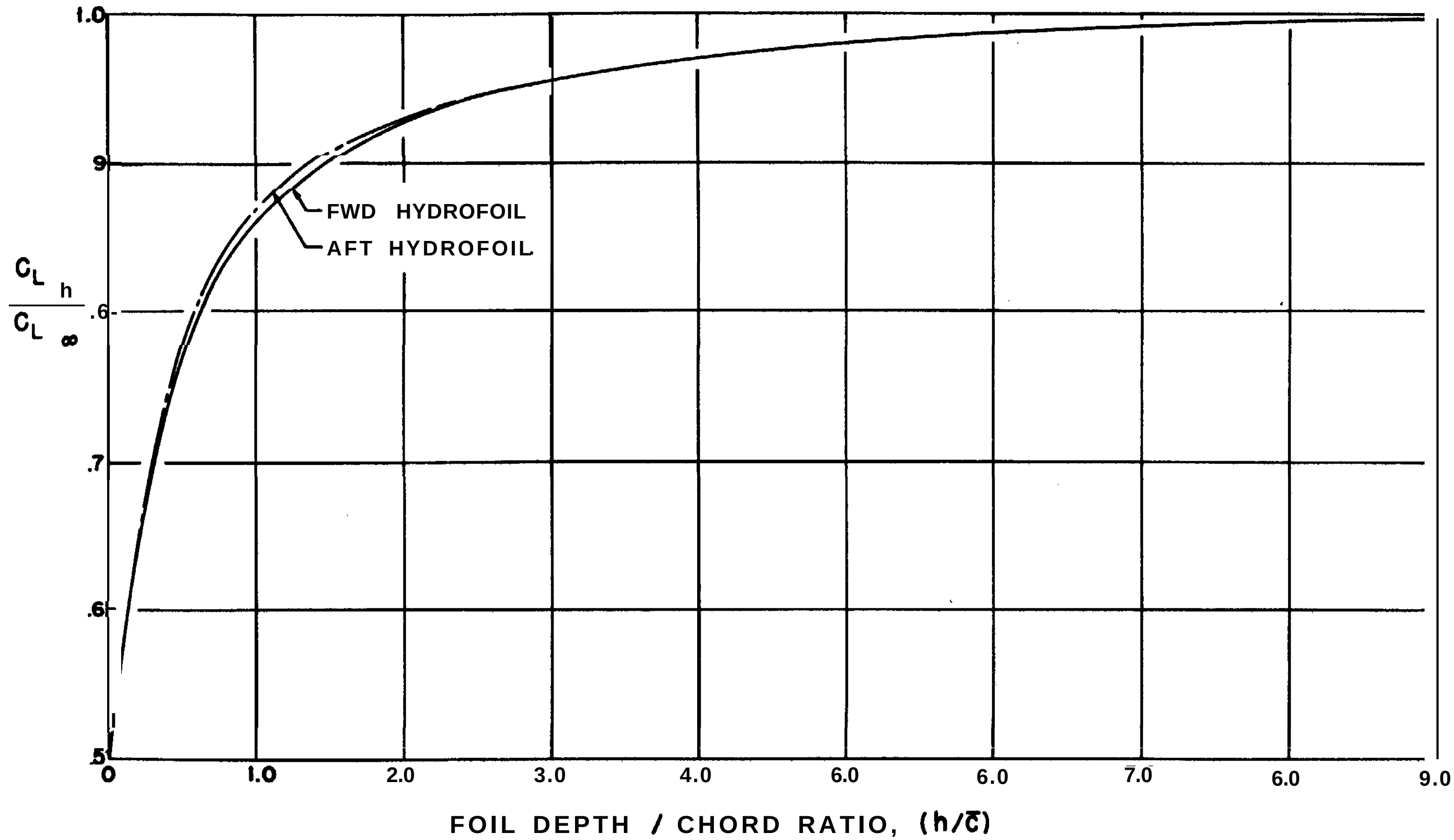


FIGURE 2 THREE DIMENSIONAL C_L RATIOS VS. FOIL DEPTH TO CHORD RATIO.

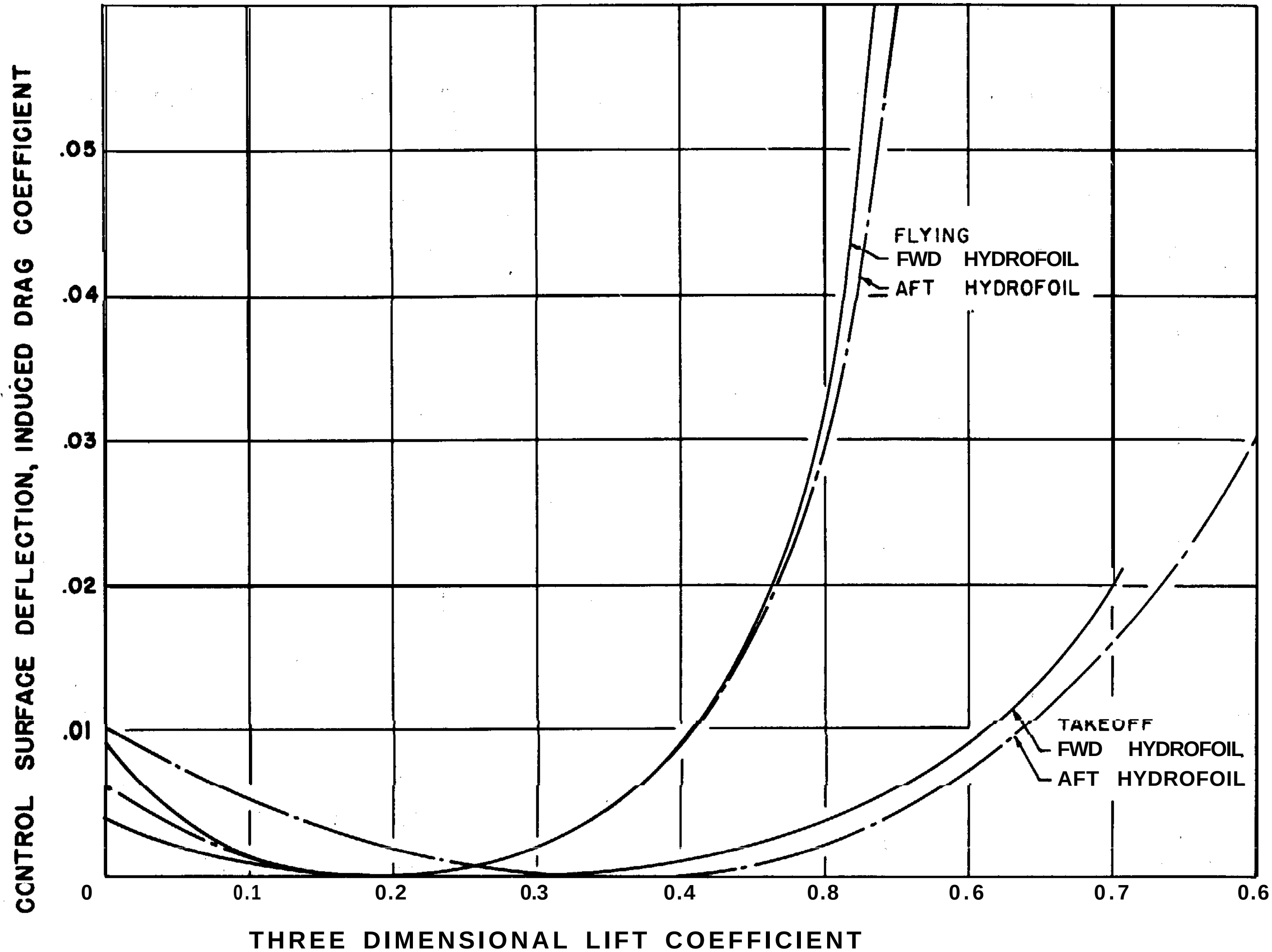


FIGURE 3 INDUCED DRAG COEFFICIENT VS. 3-D LIFT COEFFICIENT.

FROM REF. 10

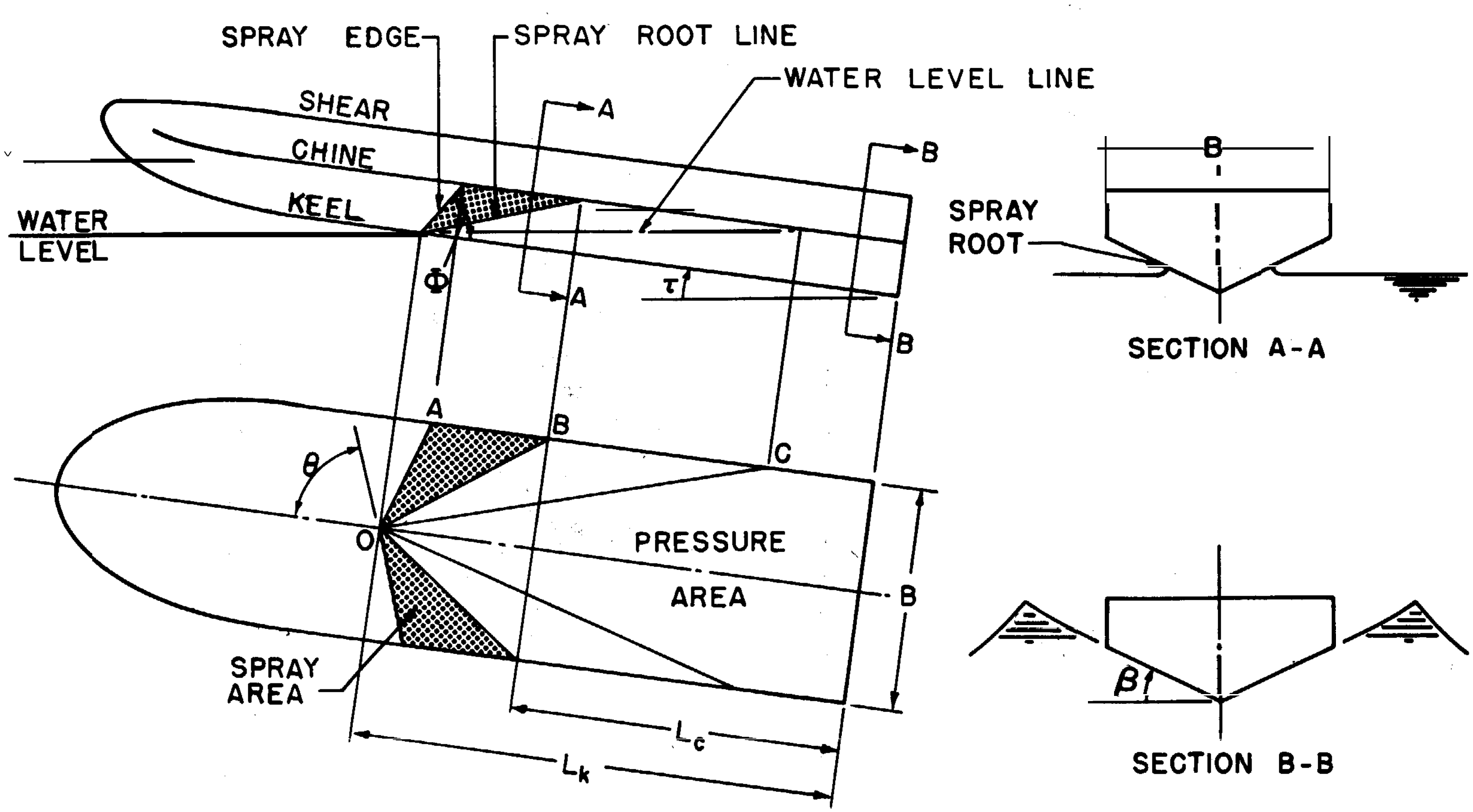
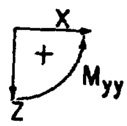


FIGURE 4 WATER LINE INTERSECTIONS FOR PRISMATIC PLANING HULLS.

SIGN CONVENTION



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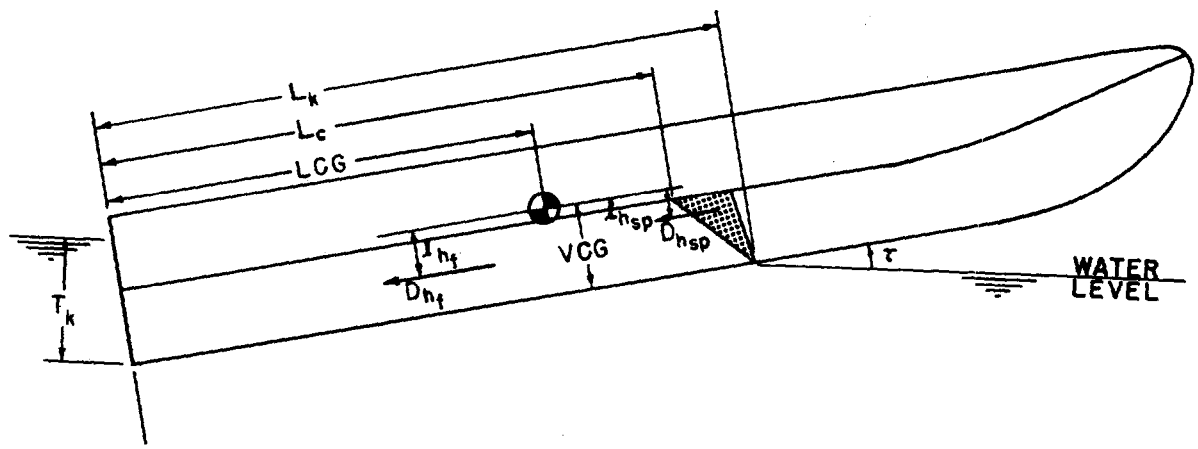

FIGURE 5 FRICTIONAL FORCES & LEVER ARMS.

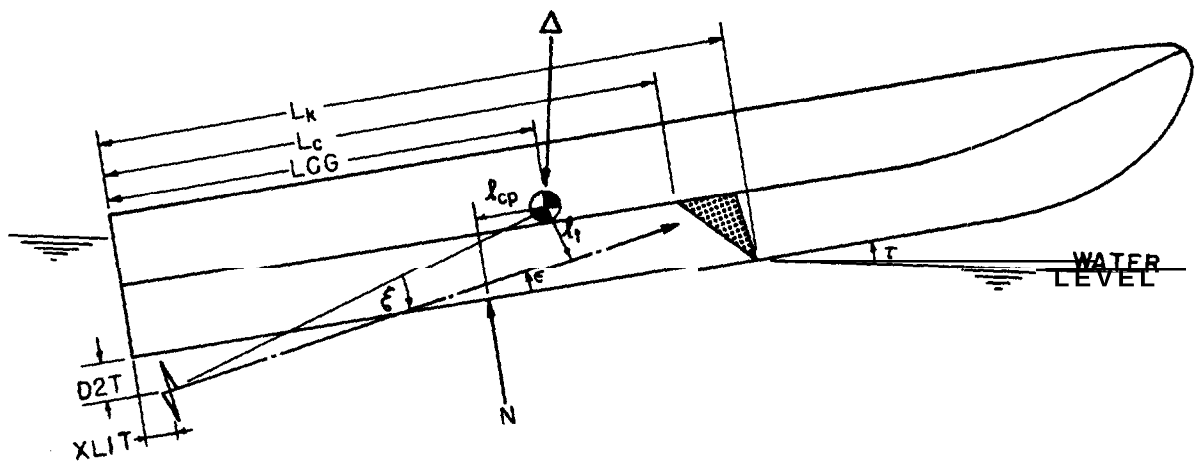

FIGURE 6 EXTERNAL FORCES & LEVER ARMS.

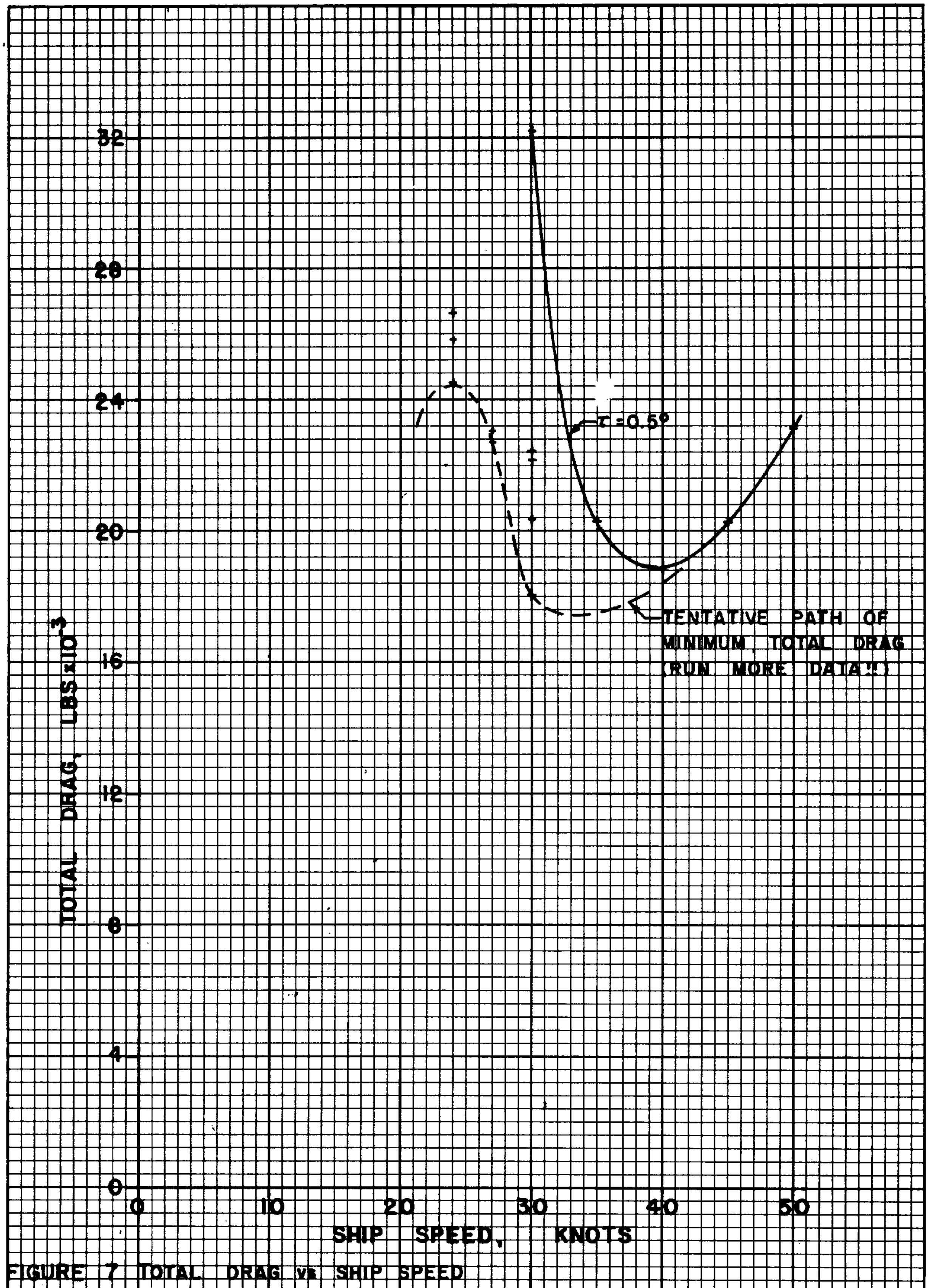

FIGURE 7 TOTAL DRAG vs SHIP SPEED

APPENDICES

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C        HYDROFOIL  SHIP  LONGITUDINAL,STATIC,  TRIM  LOAD  PROGRAM
C        CASDAC 2310  1  1-MCSA   NAVSHIPS DOC NO 0900-006-5390 JULY 1968
C        W  B  BAUMAN NAVSEC 6114C
C
C     LONGITUDINAL  STATIC  TRIM-LOAD  CALCULATION  (HY-02A)
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REOUIRED
C             PHULL(*),   FCT C1DSF(XN1RE),  INTERP(X,NO,Z,Y,VALUE)
C
      COMMON VS2,DE1W,DL1CF1,DP1PH,CG1LT,CG1VB,B1A,A3BD,V6,R1LBW,C1LOB,
     1     G1,QE,A3TAD,DG1FRH,DG1SPH,XM2,D,QPI,P2K,A3TAR,XL1KW,XL1CW,
     2     DG1PH,D1KT,SINT,COST,TANT
C
      DIMENSION R1HCT(9),R1CLT(9),C1DIC(9),R1HCTA(9),R1CLTA(9),C1DICA(9)
     1,DATAID(20),QC1DFR(8),C1LE(9),C1LEA(9)
C
C     SET OR RESET JOB CONSTANTS AT THEIR INITIAL VALUES.
    1 XJOB  =  1.
      G1      = 32.17
      NPAGE  =  1
      C1LOB=0.085
      R1LBW=3.300
      QE=2.7182818
      QPI=3.1415927
C
C     READ OVERALL CONTROL DATA CARD.
      READ (5,5)VS2,DE1W,DL1CF1,XJOBS,DL1CF2,ZL,ZM,XNTRYS
    5 FORMAT( F12.4,F9.0,F6.0,6F5.0 )
      IF(VS2-9999.)9 , 1000,1000
C
C     READ THE TITLE CARD.
    9 READ (5,10)DATAID
   10 FORMAT(20A4)
C
C     READ DATA FOR FORWARD FOIL-STRUT-NACELLE ARRAY.
   15 FORMAT(8F10.3)
   16 FORMAT(9F8.2)
      READ (5,15)D2F,D2N,D2V,XL1LT,XL1CM,XL1CS,XL1V,XL1N
      READ (5,15)A1P,A1PV,R1TCM,R1TCS,R1TCV,R1LDN,A3DD,XN2SN
      READ (5,15)C1LD,DR1PT,DR1PD,C1DSP,C1DFP,C1DNP,C1WSN,R1AS
      READ (5,16)R1HCT
      READ (5,16)R1CLT
      READ (5,16)C1LE
      READ (5,16)C1DIC
C
C     READ DATA FOR AFT FOIL-STRUT-NACELLE ARRAY.
      READ (5,15) D2FA,D2NA,D2VA,XL1LTA,XL1CMA,XL1CSA,XL1VA,XL1NA
      READ (5,15) A1PA,A1PVA,R1TCMA,R1TCSA,R1TCVA,R1LDNA,A3DDA,XN2SNA
      READ (5,15) C1LDA,DR1PTA,DR1PDA,C1DSPA,C1DFPA,C1DNPA,C1WSNA,R1ASA
      READ (5,16) R1HCTA
      READ (5,16) R1CLTA
      READ (5,16) C1LEA
      READ (5,16) C1DICA
C
C     READ HULL DATA CARDS.
   20 READ (5,15) D,C1DAIR,XL1T,PC1H
      READ (5,5) DP1P,CG1LT,CG1VB,B1A,A3BD,U1SK,D2T,A3SHD,A3TAD
```

```
C
C     SET OR RESET RUN CONSTANTS AT THEIR INITIAL VALUES.
   21 DELTNF-0.5
      DELTNR-0.5
      NTRYS=XNTRYS
      V6=1.6889*U1SK
      DP1PH=DP1P*PC1H
      R1DLN=1.0/R1LDN
      R1DLNA=1.0/R1LDNA
      P2K=0.5*DE1W*V6**2
      A3TAR=A3TAD/57.29578
      A3SHR=A3SHD/57.29578
      SINT    = SIN(A3TAR)
      COST    = COS(A3TAR)
      TANT    = TAN(A3TAR)
      A3THR   =   A3TAR +   A3SHR
C
C     EQUATION 8.2, COMPUTE THRUST LEVER ARM.
      CONST=(CG1VB+D2T)/(CG1LT-XL1T)
      A3XI =ATAN(CONST)-A3SHR
      ZCG1T=SIN(A3XI)*SQRT((CG1VB+D2T)**2 + (CG1LT-XL1T)**2)
C
C     EQUATION 7.1, COMPUTE HULL AIR DRAG.
      DG1AIR=C1DAIR*U1SK**2
C
C     EQUATION 3.11, COMPUTE STRUT SPRAY DRAG.
      A1WSS=(R1TCS*XL1CS)**2
      A1WSSA=(R1TCSA*XL1CSA)**2
      DG1SP=C1DSP*P2K*A1WSS*XN2SN
      DG1SPA=C1DSPA*P2K*A1WSSA*XN2SNA
C
C     COMPUTE COMPONENT REYNOLDS NUMBERS.
      XN1R=XL1CM*V6/VS2
      XN1RN=XL1N*V6/VS2
      XN1RS=XL1CS*V6/VS2
      XN1RA=XL1CMA*V6/VS2
      XN1RNA=XL1NA*V6/VS2
      XN1RSA=XL1CSA*V6/VS2
C
C     COMPUTE VENTRAL FIN DRAG WHEN APPLICABLE.
      IF (XL1V)45,45,50
   45 DG1V=0.000
      QC1DFR(4)=0.00
      GO TO 65
   50 XN1RV=XL1V*V6/VS2
      QC1DFR(4)=C1DSF(XN1RV)
C     EQUATION 3.10, FWD VENTRAL FIN(S) PROFILE DRAG COEFFICIENT.
      C1DVP=2.0*QC1DFR(4)*(1.2*R1TCV+60.0*R1TCV**4)
C     EQUATION 3.9, FWD VENTRAL FIN(S) DRAG.
      DG1V=(2.0*(QC1DFR(4)+DL1CF2)+C1DVP)*A1PV*P2K*XN2SN
   65 IF (XL1VA)70,70,75
   70 DG1VA=0.000
      QC1DFR(8)=0.000
      GO TO 90
   75 XN1RVA=XL1VA*V6/VS2
      QC1DFR(8)=C1DSF(XN1RVA)
C     EQUATION 3.10, AFT VENTRAL FIN(S)PROFILE DRAG COEFFICIENT.
      C1DVPA=2.*QC1DFR(8)*(1.2*R1TCVA+60.*R1TCVA**4)
```

```
C     EQUATION 3.9, AFT VENTRAL FIN(S)DRAG.
      DG1VA=(2.0*(QC1DFR(8)+DL1CF2)+C1DVPA)*A1PVA*P2K*XN2SNA
C
C     COMPUTE NACELLE DRAGS.
   90 A1WSN=C1WSN*QPI*XL1N**2*R1DLN
      A1WSNA=C1WSNA*QPI*XL1NA**2*R1DLNA
      QC1DFR(3)=C1DSF(XN1RN)
      IF (C1DNP) 95,95,100
C     EQUATION 3.8, FWD NACELLE(S)PROFILE DRAG COEFFICIENT.
   95 C1DNP=QC1DFR(3)*(1.5*R1DLN**1.5+7.0*R1DLN**3)
C     EQUATION 3.7, FWD NACELLE(S)DRAG.
  100 DG1N=(C1DNP+QC1DFR(3)+DL1CF2)*P2K*A1WSN*XN2SN
      QC1DFR(7)=C1DSF(XN1RNA)
      IF (C1DNPA) 105,105,110
C     EQUATION 3.8, AFT NACELLE(S) PROFILE DRAG COEFFICIENT.
  105 C1DNPA=QC1DFR(7)*(1.5*R1DLNA**1.5+7.0*R1DLNA**3)
C     EQUATION 3.7, AFT NACELLE(S)DRAG.
  110 DG1NA=(C1DNPA+QC1DFR(7)+DL1CF2)*P2K*A1WSNA*XN2SNA
C
C     COMPUTE STRUT PROFILE DRAG COEFFICIENTS.
      QC1DFR(2)=C1DSF(XN1RS)
      QC1DFR(6)=C1DSF(XN1RSA)
C     EQUATION 3.5, FWD STRUT(S)PROFILE DRAG COEFFICIENT.
      C1DS =2.0*QC1DFR(2)*(1.0 + 10.0*R1TCS**2)
C     EQUATION 3.5, AFT STRUT(S) PROFILE DRAG COEFFICIENT.
      C1DSA=2.0*QC1DFR(6)*(1.0 + 10.0*R1TCSA**2)
C
C     COMPUTE FOIL PROFILE DRAG COEFFICIENTS.
      QC1DFR(1)=C1DSF(XN1R)
      IF(C1DFP)111, 111, 112
C     EQUATION 3.2, FWD FOIL(S)PROFILE DRAG COEFFICIENT.
  111 C1DFP=2.0* QC1DFR(1)*(1.2*R1TCM+60.*R1TCM**4)
  112 QC1DFR(5)=C1DSF(XN1RA)
      IF(C1DFPA) 113,113,115
C     EQUATION 3.2, AFT FOIL(S)PROFILE DRAG COEFFICIENT.
  113 C1DFPA=2.0* QC1DFR(5)*(1.2*R1TCMA+60.*R1TCMA**4)
C
C     IF THE SHIP IS PARTIALLY HULL-BORNE CALL THE HULL DRAG AND HOMENT.
  115 IF (PC1H)120,120,125
  120 DG1PH  = 0.00
      DG1FRH = 0.00
      DG1SPH = 0.00
      XL1KW  = 0.00
      XL1CW  = 0.00
      XM2    = 0.00
      D1KT   = CG1LT*SINT + CG1VB*COST - D
      GO TO 130
  125 CALL PHULL ($120,255)
C
C     SET OR RESET INDICATORS.
  130 IND4=1
      IND5=1
C
C     COMPUTE FOIL DEPTH AND THEN THE DEPTH TO CHORD RATIO.
      H1F=(CG1VB+D2F)*COST-D-(XL1LT-CG1LT)*SINT
      H1FA=(CG1VB+D2FA)*COST+(CG1LT-XL1LTA)*SINT
      R1HC=H1F/XL1CM
      R1HCA=H1FA/XL1CMA
```

```
C       COMPUTE STRUT PLANFORM AREA AND LEVER ARMS ABOUT THE C.G..          HY-01680
        A1PS=(H1F-R1DLN*XL1N/2.0)*XL1CS                                     HY-01690
        A1PSA= (H1FA-R1DLNA*XL1NA/2.0)*XL1CSA                               HY-01700
        ZCG1S=  D  +  A1PS/(2.0*XL1CS)                                      HY-01710
        ZCG1SA=  D  +  A1PSA/(2.0*XL1CSA)                                   HY-01720
C                                                                           HY-01730
C       COMPLETE STRUT DRAG CALCULATION FOR THIS DEPTH.                     HY-01740
        DG1S=(2.0*(QC1DFR(2)+DL1CF2)+C1DS)*A1PS*P2K*XN2SN                   HY-01750
        DG1SA=(2.0*(QC1DFR(6)+DL1CF2)+C1DSA)*A1PSA*P2K*XN2SNA               HY-01760
C                                                                           HY-01770
C       COMPUTE FOIL LIFT COEFFICIENTS.                                     HY-01780
  135   A3DR=A3DD/57.29578                                                  HY-01790
        A3DRA=A3DDA/57.29578                                                HY-01800
        CALL INTERP(R1HC,9,R1HCT,R1CLT,R1C1L)                               HY-01810
        CALL INTERP(R1HCA,9,R1HCTA,R1CLTA,R1C1LA)                           HY-01820
C       EQUATION 2.1, FWD FOIL(S) LIFT COEFFICIENT.                         HY-01830
        C1L=(C1LD + A3TAR*DR1PT +A3DR*DR1PD)*R1C1L                          HY-01840
C       EQUATION 2.1, AFT FOIL(S) LIFT COEFFICIENT.                         HY-01850
        C1LA=(C1LDA + A3TAR*DR1PTA +A3DRA*DR1PDA)*R1C1LA                    HY-01860
C                                                                           HY-01870
C       COMPUTE FOIL LIFT.                                                  HY-01880
        XLF1K=C 1L*A1P*P2K*XN2SN                                            HY-01890
        XLF1KA=C1LA*A1PA*P2K*XN2SNA                                         HY-01900
C                                                                           HY-01910
C       COMPLETE FORWARD FOIL DRAG CALCULATION FOR THIS DEPTH.              HY-01920
        QK1C  =4.0*R1AS *( 1.0/SQRT(R1AS **2+16.0*R1HC **2+1.0) +1.0)/      HY-01930
       1 (R1AS **2 +16.0*R1HC **2)                                          HY-01940
        XN1FH =V6**2/(G1*H1F )                                              HY-01950
        QPSI  =1.0/QE**(2.0/XN1FH )                                         HY-01960
C       EQUATION 3.4, FWD FOIL(S) WAVE DRAG COEFFICIENT.                    HY-01970
        C1DW  =C1L **2*(QPSI *G1*XL1CM /(4.0*V6**2))                        HY-01980
C       EQUATION 3.3, FWD FOIL(S)INDUCED DRAG COEFFICIENT.                  HY-01990
        C1DI  =C1L **2*( 1.0/(QPI*R1AS ) +QK1C /(8.0*QPI) )                 HY-02000
        CALL INTERP (C1L,9,C1LE,C1DIC,C1DIP)                                HY-02010
C       EQUATION 3.1, FWD FOIL(S)TOTAL DRAG COEFFICIENT..                   HY-02020
        C1D=2.0*(QC1DFR(1)+DL1CF2)+C1DFP+C1DIP+C1DI+C1DW                    HY-02030
        DG1=C1D*P2K*A1P*XN2SN                                               HY-02040
C                                                                           HY-02050
C       COMPLETE AFT FOIL DRAG CALCULATION FOR THIS DEPTH.                  HY-02060
        QK1CA =4.0*R1ASA*( 1.0/SQRT(R1ASA**2+16.0*R1HCA**2+1.0) +1.0)/      HY-02070
       1 (R1ASA**2 +16.0*R1HCA**2)                                          HY-02080
        XN1FHA=V6**2/(G1*H1FA)                                              HY-02090
        QPSIA =1.0/QE**(2.0/XN1FHA)                                         HY-02100
C       EQUATION 3.4, AFT FOIL(S)WAVE DRAG COEFFICIENT.                     HY-02110
        C1DWA =C1LA**2*(QPSIA*G1*XL1CMA/(4.0*V6**2))                        HY-02120
C       EQUATION 3.3, AFT FOIL(S)INDUCED DRAG COEFFICIENT.                  HY-02130
        C1DIA =C1LA**2*(1.0/(QPI*R1ASA) +QK1CA/(8.0*QPI))                   HY-02140
        CALL INTERP(C1LA,9,C1LEA,C1DICA,C1DIPA)                             HY-02150
C       EQUATION 3.1, AFT FOIL(S)TOTAL DRAG COEFFICIENT.                    HY-02160
        C1DA=2.0*(QC1DFR(5)+DL1CF2)+C1DFPA+C1DIPA+C1DIA+C1DWA               HY-02170
        DG1A=A1PA*C1DA*P2K*XN2SNA                                           HY-02180
C                                                                           HY-02190
C       COMPUTE TOTAL SHIP DRAG.                                            HY-02200
        DG1T=DG1AIR+DG1SP+DG1SPA+DG1V+DG1VA+DG1N+DG1NA+DG1S+DG1SA+DG1+DG1AHY-02210
       1 +DG1PH+DG1FRH+DG1SPH                                               HY-02220
        T=DG1T/COS(A3THR)                                                   HY-02230
C                                                                           HY-02240
C       COMPUTE LIFT ERROR.                                                 HY-02250
```

```
      ERRL=XLF1K+XLF1KA-DP1P+T*SIN(A3THR)+DP1PH
C
C     COMPUTE MOMENT ERROR.
  138 CGM=-DG1SP*D-DG1V*(CG1VB+D2V)-DG1N*(CG1VB+D2N)-DG1NA*(CG1VB+D2NA)
      CGM=CGM-DG1S*ZCG1S - DG1SA*ZCG1SA - DG1*(D+H1F) - DG1A*(D+
     1H1FA)-DG1SPA*D-DG1VA*(CG1VB+D2VA)+T*ZCG1T
      CGM=CGM+XLF1K*(XL1LT-CG1LT+(CG1VB+D2F)*TANT)*COST
      CGM=CGM-XLF1KA*(CG1LT-XL1LTA-(CG1VB+D2FA)*TANT)*COST +XM2
      IF (IND5-NTRYS)140,140,210
  140 GO TO (145,160,165),IND4
  145 IF (ABS(ERRL)-ZL)150,150,155
  150 IF (ABS(CGM)-ZM)210,210,155
  155 TNFO=A3DD
      TNRO=A3DDA
      ERRO=ERRL
      CGMO=CGM
      IND4=2
      A3DD=A3DD+DELTNF
      GO TO 135
  160 A3DDA=A3DDA+DELTNR
      DLT=ERRL-ERRO
      DMT =CGM-CGMO
      A3DD=TNFO
      IND4=3
      GO TO 135
  165 DMD=CGM-CGMO
      DLD=ERRL-ERRO
      DEN=DMD*DLT-DLD*DMT
C
C     COMPUTE FOIL CONTROL SURFACE ANGLE CORRECTIONS.
      TNRCOR=DELTNR*(DMT*ERRO-DLT*CGMO)/DEN
      TNFCOR=DELTNF*(DLD*CGMO-DMD*ERRO)/DEN
      A3DD=TNFO+TNFCOR
      IF (ABS(TNFCOR)-1.0)175,175,170
  170 A3DD=TNFO+TNFCOR/ABS(TNFCOR)
  175 A3DDA=TNRO+TNRCOR
      IF (ABS(TNRCOR)-1.0)185,185,180
  180 A3DDA=TNRO+TNRCOR/ABS(TNRCOR)
  185 IND4=1
      IF (DELTNR-ABS(TNRCOR))195,195,190
  190 DELTNR = ABS(TNRCOR)
  195 IF (DELTNF-ABS(TNFCOR))205,205,200
  200 DELTNF = ABS(TNFCOR)
  205 IND5=IND5+1
      GO TO 135
C
C     CHECK IF FOIL INCIDENCE ANGLE LIMITS ARE EXCEEDED.
  210 IF (A3DD+10.)230,215,215
  215 IF (A3DDA+10.)230,220,220
  220 IF (A3DD-10.)225,225,245
  225 IF (A3DDA-10.)265,265,245
C
C     DECREASE FOIL DEPTH.
  230 IF (PC1H)235,235,240
  235 D=D+0.1
      GOTO 260
  240 DP1PH=DP1PH*0.9
      GO TO 260
C
```

```
C     INCREASE FOIL DEPTH.
  245 IF (PC1H)250,250,255
  250 D=D-0.1
      GO TO 260
  255 DP1PH=DP1PH*1.1
C
C     RESTORE FOIL INCIDENCE ANGLE INCREMENTS TO THEIR ORIGINAL VALUES.
  260 DELTNF-0.5
      DELTNR=0.5
      GO TO 115
C
C     WRITE HULL DESCRIPTION OUTPUT.
  265 WRITE (6,277) NPAGE
      WRITE (6,10)DATAID
      WRITE (6,295) U1SK,P2K
      WRITE (6,275) CG1LT,A3BD,D2T,CG1VB,A3SHD,XL1T,D,A3TAD,H1F
      WRITE (6,276) B1A,A3DD,H1FA,XL1KW,A3DDA,D1KT,XL1CW
      WRITE (6,300)
      WRITE (6,280) D2F,D2N,D2V,D2FA,D2NA,D2VA,XL1LT,XL1LTA,R1TCM,R1TCS,
     1 R1LDN,R1TCV,R1TCMA,R1TCSA,R1LDNA,R1TCVA,XL1CM,XL1CS,XL1N,XL1V,
     2 XL1CMA,XL1CSA,XL1NA,XL1VA
      WRITE 16,301)
      WRITE (6,305)C1DFP,C1DS,C1DNP,C1DVP,C1DFPA,C1DSA,C1DNPA,C1DVPA,
     1 QC1DFR,DL1CF2,DL1CF2,DL1CF2,DL1CF2,DL1CF2,DL1CF2,DL1CF2,DL1CF2
      WRITE (6,315) C1DI,C1DIA,C1DIP,C1DIPA
      WRITE (6,325) C1DW,C1DSP,C1DWA,C1DSPA,C1D,C1DA
      WRITE (6,330) A1P,A1PS,A1WSN,A1PV,A1PA,A1PSA,A1WSNA,A1PVA,A1WSS,
     1 A1WSSA
      WRITE (6,335) DG1,DG1S,DG1N,DG1V,DG1A,DG1SA,DG1NA,DG1VA,DG1SP,
     1 DG1SPA
      WRITE (6,340) DG1AIR,XLF1K,DG1SPH,XLF1KA,DG1FRH,DP1PH,DG1PH,DG1T,
     1 DP1P
      NPAGE = NPAGE + 1
      XJOB  = XJOB + 1.0
      IF(XJOBS - XJOB)1, 20,20
C
C     ALL OF THE OUTPUT FORMAT STATEMENTS.
  275 FORMAT(/2X15HLCG FROM TRANS=F5.1,3H FT3X14HDEADRISE ANG.=F5.1,4H D
     1EG4X12HT BELOW KEEL F5.1,3H FT/2X15HVCG FROM KEEL =F5.1,3H FT3X14H
     2SHAFT ANGLE  =F5.1,4H DEG4X12HT FWD TRANS.F5.1,3H FT/2X15HCG ABOVE
     3 FWL  =F5.1,3H FT3X14HTRIM ANGLE  =F5.1,4H DEG4X12HF DRAFT FWD.
     4 F5.1,3H FT)
  276 FORMAT (2X15HMEAN BEAM     =F5.1,3H FT3X14HCONT DEFL FWD=F5.1,4H DE
     1G4X12HF DRAFT AFT.F5.1,3H FT/2X15HWETTED KEEL   =F5.1, 3H FT3X
     214HCONT DEFL AFT=F5.1,4H DEG4X12HK DRAFT AFT.F5.1,3H FT/2X15HWETTE
     3D CHINE  =F5.1,3H FT )
  277 FORMAT(1H1//20X38HHYDRODYNAMIC DESIGN OF HYDROFOIL SHIPS 15X
     1 4HPAGE I2,/14X52HNAVSEC PROGRAM WDB-061, REF. NAVSHIPS 0900-006-
     25390 //)
  280 FORMAT(13H L BELOW KEEL 2(F8.1,8X2F8.1)/13H L FWD TRANS   F8.2,24X
     1 F8.2 /13H T/C OR L/O 8F8.2, /13H L - REYN. NO 8F8.2 //)
  295 FORMAT(//17X14HRESULTS FOR V=F5.1,5H KTS,4X2HQ=F7.0,4H PSF )
  300 FORMAT (//25X14HFORWARD ARRAY20X10HAFT ARRAY/13X2(4X4HFOIL3X5HSTR
     1UT4X3HPOD4X5HV-FIN) )
  301 FORMAT(13H TYPE OF DRAG  8(3X5HCOEFF)/)
  305 FORMAT(8H PROFILE5X8F8.5/13H FRICTION (2)8F8.5/13H ROUGHNESS(2)
     1 8F8.5 )
  315 FORMAT(8H INDUCED5XF8.5,24XF8.5/10H D PROFILE3XF8.5,24XF8.5)
```

```
325 FORMAT(14H WAVE OR SPRAYF7.5,F8.5,16X2F8.5/15H TOTAL COEEF  F8.5,  HY-03430
   1 24X F8.5 )                                                       HY-03440
330 FORMAT(/13H AREA-PROFILE 8F8.2/ 11H AREA-SPRAY10XF8.2,24XF8.2 )  HY-03450
335 FORMAT(/13H DRAG-ELEMENT 8F8.1/17H DRAG-STRUT SPRAY4XF8.1,24XF8.1)HY-03460
340 FORMAT(//14H HULL AIR DRAG7XF8.1,16X14HFWD FOIL LIFT F10.1/       HY-03470
   1 16H HULL SPRAY. DRAG 5X F8.1,16X14HAFT FOIL LIFT F10.1/20H HULL FRHY-03480
   2ICTION DRAG F9.1,20X9HHULL LIFT F11.1/20H HULL PRESSURE DRAG      HY-03490
   3 F9.1//20H TOTALS * DRAG,LBS  F9.1,9(2H *)2X9HLIFT,LBS F11.1)     HY-03500
1000 STOP                                                             HY-03510
     END                                                              HY-03520
```

```
$IBFTC HY-02B
      SUBROUTINE PHULL(*)
C
C     HYDRODYNAMIC ASPECTS Of PRISMATIC PLANING HULLS CALCULAT ION
C
C        HYDROFOIL SHIP LONGITUDINAL,STATIC, TRIM LOAD PROGRAM
C        CASDAC 231011-MCSA  NAVSHIPS DOC NO 0900-006-5390 JULY 1.968
C        W B BAUMAN NAVSEC 6114C
C
      COMMON VS2,DE1W,DL1CF1,DP1PH,CG1LT,CG1VB,B1A,A3BD,V6,R1LBW,C1LOB,
     1     G1,QE,A3TAD,DG1FRH,DG1SPH,XM2,D,QPI,P2K,A3TAR,XL1KW,XL1CW,
     2     DG1PH,D1KT,SINT,COST,TANT
C
C     TRIM ANGLE MUST BE GREATER THAN ZERO TO ENTER SUBROUTINE.
      IF(A3TAD)           1,             1,             4
    1 RETURN                              1
C
C     CALCULATE INI TIAL CONSTANTS.
    4 A3BR=A3BD/57.29578
      SINB=SIN(A3BR)
      COSB=COS(A3BR)
      TANB=TAN        (            A3BR            )
      C1V6    = V6/SQRT(G1*B1A)
      QK=.5*QPI*(1.-(3.*TANB**2*COSB)/(1.7*QPI**2)-TANB*SINB**2/(3.3*QPI
     1 ))
C     EQUATION 5.3, HULL LIFT COEFFICIENT.
      C1LB=DP1PH/(P2K*B1A**2)
C     EQUATION 6.6, SPRAY FRICTION DRAG LEVER ARM.
      ZCG1SP = CG1VB-B1A*TANB/3.0
C     EQUATION 6.4, HULL FRICTION DRAG LEVER ARM.
      ZCG1D=CG1VB-(B1A/4.)*TANB
C
C     EQUATION 5.4, ITERATION TO FIND C1LOB.
    7 QS PDT   = C1LOB**0.4
      QC1LOB =    (C1LB*QSPOT+     0.0026*A3BD*C1LOB)/(QSPOT-0.0039*A3BD)
      QCHECK=QC1LOB-C1LOB
      C1LOB=QC1LOB
      I F  (ABS(QCHECK)-.0001)10,10,7
C
C     EQUATION 5.5, ITERATION TO FIND MEAN WETTED LENGTH-BEAM RATIO.
   10 QR1LBW=(.6*R1LBW**3-.4363*C1V6**2*R1LBW+72.7272*C1V6**2*(C1LOB
     1/A3TAD **1.1)*(ABS(R1LBW))** .5)/(R1LBW**2+  .4363 *C1V6**2)
      QCHECK=QR1LBW-R1LBW
      R1LBW=QR1LBW
      I F  (ABS(QCHECK)-.0001)11,11,10
C
C     -IF WETTED CHINE IS NEGATIVE, RETURN TO MAIN PROGRAM (NO. 255).
   11 XL1CW=R1LBW*B1A-B1A*TANB/(2.*QPI*TANT)
      I F  (XL1CW)12,15,15
   12 WRITE (6,35)XL1CW
      RETURN 2
C
C     EQUATION 6.3, CALCULATION OF MEAN SPEED OVER WETTED HULL.
   15 CONST=.012*(ABS(R1LBW))**.5*A3TAD**1.1
      U1PBM=V6*(1.-(CONST-.0065*A3BD*CONST**.6)/(R1LBW*COST))**.5
C
```

```
C      REYNOLDS NUMBER FOR HULL FRICTION DRAG.
       XN1RE=U1PBM*(ABS(R1LBW))*B1A/VS2
C
C      EQUATION 6.2, HULL FRICTION DRAG CALCULATIONS.
       DG1FRH=U1PBM**2*R1LBW*B1A**2*(C1DSF(XN1RE)+DL1CF1)*
     1 DE1W*.5/COSB
C
C      SPRAY DRAG CALCULATION.
C      IF WETTED CHINE IS NEGATIVE SET SPRAY DRAG = ZERO.
       IF(XL1CW)16,17,17
    16 DG1SPH= 0.000
       GO TO 19
C      IF RUNNING TRIM ANGLE OF KEEL IS LESS THAN 4 DEGREES? SET SPRAY
C      DRAG = ZERO.
    17 IF(A3TAD - 4.0) 16, 18, 18
    18 QK1=QK*TANT/SINB
       QA     = (SINT**2*(1.-2.*QK) +QK**2*TANT**2*( (1./SINB**2) -SINT**
     1 2))**0.5/(COST +QK*TANT*SINT)
       TANP=(QA+QK1)/(1.-QA*QK1)
C      EQUATION 4.4, HULL SPRAY AREA MEAN WETTED LENGTH.
       DL1LSP=.5*(TANB/(QPI*TANT)-1./(2.*TANP*COSB))*B1A
C      REYNOLDS NUMBER FOR SPRAY FRICTION.
       XN1RE=V6*DL1LSP/VS2
C      EQUATION 6.5, HULL SPRAY DRAG CALCULATION.
       DG1SPH=P2K*(C1DSF(XN1RE)+DL1CF1)*B1A*DL1LSP/COSB
C
C      EQUATION 8.1, HULL CENTER OF PRESSURE LEVER ARM.
    19 ZCG1N=CG1LT-(.75-1./(5.21*(C1V6/R1LBW)**2 +2.39))*R1LBW*B1A
C
C      EQUATION 6.1, HULL PRESSURE DRAG CALCULATION.
       DG1PH  = DP1PH*TANT
C
C      HULL PITCHING MOMENT CALCULATION.
       XM2=-DP1PH*ZCG1N-DG1FRH*ZCG1D-DG1SPH*ZCG1SP
C
C      CALCULATE REMAINING CONSTANTS.
       XL1KW=R1LBW*B1A+B1A*TANB/(2.*QPI*TANT)
       D1KT=XL1KW*SINT
       CONST=CG1LT-XL1KW
       CONST=ABS(CONST)/CG1VB
       CONST=90./57.29578-ATAN(CONST)
       IF  (CG1LT-XL1KW)25,25,20
    20 CONST=CONST+A3TAR
       GO TO 30
    25 CONST=CONST-A3TAR
    30 D=((CG1LT-XL1KW)**2+CG1VB**2)**.5*SIN(CONST)
       RETURN
    35 FORMAT(1X,7HXL1CW = E14.7,6H - - -24HRETURNED TO MAIN PROGRAM )
       END
```

```
$IBFTC HY-02C
      FUNCTION C1DSF(XN1RE)
C
C     NEWTONS METHOD TO CALCULATE SCHOENHERR DRAG COEFFICIENT.
C
C        HYDROFOIL SHIP LONGITUDINAL,STATIC, TRIM LOAD PROGRAM
C        CASDAC 231011-MCSA NAVSHIPS DOC NO 0900-006-5390 JULY 1968
C        W B BAUMAN NAVSEC 6114C
C
      CIDSFR = 1.0/(1.5*ALOG(XN1RE) - 5.6)**2
    1 QCDF2    = C1DSFR-(.43429448*ALOG(XN1RE*C1DSFR)-.242/C1DSFR**.5)/
     1  (.43429448/C1DSFR + .121/C1DSFR**1.5)
      QCHECK   = QCDFZ - CIDSFR
      C1DSFR   = QCDF2
      IF(ABS(QCHECK) - 0.00001) 2, 2, 1
    2 C1DSF    = C1DSFR
      RETURN
      END
```

```
SIBFTC HY-020
      SUBROUTINE INTERP (X,NO,Z,Y,VALUE)
C
C     LINEAR   GRAPHICAL   INTERPOLATION.
C
C        HYDROFOIL  SHIP  LONGITUOINAL  STATIC,  TRIM  LOAD  PROGRAM
C        CASDAC 231011-MCSA NAVSHIPS DOC NO 0900-006-5390  JULY  1968
C        WB BAUMAN NAVSEC 6114C
C
      DIMENSION Y(16),Z(16)
      NL-NO-1
      DO 2 I=1,NL
      IF(X-Z(I+1)) 1,1,2
    1 DX=(X-Z(I))/(Z(I+1)-Z(I))
      VALUE=Y(I)+(Y(I+1)-Y(I))*DX
      RETURN
    2 CONTINUE
      VALUE=Y(NO) + (X-Z(NO))*(Y(NO)-Y(NL))/(Z(NO)-Z(NL))
    3 RETURN
      END
```

EQUATION SYMBOL	SYMBOLS DEFINITION	FORTRAN SYMBOL
	AREA, IN GENERAL	A1
A	AREA, PLANFORM, FWD FOIL	A1P
A	AREA, PLANFORM, AFT FOIL	A1PA
A	AREA, PLANFORM, FWD STRUT	A1PS
A	AREA, PLANFORM, AFT STRUT	A1PSA
A	AREA, PLANFORM, FW3 VENTRAL FIN	A1PV
A	AREA, PLANFORM, AFT VENTRAL FIN	A1PVA
S	AREA, WETTED SURFACE, FWD NACELLE	A1WSN
S	AREA, WETTED SURFACE, AFT NACELLE	A1WSNA
S	AREA, WETTED SURFACE, FWD STRUT SPRAY AREA	A1WSS
S	AREA, WETTED SURFACE, AFT STRUT SPRAY AREA	A1WSSA
	ANGLE IN GENERAL	A3
	ANGLE OF DEADRISE, DEGREES	A3BD
	ANGLE OF DEADRISE, RADIANS	A3BR
	ANGLE OF DEFLECTION, DEGREES, FWD FOIL CONTROL SURFACE	A3DD
	ANGLE OF DEFLECTION, DEGREES, AFT FOIL CONTROL SURFACE	A3DDA
	ANGLE OF DEFLECTION, RADIANS, FWD FOI CONTROL SURFACE	A3DR
	ANGLE OF DEFLECTION, RADIANS, AFT FO CONTROL SURFACE	A3DRA
	ANGLE OF SHAFT OR THRUST REL. TO B.L., DEGREES	A3SHD
	ANGLE OF SHAFT OR THRUST REL. TO B.L., RADIANS	A3SHR
	ANGLE OF TRIM OF KEEL, DEGREES	A3TAD
	ANGLE OF TRIM OF KEEL, RADIANS	A3TAR
	ANGLE OF THRUST TO HORIZONTAL, RADIANS	A3THR
	ANGLE OF THRUST TOL. C.G. FROM THRUST AXIS	A3X I
	COEFFICIENT, IN GENERAL	CI
C	COEFFICIENT, DRAG, IN GENERAL	C1D
C	COEFFICIENT, DRAG, TOTAL, FWD FOIL	C1D
C	COEFFICIENT, DRAG, TOTAL, AFT FOIL	C1DA
C	COEFFICIENT, DRAG, AIR	C1DAIR
C	COEFFICIENT, DRAG, INDUCED BY LIFT, FWD FOIL	C1DI
C	COEFFICIENT, DRAG, INDUCED BY LIFT, AFT FOIL	C1DIA
C	COEFFICIENT, DRAG, INDUCED DUE TO CONTROL SURFACE, FWD FOIL	C1DIC
C	COEFFICIENT, DRAG, INDUCED DUE TO CONTROL SURFACE, AFT FOIL	C1DICA
C	COEFFICIENT, DRAG, INDUCED BY CONT. SURFACE SPECIFIC DEFL, FWD	C1DIP
C	COEFFICIENT, DRAG, INDUCED BY CONT. SURFACE SPECIFIC DEFL, AFT	C1DIPA
C	COEFFICIENT, DRAG, SCHOENHERRS KIN FRICTION	C1DSF
C	COEFFICIENT, DRAG, PRESSURE, FWD FOIL	C1DFP
C	COEFFICIENT, DRAG, PRESSURE, AFT FOIL	C1DFPA
C	COEFFICIENT-, DRAG, PRESSURE, FWD STRUT	C1DS
C	COEFFICIENT, DRAG, PRESSURE, AFT STRUT	C1DSA
C	COEFFICIENT, DRAG, PRESSURE, FWD NACELLE	C1DNP
C	COEFFICIENT, DRAG, PRESSURE, AFT NACELLE	C1DNPA
C	COEFFICIENT, DRAG, PRESSURE, FWD VENTRAL	C1DVP
C	COEFFICIENT, DRAG, PRESSURE, AFT VENTRAL	C1DVPA
C	COEFFICIENT, DRAG, SPRAY, FWD STRUT	C1DSP
C	COEFFICIENT, DRAG, SPRAY, AFT STRUT	C1DSPA
C	COEFFICIENT, DRAG, WAVE, FWD FOIL	C1DW
C	COEFFICIENT, DRAG, WAVE, AFT FOIL	C1DWA

C	COEFFICIENT, LIFT, IN GENERAL	C1L
C	COEFFICIENT, LIFT, FWD FOIL	C1L
C	COEFFICIENT, LIFT, AFT FOIL	C1LA
C	COEFFICIENT, LIFT, DEADRISE SURFACE	C1LB
C	COEFFICIENT, LIFT, ZERO DEADRISE SURFACE	C1LOB
C	COEFFICIENT, LIFT, DESIGN, FWD FOIL	C1LD
C	COEFFICIENT, LIFT, DESIGN, AFT FOIL	C1LDA
C	COEFFICIENT, LIFT, FWD FOIL, EXPERIMENTAL	C1LE
C	COEFFICIENT, LIFT, AFT FOIL, EXPERIMENTAL	C1LEA
C	COEFFICIENT, WETTED SURFACE, FWD NACELLE	C1WSN
C	COEFFICIENT, WETTED SURFACE, AFT NACELLE	C1WSNA
C	COEFFICIENT, SPEED	C1VB
	DEPTH BELOW BASELINE, IN GENERAL	D2
	DEPTH BELOW BASELINE, FWD FOIL	D2F
	DEPTH BELOW BASELINE, AFT FOIL	D2FA
	DEPTH BELOW BASELINE, FWD NACELLE	D2N
	DEPTH BELOW BASELINE, AFT NACELLE	D2NA
	DEPTH BELOW BASELINE, SHAFT OR THRUST VECTOR	D2T
	DEPTH BELOW BASELINE, FWD VENTRAL FIN	D2V
	DEPTH BELOW BASELINE, AFT VENTRAL FIN	D2VA
	DRAG, IN GENERAL	DG1
D	DRAG, FWD FOIL	DG1
D	DRAG, AFT FOIL	DG1A
D	DRAG, IN AIR	DG1AIR
D	DRAG, HULL, FRICTIONAL	DG1FRH
D	DRAG, HULL, SPRAY	DG1SPH
D	DRAG, NACELLE, FWD	DG1N
n	DRAG, NACELLE, AFT	DG1NA
D	DRAG, PRESSURE, HULL	DG1PH
D	DRAG, STRUT, FWD	DG1S
D	DRAG, STRUT, AFT	DG1SA
D	DRAG, STRUT SPRAY, FWD STRUT	DG1SP
D	DRAG, STRUT SPRAY, AFT STRUT	DG1SPA
D	DRAG, TOTAL FOR VEHICLE	DG1T
D	DRAG, VENTRAL FIN, FWD	DG1V
D	DRAG, VENTRAL FIN, AFT	DG1VA
	DERIVATIVE, PARTIAL, IN GENERAL	DR1P
C	DERIVATIVE, PARTIAL, C DUE TO , FWD FOIL, INFINITE DEPTH	DR1PT
C	DERIVATIVE, PARTIAL, C DUE TO , AFT FOI, INFINITE DEPTH	DR1PTA
C	DERIVATIVE, PARTIAL, C DUE TO , FWD FOI, INFINITE DEPTH	DR1PD
C	DERIVATIVE, PARTIAL, C DUE TO , AFT FOI, INFINITE DEPTH	DR1PDA
	DRAFT, IN GENERAL	H1
H	DRAFT, FWD FOIL	H1F
H	DRAFT, AFT FOIL	H1FA

	RATIO, IN GENERAL	R1
B /A	RATIO, ASPECT, FWD FOIL	R1AS
B /A	RATIO, ASPECT, AFT FOIL	R1ASA
C /C	RATIO, FOIL C AT SPECIFIC DEPTH TO C AT INFINITE DEPTH, FWD	R1C1L
C /C	RATIO, FOIL C AT SPECIFIC DEPTH TO C AT INFINITE DEPTH, AFT	R1C1LA
C /C	RATIO, FOIL C AT DEPTH TO C AT INFINITE DEPTH, FWD	R1CLT
C /C	RATIO, FOIL C AT DEPTH TO C AT INFINITE DEPTH, AFT	R1CLTA
D/L	RATIO, DIAMETER TO LENGTH, FWD NACELLE	R1DLN
D/L	RATIO, DIAMETER TO LENGTH, AFT NACELLE	R1DLNA
H/C	RATIO, FOIL DEPTH TO CHORD, FWD FOIL, SPECIFIC	R1HC
H/C	RATIO, FOIL DEPTH TO CHORD, AFT FOIL, SPECIFIC	R1HCA
H/C	RATIO, FOIL DEPTH TO CHORD, FWD FOIL, THEORY	R1HCT
H/C	RATIO, FOIL DEPTH TO CHORD, AFT FOIL, THEORY	R1HCTA
	RATIO, LENGTH TO BEAM, MEAN WETTED.	R1LBW
L/D	RATIO, LENGTH TO DIAMETER, FWD NACELLE	R1LDN
L/D	RATIO, LENGTH TO DIAMETER, AFT NACELLE	R1LDNA
T/C	RATIO, THICKNESS TO MEAN CHORD, FWD FOIL	R1TCM
T/C	RATIO, THICKNESS TO MEAN CHORD, AFT FOIL	R1TCMA
T/C	RATIO, THICKNESS TO CHORD, FWD STRUT	R1TCS
T/C	RATIO, THICKNESS TO CHORD, AFT STRUT	R1TCSA
T/C	RATIO, THICKNESS TO CHORD, FWD VENTRAL FIN	R1TCV
T/C	RATIO, THICKNESS TO CHORD, AFT VENTRAL FIN	R1TCVA

	LENGTH, IN GENERAL	XL1
C	LENGTH, CHORD, MEAN, FWD FOIL	XL1CM
C	LENGTH, CHORD, MEAN, AFT FOIL	XL1CMA
C	LENGTH, CHORD, FWD STRUT	XL1CS
C	LENGTH, CHORD, AFT STRUT	XL1CSA
L	LENGTH, WETTED CHINE	XL1CW
L	LENGTH, WETTED KEEL	XL1KW
L	LENGTH, TO CENTER OF LIFT FROM A.P., FWD FOIL	XL1LT
L	LENGTH, TO CENTER OF LIFT, FROM A.P., AFT FOIL	XL1LTA
L	LENGTH, FWD NACELLE	XL1N
L	LENGTH, AFT NACELLE	XL1NA
L	LENGTH, THRUST LEVER ARM	XL1T
C	LENGTH, CHORD, FWD VENTRAL FIN	XL1V
C	LENGTH, CHORD, AFT VENTRAL FIN	XL1VA

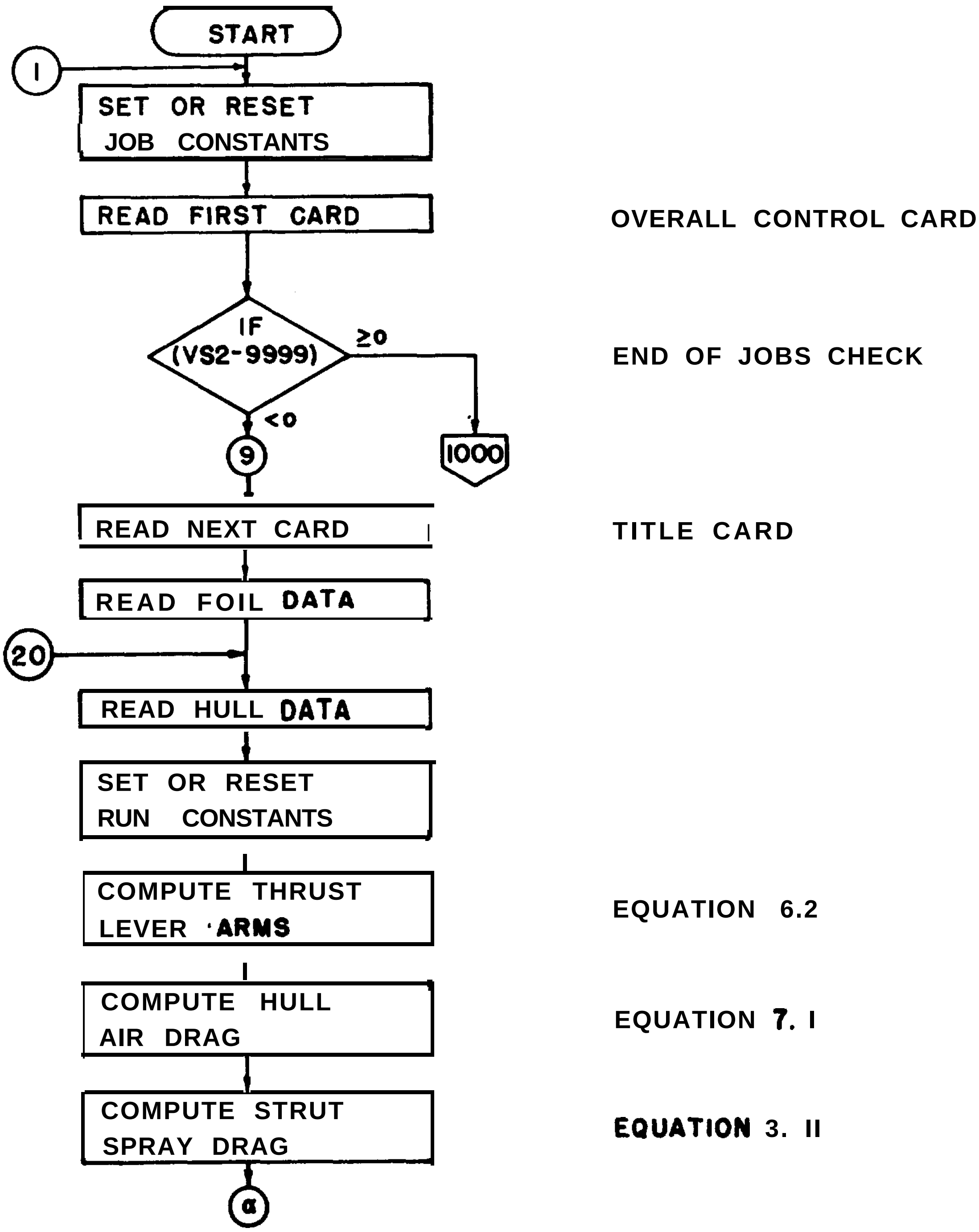
	LIFT FORCE, IN GENERAL	XLF1
L	LIFT FORCE, DYNAMIC, FWD FOIL	XLF1K
L	LIFT FORCE, DYNAMIC, AFT FOIL	XLF1KA

	REYNOLDS NUMBER, IN GENERAL	XN1R
R	REYNOLDS NUMBER, FWD FOIL	XN1R
R	REYNOLDS NUMBER, AFT FOIL	XN1RA
R	REYNOLDS NUMBER, NACELLE, FWD	XN1RN
R	REYNOLDS NUMBER, NACELLE, AFT	XN1RNA
R	REYNOLDS NUMBER, STRUT, FWD	XN1RS
R	REYNOLDS NUMBER, STRUT, AFT	XN1RSA
R	REYNOLDS NUMBER, VENTRAL FIN FWD	XN1RV
R	REYNOLDS NUMBER, VENTRAL FIN, AFT	XN1RVA

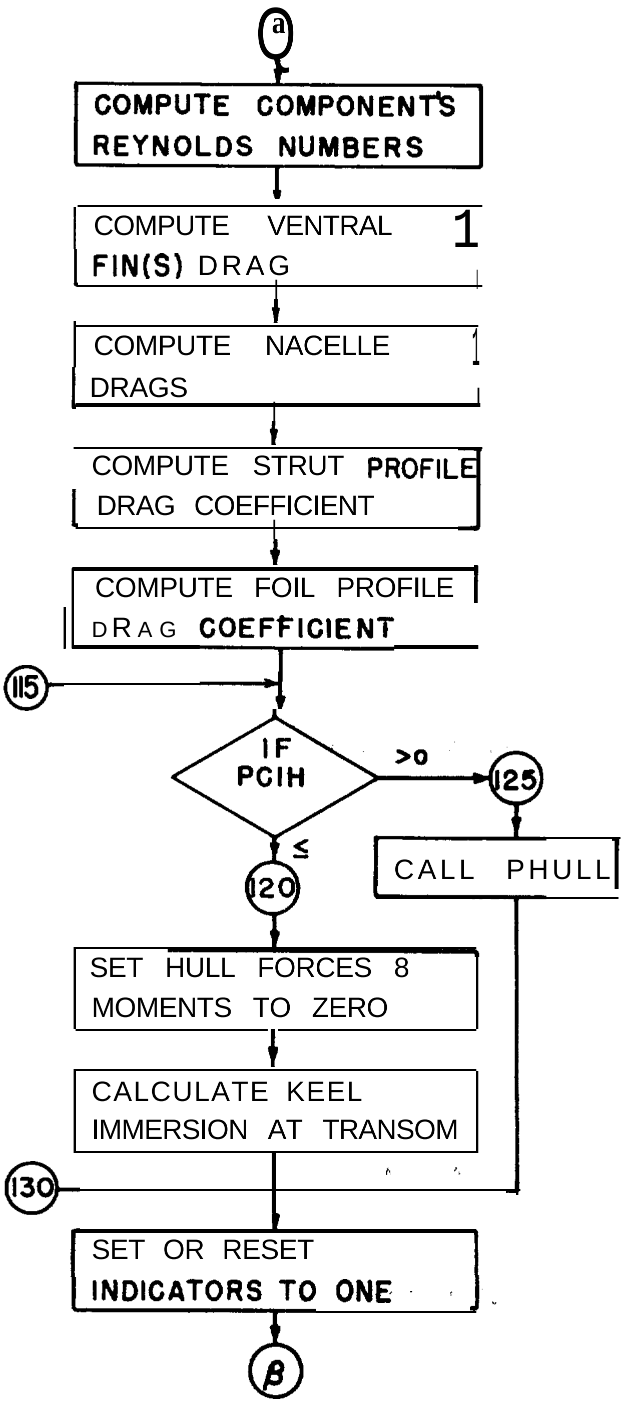
Symbol	Description	Program name
	DISTANCE HULL, LEVER ARMS IN GENERAL	ZCG1
	DISTANCE HULL, FRICTIONAL DRAG LEVER ARM	ZCG1D
	DISTANCE HULL, SPRAY DRAG LEVER ARM	ZCG1SP
	DISTANCE HULL, THRUST VECTOR LEVER ARM	ZCG1T
	DISTANCE FWD STRUT DRAG LEVER ARM	ZCG1S
	DISTANCE AFT STRUT DRAG LEVER ARM	ZCG1SA
	MISCELLANEOUS SYMBOLS	
B	BEAM, AVERAGE	B1A
	ERROR IN SUMMATION OF MOMENTS	CGM
	ERROR IN SUMMATION OF MOMENTS, ORIGINALLY	CGMO
LCG	CENTER OF GRAVITY, FROM TRANSOM	CG1LT
VCG	CENTER OF GRAVITY, ABOVE BASELINE	CG1VB
	CONSTANT, FLOATING POINT, INTERNALLY GENERATED	CONST
	COS (PITCH ANGLE, A3TAR)	COST
	HEIGHT OF C. G. ABOVE WATERLINE	D
T	DRAFT OF KEEL AT TRANSOM	D1KT
	TITLE INFORMATION	DATAID
	INCREMENT, CONTROL SURFACE DEFLECTION ANGLE, FWD FOIL	DELTNF
	INCREMENT, CONTROL SURFACE DEFLECTION ANGLE, AFT FOIL	DELTNR
	DENSITY OF WATER	DE1W
	CORRECTION FACTOR, INTERNALLY GENERATED	DEN
C	INCREMENT OF C (ROUGHNESS ALLOWANCE), FOR HULL	DL1CF1
C	INCREMENT OF C (ROUGHNESS ALLOWANCE), FOR FOILS	DL1CF2
	ERROR IN SUMMATION OF LIFT, THIRD TRY	DLD
	ERROR IN SUMMATION OF LIFT, SECOND TRY	DLT
	ERROR IN SUMMATION OF MOMENTS, SECOND TRY	DMT
	ERROR IN SUMMATION OF MOMENTS, THIRD TRY	DMD
	WEIGHT OF SHIP, POUNDS	DP1P
W	WEIGHT ON HULL, POUNDS	DP1PH
	ERROR IN SUMMATION OF LIFT	ERRL
	ERROR IN SUMMATION OF LIFT, ORIGINALLY	ERRO
	ACCELARATION DUE TO GRAVITY	G1
	INDICATOR, CONT. SURFACE DEFL. CALCULATION SEQUENCE	IND4
	INDICATOR, NO. OF TRIM-LOAD ITERATIONS TRIED	IND5
	PAGE COUNTER, OUTPUT NUMBER SHOULD = XJOBS	NPAGE
	NUMBER OF ITERATIONS AT THIS FOIL DEPTH, FIXED POINT	NTRYS
	DYNAMIC PRESSURE	P2K
	PERCENT OF TOTAL SHIP WEIGHT CARRIED BY HULL	PC1H
	COEFFICIENT OF FRICTION, REYNOLDS NO., INTERNALLY GENERATED	QC1DFR
	NAPERIAN BASE	QE
	IMAGE VORTEX FACTOR, FWD FOIL, INTERNALLY GENERATED	QK1C
	IMAGE VORTEX FACTOR, AFT FOIL, INTERNALLY GENERATED	QK1CA
	PI	QPI
	WAVE ATTENUATION WITH DEPTH, FWD FOIL, INTERNALLY GENERATED	QPSI
	WAVE ATTENUATION WITH DEPTH, AFT FOIL, INTERNALLY GENERATED	QPSIA
	SIN (PITCH ANGLE, A3TAR)	SINT
	THRUST	T
	TAN (PITCH ANGLE, A3TAR)	TANT
	CONTROL SURFACE CORRECTION FACTOR, FWD FOIL	TNFCOR
	CONTROL SURFACE DEFLECTION, FWD FOIL, ORIGINAL VALUE	TNFO
	CONTROL SURFACE CORRECTION FACTOR, AFT FOIL	TNRCOR
	CONTROL SURFACE DEFLECTION, AFT FOIL, ORIGINAL VALUE	TNRO

SPEED, SHIP, KNOTS	U1SK
VELOCITY OVER BOTTOM OF PLANING SURFACE, MEAN	U1PBM
VELOCITY OF SHIP IN X DIRECTION, FT/SEC.	V6
KINEMATIC VISCOSITY	VS2
JOB COUNTER, WHICH SEQUENTIAL CONDITION IS IN PROGRESS	XJOB
JOB COUNTER, INPUT NUMBER OF TRIM-LOAD CONDITIONS TO BE RUN	XJOBS
SUMMATION OF HULL PITCHING MOMENTS, FT-LBS	XM2
FROUDE NUMBER, BASED ON FOIL DEPTH, FWD	XN1FH
FROUDE NUMBER, BASED ON FOIL DEPTH, AFT	XN1FHA
NUMBER OF HYDROFOIL-STRUT-NACELLE ARRAYS, FWD	XN2SN
NUMBER OF HYDROFOIL-STRUT-NACELLE ARRAYS, AFT	XN2SNA
NUMBER OF ITERATIONS AT THIS FOIL DEPTH, FLOATING POINT	XNTRYS
SUMMATION OF LIFT ERROR LIMIT	ZL
SUMMATION OF MOMENT ERROR LIMIT	ZM

LONGITUDINAL STATIC TRIM- LOAD PROGRAM



PAGE 1/5



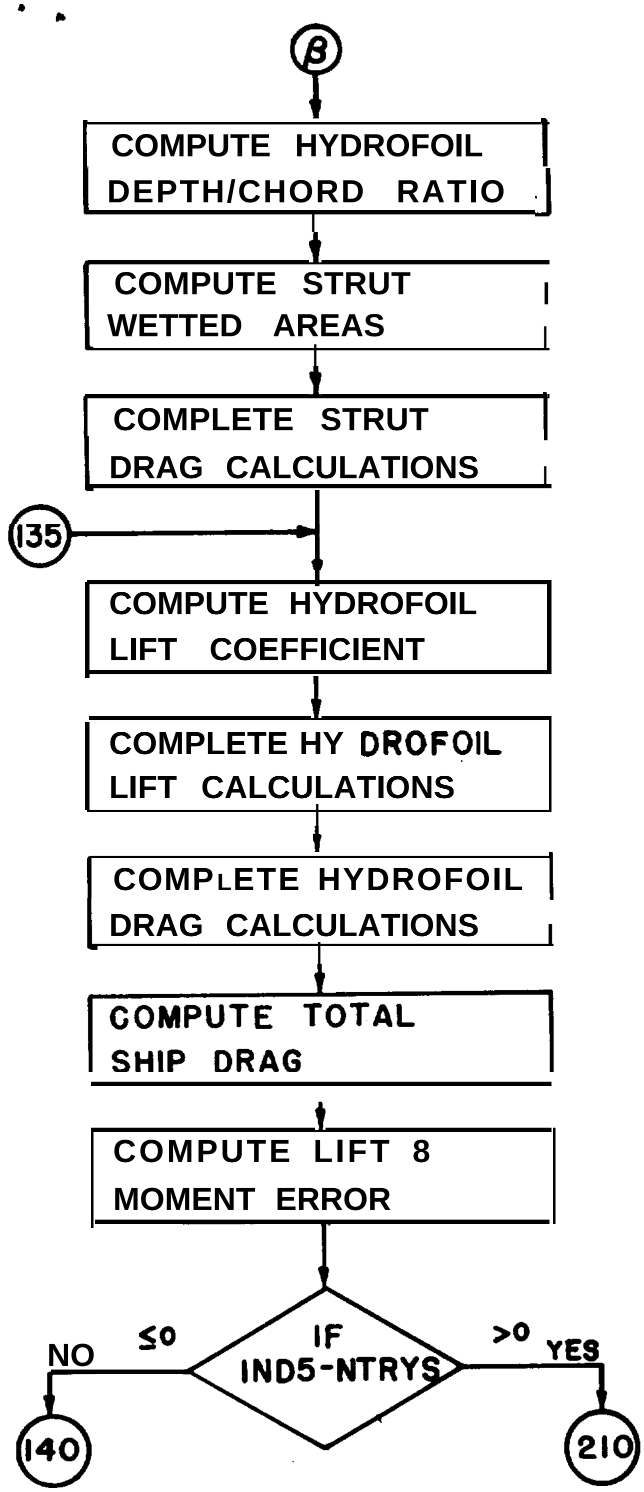
EQUATIONS 3.9 & 3.10
(IF APPLICABLE)

EQUATIONS 3.7 & 3.8

EQUATION 3.5

EQUATION 3.2

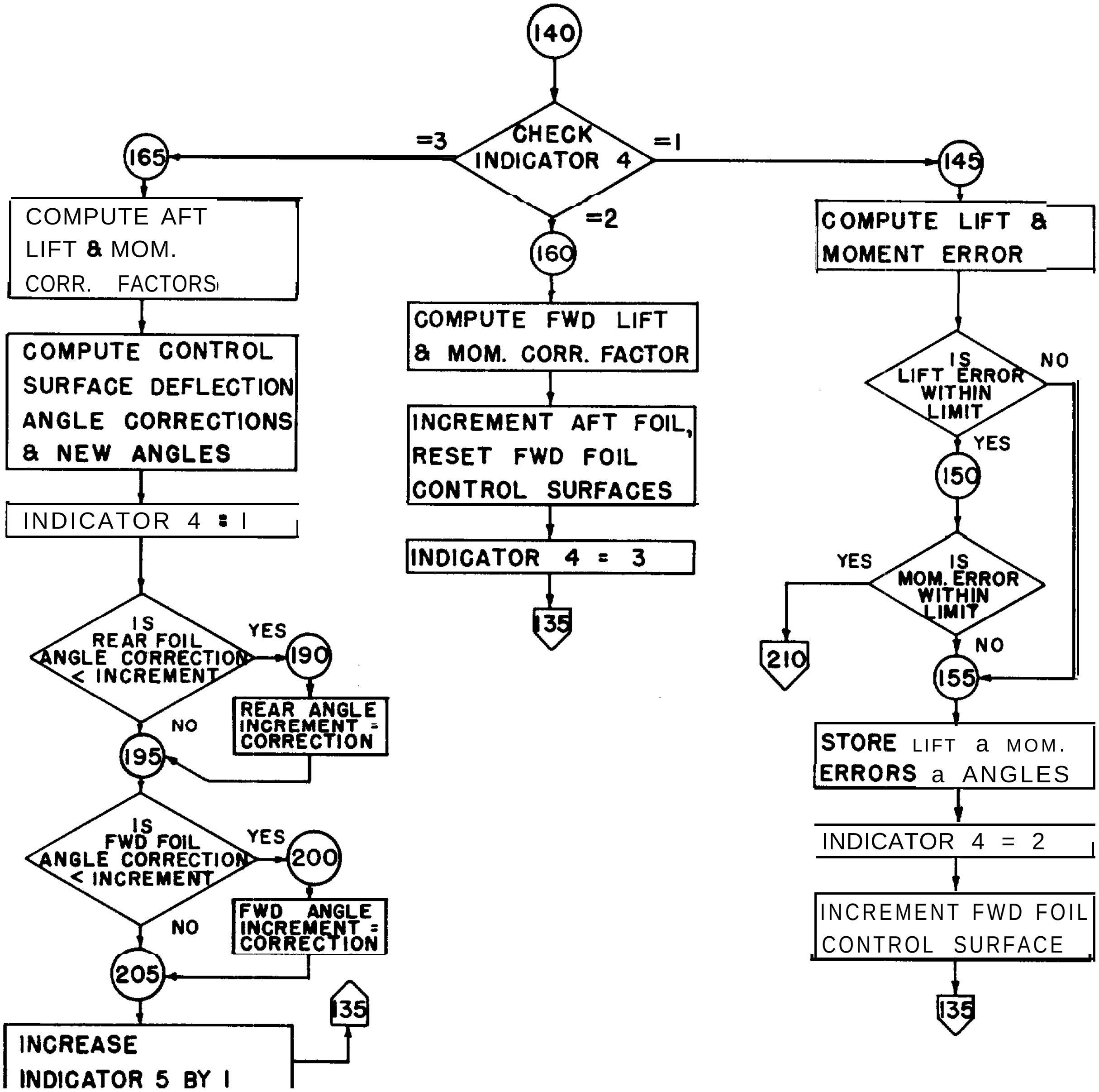
IF SHIP IS PARTIALLY HULLBORNE, CALL HULL FORCES & MOMENTS

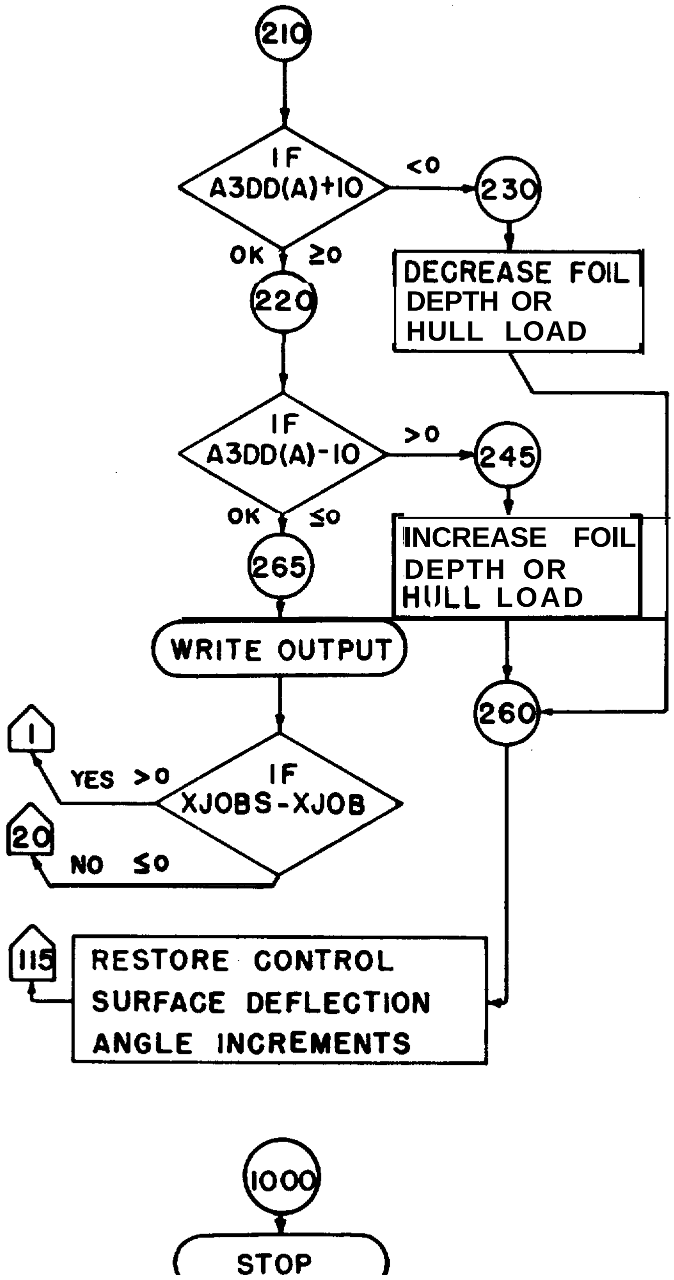


EQUATION 2.1

EQUATIONS 3.1, 3.3 8 3.4

HAVE "NTRYS" ITERATIONS BEEN PERFORMED


140
CHECK INDICATOR 4
=3
=1
=2
165
COMPUTE AFT LIFT & MOM. CORR. FACTORS
COMPUTE CONTROL SURFACE DEFLECTION ANGLE CORRECTIONS & NEW ANGLES
INDICATOR 4 = I
IS REAR FOIL ANGLE CORRECTION < INCREMENT
YES
190
REAR ANGLE INCREMENT = CORRECTION
NO
195
IS FWD FOIL ANGLE CORRECTION < INCREMENT
YES
200
FWD ANGLE INCREMENT = CORRECTION
NO
205
INCREASE INDICATOR 5 BY I
135
160
COMPUTE FWD LIFT & MOM. CORR. FACTOR
INCREMENT AFT FOIL, RESET FWD FOIL CONTROL SURFACES
INDICATOR 4 = 3
135
145
COMPUTE LIFT & MOMENT ERROR
IS LIFT ERROR WITHIN LIMIT
NO
YES
150
IS MOM. ERROR WITHIN LIMIT
YES
210
NO
155
STORE LIFT & MOM. ERRORS & ANGLES
INDICATOR 4 = 2
INCREMENT FWD FOIL CONTROL SURFACE
135



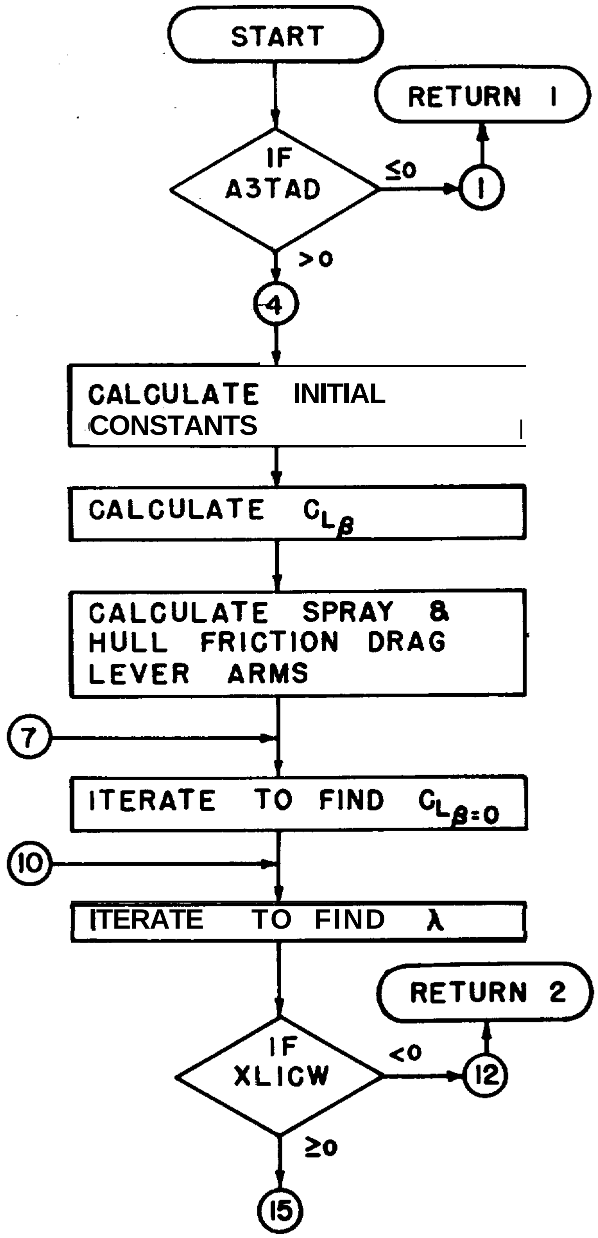
CHECK IF UPPER LIMITS FOR CONTROL SURFACE DEFLECTIONS HAVE BEEN EXCEEDED.

CHECK IF LOWER LIMITS FOR CONTROL SURFACE DEFLECTIONS HAVE BEEN EXCEEDED

IS THIS JOB DONE

SUBROUTINE PHULL

HYDRODYNAMIC ASPECTS OF PRISMATIC PLANING HULLS



RETURN TO MAIN PROGRAM IF PITCH ANGLE ≤ 0°

EQUATION 5.3

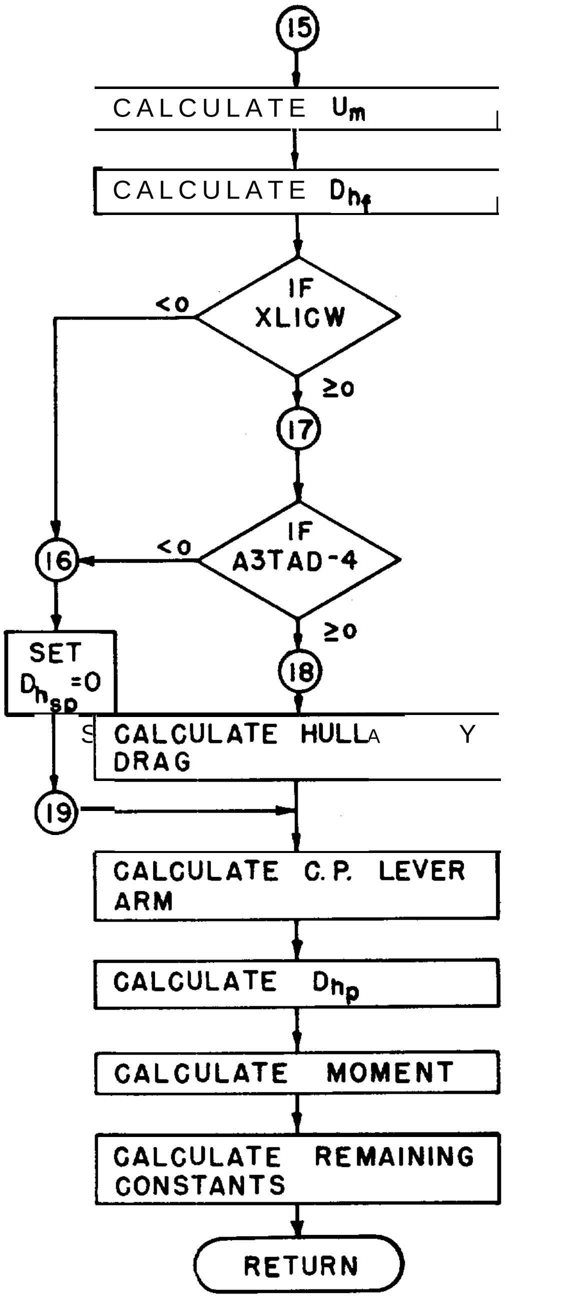
EQUATION 6.6 & 6.4

EQUATION 5.4

EQUATION 5.5

IF WETTED CHINE IS NEGATIVE, RETURN TO MAIN PROGRAM & INCREASE PCIH

PAGE 1/2



EQUATION 6.3

EQUATION 6.2

IF WETTED CHINE LENGTH IS NEGATIVE, SET SPRAY DRAG EQUAL TO ZERO

IF PITCH ANGLE IS LESS THAN 4°, SET SPRAY DRAG EQUAL TO ZERO

EQUATION 4.4 & 6.5

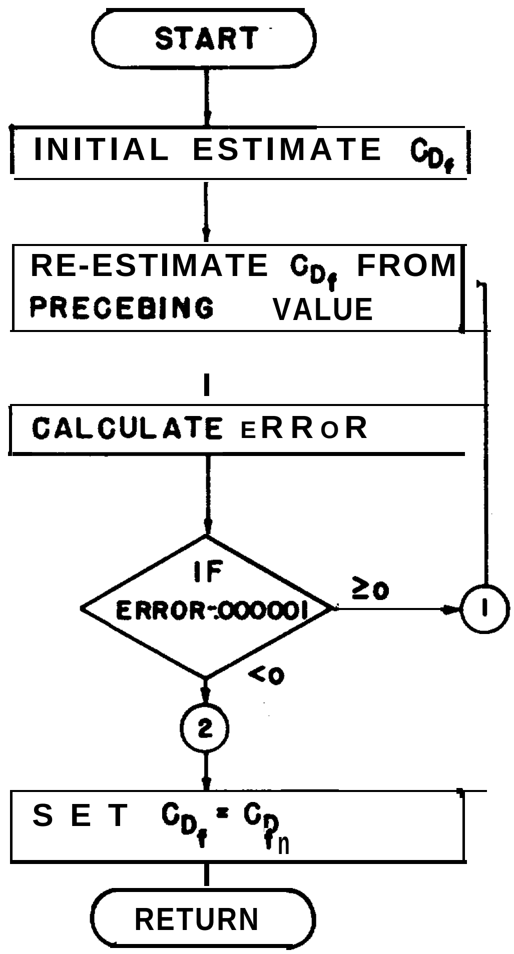
EQUATION 8.1

EQUATION 6.1

PAGE 2/2

FUNCTION CIDSF

SCHOENHERR SKIN FRICTION DRAG COEFFICIENT C_{D_f}.



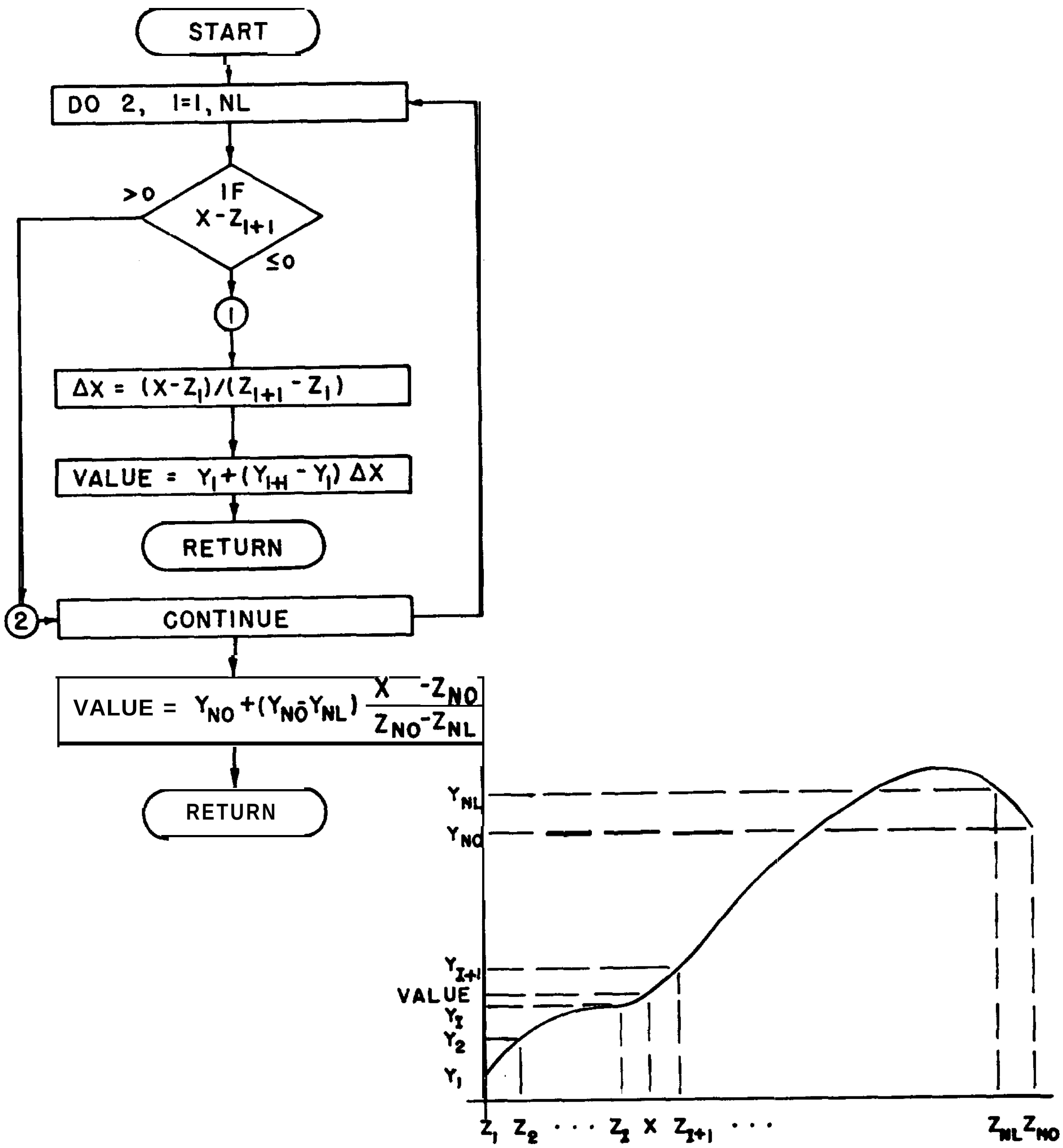
HOERNER'S APPROXIMATION.

NEWTON-RAPHSON ITERATION METHOD

ERROR = $C_{D_{f_n}} - C_{D_{f_{n-1}}}$

SUBROUTINE INTERP

LINEAR GRAPHICAL INTERPOLATION



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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ship Systems Command Department of the Navy Washington D. C. 20360

13. ABSTRACT

This program computes the foil control surface deflection angles necessary to produce static equilibrium for a hydrofoil ship operating at a specified hull clearance, pitch angle, and velocity. Assuming the hull can be represented by a prismatic planing hull, the conditions through a quasi-static (i.e., ignoring accelerations and rates) take-off can also be determined. The program computes and tabulates the individual forces acting on the ship and outputs them for ready reference.

There are two subroutines and one non-standard function.

DD FORM 1 JAN 64 1473

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Security Classification

UNCLASSIFIED

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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HYDROFOIL SHIPS						
SHIP DESIGN						
NAVAL ARCHITECTURE						
COMPUTER PROGRAM						
COMPUTER-AIDED SHIP DESIGN						

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