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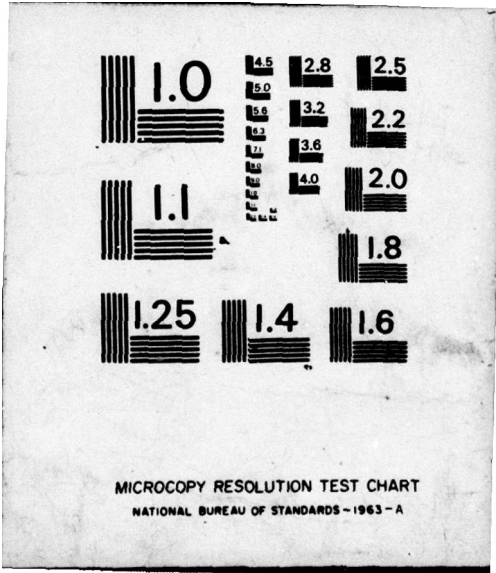
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PREDICTION OF ROLL,  
SWAY AND YAW MOTIONS OF  
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Rodney T. SCHMITKE

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NOVEMBER 1976

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PREDICTION OF ROLL  
SWAY AND YAW MOTIONS OF  
HULLBORNE HYDROFOIL SHIPS

U.S. TECHNICAL MEMORANDUM

ABSTRACT

To provide further capability for prediction and analysis of hydrofoil hullborne seakeeping, a mathematical model and computer program have been developed to predict roll, sway and yaw motions of hullborne hydrofoil ships in beam seas. Predictions agree well with towing tank data for a 1:20-scale model of the PHM hydrofoil craft.

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## SOMMAIRE

Afin d'accroître les possibilités de prédiction et d'analyse de la tenue en mer des navires hydroptères en flottaison sur leur coque, on a créé un modèle mathématique et un programme d'ordinateur pour prévoir le roulis, le tangage et l'embarquée des navires hydroptères en mers du travers. Les prédictions s'accordent bien avec les données obtenues dans un réservoir de remorquage avec un modèle à l'échelle de 1/20 de l'hydroptère PHM.

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## TABLE OF CONTENTS

Notation . . . . .	vii
1. Introduction . . . . .	1
2. Mathematical Model . . . . .	1
2.1 Equations of Motion . . . . .	2
2.2 Hull Coefficients . . . . .	3
2.2.1 Added Mass and Damping . . . . .	3
2.2.2 Hydrostatic Restoring Coefficient . . . . .	4
2.2.3 Exciting Force and Moments . . . . .	4
2.3 Foil Coefficients . . . . .	5
2.3.1 Nonzero Forward Speed . . . . .	5
2.3.2 Zero Forward Speed . . . . .	10
2.3.3 Strut Wave-Making Damping . . . . .	11
3. Computer Program . . . . .	12
4. Comparison of Theory with Experiment . . . . .	12
5. Concluding Remarks . . . . .	13
Illustrations . . . . .	14
References . . . . .	24
Appendix: Computer Program Details . . . . .	25
A. Input Description . . . . .	25
B. Sample Input . . . . .	29
C. Sample Output . . . . .	31
D. Computer Program Listing . . . . .	40



## NOTATION

A	subscript and superscript referring to aftermost hull section
$A_{jk}$	added mass coefficient
$B_{jk}$	damping coefficient
$C_{jk}$	stiffness coefficient
$C_L$	lift coefficient
$C_{L\alpha}$	lift curve slope
$C_n$	flat plate normal force coefficient
$C_w$	strut wave-making damping coefficient
$C(k)$	Theodorsen's function
F	superscript denoting foil contribution
$F_j$	exciting force or moment
$\overline{GM}$	metacentric height
H	superscript denoting hull contribution
$I_4$	rolling moment of inertia
$I_6$	yawing moment of inertia
L	foil lift, also length between perpendiculars
N	foil yawing moment
S	foil area
$S_e(k)$	Sear's function
$T_i$	coefficient dependent on flap-chord ratio
U	ship speed
$a_{jk}$	sectional added mass
$b_{jk}$	sectional wave-making damping
b	foil span

$c$	foil mean chord
$e_{\beta}$	flap effectiveness parameter
$f_j$	sectional Froude-Kriloff force
$g$	gravitational acceleration
$h$	foil mean depth
$h_j$	sectional diffraction force
$k$	reduced frequency
$k_w$	wave number
$k_{\phi}, k_{\psi}, \text{ etc.}$	control systems gains
$m$	ship mass
$n_2, n_3$	y and z components of unit outward normal to hull
$p$	distance from flap hinge line to mid chord $\div$ semi-chord
$s$	x - coordinate of foil mid chord
$t$	time variable
$u$	wave horizontal orbital velocity
$w$	wave vertical orbital velocity
$\hat{w}$	component of wave orbital velocity perpendicular to the foil
$x, y, z$	coordinate system (Fig. 2)
$\Gamma$	foil dihedral angle
$\alpha$	foil angle of attack
$\beta$	flap deflection
$\delta$	rudder deflection
$\phi_j$	two-dimensional section potential
$\zeta$	wave amplitude
$\zeta_{\beta}$	flap control system damping ratio

$\zeta_{\delta}$	rudder control system damping ratio
$\eta$	wave elevation
$\eta_2$	sway displacement
$\eta_4$	roll angle
$\hat{\eta}_4$	roll amplitude
$\eta_6$	yaw angle
$\xi$	variable of integration in longitudinal direction
$\rho$	density of water
$\omega$	frequency of encounter (= wave frequency for beam sea)
$\omega_{\beta}$	flap control system natural frequency
$\omega_{\delta}$	rudder control system natural frequency

## 1. INTRODUCTION

Although hydrofoil ships will spend some of their operational time in the displacement condition, little attention has been paid to the theoretical analysis of hullborne hydrofoil seakeeping until recently. Indeed, Ref. 1, which treats pitch and heave motions in head seas, appears to be the first published work to address this problem. The present report describes a mathematical model to predict roll, sway and yaw motions of hullborne hydrofoil ships in beam seas; also included is a computer program which applies to craft with fully submerged foil systems arranged in either a canard or airplane configuration. This work is thus a logical extension of Ref. 1 and together they furnish computerized procedures for predicting hullborne hydrofoil motions in the five major degrees of freedom. Further, these programs are applicable to a wide range of hull and foil configurations.

As in Ref. 1, hull exciting forces, added mass, and damping are computed by the usual means of strip theory, and upon these are superposed linearized hydrofoil terms. Predictions agree well with towing tank data for a 1:20-scale model of the PHM hydrofoil craft. However, because of the limited scope of the test results, one should not base general conclusions on this comparison.

## 2. MATHEMATICAL MODEL

The mathematical model is obtained by adding linearized hydrofoil terms to the strip theory of Ref. 2. The most important assumptions and restrictions are:

- (1) Ship response is a linear function of wave excitation.
- (2) Ship length is much greater than either beam or draft.
- (3) The hull does not develop appreciable planing lift.
- (4) All viscous effects are negligible except for zero speed foil and strut damping.
- (5) Hull-foil interaction is negligible.

In applying strip theory to a displacement hull, (1) to (3) are normally assumed, but (4) is changed to "all viscous effects other than roll damping are negligible", and the effect

of viscosity on roll damping is included at all speeds. For hydrofoil ships, however, which do not have bilge keels, hull viscous damping is always negligible compared with foil and strut damping. Assumption (5) makes the problem theoretically tractable by permitting direct superposition of hull and foil terms.

## 2.1 EQUATIONS OF MOTION

Consider a hydrofoil ship whose length is significantly greater than either its beam or draft and assume that this ship is travelling at constant speed  $U$  along a mean course at right angles to the direction of propagation of a train of long-crested regular waves of frequency  $\omega$  (Fig. 1). Let  $x, y, z$  be a right-handed orthogonal coordinate system fixed with respect to the mean position of the ship with the origin at the mean position of the centre of gravity. The positive  $x$ -axis points forward in the direction of motion, the positive  $y$ -axis to port, and the positive  $z$ -axis vertically upward (Fig. 2). Denote sway by  $\eta_2$ , roll by  $\eta_4$ , and yaw by  $\eta_6$ .

The coupled sway, roll and yaw equations are given below, using the same subscript convention as in Ref. 2. Flap ( $\beta$ ) and rudder ( $\delta$ ) equations are also given, with notation similar to Ref. 1.

$$\begin{aligned} \text{Sway: } & (A_{22}+m)\ddot{\eta}_2 + B_{22}\dot{\eta}_2 + A_{24}\ddot{\eta}_4 + B_{24}\dot{\eta}_4 + C_{24}\eta_4 + A_{26}\ddot{\eta}_6 \\ & + B_{26}\dot{\eta}_6 + C_{26}\eta_6 + A_{2\beta}\ddot{\beta} + B_{2\beta}\dot{\beta} + C_{2\beta}\beta + A_{2\delta}\ddot{\delta} + B_{2\delta}\dot{\delta} \\ & + C_{2\delta}\delta = F_2 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{Roll: } & A_{42}\ddot{\eta}_2 + B_{42}\dot{\eta}_2 + (A_{44}+I_4)\ddot{\eta}_4 + B_{44}\dot{\eta}_4 + C_{44}\eta_4 + A_{46}\ddot{\eta}_6 \\ & + B_{46}\dot{\eta}_6 + C_{46}\eta_6 + A_{4\beta}\ddot{\beta} + B_{4\beta}\dot{\beta} + C_{4\beta}\beta + A_{4\delta}\ddot{\delta} + B_{4\delta}\dot{\delta} \\ & + C_{4\delta}\delta = F_4 \quad (2) \end{aligned}$$

$$\begin{aligned} \text{Yaw: } & A_{62}\ddot{\eta}_2 + B_{62}\dot{\eta}_2 + A_{64}\ddot{\eta}_4 + B_{64}\dot{\eta}_4 + C_{64}\eta_4 + (A_{66}+I_6)\ddot{\eta}_6 \\ & + B_{66}\dot{\eta}_6 + C_{66}\eta_6 + A_{6\beta}\ddot{\beta} + B_{6\beta}\dot{\beta} + C_{6\beta}\beta + A_{6\delta}\ddot{\delta} + B_{6\delta}\dot{\delta} \\ & + C_{6\delta}\delta = F_6 \quad (3) \end{aligned}$$

$$\text{Flap: } -\omega_\beta^2(k_\phi\ddot{\eta}_4 + k_\phi\dot{\eta}_4 + k_\phi\eta_4) + \ddot{\beta} + 2\zeta_\beta\omega_\beta\dot{\beta} + \omega_\beta^2\beta = 0 \quad (4)$$

$$\text{Rudder: } -\omega_\delta^2(k_\psi\ddot{\eta}_6 + k_\psi\dot{\eta}_6 + k_\psi\eta_6) + \ddot{\delta} + 2\zeta_\delta\omega_\delta\dot{\delta} + \omega_\delta^2\delta = 0 \quad (5)$$

The  $A_{ij}$ 's,  $B_{ij}$ 's,  $C_{ij}$ 's, and  $F_i$ 's are ascribed the general form

$$A_{ij} = A_{ij}^H + A_{ij}^F \quad (6)$$

where  $A_{ij}^H$  and  $A_{ij}^F$  denote contributions from the hull and foils, respectively. Interaction between hull and foils has been ignored. Expressions for the  $A_{ij}^H$ ,  $A_{ij}^F$ , etc. are given below.

## 2.2 HULL COEFFICIENTS

The strip theory used to compute hull coefficients is obtained from Ref. 2. Since an adequate derivation is given therein, only the final results are presented here.

### 2.2.1 Added Mass and Damping

$$A_{22}^H = \int_L a_{22} d\xi - \frac{U}{\omega^2} b_{22}^A \quad (7)$$

$$B_{22}^H = \int_L b_{22} d\xi + U a_{22}^A \quad (8)$$

$$A_{24}^H = A_{42}^H = \int_L a_{24} d\xi - \frac{U}{\omega^2} b_{24}^A \quad (9)$$

$$B_{24}^H = B_{42}^H = \int_L b_{24} d\xi + U a_{24}^A \quad (10)$$

$$A_{26}^H = \int_L a_{22} \xi d\xi - \frac{U}{\omega^2} [x_A b_{22}^A - \int_L b_{22} d\xi] + \frac{U^2}{\omega^2} a_{22}^A \quad (11)$$

$$B_{26}^H = \int_L b_{22} \xi d\xi + U [x_A a_{22}^A - \int_L a_{22} d\xi] + \frac{U^2}{\omega^2} b_{22}^A \quad (12)$$

$$A_{44}^H = \int_L a_{44} d\xi - \frac{U^2}{\omega^2} b_{44}^A \quad (13)$$

$$B_{44}^H = \int_L b_{44} d\xi + U a_{44}^A \quad (14)$$

$$A_{46}^H = \int_L a_{24} \xi d\xi - \frac{U}{\omega^2} [x_A b_{24}^A - \int_L b_{24} d\xi] + \frac{U^2}{\omega^2} a_{24}^A \quad (15)$$

$$B_{46}^H = \int_L b_{24} \xi d\xi + U [x_A a_{24}^A - \int_L a_{24} d\xi] + \frac{U^2}{\omega^2} b_{24}^A \quad (16)$$

$$A_{62}^H = \int_L a_{22} \xi d\xi - \frac{U}{\omega^2} [x_A b_{22}^A + \int_L b_{22} d\xi] \quad (17)$$

$$B_{62}^H = \int_L b_{22} \xi d\xi + U[x_A a_{22}^A + \int_L a_{22} d\xi] \quad (18)$$

$$A_{64}^H = \int_L a_{24} \xi d\xi - \frac{U}{\omega^2} [x_A b_{24}^A + \int_L b_{24} d\xi] \quad (19)$$

$$B_{64}^H = \int_L b_{24} \xi d\xi + U[x_A a_{24}^A + \int_L a_{24} d\xi] \quad (20)$$

$$A_{66}^H = \int_L a_{22} \xi^2 d\xi - \frac{U}{\omega^2} x_A^2 b_{22}^A + \frac{U^2}{\omega^2} [x_A a_{22}^A + \int_L a_{22} d\xi] \quad (21)$$

$$B_{66}^H = \int_L b_{22} \xi^2 d\xi + U x_A^2 a_{22}^A + \frac{U^2}{\omega^2} [x_A b_{22}^A + \int_L b_{22} d\xi] \quad (22)$$

The above integrations are over the length of the ship. In practice, the length of ship is divided into ten or more sections and the two-dimensional sectional added mass (a) and wave-making damping (b) computed for each section using, for example, the Frank close-fit method.  $a_{22}$  and  $b_{22}$  result from sway motions,  $a_{44}$  and  $b_{44}$  apply to roll, while  $a_{24}$  and  $b_{24}$  are due to cross-coupling between sway and roll. Subscript and superscript A refer to the aftermost section.

Note that  $B_{44}^H$  contains no hull viscous damping term. This simplification has been made since extensive calculations have shown that hull viscous damping is negligible in comparison to the viscous effects of the foils and struts.

### 2.2.2 Hydrostatic Restoring Coefficient

The only hydrostatic restoring coefficient affecting lateral motions is  $C_{44}$ , given by

$$C_{44}^H = \Delta \overline{GM} \quad (23)$$

where  $\Delta$  is displacement and  $\overline{GM}$  the metacentric height.

### 2.2.3 Exciting Force and Moments

$$F_2^H = \rho \zeta \left[ \int_L (f_2 + h_2) d\xi - i \frac{U}{\omega} h_2^A \right] \quad (24)$$

$$F_4^H = \rho \zeta \left[ \int_L (f_4 + h_4) d\xi - i \frac{U}{\omega} h_4^A \right] \quad (25)$$

$$F_6^H = \rho \zeta \left\{ \int_L [\xi (f_2 + h_2) - i \frac{U}{\omega}] d\xi - i \frac{U}{\omega} x_A h_2^A \right\} \quad (26)$$

where  $\zeta$  is the amplitude of the incident wave and the integration is over the length of the hull.  $f_j$  and  $h_j$  are the sectional incident and diffraction forces, respectively, given by

$$f_2(\xi) = g \int_{C_\xi} n_2 \exp(k_w z' + ik_w y) d\ell \quad (27)$$

$$f_4(\zeta) = g \int_{C_\xi} (yn_3 - zn_2) \exp(k_w z' + ik_w y) d\ell \quad (28)$$

$$h_2(\zeta) = \omega \int_{C_\xi} \phi_2 (in_3 - n_2) \exp(k_w z' + ik_w y) d\ell \quad (29)$$

$$h_4(\xi) = \omega \int_{C_\xi} \phi_4 (in_3 - n_2) \exp(k_w z' + ik_w y) d\ell \quad (30)$$

The integrations are performed over the submerged hull section.  $n_2$  and  $n_3$  are the y and z components of the unit outward normal to the hull at  $(\xi, y, z)$ .  $\phi_2$  and  $\phi_4$  are the two-dimensional section potentials for sway and roll oscillations, respectively.  $k_w$  is the wave number, given by

$$k_w = \frac{\omega^2}{g} \quad (31)$$

$$\text{and } z' = z + h_{CG} \quad (32)$$

where  $h_{CG}$  is the height of the CG above the waterplane. The Frank close-fit method may be used to evaluate  $\phi_2$  and  $\phi_4$ .

## 2.3 FOIL COEFFICIENTS

### 2.3.1 Nonzero Forward Speed

The foil coefficients are derived in much the same way as in Ref. 1. We begin by considering a foil of dihedral angle  $\Gamma$  and resolving its lift force  $L$  and moment  $N$  into sway, roll and yaw components.

$$\text{sway force} = -L \sin \Gamma \quad (33)$$

$$\text{roll moment} = L(y \cos \Gamma + z \sin \Gamma) \quad (34)$$

$$\text{yaw moment} = N \sin \Gamma \quad (35)$$

Here, no distinction is made between foils and struts. The following sign convention is adopted for dihedral and anhedral angles:

$$\begin{aligned}
&\text{for a port dihedral foil of angle } \Gamma_{DP}, \Gamma_i = \Gamma_{DP} \\
&\text{for a starboard dihedral foil of angle } \Gamma_{DS}, \Gamma_i = -\Gamma_{DS} \\
&\text{for a port anhedral foil of angle } \Gamma_{AP}, \Gamma_i = -\Gamma_{AP} \\
&\text{for a starboard anhedral foil of angle } \Gamma_{AS}, \Gamma_i = \Gamma_{AS}
\end{aligned} \tag{36}$$

Denote by  $L_d$  and  $N_d$  the lift and moment acting on a foil as a result of swaying, yawing and rolling motions. Then, from Ref. 1, equation (21),

$$L_d = L_{NC} + L_C \tag{37}$$

where the subscript NC denotes noncirculatory and C circulatory. In equations (23) and (24) of Ref. 1, we substitute

$$-\dot{\eta}_2 \sin \Gamma + (y \cos \Gamma + z \sin \Gamma) \dot{\eta}_4 \text{ for } \dot{z}$$

$$\eta_6 \sin \Gamma \text{ for } \theta$$

and obtain

$$\begin{aligned}
L_{NC} = \pi \rho b \left(\frac{c}{2}\right)^2 &[(s \ddot{\eta}_6 - U \dot{\eta}_6) \sin \Gamma + \ddot{\eta}_2 \sin \Gamma \\
&- (y \cos \Gamma + z \sin \Gamma) \ddot{\eta}_4]
\end{aligned} \tag{38}$$

$$\begin{aligned}
L_C = \frac{1}{2} \rho U S C_{L\alpha} C(k) &[(s - \frac{c}{4}) \dot{\eta}_6 - U \eta_6] \sin \Gamma \\
&+ \dot{\eta}_2 \sin \Gamma - (y \cos \Gamma + z \sin \Gamma) \dot{\eta}_4] - \frac{\partial L}{\partial h} C(k) y \eta_4
\end{aligned} \tag{39}$$

where the last term in (39) has been obtained by intuitive analogy with the last term of equation (24) in Ref. 1.

Similarly, from equation (22) of Ref. 1

$$N_d = -L_{NC} s - L_C x - \frac{\pi \rho b c^3 \sin \Gamma}{16} (U \dot{\eta}_6 + \frac{c}{8} \ddot{\eta}_6) \tag{40}$$

Consider now the foil exciting force and moment and denote by  $L_W$  and  $N_W$  the lift and moment due to wave action on the foil. Then from equations (38) and (39) of Ref. 1,

$$L_W = \frac{1}{2} \rho U S C_{L\alpha} S_e(k) \hat{w} + \frac{\partial L}{\partial h} C(k) \eta \tag{41}$$

$$N_W = -x L_W \tag{42}$$

where  $\eta$  is wave elevation at mid-chord and  $\hat{w}$  the component of wave orbital velocity acting perpendicular to the foil:

$$\hat{w} = w \cos \Gamma + u \sin \Gamma \quad (43)$$

where  $w$  is the vertical component and  $u$  the horizontal component.  $u$  is regarded as positive in the direction of propagation of the seaway. For beam waves,

$$u = w e^{-k_w h} e^{i k_w y} \quad (44)$$

$$w = i w e^{-k_w h} e^{i k_w y} \quad (45)$$

$$\eta = e^{i k_w y} \quad (46)$$

where  $k_w$  is wave number.

Substitution of equations (37) to (46) into (33) to (35) yields the foil coefficients listed below. Summation is over all foil and strut elements.

$$A_{22}^F = \pi \rho \Sigma b \left(\frac{c}{2}\right)^2 \sin^2 \Gamma \quad (47)$$

$$B_{22}^F = \frac{1}{2} \rho U \Sigma S C_{L\alpha} C(k) \sin^2 \Gamma \quad (48)$$

$$A_{24}^F = A_{42}^F = -\pi \rho \Sigma b \left(\frac{c}{2}\right)^2 \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \quad (49)$$

$$B_{24}^F = B_{42}^F = -\frac{1}{2} \rho U \Sigma S C_{L\alpha} C(k) \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \quad (50)$$

$$C_{24}^F = -\frac{1}{2} \rho U^2 \Sigma S \frac{\partial C_L}{\partial h} C(k) y \sin \Gamma \quad (51)$$

$$A_{26}^F = A_{62}^F = \pi \rho \Sigma b \left(\frac{c}{2}\right)^2 s \sin^2 \Gamma \quad (52)$$

$$B_{26}^F = \rho U \Sigma s \sin^2 \Gamma \left[ -\pi b \left(\frac{c}{2}\right)^2 + \frac{1}{2} S C_{L\alpha} C(k) \left(s - \frac{c}{4}\right) \right] \quad (53)$$

$$C_{26}^F = -\frac{1}{2} \rho U^2 \Sigma S C_{L\alpha} C(k) \sin^2 \Gamma \quad (54)$$

$$F_2^F = -\frac{1}{2} \rho U \Sigma S e^{i k_w y} \sin \Gamma \left[ U \frac{\partial C_L}{\partial h} C(k) + C_{L\alpha} S_e(k) w e^{-k_w h} (\sin \Gamma + i \cos \Gamma) \right] \quad (55)$$

$$A_{44}^F = \pi \rho \Sigma b \left(\frac{c}{2}\right)^2 (y \cos \Gamma + z \sin \Gamma)^2 \quad (56)$$

$$B_{44}^F = \frac{1}{2} \rho U \Sigma S C_{L\alpha} C(k) (y \cos \Gamma + z \sin \Gamma)^2 \quad (57)$$

$$C_{44}^F = \frac{1}{2} \rho U^2 \Sigma S \frac{\partial C_L}{\partial h} C(k) y (y \cos \Gamma + z \sin \Gamma) \quad (58)$$

$$A_{46}^F = A_{64}^F = -\pi \rho \Sigma b \left(\frac{c}{2}\right)^2 s \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \quad (59)$$

$$B_{46}^F = \rho U \Sigma s \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \left[ \pi b \left(\frac{c}{2}\right)^2 - \frac{1}{2} S C_{L\alpha} C(k) \left(s - \frac{c}{4}\right) \right] \quad (60)$$

$$C_{46}^F = \frac{1}{2} \rho U^2 \Sigma S C_{L\alpha} C(k) \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \quad (61)$$

$$F_4^F = \frac{1}{2} \rho U \Sigma S e^{ik_w y} (y \cos \Gamma + z \sin \Gamma) \left[ U \frac{\partial C_L}{\partial h} C(k) + C_{L\alpha} S_e(k) e^{-k_w h} \omega (\sin \Gamma + i \cos \Gamma) \right] \quad (62)$$

$$B_{62}^F = \frac{1}{2} \rho U \Sigma x S C_{L\alpha} C(k) \sin^2 \Gamma \quad (63)$$

$$B_{64}^F = -\frac{1}{2} \rho U \Sigma x S C_{L\alpha} C(k) \sin \Gamma (y \cos \Gamma + z \sin \Gamma) \quad (64)$$

$$C_{64}^F = -\frac{1}{2} \rho U^2 \Sigma x S \frac{\partial C_L}{\partial h} C(k) y \sin \Gamma \quad (65)$$

$$A_{66}^F = \pi \rho \Sigma \left[ s^2 b \left(\frac{c}{2}\right)^2 + \frac{bc^4}{128} \right] \sin^2 \Gamma \quad (66)$$

$$B_{66}^F = \rho U \Sigma \left[ -\pi b \left(\frac{c}{2}\right)^2 + \frac{1}{2} x S C_{L\alpha} C(k) \right] \left(s - \frac{c}{4}\right) \sin^2 \Gamma \quad (67)$$

$$C_{66}^F = -\frac{1}{2} \rho U^2 \Sigma x S C_{L\alpha} C(k) \sin^2 \Gamma \quad (68)$$

$$F_6^F = -\frac{1}{2} \rho U \Sigma x S e^{ik_w y} \sin \Gamma \left[ U \frac{\partial C_L}{\partial h} C(k) + C_{L\alpha} S_e(k) \omega e^{-k_w h} (\sin \Gamma + i \cos \Gamma) \right] \quad (69)$$

The flap coefficients are obtained by using equations (50) to (53) of Ref. 1 to evaluate the lift and moment due to deflecting a flap through angle  $\beta$  (Fig. 3). Resolution of this force and moment via equations (33) to (35) results in the flap terms given below.

$$A_{2\beta} = -2\rho b_F T_1 \left(\frac{c_F}{2}\right)^3 \sin\Gamma \quad (70)$$

$$B_{2\beta} = -\frac{1}{2}\rho U b_F c_F^2 \left(T_4 - \frac{1}{2\pi} C_{L\alpha} C(k) T_{11}\right) \sin\Gamma \quad (71)$$

$$C_{2\beta} = \rho U^2 b_F c_F C_{L\alpha} C(k) e_\beta \sin\Gamma \quad (72)$$

$$A_{4\beta} = 2\rho b_F T_1 \left(\frac{c_F}{2}\right)^3 (y_F \cos\Gamma + z_F \sin\Gamma) \quad (73)$$

$$B_{4\beta} = \frac{1}{2}\rho U b_F c_F^2 \left(T_4 - \frac{1}{2\pi} C_{L\alpha} C(k) T_{11}\right) (y_F \cos\Gamma + z_F \sin\Gamma) \quad (74)$$

$$C_{4\beta} = -\rho U^2 b_F c_F C_{L\alpha} C(k) e_\beta (y_F \cos\Gamma + z_F \sin\Gamma) \quad (75)$$

$$A_{6\beta} = A_{2\beta} s + 2\rho b_F \left(\frac{c_F}{2}\right)^4 (T_7 + p T_1) \sin\Gamma \quad (76)$$

$$B_{6\beta} = \frac{1}{2}\rho U b_F c_F^2 \sin\Gamma \left[-T_4 s + \frac{1}{2\pi} C_{L\alpha} C(k) T_{11} x - \frac{c_F}{2} (T_1 - T_8 - p T_4 + \frac{1}{2} T_{11})\right] \quad (77)$$

$$C_{6\beta} = C_{2\beta} x - 2\rho U^2 b_F \left(\frac{c_F}{2}\right)^2 (T_4 + T_{10}) \sin\Gamma \quad (78)$$

where  $p$  is the distance from the flap hinge line to mid-chord divided by the semi-chord (see Fig. 3).  $e_\beta$  is the flap effectiveness parameter. The  $T_i$ 's are given in Ref. 1. The contribution from both port and starboard flaps has been summed in the above equations.  $y_F$  and  $z_F$  apply to the port flap, and  $\beta$  is positive for port flap down.

Consider now the rudder. Side force due to rudder deflection may be calculated by substituting  $\delta$  for  $\phi$  and  $-\frac{c}{4}$  for  $s$  in equations (23) and (24) of Ref. 1. Then

$$L_R = \pi\rho b \left(\frac{c}{2}\right)^2 \left(-\frac{c}{4} \ddot{\delta} - U\dot{\delta}\right) + \frac{1}{2}\rho U S C_{L\alpha} C(k) \left(-\frac{c}{2} \dot{\delta} - U\delta\right) \quad (79)$$

where  $L_R$  is rudder side force, assumed positive when acting in the negative  $y$ -direction in keeping with our convention regarding dihedral angles. Rudder moment is given by

$$N_R = \pi \rho b \left(\frac{c}{2}\right)^2 s \left(\frac{c}{4} \ddot{\delta} + U \dot{\delta}\right) + \frac{1}{2} \rho U S C_{L\alpha} C(k) x \left(\frac{c}{2} \dot{\delta} + U \delta\right) - \pi \rho b \frac{c^3}{16} \left(U \dot{\delta} + \frac{c \ddot{\delta}}{8}\right) \quad (80)$$

Substitution of (79) and (80) into (33) to (35) yields the rudder terms.

$$A_{2\delta} = -\pi \rho b \frac{c_R^3}{16} \quad (81)$$

$$B_{2\delta} = -\rho U S \frac{c_R}{4} (\pi + C_{L\alpha} C(k)) \quad (82)$$

$$C_{2\delta} = -\frac{1}{2} \rho U^2 S_R C_{L\alpha} C(k) \quad (83)$$

$$A_{4\delta} = -A_{2\delta} z_R \quad (84)$$

$$B_{4\delta} = -B_{2\delta} z_R \quad (85)$$

$$C_{4\delta} = -C_{2\delta} z_R \quad (86)$$

$$A_{6\delta} = A_{2\delta} s_R + \pi \rho b \frac{c_R^4}{128} \quad (87)$$

$$B_{6\delta} = -\rho U S \frac{c_R}{4} \left(\pi \left[s_R - \frac{c_R}{4}\right] + C_{L\alpha} C(k) x_R\right) \quad (88)$$

$$C_{6\delta} = C_{2\delta} x_R \quad (89)$$

### 2.3.2 Zero Forward Speed

At zero forward speed, viscous drag forces opposing lateral motions act on the foils. By regarding the foils as oscillating flat plates and equating the energy dissipated by the non-linear viscous effect during one cycle to that dissipated by a linear damping term, we obtain the following viscous roll damping coefficient:

$$B_{44}^F = \frac{4}{3\pi} \rho \omega \hat{\eta}_4 \Sigma (y^2 + z^2)^{3/2} S C_n \sin \alpha \quad (90)$$

where  $\hat{\eta}_4$  is roll amplitude and  $C_n$  is the normal-force coefficient for a flat plate tilted at angle  $\alpha$  to the flow. From Ref. 3,

$$C_n = \begin{cases} 0.0467\alpha & \alpha < 40^\circ \\ 1.17 & \alpha > 40^\circ \end{cases} \quad (91)$$

and from geometrical considerations

$$\tan\alpha = \left| \frac{y/z + \tan\Gamma}{1 - (y/z)\tan\Gamma} \right| \quad (92)$$

Similar equations may be derived for the other foil damping terms, but these are much less significant than the viscous roll damping term. Equations are given below for  $B_{22}^F$  and  $B_{66}^F$ .

$$B_{22}^F = \frac{4}{3\pi} \rho\omega\eta_2 \Sigma SC_n \sin\alpha \quad (93)$$

$$B_{66}^F = \frac{4}{3} \rho\omega\eta_2 \Sigma SC_n |s|^3 \sin\alpha \quad (94)$$

where  $\hat{\eta}_2$  and  $\hat{\eta}_6$  are sway and yaw amplitudes, and

$$\alpha = |\Gamma| \quad (95)$$

### 2.3.3 Strut Wave-Making Damping

A strut in or near the free surface will generate waves when oscillated laterally. The resultant damping terms due to wave-making affect roll significantly at low speeds. For a vertical strut, the sway wave-making damping term is

$$B_{22}^W = \frac{\pi}{2} \rho\omega b^2 c C_W \quad (96)$$

where  $C_W$  is a function of  $\frac{\omega^2 b}{g}$ . A curve obtained using the Frank close-fit method is given in Fig. 4.

Roll and yaw wave-making damping terms are obtained by multiplying  $B_{22}^W$  by the appropriate foil coordinates.

### 3. COMPUTER PROGRAM

Based on the foregoing mathematical model, a computer program has been developed to predict hullborne hydrofoil lateral motions in beam seas. A program listing is given in the Appendix, together with detailed descriptions of input and output. Note that since hull viscous damping is neglected, this program applies only to the "foils down" case. A further restriction is that the foil system must be of the fully submerged type and either canard or airplane in configuration, i.e. one foil unit in an inverted T while the other is either an inverted  $\pi$  or two inverted T's. Full details are given in the Appendix.

### 4. COMPARISON OF THEORY WITH EXPERIMENT

The Davidson Laboratory has recently measured wave-induced motions for a 1:20-scale model of the 220-ton PHM hydrofoil craft during hullborne operation in sea states 3 and 5 (Ref. 4). Representative wave height spectra, as measured during the tests, are shown in Fig. 5 for the full-scale craft.

Unfortunately, Ref. 4 gives rather scanty lateral motion data because of towing tank test restrictions. The only useful frequency response measurements are for beam sea rolling at zero speed (Fig. 6). Root mean square roll, yaw rate, and lateral acceleration were measured across the speed range in sea state 3 (Fig. 7), but the rather academic nature of this spectrum (Fig. 5) does not permit generalizations based on these results, since little or no seaway energy is present in the frequency range of greatest interest (.3 to 1.5 rad/sec).

Fig. 6 shows generally satisfactory agreement between computed and measured beam sea roll response at zero speed. One may reasonably conclude from this comparison that heave-to rolling predictions should be satisfactory.

Predicted and measured beam sea root mean square lateral motions are compared in Fig. 7. Agreement is satisfactory but, as mentioned above, because of the peculiar nature of the seaway spectrum, one cannot base general conclusions on this comparison.

## 5. CONCLUDING REMARKS

Although, as demonstrated above, predictions agree well with the measurements available, the latter are not sufficiently extensive to permit meaningful assessment of the general reliability of predictions. One may reasonably expect, however, that hove-to rolling predictions should be satisfactory as indicated by the agreement between limited experimental data and predictions.

Computational experience has shown that the foils and struts dominate hullborne lateral motions, even at zero speed, and this dominance becomes more pronounced with increasing speed. Foil system damping completely swamps hull damping, and at nonzero speeds the dominant forcing function arises from action of the horizontal component of wave orbital velocity on the struts. Further, the control system is effective in reducing roll angles, particularly for full-scale speeds in excess of 10 knots.

The present work and Ref. 1 together furnish computerized procedures for predicting hullborne hydrofoil motions in the five major degrees of freedom. However, the present work applies to beam seas and Ref. 1 to head seas. Work is in progress to synthesize the two and produce a computer program which will predict motions in five degrees of freedom at arbitrary headings to the sea.

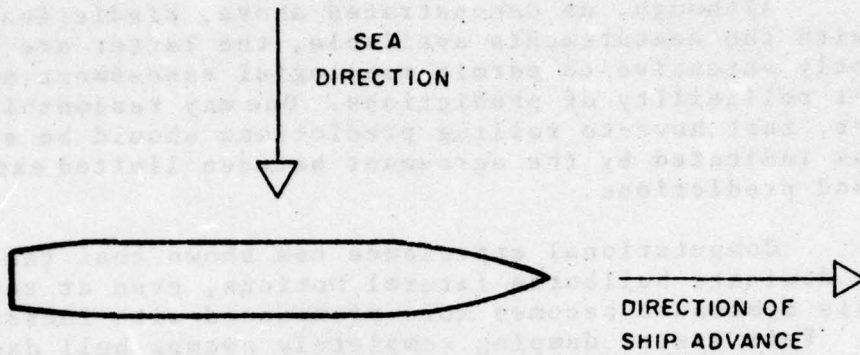


FIG 1 SHIP AND SEA DIRECTIONS

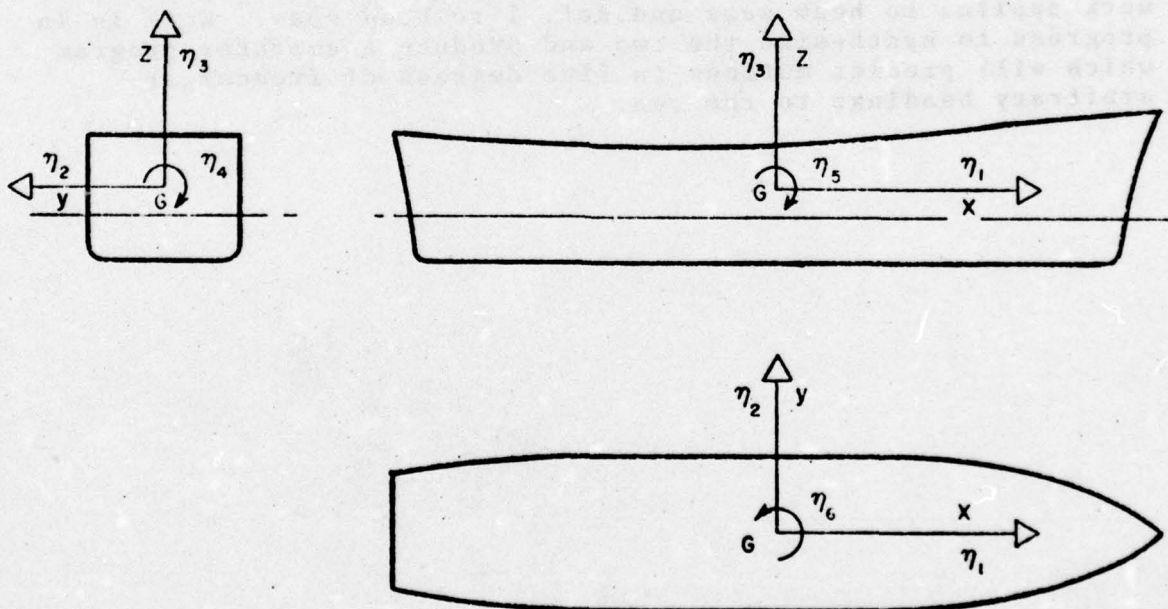


FIG 2 AXIS SYSTEM

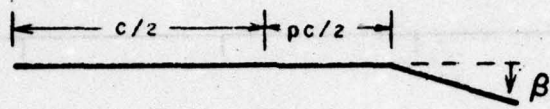


FIG 3 IDEALIZED FLAPPED HYDROFOIL

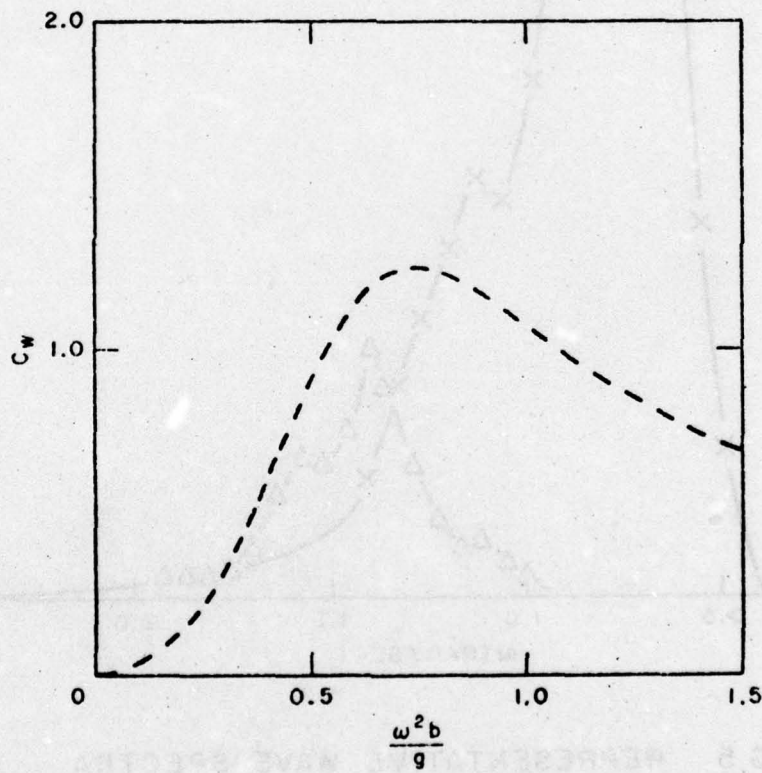


FIG 4 STRUT WAVE-MAKING DAMPING COEFFICIENT

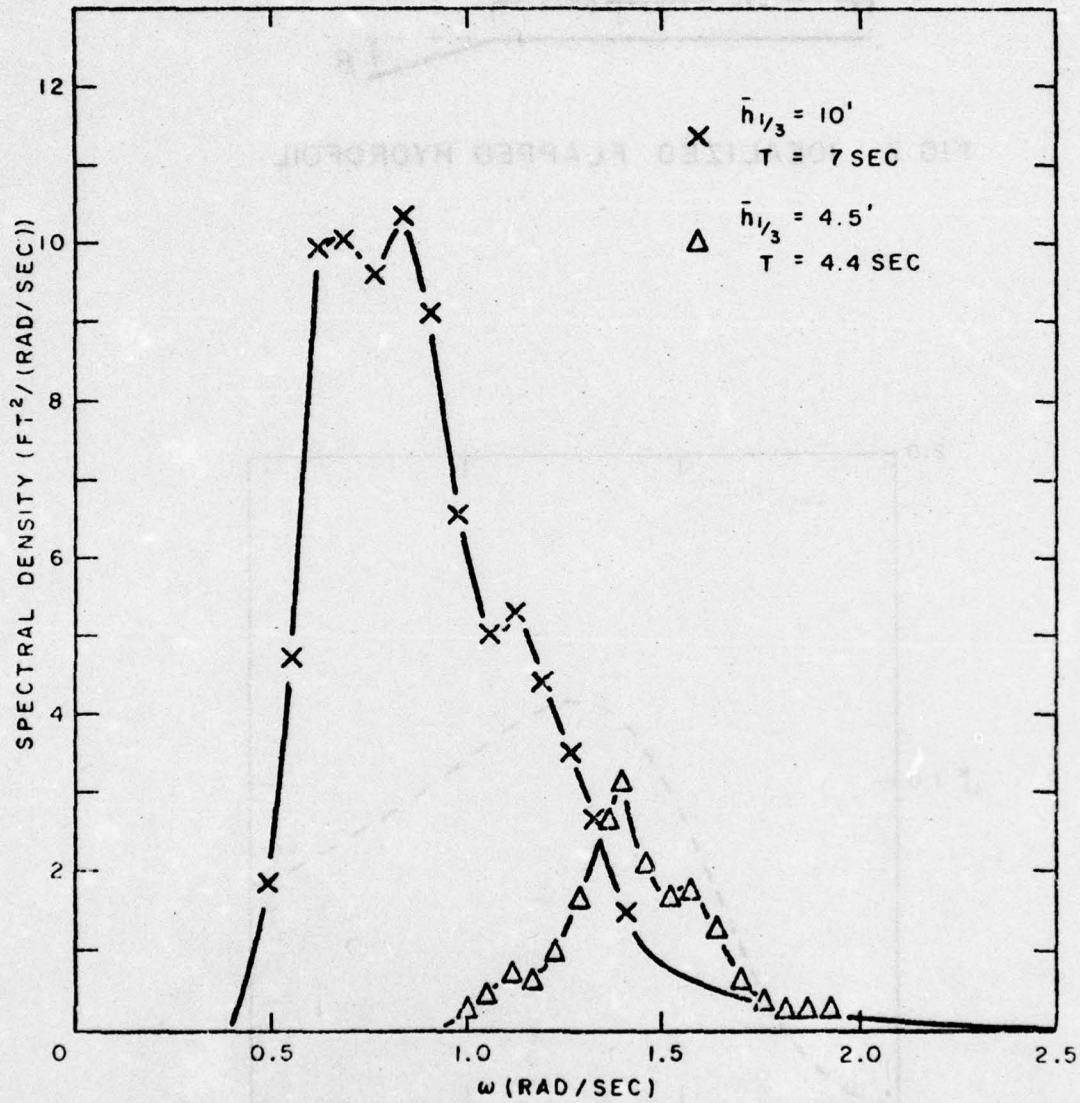


FIG 5 REPRESENTATIVE WAVE SPECTRA

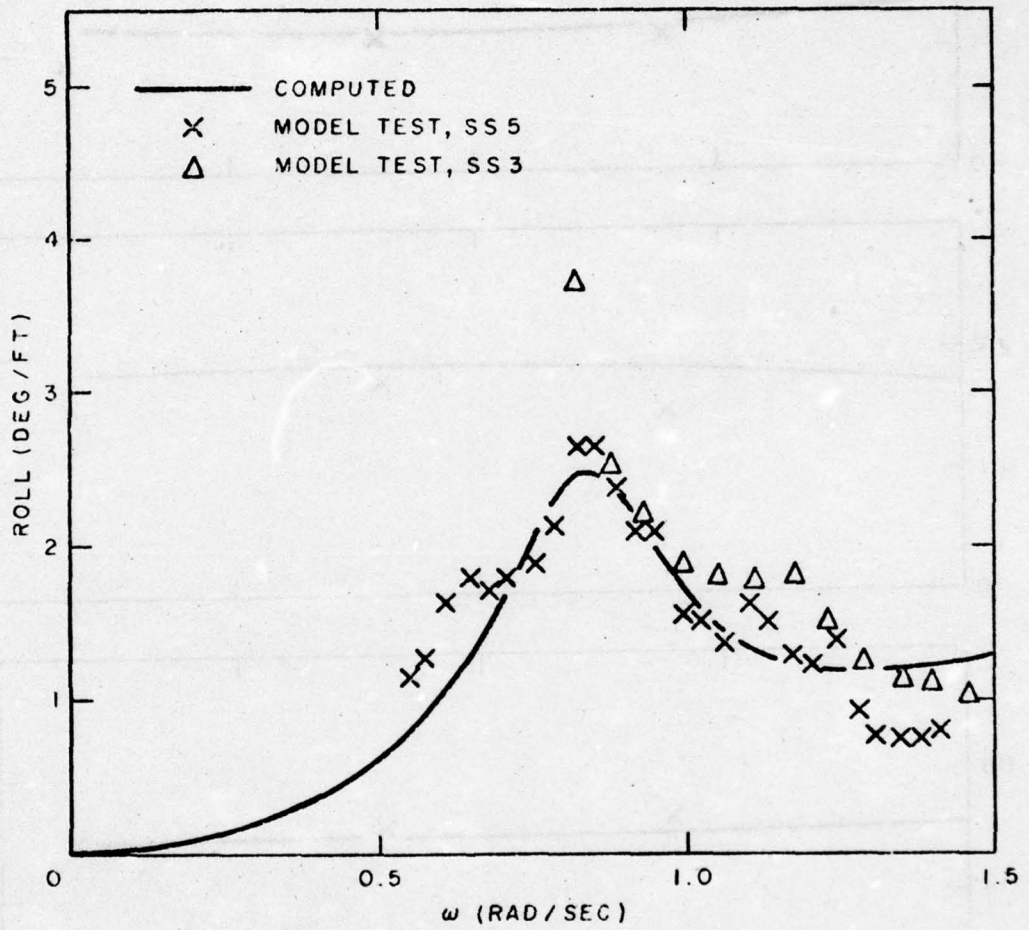


FIG 6 BEAM SEA ROLL RESPONSE, 0 KT

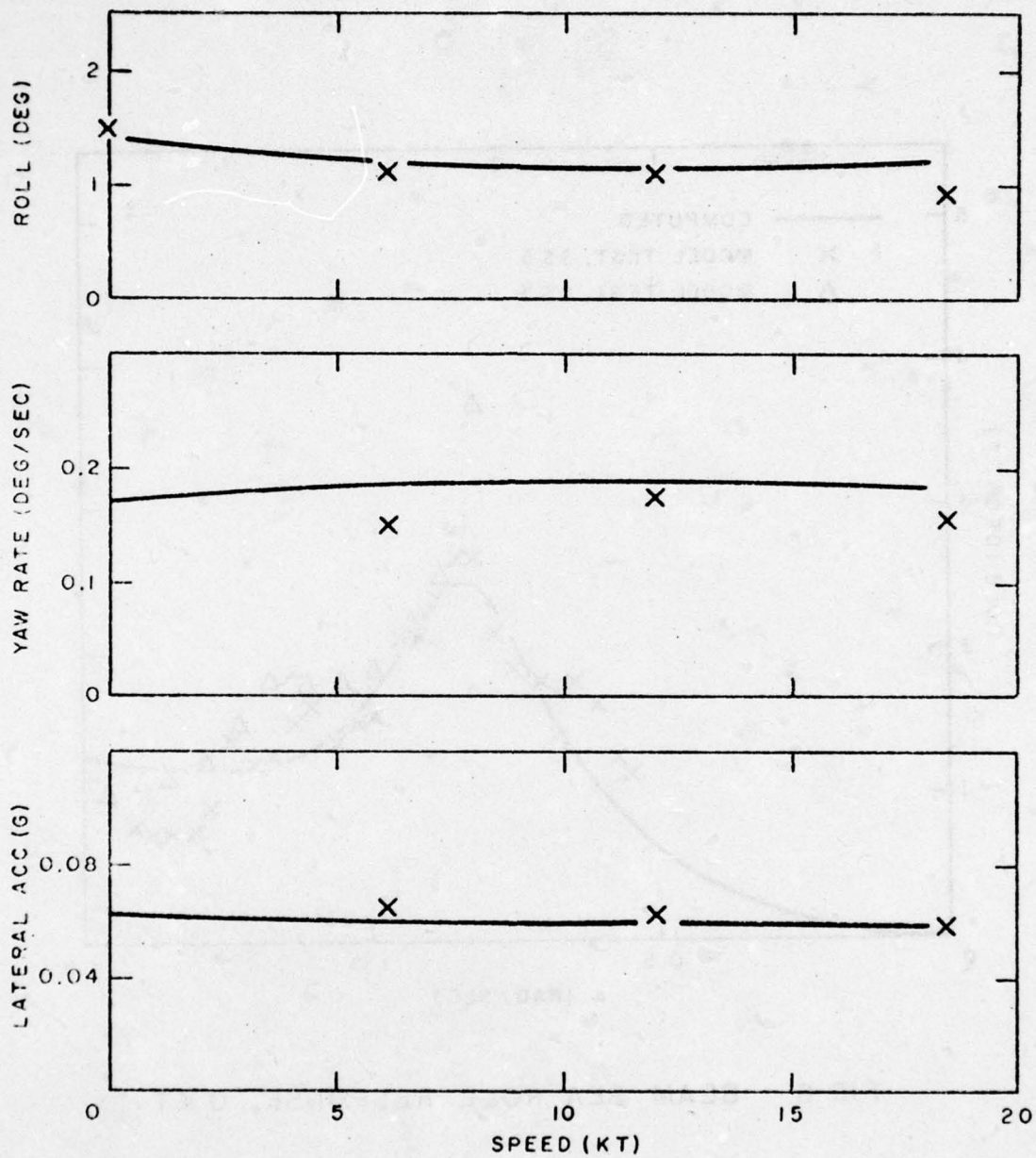


FIG 7 RMS LATERAL MOTIONS IN BEAM SEA STATE 3

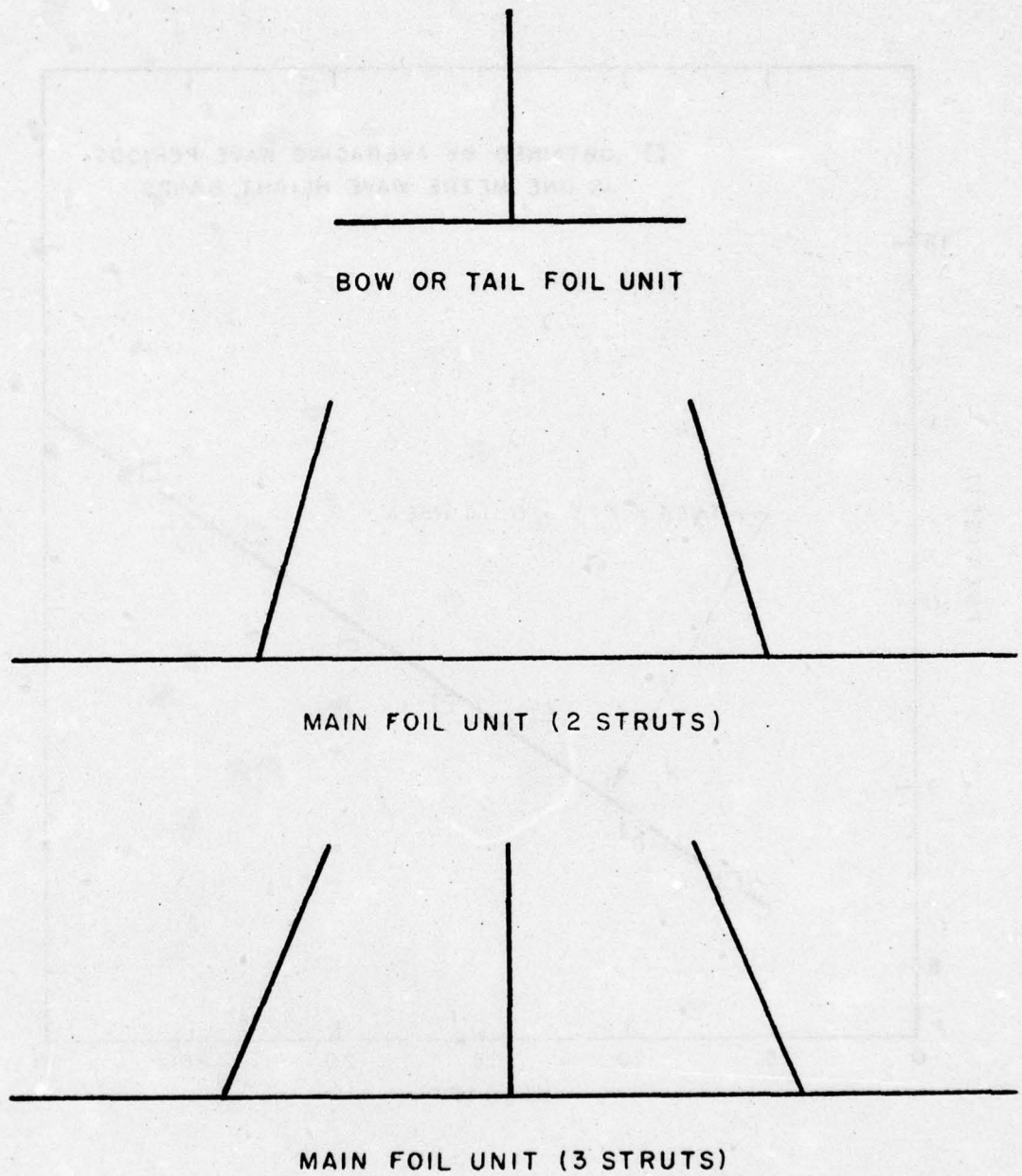


FIG 8 SIMPLIFIED SKETCH OF FOIL UNITS

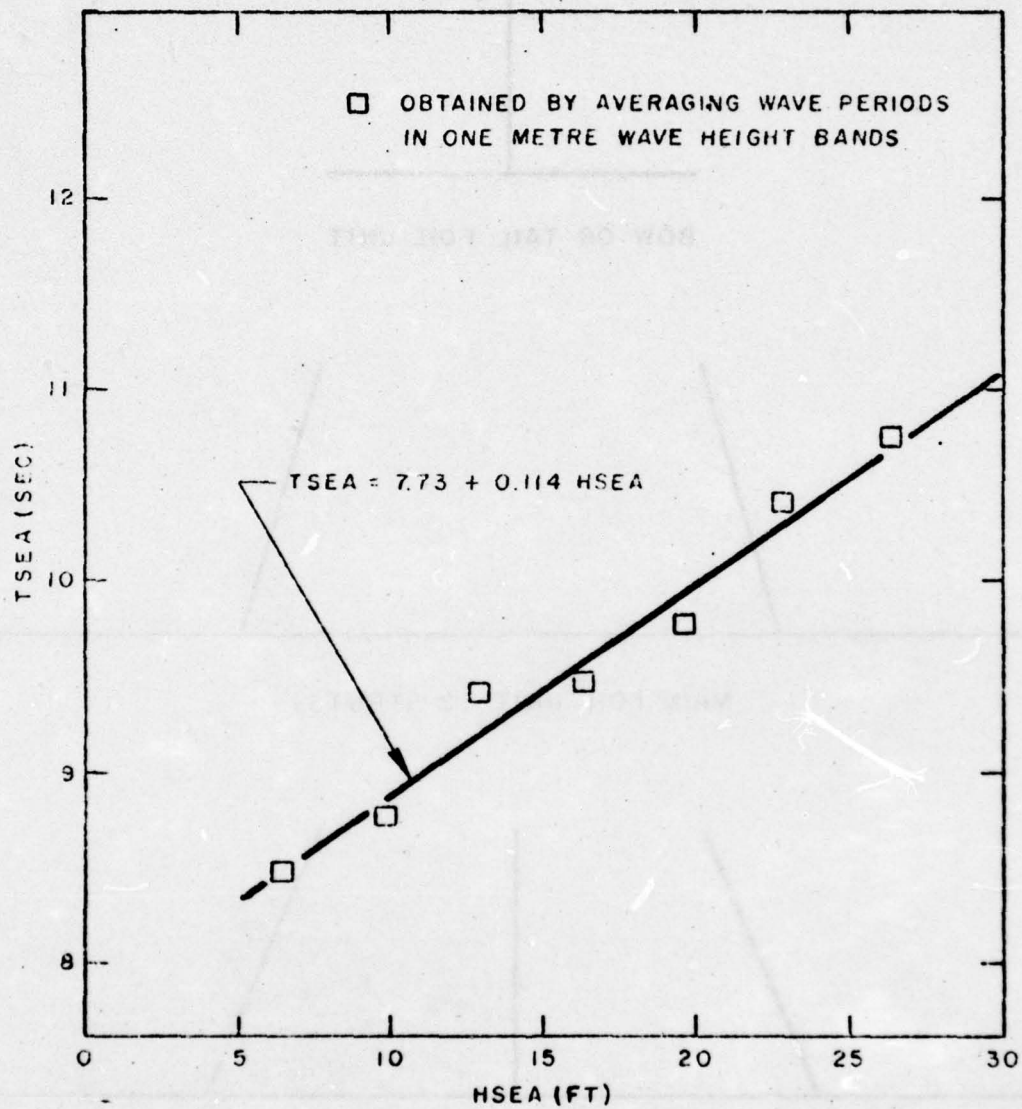


FIG 9 TSEA vs HSEA

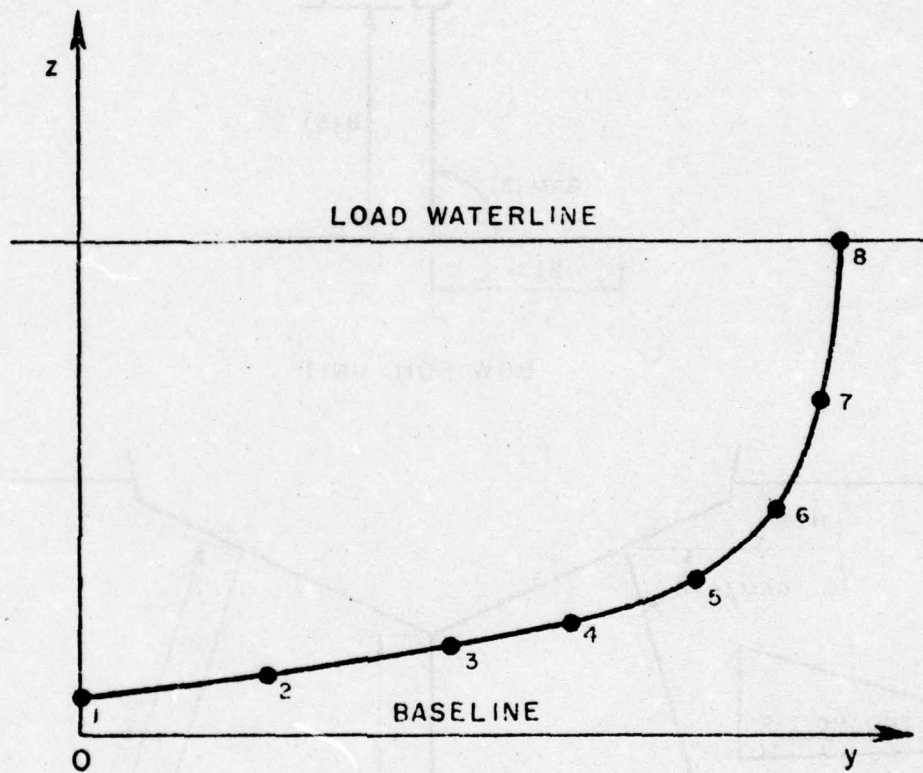
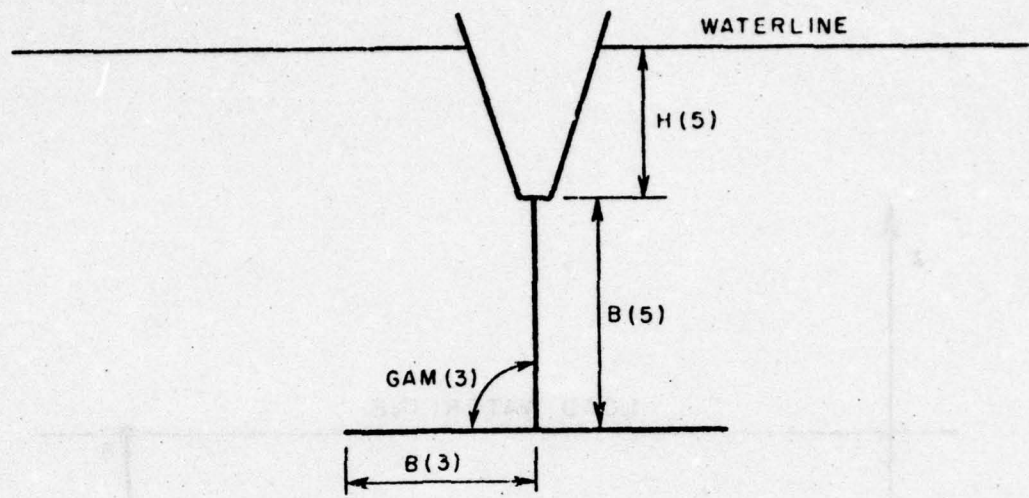
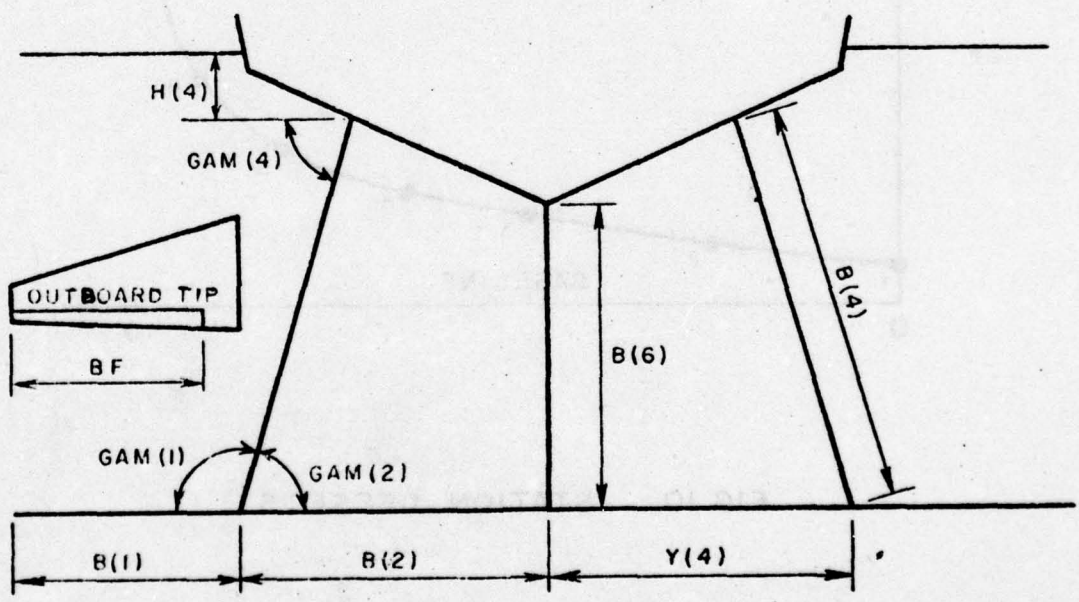


FIG 10 STATION OFFSETS



BOW FOIL UNIT



MAIN FOIL UNIT

FIG II FOIL SYSTEM INPUTS

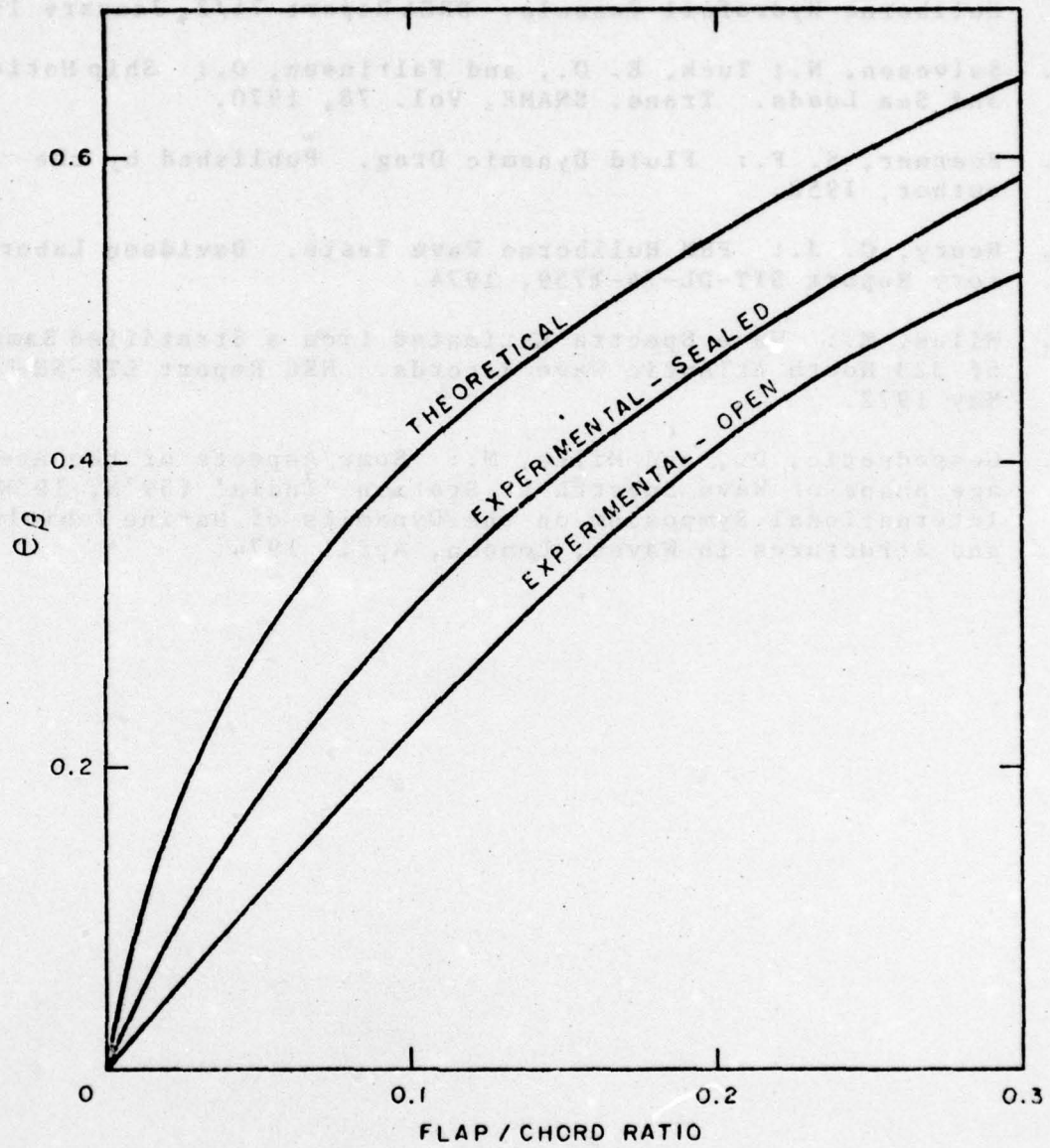


FIG 12 FLAP EFFECTIVENESS

## REFERENCES

1. Schmitke, R. T.: Prediction of Pitch and Heave Motions of Hullborne Hydrofoil Vessels. DREA Report 74/2, January 1974.
2. Salvesen, N.; Tuck, E. O., and Faltinsen, O.: Ship Motions and Sea Loads. Trans. SNAME, Vol. 78, 1970.
3. Hoerner, S. F.: Fluid Dynamic Drag. Published by the author, 1958.
4. Henry, C. J.: PHM Hullborne Wave Tests. Davidson Laboratory Report SIT-DL-74-1759, 1974.
5. Miles, M.: Wave Spectra Estimated from a Stratified Sample of 323 North Atlantic Wave Records. NRC Report LTR-SH-118A, May 1972.
6. Gospodnetic, D., and Miles, M.: Some Aspects of the Average Shape of Wave Spectra at Station 'India' (59°N, 19°W). International Symposium on the Dynamics of Marine Vehicles and Structures in Waves, London, April 1974.

## APPENDIX

### COMPUTER PROGRAM DETAILS

The computer program applies to a hydrofoil ship with a fully submerged foil system of either a canard or airplane configuration. The main foil is an inverted  $\pi$  (Fig. 8), while the bow foil (canard configuration) or tail foil (airplane configuration) is an inverted T. Specification of a third strut on the main foil unit is an optional input; another option is to split the main foil into two T's. The bow (or tail) foil also acts as the ship's rudder, and the flaps for roll control are on the outboard tips of the main lifting foil.

#### A. INPUT DESCRIPTION

##### (a) ONE CARD, FORMAT (8F10.4)

U            speed (kt)  
EL           length between perpendiculars (ft)  
HCG          height of CG above waterplane (ft)  
XCG          distance from CG to forward perpendicular (ft)  
RRG          roll radius of gyration  $\div$  EL  
YRG          yaw radius of gyration  $\div$  EL  
DISP        displacement (tons)  
RHO          fluid density (slug/ft<sup>3</sup>)

##### (b) ONE CARD (12,2F10.3)

NFR          number of frequencies at which responses are to be  
              calculated  
FR1          lowest frequency (rad/sec)  
DFR          increment in frequency (rad/sec)

Notes        (1) If computing motions in irregular seas with  
               $U > 0$ , set NFR=18, FR1=.3, and DFR=.1. If  $U=0$ , it  
              may be necessary to set DFR=.05.

##### (c) ONE CARD (213)

NSEA        number of sea states (maximum of 10)  
NPOS        number of positions at which swaying motions in  
              irregular seas are to be computed (maximum of 10)

Notes        (1) If motions in irregular waves are not desired,  
              use a blank card for (c).  
              (2) If NSEA=0, ignore data cards (d) and (e). If  
              NSEA  $> 0$ , but NPOS=0, ignore data card (e).

(d) NSEA CARDS (2F10.4)

HSW(I) significant wave height (ft)  
TSW(I) energy-averaged wave period (sec)

Notes (1) Fig. 9, obtained using the data of Ref. 5, is offered as a guide to the variation of TSEA with HSEA. Caution should be exercised in applying this curve, however, since considerable variation of wave period with significant wave height is exhibited by natural seaways (see, for example, Fig. 1 in Ref. 6).

(e) NPOS CARDS (2F10.4)

XPOS(I) x - coordinate of position I (stations aft of FP)  
z - coordinate of position I (ft above CG)

(f) ONE CARD (F10.4)

GMIN metacentric height (ft)

Notes (1) If metacentric height is not specified on input, (i.e. GMIN=0), the program will use a value computed from the offset data. This GM is not, however, corrected for internal free surfaces.

(g) ONE CARD (3F10.4)

FIAV expected roll amplitude (deg)  
YAWAV expected yaw amplitude (deg)  
SWAYAV expected sway amplitude (ft)

Notes (1) These data are only required for U=0. For U > 0, use a blank card.  
(2) When computing motions in irregular seas, set these inputs equal to 1.25 times the expected root mean square values.

(h) ONE CARD (12)

NST number of stations for which offsets are input

Notes (1) The program assumes a 20-station hull representation, with station 0 at the forward perpendicular and station 20 at the transom.  
(2) The maximum value of NST is 25. However, since the foil system dominates lateral response, in the interest of computational efficiency it is generally desirable to use no more than 10 stations to define the hull. These should, however, be equally spaced and include the transom.  
(3) One each of data cards (i), (j) and (k) is required for each of the NST stations.

(i) ONE CARD (F10.3)

XA(I) station number

(j) ONE CARD (8F10.4)

YA(I,J) J=1, 8 horizontal offsets of station I (ft)

(k) ONE CARD (8F10.4)

ZA(I,J) J=1, 8 vertical offsets of station I (ft)

Notes (1) Exactly 8 offset points must be specified for each station.  
(2) The first point is at the intersection of the centerline with the station contour while the eighth point is at the intersection of the load waterline with the station contour (see Fig. 10).  
(3) The vertical offsets are input as heights above hull baseline (waterline zero).  
(4) The points and the straight lines between them should provide a good geometric description of the station shape.

(l) ONE CARD (I1)

NSTRUT number of struts on main foil unit (2 or 3)

(m) NSTRUT + 3 CARDS (8F10.4)

GAM(I) input dihedral angle (deg)  
SWEEP(I) quarter-chord sweep angle (deg)  
ALF(I) angle-of-attack relative to zero lift (deg)  
B(I) span (ft)  
CR(I) root chord (ft)  
CE(I) tip chord (ft)  
TC(I) thickness/chord ratio

Notes (1) The number system is shown in Fig. 11.  
No. 1 - main foil outboard tip  
No. 2 - main foil inboard span  
No. 3 - bow lifting foil  
No. 4 - main foil outboard strut  
No. 5 - bow foil strut  
No. 6 - main foil centre strut (if present)  
(2) The method of inputting dihedral angles is shown in Fig. 11. These angles are converted to the conventional form (equation (36)) internally.

(n) ONE CARD (5F10.4)

X(4) main foil strut x - coordinate (ft)  
Y(4) distance from main foil strut tip to centre line (ft)  
H(4) depth of main foil strut root (ft)  
X(5) bow foil strut x - coordinate (ft)  
H(5) bow foil strut root depth (ft)

Notes (1) Strut x - coordinates are measured from the quarter-chord line to the CG. X(4) is negative, X(5) is positive.  
(2) Y(4) and H(4) are shown in Fig. 11. For the particular case shown,  $Y(4)=B(2)$ . If  $Y(4) >$  horizontally projected value of B(2), the main foil is assumed to be split.  
(3) Strut tips are taken to be at the intersection of the struts with the lifting foils (i.e. project the foils and struts through the intersection pods).

(o) ONE CARD (5F10.4)

BF flap span (ft)  
PF distance from hinge line to mid-chord  $\div$  semi-chord  
EFF flap effectiveness  
WF flap control system natural frequency (rad/sec)  
ZETF flap control system damping ratio

Notes (1) The flap is assumed to extend to the tip of foil No. 1 (Fig. 11).  
(2) Flap effectiveness is plotted against flap-chord ratio in Fig. 12. Note that this plot is based on aerodynamic data and that considerable doubt exists as to whether flaps are as effective in water as they are in air.

(p) ONE CARD (2F10.4)

WR rudder control system natural frequency (rad/sec)  
ZETR rudder control system damping ratio

Notes (1) It is assumed that the bow foil is the rudder.

(q) ONE CARD (3F10.4)

QFDD roll acceleration gain ( $\text{sec}^2$ )  
QFD roll velocity gain (sec)  
QF roll gain

(r) ONE CARD (3F10.4)

QRDD yaw acceleration gain ( $\text{sec}^2$ )  
QRD yaw velocity gain (sec)  
QR yaw gain

**B. SAMPLE INPUT**

A sample case of FHROLL input data is given on the following page for a hypothetical 400-ton hydrofoil ship at a speed of 10 knots. Note that the hull is trimmed up  $1\frac{1}{2}^\circ$  and that offsets are given in local section coordinates, i.e. the first point is (0,0) for all stations.

10.0	150.0	2.0	95.25	.086	.258	400.0	1.99
18 .3	.1						
3 8							
8.0	8.64						
10.0	8.87						
12.0	9.10						
0.0	10.0						
5.0	9.0						
10.0	8.0						
15.0	7.0						
20.0	6.0						
10.0	1.0						
10.0	15.0						
10.0	22.0						
0.0							
10							
2.	2						
0.0	.4592	.4184	1.3776	1.8369	2.1801	2.7553	3.2145
0.0	.7379	1.4759	2.2138	2.9519	3.3898	4.4278	5.166
4.0	2						
0.0	.8639	1.7279	2.5918	3.4558	4.3197	5.1836	6.0475
0.0	.7974	1.5949	2.3922	3.1897	3.9871	4.7845	5.582
6.	2						
0.0	1.277	2.554	3.831	5.108	6.385	7.562	8.939
0.0	.8564	1.7137	2.5706	3.4275	4.2843	5.1412	5.998
8.0	2						
0.0	1.6291	3.2583	4.8874	6.5166	8.1457	9.7749	11.404
0.0	.9172	1.8344	2.7516	3.6688	4.5860	5.5033	6.415
10.	2						
0.0	2.2417	4.4833	6.7250	8.9667	11.2083	13.45	13.5015
0.0	1.1052	2.2103	3.3154	4.4206	5.5257	6.63	6.831
12.0	2						
0.0	2.3233	4.6467	6.9700	9.2933	11.6167	13.94	14.102
0.0	1.0827	2.1654	3.2480	4.3307	5.4134	6.5	7.247
14.	2						
0.0	2.3233	4.6467	6.9700	9.2933	11.6167	13.94	14.192
0.0	1.0827	2.1654	3.2480	4.3307	5.4134	6.5	7.663
16.0	2						
0.0	2.3233	4.6467	6.9700	9.2933	11.94	13.94	14.2825
0.0	1.0827	2.1654	3.2480	4.3307	5.4134	6.5	8.079
18.	2						
0.0	2.145	4.29	6.435	8.58	10.725	12.87	13.2405
0.0	.5996	1.9991	2.9987	3.9983	4.9979	6.0	7.495
20.0	2						
0.0	1.7867	3.5733	5.3600	7.1467	8.933	10.72	10.9455
0.0	.8326	1.6652	2.4978	3.3304	4.1629	5.0	5.912
2							
104.0	15.0	4.2	18.5	11.4	3.8	.065	
76.0	0.0	4.2	14.5	11.4	11.4	.065	
90.0	15.0	4.2	9.75	6.3	2.1	.065	
76.0	0.0	0.0	21.3	12.5	12.5	.12	
90.0	6.0	0.0	13.0	7.0	6.0	.12	
-9.75	14.5	2.9	87.75	5.0			
14.0	.5	.45	17.45	1.45			
17.45	1.45						
0.0	-2.0	0.0					
0.0	-2.0	0.0					

### C. SAMPLE OUTPUT

A sample case of FHROLL output is given below. This output results from the above input data and is fairly self-explanatory. Running time is about 100 seconds on a CDC-6400.

The first three pages of output are basically a listing of input data. On the next page are the principal coefficients of the roll equation; at each frequency the foil coefficients form the first line, with the hull coefficients immediately below.

Sway, roll and yaw transfer functions are then listed, with phases relative to wave elevation at the CG. The final three pages give root mean square values of roll, yaw, flap angle and sway in the three specified sea states; also output are absolute motions at the locations specified. The quadratic regression spectrum of Ref. 6, obtained by analyzing 295 wave spectra measured at station 'India' in the North Atlantic ( $59^{\circ}\text{N}$ ,  $19^{\circ}\text{W}$ ), is used in the irregular sea computations.

U EL HCG XCG HMG YMG DISP HHO  
 10.0000 150.0000 2.0000 95.2500 .0860 .2580 400.0000 1.9900

NFH= 18 FH1= .300 DFK= .100

NSEA= 3 NPOS= 8

MSW TSW  
 8.0000 8.6400  
 10.0000 8.8700  
 12.0000 9.1000

XPOS ZPOS

( 1) 0.0000 10.0000  
 ( 2) 5.0000 9.0000  
 ( 3) 10.0000 8.0000  
 ( 4) 15.0000 7.0000  
 ( 5) 20.0000 6.0000  
 ( 6) 10.0000 1.0000  
 ( 7) 10.0000 15.0000  
 ( 8) 10.0000 22.0000

GMIN= 0.0000

FIAY= -0.0000 YAWAV= -0.0000 SWAYAV= -0.0000

STATION 2.00

ABSCISSAS  
 0.0000 .4592 .9184 1.3775 1.8369 2.2961 2.7553 3.2145

ORDINATES  
 0.0000 .7379 1.4759 2.2138 2.9519 3.3898 4.4278 5.1660

STATION 4.00

ABSCISSAS  
 0.0000 .8639 1.7279 2.5918 3.4558 4.3197 5.1836 6.0475

ORDINATES  
 0.0000 .7974 1.5949 2.3922 3.1897 3.9871 4.7845 5.5820

STATION 6.00

ABSCISSAS  
 0.0000 1.2770 2.5540 3.8310 5.1080 6.3850 7.6620 8.9390

ORDINATES  
 0.0000 .8569 1.7137 2.5706 3.4275 4.2843 5.1412 5.9980

STATION 8.00							
ABSCISSAS							
0.0000	1.6291	3.2583	4.8874	6.5166	8.1457	9.7749	11.4040
ORDINATES							
0.0000	.9172	1.8344	2.7516	3.6688	4.5860	5.5033	6.4150
STATION 10.00							
ABSCISSAS							
0.0000	2.2417	4.4833	6.7250	8.9667	11.2083	13.4500	15.6917
ORDINATES							
0.0000	1.1052	2.2103	3.3154	4.4206	5.5257	6.6308	7.7359
STATION 12.00							
ABSCISSAS							
0.0000	2.3233	4.6467	6.9700	9.2933	11.6167	13.9400	16.2633
ORDINATES							
0.0000	1.0827	2.1654	3.2480	4.3307	5.4134	6.4960	7.5787
STATION 14.00							
ABSCISSAS							
0.0000	2.3233	4.6467	6.9700	9.2933	11.6167	13.9400	16.2633
ORDINATES							
0.0000	1.0827	2.1654	3.2480	4.3307	5.4134	6.4960	7.5787
STATION 16.00							
ABSCISSAS							
0.0000	2.3233	4.6467	6.9700	9.2933	11.6167	13.9400	16.2633
ORDINATES							
0.0000	1.0827	2.1654	3.2480	4.3307	5.4134	6.4960	7.5787
STATION 18.00							
ABSCISSAS							
0.0000	2.1450	4.2900	6.4350	8.5800	10.7250	12.8700	15.0150
ORDINATES							
0.0000	.9996	1.9991	2.9987	3.9983	4.9979	6.0000	7.4950
STATION 20.00							
ABSCISSAS							
0.0000	1.7867	3.5733	5.3600	7.1467	8.9333	10.7200	12.5067
ORDINATES							
0.0000	.8326	1.6652	2.4978	3.3304	4.1629	5.0000	5.9120

GMCALC= H.0188

NFOIL= 3 NSTRUT= 2

GAM	SWEEP	ALF	H	CR	CE	TC
104.0000	15.0000	4.2000	18.5000	11.4000	3.8000	.0650
76.0000	0.0000	4.2000	14.5000	11.4000	11.4000	.0650
90.0000	15.0000	4.2000	9.7500	6.3000	2.1000	.0650
76.0000	0.0000	0.0000	21.3000	12.5000	12.5000	.1200
90.0000	6.0000	0.0000	13.0000	7.0000	6.0000	.1200

X(4) = -9.7500 Y(4) = 14.5000 H(4) = 2.9000 X(5) = 17.7500 H(5) = 5.0000

WF = 14.0000 PF = .5000 EF = .4500 WF = 17.4500 ZETF = 1.4500

WR = 17.4500 ZETR = 1.4500

CFDU = 0.0000 QFD = -2.0000 QF = 0.0000

QRDU = 0.0000 QRD = -2.0000 QR = 0.0000

HOLL COEFFICIENTS

#	A44	B44H	S44I	C44H	C44I	F4H	F4I
.300	.2906E+07	.1317E+08	-.1363E+07	.1040E+05	-.7552E+03	-.1078E+06	.2554E+05
.400	.3486E+07	.1321E+08	-.1363E+07	.3578E+07	-.7552E+03	-.1078E+06	.1570E+05
.500	.2906E+07	.1296E+08	-.1690E+07	.1029E+05	-.9721E+03	-.1368E+06	.4080E+05
.600	.3498E+07	.1300E+08	-.1690E+07	.3578E+07	-.9721E+03	-.1367E+06	.2335E+05
.700	.2906E+07	.1274E+08	-.1959E+07	.1016E+05	-.1170E+04	-.1617E+06	.5676E+05
.800	.3512E+07	.1278E+08	-.1959E+07	.3577E+07	-.1170E+04	-.1614E+06	.2983E+05
.900	.2906E+07	.1286E+08	-.2169E+07	.1002E+05	-.1347E+04	-.1826E+06	.7228E+05
1.000	.3528E+07	.1292E+08	-.2169E+07	.3577E+07	-.1347E+04	-.1816E+06	.3420E+05
1.100	.2906E+07	.1362E+08	-.2327E+07	.9871E+04	-.1501E+04	-.1991E+06	.8646E+05
1.200	.3543E+07	.1370E+08	-.2327E+07	.3577E+07	-.1501E+04	-.1970E+06	.3586E+05
1.300	.2906E+07	.1503E+08	-.2439E+07	.9709E+04	-.1632E+04	-.2110E+06	.9858E+05
1.400	.3553E+07	.1514E+08	-.2439E+07	.3577E+07	-.1632E+04	-.2072E+06	.3432E+05
1.500	.2906E+07	.1709E+08	-.2512E+07	.9544E+04	-.1742E+04	-.2179E+06	.1080E+06
1.600	.3557E+07	.1724E+08	-.2512E+07	.3577E+07	-.1742E+04	-.2118E+06	.2907E+05
1.700	.2906E+07	.1884E+08	-.2555E+07	.9378E+04	-.1830E+04	-.2193E+06	.1143E+06
1.800	.3549E+07	.1904E+08	-.2555E+07	.3577E+07	-.1830E+04	-.2111E+06	.1941E+05
1.900	.2906E+07	.1977E+08	-.2573E+07	.9213E+04	-.1899E+04	-.2151E+06	.1171E+06
2.000	.3531E+07	.2003E+08	-.2573E+07	.3576E+07	-.1899E+04	-.2056E+06	.4545E+04
2.100	.2906E+07	.1953E+08	-.2571E+07	.9053E+04	-.1951E+04	-.2054E+06	.1162E+06
2.200	.3504E+07	.1986E+08	-.2571E+07	.3576E+07	-.1951E+04	-.1964E+06	.1620E+05
2.300	.2906E+07	.1850E+08	-.2555E+07	.8698E+04	-.1988E+04	-.1908E+06	.1116E+06
2.400	.3470E+07	.1928E+08	-.2555E+07	.3576E+07	-.1988E+04	-.1850E+06	.4306E+05
2.500	.2906E+07	.1813E+08	-.2527E+07	.8750E+04	-.2011E+04	-.1720E+06	.1037E+06
2.600	.3433E+07	.1856E+08	-.2527E+07	.3576E+07	-.2011E+04	-.1725E+06	.7566E+05
2.700	.2906E+07	.1726E+08	-.2492E+07	.8610E+04	-.2023E+04	-.1502E+06	.9316E+05
2.800	.3398E+07	.1773E+08	-.2492E+07	.3576E+07	-.2023E+04	-.1602E+06	.1130E+06
2.900	.2906E+07	.1627E+08	-.2450E+07	.8478E+04	-.2025E+04	-.1267E+06	.8059E+05
3.000	.3361E+07	.1677E+08	-.2450E+07	.3576E+07	-.2025E+04	-.1492E+06	.1534E+06
3.100	.2906E+07	.1504E+08	-.2404E+07	.8353E+04	-.2019E+04	-.1028E+06	.6940E+05
3.200	.3329E+07	.1556E+08	-.2404E+07	.3576E+07	-.2019E+04	-.1402E+06	.1949E+06
3.300	.2906E+07	.1357E+08	-.2355E+07	.8237E+04	-.2007E+04	-.7976E+05	.5294E+05
3.400	.3301E+07	.1410E+08	-.2355E+07	.3576E+07	-.2007E+04	-.1337E+06	.2354E+06
3.500	.2906E+07	.1183E+08	-.2304E+07	.8129E+04	-.1989E+04	-.5856E+05	.3949E+05
3.600	.3277E+07	.1237E+08	-.2304E+07	.3575E+07	-.1989E+04	-.1298E+06	.2726E+06
3.700	.2906E+07	.9977E+07	-.2252E+07	.8028E+04	-.1967E+04	-.3995E+05	.2719E+05
3.800	.3256E+07	.1052E+08	-.2252E+07	.3575E+07	-.1967E+04	-.1284E+06	.3045E+06

FREQUENCY RESPONSE

SWAY AMP IS NON-DIMENSIONAL, ROLL AND YAW AMPS IN DEG/FT

W	SWAY		ROLL		YAW		W.L./L
	AMP	PHASE	AMP	PHASE	AMP	PHASE	
.300	1.296	48.474	.923	-165.209	.241	-176.369	14.987
.400	1.241	26.472	1.328	171.154	.278	157.245	4.430
.500	1.110	7.628	1.560	151.444	.285	134.347	5.395
.600	.914	-4.345	1.529	136.183	.256	116.406	3.747
.700	.717	-8.282	1.307	125.526	.206	103.366	2.753
.800	.563	-7.490	1.043	118.250	.157	93.397	2.107
.900	.448	-5.041	.804	113.303	.119	84.078	1.665
1.000	.380	-4.724	.653	111.074	.097	76.392	1.349
1.100	.343	-6.823	.567	111.482	.083	72.522	1.115
1.200	.332	-11.605	.536	114.039	.078	72.276	.937
1.300	.330	-17.518	.530	117.795	.076	74.205	.798
1.400	.334	-24.104	.541	122.022	.078	76.727	.688
1.500	.342	-31.234	.573	125.851	.083	78.557	.599
1.600	.355	-38.790	.623	128.479	.091	79.089	.527
1.700	.372	-46.956	.695	129.222	.098	78.042	.467
1.800	.393	-55.794	.787	127.728	.105	75.281	.416
1.900	.416	-65.561	.898	123.686	.110	70.570	.374
2.000	.434	-75.974	1.014	117.254	.112	64.017	.337

ROOT MEAN SQUARES IN SEA STATE 4      HSEA = 8.00      TSEA = 8.64

	POLL AND YAW DISPLACEMENT DEG	VELOCITY DEG/SEC	ACCELERATION DEG/SEC**2
ROLL	2.379	1.674	1.473
YAW	.392	.265	.219
FLAP	3.322	2.902	3.524

	SWAY AT POSITION INDICATED DISPLACEMENT FT	VELOCITY FT/SEC	ACCELERATION FT/SEC**2
CG	1.446	.977	.828
x= 0.0.z=10.0	1.494	1.048	.925
x= 5.0.z= 9.0	1.547	1.069	.934
x= 10.0.z= 8.0	1.628	1.110	.959
x= 15.0.z= 7.0	1.733	1.169	.998
x= 20.0.z= 6.0	1.858	1.243	1.051
x= 10.0.z= 1.0	1.419	.966	.825
x= 10.0.z=15.0	1.859	1.271	1.106
x= 10.0.z=22.0	2.105	1.443	1.262

ROOT MEAN SQUARES IN SEA STATE 5      HSEA = 10.00      TSEA = 8.87

	ROLL AND YAW DISPLACEMENT DEG	VELOCITY DEG/SEC	ACCELERATION DEG/SEC**2
ROLL	3.054	2.100	1.821
YAW	.508	.335	.272
FLAP	4.167	3.586	4.352

	SWAY AT POSITION INDICATED DISPLACEMENT FT	VELOCITY FT/SEC	ACCELERATION FT/SEC**2
CG	1.883	1.237	1.028
X= 0.0,Z=10.0	1.930	1.317	1.144
X= 5.0,Z= 9.0	2.005	1.349	1.157
X= 10.0,Z= 8.0	2.116	1.405	1.190
X= 15.0,Z= 7.0	2.258	1.483	1.241
X= 20.0,Z= 6.0	2.424	1.579	1.308
X= 10.0,Z= 1.0	1.844	1.222	1.022
X= 10.0,Z=15.0	2.415	1.608	1.373
X= 10.0,Z=22.0	2.732	1.825	1.566

ROOT MEAN SQUARES IN SEA STATE 5

HSEA = 12.00

TSEA = 9.10

	ROLL AND YAW DISPLACEMENT DEG	VELOCITY DEG/SEC	ACCELERATION DEG/SEC**2
ROLL	3.734	2.511	2.140
YAW	.628	.404	.322
FLAP	4.984	4.215	5.072

	SWAY AT POSITION INDICATED DISPLACEMENT FT	VELOCITY FT/SEC	ACCELERATION FT/SEC**2
CG	2.338	1.497	1.217
X= 0.0,Z=10.0	2.378	1.582	1.350
X= 5.0,Z= 9.0	2.478	1.624	1.367
X= 10.0,Z= 8.0	2.622	1.696	1.407
X= 15.0,Z= 7.0	2.802	1.794	1.469
X= 20.0,Z= 6.0	3.013	1.913	1.550
X= 10.0,Z= 1.0	2.286	1.475	1.209
X= 10.0,Z=15.0	2.990	1.941	1.623
X= 10.0,Z=22.0	3.379	2.201	1.851

D. COMPUTER PROGRAM LISTING

A complete listing for FHROLL follows. It is worth noting that FHROLL departs slightly from Ref. 1 in using the methods of Jones\* to calculate  $C(k)$  and  $S_e(k)$ ; this modification is made because Jones' formulation takes aspect ratio into account. Another noteworthy point is that in calculating strut roll damping terms, account is taken of the variation in roll velocity along the strut's span.

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\*Jones, R. T.: The Unsteady Lift of a Wing of Finite Aspect Ratio. NACA Report 681, 1940.

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PROGRAM FHRULL (INPUT, OUTPUT, TAPE5=INPUT, TAPE2=INPUT, TAPE6=OUTPUT)
COMMON/COM1/QU,G(10,11)
COMMON/NEW/XA(25),DXA(25),XCG,EL,NST,HCG,C44H,DISP,RHO
COMMON/NEW2/W,U,A22,B22,A24,B24,A26,B26,A44,B44,A46,B46,
IA62,B62,A64,B64,A66,B66,EF(10)
COMMON/NEW3/A22F,A24F,A26F,A44F,A46F,A66F
COMMON/NEW5/GAM(6),S(6),SX(6),Y(6),Z(6),NFS,d(6),COSS(6),SING(6)
COMMON/NEW6/FIAV,YAWAV,SWAYAV
COMPLEX AI,B22,B24,B26,C24,C26,F2,B44,B46,C44,C46,F4,B62,B64,B66,
IC64,C66,F6,CK,SE,UI,JQ,H2F,C2F,B4F,C4F,B6F,C6F,B2R,C2R,B4H,
2C4R,B6H,C6R,AIW
COMMON PI,HPI,UPI,TPI,MD,MODE,DPH,CR,RAT,SUR,DEG,IST,DRT,HBM,SG,N
10E,PDM,VOL,DEW,UN,OMEGA,CP,WVH,IO,DOG,IG,XX(25,7),YY(25,7),DEL(25,
27),SNE(25,7),CSE(25,7),FR(7),BLOG(25,7,7),YLOG(25,7,7),CON(14,1),C
3T(14,14),PSI1(7,7),PSI2(7,7),PHA(7),PHV(7)
DIMENSION XPOS(10),ZPOS(10),SWEEP(6),ALF(6),CR(6),TC(6),
ICE(6),CHAR(6),X(6),H(6),CLA(6),CLH(6),A0(6),ZP1(6),HB(6),
2A(6),SC(6),YZ(6),OUTM(40,10),DSP(15),
3VEL(15),ACC(15),SPEC(10),SPP(2),Y4(6),HSW(10),TSW(10)
PI=3.1415927
TPI=2.*PI
999 READ 13,U,EL,HCG,XCG,RRG,YRG,DISP,RHO
IF (EOF(5LINPUT).NE.0.0) STOP 1111
WRITE 101
WRITE 13,U,EL,HCG,XCG,RRG,YRG,DISP,RHO
READ 40,NFR,FR1,DFR
WRITE 43,NFR,FR1,DFR
READ 50,NSEA,NPOS
WRITE 51,NSEA,NPOS
IF (NSEA.LE.0) GO TO 67
WRITE 53
DO 52 I=1,NSEA
READ 13,HSW(I),TSW(I)
52 WRITE 13,HSW(I),TSW(I)
IF (NPOS.LE.0) GO TO 67
WRITE 1009
DO 82 I=1,NPOS
READ 13,XPOS(I),ZPOS(I)
82 WRITE 1001,I,XPOS(I),ZPOS(I)
67 CONTINUE
CALL HULLI
NFOIL = 3
READ 18,NSTRUT
WRITE 1014,NFOIL,NSTRUT
NFS=NFOIL*NSTRUT
WRITE 1002
DO 83 I=1,NFS
READ 13,GAM(I),SWEEP(I),ALF(I),B(I),CR(I),CE(I),TC(I)
H3 WRITE 13,GAM(I),SWEEP(I),ALF(I),B(I),CR(I),CE(I),TC(I)
READ 13,X(4),Y(4),H(4),X(5),H(5)
WRITE 1003,X(4),Y(4),H(4),X(5),H(5)
IF (NSTRUT.LE.2) GO TO 24
X(NFS)=X(4)
Y(NFS) = 0.0
H(NFS)=-.5*H(NFS)
24 CONTINUE
READ 13, BF,PF,EFF,WF,ZETF

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WRITE 1004,WF,PF,EF,WF,ZEF
READ 13,WR,ZETR
WRITE 1005,WR,ZETR
READ 13,WFDD,WF,GF
WRITE 1006,GFDD,GF,GF
READ 13,WRDD,WR,GR
WRITE 1007,GRDD,GR,QR
YF = B(1)-BF
CF=CR(1)-(CR(1)-CE(1))*(YF+.5*BF)/d(1)
C PUT DIHEDRAL ANGLES IN CONVENTIONAL FORM
G1 = (GAM(1)-90.)/57.3
GAM(1)=180.-GAM(1)-GAM(4)
GAM(2)=GAM(2)-GAM(4)
GAM(3)=90.-GAM(3)
GAM(4)=-GAM(4)
GAM(5)=-90.
GAM(6)=-90.
C CHANGE ANGLES FROM DEGREES TO RADIANs
DO 1 I=1,NFS
SWEEP(I)=SWEEP(I)/57.3
P=GAM(I)/57.3
SING(I)=SIN(P)
COSS(I)=COS(P)
1 DO 2 I=1,NFS
ALF(I)=ALF(I)/57.3
CHAR(I)=.5*(CR(I)+CE(I))
2 CONTINUE
DO 3 I=1,NFS
3 S(I)=B(I)*CHAR(I)
HINT=H(4)+H(4)*ABS(SING(4))
H(6)=H(6)+HINT+B(2)*SING(2)
ZF=-HCG-HINT+(YF+.42*BF)*SING(1)
YF=Y(4)+(YF+.42*BF)*COSS(1)
O=(B(1)*COSS(1)+B(2)*COSS(2))*2/(S(1)*COSS(1)+S(2)*COSS(2))
T=B(2)*COSS(2)-Y(4)
IF (ABS(T).LE.0.01)GO TO 4
ISPLIT=1
H(2)=HINT+.42*B(2)*SING(2)
Y(2)=Y(4)-.42*B(2)*COSS(2)
A(2)=O
GO TO 5
4 ISPLIT=0
H(2)=Y(4)/COSS(2)
H(2)=HINT+.5*B(2)*SING(2)
Y(2)=Y(4)-.5*B(2)*COSS(2)
A(2)=2.*O
5 CONTINUE
H(1)=HINT-.42*B(1)*SING(1)
H(3)=B(5)-.42*B(3)*SING(3)+H(5)
H(4)=HINT-.5*B(4)*ABS(SING(6))
H(5)=.50*B(5)+H(5)
X(1)=X(2)+X(4)
X(3)=X(5)
DO 6 I=1,NFS
SX(I)=X(I)-.25*CHAR(I)
6 Z(I)=-HCG-H(I)
Y(1)=Y(4)+.42*B(1)*COSS(1)

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Y(3) = .42 * H(3) * COSS(3)
Y(4) = Y(4) - .50 * J(4) * COSS(4)
Y(5) = 0.0
A(1) = A(2)
DO 7 I = 3, NFS
7  A(I) = 2. * B(I) / CBAR(I)
EM = 2240. * DISP / (32.2 * RHO)
U = 1.689 * U
XI = (RRG * EL) ** 2 * EM
ZI = (YRG * EL) ** 2 * EM
AI = (0.0, 1.0)
C  LIFT CURVE SLOPE CALCULATIONS
C
C  INCLUDE FREE SURFACE EFFECTS FOR FOILS 1 AND 3
DO 22 I = 1, NFS
22  CLA(I) = CLH(I) = 0.0
A0(I) = TPI * (1. - .96 * TC(I)) * COS(SWEEP(I))
IF (U .LE. 0.0) GO TO 28
DO 23 I = 1, 3, 2
HCSQ = 20.0 * (H(I) / CBAR(I)) ** 2
A0(I) = A0(I) * (1. + HCSQ) / (2. + HCSQ)
HS = H(I) / B(I)
ZP1(I) = 1.0 + BIPL(HS)
23  CONTINUE
ZP1(2) = ZP1(5) = 1.0
C  STRUT END PLATE EFFECTS
HB(4) = 1.9 * B(1) * COS(G1) / B(4)
HB(5) = 1.9 * B(3) * COSS(3) / B(5)
IF (NSTRUT .LE. 2) GO TO 25
HB(6) = 1.9 * (B(1) * COSS(1) + B(2) * COSS(2)) / B(6)
ZP1(6) = 1.0
25  CONTINUE
DO 26 I = 4, NFS
26  A(I) = A(I) * (1.0 + HB(I))
HS = Y(4) / B(4) * 2 ** (3 - NSTRUT)
ZP1(4) = 1.0 + BIPL(HS)
DO 27 I = 1, NFS
27  CLA(I) = CLALF(A0(I), A(I), ZP1(I))
CONTINUE
DO 9 I = 1, 3, 2
HCSQ = 20.0 * (1.05 * H(I) / CBAR(I)) ** 2
A0(I) = TPI * (1. - .96 * TC(I)) * COS(SWEEP(I)) * (1. + HCSQ) / (2. + HCSQ)
HS = 1.05 * H(I) / B(I)
ZP1(I) = 1.0 + BIPL(HS)
CLH(I) = ALF(I) * (CLALF(A0(I), A(I), ZP1(I)) - CLA(I)) / (.05 * H(I))
9  CONTINUE
28  CONTINUE
DO 91 I = 1, NFS
CLH(I) = S(I) * CLH(I)
SC(I) = S(I) * CLA(I)
YZ(I) = Y(I) * COSS(I) + Z(I) * SING(I)
91  CONTINUE
DO 92 I = 4, NFS
YR = Y(I) - .5 * B(I) * COSS(I)
ZR = Z(I) + .5 * B(I) * ABS(SING(I))
YRR = YR * COSS(I) + ZR * SING(I)
Y4(I) = ((YRR + B(I)) ** 3 - YRR ** 3) / (3.0 * H(I))

```

```

92 CONTINUE
DO 93 I=1,3
93 Y4(I)=YZ(I)**2
B(5)=.5*B(5)
SC(5)=.5*SC(5)
IF(NSTRUT.LE.2)GO TO 130
H(NFS)=.5*B(NFS)
SC(NFS)=.5*SC(NFS)
130 CONTINUE
C COMPUTE FREQUENCY INDEPENDENT TERMS
A22=A24=A26=A44=A46=A66=0.0
DO 10 I=1,NFS
Q=TPI*B(I)*(CBAR(I)/2.)**2
QQ=Q*SING(I)**2
A22=A22+QQ
A24=A24-Q*SING(I)*YZ(I)
A26=A26+QQ*SX(I)
A44=A44+Q*Y4(I)
A46=A46-Q*SX(I)*SING(I)*YZ(I)
A66=A66+QQ*SX(I)**2+TPI*B(I)*CBAR(I)**4/128.*SING(I)**2
10 CONTINUE
A64=A46
A62=A26
A22F=A22
A24F=A24
A26F=A26
A44F=A44
A46F=A46
A66F=A66
YZF=YF*COSS(1)+ZF*SING(1)
CALL FLAP(PF,T1,T4,T7,T8,T10,T11)
A2F=-2.*BF*T1*(CF/2.)**3
A4F=-A2F*YZF
A2F=A2F*SING(1)
A6F=A2F*SX(1)+2.*BF*(CF/2.)**4*(T7+PF*T1)*SING(1)
A2R=-TPI*B(5)*CBAR(5)**3/16.
A4R=-A2R*Z(5)
A6R=A2R*SX(5)+TPI*B(5)*CBAR(5)**4/128.
WRITE 1042
WRITE 1043
DO 99 IFR=1,NFR
W=FR1+(IFR-1)*DFR
QW=W*W/32.2
B22=B24=C24=B26=C26=F2=(0.0,0.0)
B44=C44=B46=C46=F4=(0.0,0.0)
B62=B64=C64=B66=C66=F6=(0.0,0.0)
BB=B(4)
DO 20 I=4,5
IF(I.EQ.4)GO TO 19
BB=2.*B(5)
19 CONTINUE
Q=PI*B(I)*CBAR(I)*SDAMP(W*BB)
B22=B22+Q
B44=B44+Q*Y4(I)
H66=B66+Q*SX(I)**2
20 CONTINUE
IF(NSTRUT.LE.2)GO TO 133

```

```

I=NFS
BB=2.*B(NFS)
Q=PI*B(I)*CHAR(I)*SDAMP(W,BB)
B22=B22+Q
B44=B44+Q*Y4(I)
B66=B66+Q*SA(I)**2
133 CONTINUE
IF(U.GT.0.0)GO TO 16
CALL ZERO(W,B22,B44,B66)
B2F=B4F=B6F=C2F=C4F=C6F=(0.0,0.0)
B2R=B4R=B6R=C2R=C4R=C6R=(0.0,0.0)
GO TO 17
16 CONTINUE
DO 11 I=1,NFS
Q=.5*CHAR(I)*W/U
CALL THEOJON(A(I),Q,CK,SE)
P=SING(I)**2
R=SING(I)*YZ(I)
T=SX(I)-CHAR(I)/4.
QI=U*SC(I)*CK
QQ=P*QI
B22=B22+QQ
B62=B62+QQ*X(I)
B24=B24-QI*R
B44=B44+QI*Y4(I)
B64=B64-QI*R*X(I)
BA=-U*PI*B(I)*(CHAR(I)/2. )**2
QQ=QI*T
B26=B26+P*(BA+QQ)
B46=B46-R*(BA+QQ)
B66=B66+P*(T*BA+X(I)*QQ)
QI=-U**2*CLH(I)*CK*Y(I)
C24=C24+QI*SING(I)
C44=C44-QI*YZ(I)
C64=C64+QI*SING(I)*X(I)
QI=-U**2*SC(I)*CK*SING(I)
C26=C26+QI*SING(I)
C46=C46-QI*YZ(I)
C66=C66+QI*SING(I)*X(I)
IF (I .LE. 3) GO TO 94
IF (I .GT. 4) GO TO 95
YR = Y(I)-.5*B(I)*COSS(I)
ZR = Z(I)+.5*B(I)*ABS(SING(I))
YRR = YR*COSS(I)+ZR*SING(I)
BB = B(I)
H0 = H(I)-.5*B(I)*ABS(SING(I))
HT = H(I)+.5*B(I)*ABS(SING(I))
GO TO 96
95 CONTINUE
BB = 2.*B(I)
YRR = -Z(I) - B(I)
H0 = H(I) - B(I)
HT = H0 + BB
96 CONTINUE
QWW = Q*ABS(SING(I))
YTT = YRR + BB
TR = QWW*YRR

```

```

TT = QW*YTT
T = EXP(TR-QW*H0)/(BH*QW**2)
P = -T*(EXP(-TR)*(TR+1.)-EXP(-TT)*(TT+1.))
R = -SING(I)
T = -Y(I)
TT = EXP(-QW*H0)-EXP(-QW*HT)
TT = TT/(QW*(HT-H0))
DO 97 J=1,2
P = -P
R = -R
T = -T
QI = -.5*U*CEXP(AI*QW*T)*SC(I)*SE***(R+AI*COSS(I))
F2 = F2 + QI*R*TT
F4 = F4 - QI*P
F6 = F6 + QI*R*X(I)*TT
97 CONTINUE
GO TO 98
94 CONTINUE
P=-Y2(I)
R=-SING(I)
T=-Y(I)
DO 12 J=1,2
P=-P
R=-R
T=-T
QI=-.5*U*CEXP(AI*QW*T)*(U*CLH(I)*CK+SC(I)*SE***(EXP(-QW*H(I))*R
1+AI*COSS(I)))
F2=F2+QI*R
F4=F4-QI*P
F6=F6+QI*R*X(I)
12 CONTINUE
98 CONTINUE
IF(I.NE.1)GO TO 11
P=YF*COSS(1)+ZF*SING(1)
QI=T4-CLA(1)*CK*T11/TPI
QI=-.5*U*BF*CF**2*QI
B2F=QI*SING(1)
B4F=-QI*P
QI=T4*SX(1)-CLA(1)*CK*T11*X(1)/TPI
QI=QI+.5*CF*(T1-T8-PF*T4+.5*T11)
B6F=-.5*U*SF*CF**2*QI*SING(1)
QI=U**2*BF*CF*CLA(1)*CK*EFF
C2F=QI*SING(1)
C4F=-QI*P
C6F=C2F*X(1)-.5*U**2*BF*CF**2*(T4+T10)*SING(1)
11 CONTINUE
QI=CLA(5)*CK
P=-.25*U*S(5)*CBAR(5)
B2R=P*(PI+QI)
B4R=-B2R*Z(5)
B6R=P*(PI*(SX(5)-.25*CBAR(5))+.1*X(5))
C2R=-.5*U**2*S(5)*QI
C4R=-C2R*Z(5)
C6R=C2R*X(5)
17 CONTINUE
WRITE 1040,4,A44F,B44,C44,F4
C44=C*4+C44H

```

```

CALL HULLW
C   CALCULATION OF A'S, B'S, C'S AND F'S NOW COMPLETE
C   COMPUTE HYDRODYNAMIC MATRIX
AIW=AI*W
W2=W*W
QQ=-W2*(A22+EM)+AIW*H22
CALL MATG(1,1)
QQ=-W2*A24+AIW*B24+C24
CALL MATG(1,3)
QQ=-W2*A26+AIW*B26+C26
CALL MATG(1,5)
QQ=-W2*A2F+AIW*B2F+C2F
CALL MATG(1,7)
QQ=-W2*A2R+AIW*B2R+C2R
CALL MATG(1,9)
QQ=-W2*A24+AIW*B24
CALL MATG(3,1)
QQ=-W2*(A44+XI)+AIW*B44+C44
CALL MATG(3,3)
QQ=-W2*A46+AIW*B46+C46
CALL MATG(3,5)
QQ=-W2*A4F+AIW*B4F+C4F
CALL MATG(3,7)
QQ=-W2*A4R+AIW*B4R+C4R
CALL MATG(3,9)
QQ=-W2*A62+AIW*B62
CALL MATG(5,1)
QQ=-W2*A64+AIW*B64+C64
CALL MATG(5,3)
QQ=-W2*(A66+ZI)+AIW*B66+C66
CALL MATG(5,5)
QQ=-W2*A6F+AIW*B6F+C6F
CALL MATG(5,7)
QQ=-W2*A6R+AIW*B6R+C6R
CALL MATG(5,9)
QQ=(-W2*QFDD+AIW*QFD+QF)*(-WF**2)
CALL MATG(7,3)
QQ=-W2+AIW*2.*ZETF*WF+WF**2
CALL MATG(7,7)
QQ=(-W2*QRDD+AIW*QRD+QR)*(-WR**2)
CALL MATG(9,5)
QQ=-W2+AIW*2.*ZETR*WR+WR**2
CALL MATG(9,9)
QQ=(0.0,0.0)
CALL MATG(7,1)
CALL MATG(7,5)
CALL MATG(7,9)
CALL MATG(9,1)
CALL MATG(9,3)
CALL MATG(9,7)
C   COMPUTE EXCITING FORCE VECTOR
EF(1)=REAL(F2)+EF(1)
EF(2)=AIMAG(F2)+EF(2)
EF(3)=REAL(F4)+EF(3)
EF(4)=AIMAG(F4)+EF(4)
EF(5)=REAL(F6)+EF(5)
EF(6)=AIMAG(F6)+EF(6)

```

```

DO 14 I=7,10
14 EF(I)=0.0
C SOLVE FOR MOTIONS
DO 15 I=1,10
15 G(I,11)=EF(I)
WRITE 1041,A44,B44,C44,EF(3),EF(4)
CALL SOLV(G,EF,10,11,INDX,ICK)
DO 225 J=1,10
225 OUTM(IFR,J)=EF(J)
99 CONTINUE
C OUTPUT FREQUENCY RESPONSE
WRITE(6,212)
WRITE(6,231)
WRITE(6,214)
WRITE(6,215)
DO 227 LW=1,NFR
W=FR1+(LW-1)*DFR
WL=TPI*32.2/W**2
WSLP=TPI/WL
WL=WL/EL
SAMP=SQRT(OUTM(LW,1)**2+OUTM(LW,2)**2)
SPH=57.3*ATAN2(OUTM(LW,2),OUTM(LW,1))
RAMP=SQRT(OUTM(LW,3)**2+OUTM(LW,4)**2)*57.3
RPH=57.3*ATAN2(OUTM(LW,4),OUTM(LW,3))
YAMP=SQRT(OUTM(LW,5)**2+OUTM(LW,6)**2)*57.3
YPH=57.3*ATAN2(OUTM(LW,6),OUTM(LW,5))
WRITE(6,216)W,SAMP,SPH,RAMP,RPH,YAMP,YPH,WL
227 CONTINUE
IF(NSEA.LE.0)GO TO 1000
DO 54 JS=1,NSEA
HSEA=H5W(JS)
TSEA=TSW(JS)
IF(HSEA.GT.0.0) GO TO 30
ISEA=0
GO TO 35
30 IF(HSEA.GT.1.0) GO TO 31
ISEA=1
GO TO 35
31 IF(HSEA.GT.3.0) GO TO 32
ISEA=2
GO TO 35
32 IF(HSEA.GT.5.0) GO TO 33
ISEA=3
GO TO 35
33 IF(HSEA.GT.8.0) GO TO 34
ISEA=4
GO TO 35
34 IF(HSEA.GT.12.0) GO TO 46
ISEA=5
GO TO 35
46 IF(HSEA.GT.20.0) GO TO 47
ISEA=6
GO TO 35
47 IF(HSEA.GT.40.0) GO TO 48
ISEA=7
GO TO 35
48 ISEA=8

```

```

35  CONTINUE
    NTOT=NPOS+3
    DO 70 I=1,NTOT
70  DSP(I)=VEL(I)=ACC(I)=0
    BETD=BETV=BETA=0.0
    DO 71 LW=1,NFH
    W=FR1+(LW-1)*DFR
    W2=W*W
    W4=W2*W2
    FW=SEAST(HSEA,TSEA,W)
    Q=FW*(OUTM(LW,7)**2+OUTM(LW,8)**2)
    BETD=BETD+Q
    BETV=BETV+Q*W2
    BETA=BETA+Q*W4
    DO 72 I=1,3
    J=2*I
72  SPEC(I)=FW*(OUTM(LW,J-1)**2+OUTM(LW,J)**2)
    DO 73 I=1,3
    DSP(I)=DSP(I)+SPEC(I)
    VEL(I)=VEL(I)+SPEC(I)*W2
73  ACC(I)=ACC(I)+SPEC(I)*W4
    IF(NPOS.LE.0) GO TO 71
    DO 76 I=1,NPOS
    DO 77 J=1,2
77  SPP(J)=OUTM(LW,J)-ZPOS(I)*OUTM(LW,J+2)-(XPOS(I)*EL/20.-XCG)*OUTM(L
    *W,J+4)
76  SPEC(I)=FW*(SPP(1)**2+SPP(2)**2)
    DO 78 J=4,NTOT
    DSP(J)=DSP(J)+SPEC(J-3)
    VEL(J)=VEL(J)+SPEC(J-3)*W2
78  ACC(J)=ACC(J)+SPEC(J-3)*W4
71  CONTINUE
    DO 74 I=2,3
    DSP(I)=SQRT(DFR*DSP(I))*57.3
    VEL(I)=SQRT(DFR*VEL(I))*57.3
74  ACC(I)=SQRT(DFR*ACC(I))*57.3
    WRITE(6,217)ISEA,HSEA,TSEA
    WRITE(6,218)
    WRITE(6,219)
    WRITE(6,220)
    WRITE(6,221)DSP(2),VEL(2),ACC(2)
    WRITE(6,222)DSP(3),VEL(3),ACC(3)
    BETD=SQRT(DFR*BETD)*57.3
    BETV=SQRT(DFR*BETV)*57.3
    BETA=SQRT(DFR*BETA)*57.3
    WRITE(6,226)BETD,BETV,BETA
    DSP(3)=DSP(1)
    VEL(3)=VEL(1)
    ACC(3)=ACC(1)
    DO 75 I=3,NTOT
    DSP(I)=SQRT(DFR*DSP(I))
    VEL(I)=SQRT(DFR*VEL(I))
75  ACC(I)=SQRT(DFR*ACC(I))
    WRITE(6,223)
    WRITE(6,219)
    WRITE(6,224)
    WRITE(6,228)DSP(3),VEL(3),ACC(3)

```

```

      IF (NPOS.LE.0) GO TO 54
      WRITE (6,240) (XPOS(I-3),ZPOS(I-3),DSP(I),VEL(I),ACC(I),I=4,NTOT)
54  CONTINUE
1000 IF (EOF(SLINPUT)) 909,999
909  STOP
      18  FORMAT(I11)
212  FORMAT(1H1//25X*FREQUENCY RESPONSE*)
214  FORMAT(//15X4H$WAY,19X4H$ROLL,20X3H$YAW,15X6H$.L./L)
215  FORMAT(3X,1H$,7X,3HAMP,5X,5H$PHASE,10X,3HAMP,5X,5H$PHASE,10X,3HAMP,5
1X,5H$PHASE)
216  FORMAT(F7.3,2F9.3,5X,2F9.3,5X,2F9.3,F15.3)
217  FORMAT(1H1//10X*ROOT MEAN SQUARES IN SEA STATE*12.5X*HSEA =*F5.2,5
1X*TSEA =*F5.2)
218  FORMAT(//15X*ROLL AND YAW*)
219  FORMAT(15X*DISPLACEMENT*11X*VELOCITY*11X*ACCELERATION*)
220  FORMAT(20X*DEG*15X*DEG/SEC*12X10HDEG/SEC**2)
221  FORMAT(/6X*ROLL*F15.3,2F20.3)
222  FORMAT(/6X*YAW*F16.3,2F20.3)
223  FORMAT(//15X*$WAY AT POSITION INDICATED*)
224  FORMAT(20X*FT*16X*FT/SEC*13X9HFT/SEC**2)
226  FORMAT(/6X*FLAP*F15.3,2F20.3)
228  FORMAT(/5X*CG*3XF15.3,2F20.3)
231  FORMAT(//5X*$WAY AMP IS NON-DIMENSIONAL, ROLL AND YA* AMPS IN DEG/
FFT*)
240  FORMAT(/2X,*X=*F5.1*,Z=*F4.1,F9.3,2F20.3)
13   FORMAT(8F10.4)
40   FORMAT(I2,2F10.3)
43   FORMAT(/3X*NFH=*I3,5X*FR1=*F5.3,5X*DFR=*F5.3)
81   FORMAT(2F10.4,I2)
101  FORMAT(1H1,5X*U*9X*EL*8X*HCG*7X*XCG*6X*RRG*7X*YRG*7X*UI$P*7X*RH0*)
1001 FORMAT(/3X,*(*I2*)*2F10.4)
1002 FORMAT (/5X*GAM*7X*$WEEP*5X*ALF*7X*$R*9X*CR*8X*CE*9X*TC*)
1003 FORMAT (/1X*X(4) = *F8.4,5X*Y(4) = *F7.4,5X*H(4) = *F7.4,5X*X(5) =
$ *F8.4,5X*H(5) = *F7.4)
1004 FORMAT (/1X*$F = *F8.4,5X*$PF = *F6.4,5X*$EF = *F6.4,5X*$WF = *F8.4,
$5X*$ZETF = *F7.4)
1005 FORMAT (/1X*$WR = *F8.4,5X*$ZETR = *F7.4)
1006 FORMAT (/1X*$QFD = *F8.4,5X*$QFD = *F8.4,5X*$QF = *F8.4)
1007 FORMAT (/1X*$QRD = *F8.4,5X*$QRD = *F8.4,5X*$QR = *F8.4)
1008 FORMAT(/3X*$HSEA=*F12.2,3X*$TSEA=*F12.2,3X,*NPOS=*,I3)
1009 FORMAT(/13X,*XPOS*10X*ZPOS*)
1010 FORMAT(/3X*GAM(I)*2X*$WEEP(I)*,4X,*ALF(I)*6X,*H(I)*5X* CR(I)*
15X,*CT(I)*)
1014 FORMAT(/1X,*NFOIL= *I1,4X*$NSTRUT= *,I1)
1040 FORMAT(F10.3,7E12.4)
1041 FORMAT(10X,7E12.4)
1042 FORMAT(1H1//,5X*ROLL COEFFICIENTS*)
1043 FORMAT(/6X*$W*10X*$A44*8X*$B44R*8X*$B44I*8X*$C44R*8X*$C44I*9X*$F4R*9X
1*$F4I**/)
50  FORMAT(2I3)
51  FORMAT(/5X*$NSEA=*I2,5X*$NPOS=*I2)
53  FORMAT(/4X*$HSW*7X*$TSW*)
      END

```

```

SUBROUTINE SOLV(A,X,N,M,INDX,ICK)
C
C SOLUTIONS OF N LINEAR EQUATIONS IN N UNKNOWNNS.
C
C M=N+1
C
C MATRIX EQUATION SOLVED IS
C
C          B*Y=C
C
C WHERE   B(I,J)=A(I,J)           I,J=1,N
C          Y(I)=X(I)              I=1,N
C          C(I)=A(I,M)            I=1,N
C
C IF NO SOLUTION FOUND IOK IS SET EQUAL TO 1 FOR RETURN.
C
C DIMENSION A(N,M),X(N),INDX(N)
C ICK=0
C DO 10 I=1,N
C   INDX(I)=0
10  X(I)=0.0
C   DO 20 J=1,N
C     ZZ=1.0E-10
C     IROW=0
C     DO 30 I=1,N
C       IF(INDX(I).NE.0) GO TO 30
C       TEST=ABS(A(I,J))
C       IF(TEST.LE.ZZ) GO TO 30
C       ZZ=TEST
C       IROW=I
30  CONTINUE
C     IF(IROW.EQ.0) GO TO 20
40  INDX(IROW)=J
C     ZN=A(IROW,J)
C     II=N+1
C     DO 50 K=1,II
50  A(IROW,K)=A(IROW,K)/ZN
C     DO 60 I=1,N
C       IF(I.EQ.IROW) GO TO 60
C       II=J+1
C       II=N+1
C       DO 61 K=II,II
C         A(I,K)=A(I,K)-A(I,J)*A(IROW,K)
61  CONTINUE
60  CONTINUE
20  CONTINUE
C     DO 80 I=1,N
C       IF(INDX(I).GT.0) GO TO 80
C       TEST=ABS(A(I,N+1))
C       IF(TEST.GT.1.0E-8) GO TO 99
30  CONTINUE
C     DO 70 I=1,N
C       IF(INDX(I).EQ.0) GO TO 70
C       X(INDX(I))=A(I,N+1)
70  CONTINUE
C     RETURN
99  WRITE(2,100)

```

```

100 FORMAT(20X11HNO SOLUTION)
    ICK=1
    RETURN
    END

```

```

SUBROUTINE MATG(I,J)
COMMON/COM1/qq,G(10,11)
COMPLEX qq
G(I,J)=REAL(qq)
G(I,J+1)=-AIMAG(qq)
G(I+1,J+1)=G(I,J)
G(I+1,J)=-G(I,J+1)
RETURN
END

```

```

C      FUNCTION SEAST(HH,TT,WW)
C      HH IS SIG. WAVE HT. IN FT, TT IS PERIOD IN SEC, WW IS FREQUENCY IN
C      RAD/SEC. OUTPUT SPECTRUM HAS UNITS FT**2/(RAD/SEC).
COMMON/SSGM/A00(80),A10(80),A01(80),A20(80),A11(80),A02(80)
DIMENSION F(2)
H=HH*.3048-4.016
T=TT-9.159
W=WW*TT/6.283185
IF (W.GT.0.05) GO TO 2
SEAST=0.
RETURN
2     IF (W.LE.4.0) GO TO 3
SEAST=0.
RETURN
3     CONTINUE
N=INT(W/.05)
DO 1 I=1,2
M=N+I-1
1     F(I)=A00(M)+A10(M)*H+A01(M)*T+A20(M)*H*H+A11(M)*H*T+A02(M)*T*T
S=F(1)+(F(2)-F(1))*(W-N*.05)*20.
SEAST=S*HH**2*TT/101.1593
RETURN
END

```

BLOCK DATA SEASTGM

COMMON/SSGM/A00(80),A10(80),A01(80),A20(80),A11(80),A02(80)

DATA A00/0.0,0.0,0.0001,0.0018,0.00133,0.00324,0.00709,0.01325,0.02618,  
 1.05336,0.11641,0.2503,0.4943,0.83054,1.23195,1.59871,1.79955,1.76253,  
 21.56762,1.30231,1.07908,0.91784,0.77733,0.66816,0.57326,0.49269,0.43533,  
 3.38482,0.33183,0.28287,0.25230,0.23205,0.21658,0.2037,0.19481,0.18371,  
 4.17350,0.16129,0.14752,0.14327,0.13558,0.12091,0.10697,0.09764,0.09052,  
 5.08372,0.07646,0.06884,0.05932,0.05150,0.04350,0.03660,0.03037,0.02363,  
 6.01831,0.01466,0.01117,0.00829,0.00561,0.00395,0.00283,0.00225,0.00143,  
 7.00057,0.00006,-0.00041,-0.00032,-0.00012,-0.00005,-0.00032,-0.00059,  
 8.-0.00077,-0.00097,-0.00080,-0.00047,-0.00032,-0.00022,-0.00014,-0.00008,  
 9.-0.00003/  
 DATA A10/0.0,0.0,-0.00001,-0.00004,-0.00043,-0.00134,0.00255,0.00387,  
 1.-0.00543,-0.00475,-0.00017,0.00901,0.02629,0.04943,0.06652,0.06000,0.03906,  
 2.00467,-0.03727,-0.06926,-0.07963,-0.06424,-0.05265,-0.04332,-0.03261,  
 3.-0.01857,-0.01263,-0.00911,-0.00801,-0.00336,0.00342,0.00539,0.00458,0.004,  
 4.00652,0.00907,0.00923,0.01084,0.01613,0.01451,0.01063,0.00839,0.00592,  
 5.00532,0.00714,0.00877,0.01007,0.01077,0.01001,0.00923,0.00750,0.00467,  
 6.00175,0.00034,0.00066,0.00106,0.00095,0.00090,0.00102,0.00091,0.00068,  
 7.00036,0.00050,0.00077,0.00093,0.00073,0.00027,0.00018,0.00015,0.00003,  
 8.-0.00009,-0.00013,-0.00013,-0.00009,-0.00006,-0.00003,-0.00001,-0.00001,  
 90.0,0.0/  
 DATA A01/0.0,0.0,0.00001,0.00003,0.0,-0.00067,-0.0024,-0.00558,-0.00822,  
 1.-0.01065,-0.01169,-0.01241,-0.00664,0.01278,0.03974,0.06999,0.08177,0.0558,  
 2.01841,0.0027,-0.00276,-0.01522,-0.03524,-0.03485,-0.03189,-0.03983,  
 3.-0.03554,-0.03005,-0.02822,-0.02864,-0.02787,-0.02231,-0.01716,-0.01219,  
 4.-0.01098,-0.01213,-0.01061,-0.01317,-0.02021,-0.00812,0.00344,0.00783,  
 5.01083,0.01190,0.01113,0.01021,0.00988,0.00930,0.01115,0.01152,0.01164,  
 6.01193,0.01243,0.01189,0.01054,0.00913,0.00785,0.00674,0.00554,0.00475,  
 7.00422,0.00403,0.00345,0.00256,0.00184,0.00129,0.00124,0.00120,0.00109,  
 8.00093,0.00073,0.00051,0.00027,0.00021,0.00023,0.00021,0.00017,0.00013,  
 9.00007,0.00004/  
 DATA A20/0.0,0.0,0.0,0.0,0.00005,0.00009,0.00016,0.00035,0.00033,0.00022,  
 1.00079,0.00172,0.00417,0.00481,0.00119,-0.0066,-0.00935,-0.00604,-0.00044,  
 2.00188,0.00049,0.00021,-0.00021,-0.0003,-0.00107,-0.00137,-0.00081,  
 3.00131,0.00251,0.00183,0.00020,-0.00063,-0.00076,-0.00087,-0.0006,-0.0005,  
 4.00013,0.00108,0.0005,-0.00001,0.00023,0.00042,0.00046,0.00045,0.00052,  
 5.00003,0.00017,-0.00002,-0.00015,-0.00011,0.00002,0.00011,0.00008,-0.00012,  
 6.-0.00028,-0.00012,0.00011,0.00036,0.0004,0.00035,0.00013,0.00027,0.00054,  
 7.00058,0.00040,-0.00003,-0.00014,-0.0001,0.00001,0.00014,0.0002,0.00022,  
 8.00015,0.00004,-0.00001,-0.00003,-0.00003,-0.00002,-0.00001/  
 DATA A11/0.0,0.0,0.00002,0.0002,0.00041,0.00077,0.00112,0.00146,0.00103,  
 1.-0.00103,-0.00667,-0.01387,-0.02494,-0.02849,-0.01366,0.01256,0.02414,  
 2.02513,0.01785,0.01365,0.01369,0.01287,0.0119,0.00914,0.00604,0.00441,  
 3.00222,-0.00303,-0.00754,-0.00807,-0.00403,-0.00067,0.00046,0.00026,  
 4.-0.00086,-0.00096,-0.0031,-0.00798,-0.00544,-0.00238,-0.00232,-0.00222,  
 5.-0.00222,-0.00281,-0.00349,-0.00324,-0.00292,-0.00199,-0.00146,-0.00011,  
 6.-0.00044,-0.00047,-0.00007,0.00031,0.00056,0.00019,-0.00028,-0.00073,  
 7.-0.00075,-0.00059,-0.00010,-0.00016,-0.00055,-0.00054,-0.0003,0.0003,  
 8.00048,0.00036,0.00016,-0.00002,-0.0001,-0.00011,-0.00005,0.00006,0.00013,  
 9.00015,0.00014,0.00009,0.00005/  
 DATA A02/0.0,0.0,0.00004,-0.00021,-0.00016,0.00027,0.0014,0.00193,  
 1.00188,0.00082,0.00042,-0.00032,0.00428,0.00436,-0.00658,-0.02142,-0.0177,  
 2.-0.0106,-0.00411,0.00016,0.00259,0.00845,0.00818,0.00924,0.01304,0.01044,  
 3.00776,0.00819,0.00995,0.00943,0.00585,0.00222,-0.00011,-0.00139,-0.00171,  
 4.-0.00314,-0.00183,0.00268,-0.00207,-0.00614,-0.0063,-0.00615,-0.00599,  
 5.-0.00532,-0.00432,-0.0036,-0.0029,-0.003,-0.00267,-0.00211,-0.00171,

```

6-.00145,-.00095,-.00043,-.00001,.00051,.00094,.00126,.00134,
7.00133,.00118,.00108,.00104,.0009,.00078,.00062,.0005,.00044,
8.00043,.00035,.00029,.00025,.00022,.00018,.00014,.00008,.00004,
9.00002,.00001/
END

```

```

SUBROUTINE ZERO(W,B22,B44,B66)
COMMON/NEW6/FIAV,YAWAV,SWAYAV
COMMON/NEW5/GAM(6),S(6),SX(6),Y(6),Z(6),NFS,B(6),COSS(6),SING(6)
COMPLEX B22,B44,B66
DO 1 I=1,NFS
T=.8488*W*S(I)
P=GAM(I)/57.3
IF(I.LE.3)GO TO 94
IF(I.GT.4)GO TO 95
YR=Y(I)-.5*B(I)*COSS(I)
ZR=Z(I)+.5*B(I)*ABS(SING(I))
YRR=YR*COSS(I)+ZR*SING(I)
BB=B(I)
GOTO 96
95 CONTINUE
BB=2.*B(I)
YRR = -Z(I) - B(I)
96 CONTINUE
ARM3=((YRR+BB)**4-YR**4)/(4.*BB)
B44=B44+1.17*T*ARM3*FIAV
GO TO 3
94 CONTINUE
SI=TAN(P)
S2=-Y(I)/Z(I)
ALF=ABS((S2-SI)/(1.+SI*S2))
ALF=ATAN(ALF)
ARM=SQRT(Y(I)**2+Z(I)**2)
B44=B44+T*ARM**3*CNS(ALF)*FIAV
3 CONTINUE
ALF=ABS(P)
T=T*CNS(ALF)
B22=B22+T*SWAYAV
B66=B66+T*YAWAV*(ABS(SX(I)))**3
1 CONTINUE
RETURN
END

```

```

FUNCTION CNS(ALF)
A=57.3*ALF
IF(A.LT.40) GO TO 1
CNS=1.17*SIN(ALF)
RETURN
1 CNS=.0467*A*SIN(ALF)
RETURN
END

```

```

FUNCTION SDAMP(W,B)
DIMENSION F(16)
DATA F/0.0,.024,.048,.298,.574,.905,1.124,1.238,1.238,1.167,1.071
*.981,.893,.821,.747,.686/
T=W*W*B/32.2
IF(T.GT.0.0) GO TO 1
SDAMP=0.0
RETURN
1  P=T/0.1+1.0
   N=INT(P)
   IF(N.LT.15)GO TO 2
   N=15
2  C=F(N)+(P-N)*(F(N+1)-F(N))
   IF(C.GE.0.0)GO TO 3
   C=0.0
3  CONTINUE
   SDAMP=C*W*B
   RETURN
END

```

```

FUNCTION CLALF(A0,A,ZP1)
A0PI = A0/3.141593
CLALF = A0*A/(A0PI*ZP1+SQRT(A**2+A0PI**2))
RETURN
END

```

```

FUNCTION BIPL(H)
BIPL = (1.0-.66*H)/(1.055+3.7*H)
IF (BIPL .GE. 0.0) GO TO 1
BIPL = 0.0
1  RETURN
END

```

```

SUBROUTINE FLAP(P,T1,T4,T7,T8,T10,T11)
P2=P*P
X1=SQRT(1.-P2)
X2=ASIN(X1)
T1=-X1*(2.+P2)/3.+P*X2
T4=-X2+P*X1
T7=-X2*(.125+P2)+.125*P*X1*(7.+2.*P2)
T8=-X1*(1.+2.*P2)/3.+P*X2
T10=X1+X2
T11=X2*(1.-2.*P)+(2.-P)*X1
RETURN
END

```

```

SUBROUTINE THEUJON(A,Q,CK,SE)
COMPLEX AI,C,C6,C3,G,G6,G3,QI,CK,SE
AI = (0.0,1.0)
QI=AI*Q
C=1.0-QI*(.165/(.045+QI)+.335/(.3+QI))
C6=1.0-.361*QI/(.381+QI)
C3=1.0-.283*QI/(.54+QI)
G=1.0-QI*(.236/(.058+QI)+.513/(.364+QI)+.171/(2.42+QI))
G6=1.0-QI*(.448/(.29+QI)+.272/(.725+QI)+.193/(3.0+QI))
G3=1.0-QI*(.679/(.558+QI)+.227/(3.2+QI))
AC=CABS(C)
PC=ARGD(C)
AC6=CABS(C6)
PC6=ARGD(C6)
AC3=CABS(C3)
PC3=ARGD(C3)
AG=CABS(G)
PG=ARGD(G)
AG6=CABS(G6)
PG6=ARGD(G6)
AG3=CABS(G3)
PG3=ARGD(G3)
IF (A .GT. 6.0) GO TO 1
AF = F36(A,AC3,AC6)
PF = F36(A,PC3,PC6)
AG = F36(A,AG3,AG6)
PG = F36(A,PG3,PG6)
GO TO 2
1 CONTINUE
AF = FGT6(A,AC3,AC6,AC)
PF = FGT6(A,PC3,PC6,PC)
AG = FGT6(A,AG3,AG6,AG)
PG = FGT6(A,PG3,PG6,PG)
2 CONTINUE
CK = AF*(COS(PF) + AI*SIN(PF))
SE = AG*(COS(PG) + AI*SIN(PG))
RETURN
END

```

```
FUNCTION F36(A,Y3,Y6)
F36 = Y3 + (Y6-Y3)/3.0*(A-3.0)
RETURN
END
```

```
FUNCTION FGT6(A,Y3,Y6,YC)
S = (Y6-Y3)/3.0
AA = 12.0*(Y6-YC + 3.0*S)
B = -36.0*(6.0*S + Y6 - YC)
FGT6 = YC + AA/A + B/A**2
RETURN
END
```

```
FUNCTION ARGD(Z)
COMPLEX Z
X=REAL(Z)
Y=AIMAG(Z)
ARGD=ATAN2(Y,X)
RETURN
END
```

```

SUBROUTINE MULLI
COMMON/GR/NUT, NON, CAY, AMC, DFC, YA(25,8), ZA(25,8)
COMMON PI, HPI, GPI, TPI, MU, MODE, DPH, CR, RAT, SUK, DEG, IST, DMT, HBM, SG, N
IOE, PDM, VOL, DEW, UN, OMEGA, CP, WVH, ID, DOG, IG, XX(25,7), YY(25,7), DEL(25,
27), SNE(25,7), CSE(25,7), FR(7), BLOG(25,7,7), YLOG(25,7,7), CON(14,1), C
3T(14,14), PSI1(7,7), PSI2(7,7), PRA(7), PRV(7)
COMMON/NEW/XA(25), DXA(25), XCG, EL, NST, HCG, C44H, DISP, RHO
COMMON/NEW6/FIAV, YAWAV, SWAYAV
HPI=.5*PI
GPI=.5*HPI
67 HEAD(5,13)GMIN
WRITE(6,206)GMIN
READ(5,13)FIAV, YAWAV, SWAYAV
WRITE(6,207)FIAV, YAWAV, SWAYAV
YAWAV=YAWAV/57.3
FIAV = FIAV/57.3
READ(5,201)NST
DO 1 IST=1, NST
READ (5,44)XA(IST)
READ(5,13) (YA(IST,J), J=1,8)
READ(5,13) (ZA(IST,J), J=1,8)
WRITE(6,205)XA(IST)
WRITE(6,36)
WRITE(6,13) (YA(IST,J), J=1,8)
WRITE(6,37)
1 WRITE(6,13) (ZA(IST,J), J=1,8)
DO 45 I=1, NST
45 XA(I)=XA(I)*EL/20.
DXA(1)=.5*XA(2)
NP=NST-1
DO 65 I=2, NP
65 DXA(I)=.5*(XA(I+1)-XA(I-1))
DXA(NST)=EL-.5*(XA(NST)+XA(NST-1))
DO 66 I=1, NST
66 XA(I)=XCG-XA(I)
NON=7
NUT=8
DO 424 I=1, NST
DO 424 J=1, NUT
424 ZA(I,J)=ZA(I,J)-ZA(I, NUT)
NOE=2*NON
C44H=0.0
DO 90 IST=1, NST
C4=0.
DO 89 I=1, NON
XINT=YA(IST, I+1)-YA(IST, I)
YINT=ZA(IST, I+1)-ZA(IST, I)
DEL(IST, I)=SQRT(XINT*XINT+YINT*YINT)
SNE(IST, I)=YINT/DEL(IST, I)
CSE(IST, I)=XINT/DEL(IST, I)
XX(IST, I)=.5*(YA(IST, I+1)+YA(IST, I))
YY(IST, I)=.5*(ZA(IST, I+1)+ZA(IST, I))
89 C4=XX(IST, I)*(XINT*XX(IST, I)+YINT*(YY(IST, I)-HCG))+C4
90 C44H=C44H+64.4*C4*DXA(IST)
GMCALC=C44H*RHO/(2240.*DISP)
WRITE(6,208)GMCALC
IF(GMIN.LE.0.0)GO TO 230

```

```

C44H=2240.*DISP*GMIN/RHO
230 CONTINUE
SG=-1.0
MD=2
CR=0
DPH=0.
DO 300 IST=1,NST
DO 301 J=1,NUT
YA(IST,J)=YA(IST,J)/EL
301 ZA(IST,J)=ZA(IST,J)/EL
DO 302 J=1,NON
DEL(IST,J)=DEL(IST,J)/EL
XX(IST,J)=XX(IST,J)/EL
302 YY(IST,J)=YY(IST,J)/EL
CALL FIND
300 CONTINUE
RETURN
13 FORMAT(8F10.4)
36 FORMAT(1H0,5X,9HABSCISSAS)
37 FORMAT(1H0,5X,9HORDINATES)
44 FORMAT(F10.3)
201 FORMAT(I2)
205 FORMAT(1H0,7HSTATION,F6.2)
206 FORMAT(/5X*GMIN=*F8.4)
207 FORMAT(/5X*FIAV=*F8.4,5X*YAWAV=*F8.4,5X*SwayAV=*F8.4)
208 FORMAT(/5X*GMCALC=*F8.4)
END

```

```

SUBROUTINE HULLW
COMPLEX B22,B24,B26,B44,B46,B62,B64,B66
COMMON/GR/NUT,NUN,CAY,AMC,DFC,YA(25,8),ZA(25,8)
COMMON PI,HPI,GPI,TPI,MD,MODE,DPH,CR,RAI,SUR,DEG,IST,DRT,HBM,SG,N
10E,PDM,VOL,DE*,UN,OMEGA,CP,WVH,ID,DUG,IG,XX(25,7),YY(25,7),DEL(25,
27),SNE(25,7),CSE(25,7),FR(7),BLUG(25,7,7),YLOG(25,7,7),CON(14,1),C
3T(14,14),PSI1(7,7),PSI2(7,7),PRA(7),PRV(7)
COMMON/NEW/XA(25),DXA(25),XCG,EL,NST,HCG,C44H,DISP,RHO
COMMON/NEW2/W,U,A22,B22,A24,B24,A26,B26,A44,B44,A46,B46,
1A62,B62,A64,B64,A66,B66,EF(10)
COMMON/NEW3/A22F,A24F,A26F,A44F,A46F,A66F
DIMENSION ER(3,25),FI(3,25),HR(3,25),HI(3,25),AM(3,25),DF(3,25)
Q=W**2/32.2
WL=TPI*32.2/W**2
DD=EL
CAY=Q*DD
UN=CAY
OMEGA=SQRT(UN)
DO 100 IST=1,NST
DO 100 MODE=2,3
GO TO (303,303,304)MODE
303 DO 305 J=1,NUN
305 FR(J)=-SNE(IST,J)
GO TO 80
304 DO 306 J=1,NUN
306 FR(J)=(YY(IST,J)-HCG/DD)*SNE(IST,J)+XX(IST,J)*CSE(IST,J)
80 CALL FREQ
ER(MODE,IST)=0.
FI(MODE,IST)=0.
HR(MODE,IST)=0.
HI(MODE,IST)=0.
DO 41 I=1,NUN
Q2=EXP(CAY*YY(IST,I))*DEL(IST,I)*32.2*DD
Q3=CAY*XX(IST,I)
Q4=SIN(Q3)
Q5=COS(Q3)
Q6=SNE(IST,I)*Q5-CSE(IST,I)*Q4
FI(MODE,IST)=FI(MODE,IST)-FR(I)*Q2*Q4
HR(MODE,IST)=HR(MODE,IST)+Q2*PRV(I)*Q6
41 HI(MODE,IST)=HI(MODE,IST)+Q2*PRV(I)*Q6
GO TO (50,50,51)MODE
50 AM(MODE,IST)=AMC*DD*DD
DF(MODE,IST)=W*DFC*DD*DD
GO TO 100
51 AM(1,IST)=0.
DF(1,IST)=0.
ER(3,IST)=DD*ER(3,IST)
FI(3,IST)=DD*FI(3,IST)
HR(3,IST)=DD*HR(3,IST)
HI(3,IST)=DD*HI(3,IST)
DO 52 I=1,NUN
AM(1,IST)=AM(1,IST)-SNE(IST,I)*PRA(I)*DEL(IST,I)
52 DF(1,IST)=DF(1,IST)-SNE(IST,I)*PRV(I)*DEL(IST,I)
AM(1,IST)=AM(1,IST)*64.4*(DD/W)**2
DF(1,IST)=DF(1,IST)*64.4*DD**2/W
AM(MODE,IST)=AMC*DD**4
DF(MODE,IST)=DFC*DD**4*W

```

```

100  CONTINUE
      UW=U/W**2
307  A22=-UW*DF(2,NST)+A22F
      B22=U*AM(2,NST)+B22
      A24=-UW*DF(1,NST)+A24F
      B24=U*AM(1,NST)+B24
      A26=-UW*XA(NST)*DF(2,NST)+U*UW*AM(2,NST)+A26F
      B26=U*XA(NST)*AM(2,NST)+U*UW*DF(2,NST)+B26
      A44=-UW*DF(3,NST)+A44F
      B44=U*AM(3,NST)+B44
      A46=-UW*XA(NST)*DF(1,NST)+U*UW*AM(1,NST)+A46F
      B46=U*XA(NST)*AM(1,NST)+U*UW*DF(1,NST)+B46
      A62=-UW*XA(NST)*DF(2,NST)+A26F
      B62=U*XA(NST)*AM(2,NST)+B62
      A64=-UW*XA(NST)*DF(1,NST)+A46F
      B64=U*XA(NST)*AM(1,NST)+B64
      A66=-UW*XA(NST)**2*DF(2,NST)+U*UW*XA(NST)*AM(2,NST)+A66F
      B66=U*XA(NST)**2*AM(2,NST)+U*UW*XA(NST)*DF(2,NST)+B66
      U2=2.*U/W
      EF(1)=U2*HI(2,NST)
      EF(2)=-U2*HR(2,NST)
      EF(3)=U2*HI(3,NST)
      EF(4)=-U2*HR(3,NST)
      EF(5)=EF(1)*XA(NST)
      EF(6)=EF(2)*XA(NST)
308  CONTINUE
      DO 103 IST=1,NST
      XDX=XA(IST)*DXA(IST)
      XDX2=XA(IST)**2*DXA(IST)
      D2=2.*DXA(IST)
      A22=A22+AM(2,IST)*DXA(IST)
      B22=B22+DF(2,IST)*DXA(IST)
      A24=A24+AM(1,IST)*DXA(IST)
      B24=B24+DF(1,IST)*DXA(IST)
      A26=A26+AM(2,IST)*XDX+UW*DF(2,IST)*DXA(IST)
      B26=B26+DF(2,IST)*XDX-U*AM(2,IST)*DXA(IST)
      A44=A44+AM(3,IST)*DXA(IST)
      B44=B44+DF(3,IST)*DXA(IST)
      A46=A46+AM(1,IST)*XDX+UW*DF(1,IST)*DXA(IST)
      B46=B46+DF(1,IST)*XDX-U*AM(1,IST)*DXA(IST)
      A62=A62+AM(2,IST)*XDX-UW*DF(2,IST)*DXA(IST)
      B62=B62+DF(2,IST)*XDX+U*AM(2,IST)*DXA(IST)
      A64=A64+AM(1,IST)*XDX-UW*DF(1,IST)*DXA(IST)
      B64=B64+DF(1,IST)*XDX+U*AM(1,IST)*DXA(IST)
      A66=A66+AM(2,IST)*XDX2+U*UW*AM(2,IST)*DXA(IST)
      B66=B66+DF(2,IST)*XDX2+U*UW*DF(2,IST)*DXA(IST)
      EF(1)=EF(1)+D2*(ER(2,IST)+HR(2,IST))
      EF(2)=EF(2)+D2*(FI(2,IST)+HI(2,IST))
      EF(3)=EF(3)+D2*(ER(3,IST)+HR(3,IST))
      EF(4)=EF(4)+D2*(FI(3,IST)+HI(3,IST))
      EF(5)=EF(5)+D2*(XA(IST)*(ER(2,IST)+HR(2,IST))+U*HI(2,IST)/W)
      EF(6)=EF(6)+D2*(XA(IST)*(FI(2,IST)+HI(2,IST))-U*HR(2,IST)/W)
103  RETURN
      END

```

```

SUBROUTINE FIND
COMMON/GR/NUT,NON,CAY,AMC,DFC,YA(25,8),ZA(25,8)
COMMON PI,HPI,UPI,TPI,MD,MODE,DPH,CR,RAT,SUK,DEG,IST,URT,HBM,SG,N
10E,PDM,VOL,DEW,UN,OMEGA,CP,*VM, ID,DOG,IG,XX(25,7),YY(25,7),UEL(25,
27),SNE(25,7),CSE(25,7),FR(7),BLOG(25,7,7),YLOG(25,7,7),CON(14,1),C
3T(14,14),PSI1(7,7),PSI2(7,7),PRA(7),PRV(7)
DO 1 I=1,NON
  XM1=XX(IST,I)-YA(IST,I)
  YM1=YY(IST,I)-ZA(IST,I)
  XP1=XX(IST,I)+YA(IST,I)
  YP1=YY(IST,I)+ZA(IST,I)
  FPR1=.5*ALOG(XM1**2+YM1**2)
  FPL1=.5*ALOG(XP1**2+YM1**2)
  FCR1=.5*ALOG(XM1**2+YP1**2)
  FCL1=.5*ALOG(XP1**2+YP1**2)
  APR1=ATAN2(YM1,XM1)
  APL1=ATAN2(YM1,XP1)
  ACR1=ATAN2(YP1,XM1)
  ACL1=ATAN2(YP1,XP1)
DO 1 J=1,NON
  XM2=XX(IST,I)-YA(IST,J+1)
  YM2=YY(IST,I)-ZA(IST,J+1)
  XP2=XX(IST,I)+YA(IST,J+1)
  YP2=YY(IST,I)+ZA(IST,J+1)
  FPR2=.5*ALOG(XM2**2+YM2**2)
  FPL2=.5*ALOG(XP2**2+YM2**2)
  FCR2=.5*ALOG(XM2**2+YP2**2)
  FCL2=.5*ALOG(XP2**2+YP2**2)
  APR2=ATAN2(YM2,XM2)
  J1=J+1
  IF(XM2.GT.0.0)GO TO 4
  IF(J1.GT.I) GO TO 6
  IF(YM2.LT.0.0)APR2=APR2+TPI
  GO TO 5
6  IF(YM2.GE.0.0)APR2=APR2-TPI
5  IF(YP2.LT.0.0) GO TO 4
  ACR2=-PI
  GO TO 3
4  CONTINUE
  ACR2=ATAN2(YP2,XM2)
3  CONTINUE
  ACL2=ATAN2(YP2,XP2)
  APL2=ATAN2(YM2,XP2)
  SIMJ=SNE(IST,I)*CSE(IST,J)-SNE(IST,J)*CSE(IST,I)
  CIMJ=CSE(IST,I)*CSE(IST,J)+SNE(IST,I)*SNE(IST,J)
  SIPJ=SNE(IST,I)*CSE(IST,J)+SNE(IST,J)*CSE(IST,I)
  CIPJ=CSE(IST,I)*CSE(IST,J)-SNE(IST,I)*SNE(IST,J)
  DPNR=SIMJ*(FPR1-FPR2)+CIMJ*(APR1-APR2)
49 PPR=CSE(IST,J)*(XM1*FPR1-YM1*APR1-XM1-XM2*FPR2+YM2*APR2+
  IXM2)+SNE(IST,J)*(YM1*FPR1+XM1*APR1-YM1-YM2*FPR2-XM2*APR2+YM2)
  DPNL=SIPJ*(FPL2-FPL1)+CIPJ*(APL2-APL1)
  PPL=CSE(IST,J)*(XP2*FPL2-YM2*APL2-XP2-XP1*FPL1+YM1*APL1+
  IXP1)+SNE(IST,J)*(YM1*FPL1+XP1*APL1+YM2-YM2*FPL2-XP2*APL2-YM1)
  DCNR=SIPJ*(FCR1-FCR2)+CIPJ*(ACR1-ACR2)
  PCR=CSE(IST,J)*(XM1*FCR1-YP1*ACR1-XM1-XM2*FCR2+YP2*ACR2+
  IXM2)+SNE(IST,J)*(YP2*FCR2+XM2*ACR2+YP1-YP1*FCR1-XM1*ACR1-YP2)
  DCNL=SIMJ*(FCL2-FCL1)+CIMJ*(ACL2-ACL1)

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PCL=CSE(IST,J)*(XP2*FCL2-YP2*ACL2-XP2-XP1*FCL1+YP1*ACL1+XP
11)+SNE(IST,J)*(YP2*FCL2+XP2*ACL2-YP2-YP1*FCL1-XP1*ACL1+YP1)
BLOG(IST,I,J)=DPNR+SG*DPNL-DCNR-SG*DCNL
YLOG(IST,I,J)=PPR+SG*PPL-PCR-SG*PCL
IF(J-NUN)2,1,1
2  XM1=XM2
   YM1=YM2
   XP1=XP2
   YP1=YP2
   FPR1=FPR2
   FPL1=FPL2
   FCR1=FCR2
   FCL1=FCL2
   APR1=APR2
   APL1=APL2
   ACR1=ACR2
   ACL1=ACL2
1  CONTINUE
   RETURN
   END

```

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SUBROUTINE FREJ
COMMON PI,HP1,UP1,TPI,MD,MODE,DPH,CR,RAT,SUR,DEG,IST,DHT,HBM,SG,N
10E,PDM,VOL,DEW,UN,OMEGA,CP,VH,ID,DOG,IG,XX(25,7),YY(25,7),DEL(25
2,7),SNE(25,7),CSE(25,7),FR(7),BLUG(25,7,7),YLOG(25,7,7),CON(14,1)
3,CT(14,14),PSI1(7,7),PSI2(7,7),PHA(7),PHV(7)
COMMON/GH/NUT,NUN,CAY,AMC,DFC,YA(25,8),ZA(25,8)
DO 1 I=1,NON
NI=NON+I
CON(I,1)=0.
CON(NI,1)=OMEGA*FR(I)
XR1=UN*(XX(IST,I)-YA(IST,1))
YR1=-UN*(YY(IST,I)+ZA(IST,1))
XL1=UN*(XX(IST,I)+YA(IST,1))
YL1=YR1
CALL DAVID (XR1,YR1,EJ1,CXR1,SXR1,HAR1,HBR1,CR1,SR1)
CALL DAVID (XL1,YL1,EJ1,CXL1,SXL1,RAL1,RBL1,CL1,SL1)
DO 1 J=1,NON
NJ=NON+J
XR2=UN*(XX(IST,I)-YA(IST,J+1))
YR2=-UN*(YY(IST,I)+ZA(IST,J+1))
XL2=UN*(XX(IST,I)+YA(IST,J+1))
YL2=YR2
CALL DAVID (XR2,YR2,EJ2,CXR2,SXR2,HAR2,HBR2,CR2,SR2)
CALL DAVID (XL2,YL2,EJ2,CXL2,SXL2,RAL2,RBL2,CL2,SL2)
SIPJ=SNE(IST,I)*CSE(IST,J)+SNE(IST,J)*CSE(IST,I)
CIPJ=CSE(IST,I)*CSE(IST,J)-SNE(IST,I)*SNE(IST,J)
SIMJ=SNE(IST,I)*CSE(IST,J)-SNE(IST,J)*CSE(IST,I)
CIMJ=CSE(IST,I)*CSE(IST,J)+SNE(IST,I)*SNE(IST,J)
CT(I,J)=BLOG(IST,I,J)+2.*(SIPJ*(CR1-CR2)-CIPJ*(SR1-SR2)-SG*(SI
1MJ*(CL1-CL2)-CIMJ*(SL1-SL2)))
PSI1(I,J)=YLOG(IST,I,J)+2./UN*(SNE(IST,J)*(HAR1-HAR2)+CSE(IST,J
1)*(RBR1-RBR2)+SG*(SNE(IST,J)*(RAL1-RAL2)+CSE(IST,J)*(RBL2-RBL1)))
CT(NI,NJ)=CT(I,J)
CT(I,NJ)=TPI*(EJ2*(SXR2*CIPJ-CXR2*SIPJ)-EJ1*(SXR1*CIPJ-CX
1R1*SIPJ)-SG*(EJ2*(SXL2*CIMJ-CXL2*SIMJ)-EJ1*(SXL1*CIMJ-CXL
2*SIMJ)))
PSI2(I,J)=TPI/UN*(EJ1*(SXR1*CSE(IST,J)-CXR1*SNE(IST,J))-EJ2*
1(SXR2*CSE(IST,J)-CXR2*SNE(IST,J))-SG*(EJ1*(SXL1*CSE(IST,J)+CXL1*SN
2E(IST,J))-EJ2*(SXL2*CSE(IST,J)+CXL2*SNE(IST,J))))
CT(NI,J)=-CT(I,NJ)
IF (J-NON) 7,1,1
7
XR1=XR2
YR1=YR2
XL1=XL2
YL1=YL2
EJ1=EJ2
CR1=CR2
SR1=SR2
CL1=CL2
SL1=SL2
HAR1=HAR2
RBR1=RBR2
RAL1=RAL2
RBL1=RBL2
CXR1=CXR2
SXR1=SXR2
CXL1=CXL2

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SXL1=SXL2
1 CONTINUE
CALL MATINV(CT,NOE,CON,1,DUG,IG)
GO TO (2,6).ID
2 DO 3 I=1,NON
PRA(I)=0.
PRV(I)=0.
DO 4 J=1,NON
NJ=NON+J
PRA(I)=PRA(I)+CON(J,1)*PSI2(I,J)-CON(NJ,1)*PSI1(I,J)
4 PRV(I)=PRV(I)+CON(J,1)*PSI1(I,J)+CON(NJ,1)*PSI2(I,J)
PRA(I)=OMEGA*PRA(I)
3 PRV(I)=OMEGA*PRV(I)
AMC=0.0
DFC=0.0
DO 5 I=1,NON
AMC=AMC+PRA(I)*DEL(IST,I)*FR(I)
5 DFC=DFC+PRV(I)*DEL(IST,I)*FR(I)
AMC=2.0*AMC
DFC=2.0*DFC
AMC=AMC/UN
DFC=DFC/UN
6 RETURN
END

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C   DAVI - COMPUTATION OF FREQUENCY DEPENDENT PARTS OF
C   2-D POTENTIALS AND KERNELS
SUBROUTINE DAVID(X,Y,E,C,S,RA,HB,CIN,SON)
AT=ATAN2(X,Y)
ARG=AT-1.5707963
E=EXP(-Y)
C=COS(X)
S=SIN(X)
R=X**2+Y**2
TEST=0.0001
IF(R.LT.1.0) GO TO 5
TEST=0.1*TEST
IF(R.LT.2.0) GO TO 5
TEST=0.1*TEST
IF(R.LT.4.0) GO TO 5
TEST=0.1*TEST
5 AL=0.5*ALOG(R)
SUMC=0.57721566+AL*Y
SUMS=AT*X
TC=Y
TS=X
DO 1 K=1,500
TO=TC
COX=K
CAY=K+1
FACT=COX/(CAY+CAY)
TC=FACT*(Y*TC-X*TS)
TS=FACT*(Y*TS+X*TO)
SUMC=SUMC+TC
SUMS=SUMS+TS
IF(K.GE.500) GO TO 3
IF((ABS(TC)+ABS(TS)).GT.TEST) GO TO 1
3 CIN=E*(C*SUMC+S*SUMS)
SON=E*(S*SUMC-C*SUMS)
RA=AL-CIN
RB=ARG+SON
GO TO 4
1 CONTINUE
4 RETURN
END

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SUBROUTINE MATINV(A,NR,B,NC,DETERM,ID)
C   MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C   PIVOT METHOD
C   FORTRAN IV SINGLE PRECISION WITH ADJUSTABLE DIMENSION
C   FEBRUARY 1966 S GOOD DAVID TAYLOR MODEL BASIN AM MAT4
C   WHERE CALLING PROGRAM MUST INCLUDE
C       DIMENSION A(NR,NR), B(NR,NC), INDEX(NR,3)
C       N   IS THE ORDER OF A
C       M   IS THE NUMBER OF COLUMN VECTORS IN B(MAY BE 0)
C   DETERM WILL CONTAIN DETERMINANT ON EXIT
C   ID   WILL BE SET BY ROUTINE TO 2 IF MATRIX A IS SINGULAR
C       1 IF INVERSION WAS SUCCESSFUL
C       A   THE INPUT MATRIX WILL BE REPLACED BY A INVERSE
C       B   THE COLUMN VECTORS WILL BE REPLACED BY CORRESPONDING
C           SOLUTION VECTORS
C       INDEX WORKING STORAGE ARRAY
C       IF IT IS DESIRED TO SCALE THE DETERMINANT CARD   MAY BE
C       DELETED AND DETERM PRESET BEFORE ENTERING THE ROUTINE
C
EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)
DIMENSION A(NR,NR),B(NR,NC),INDEX(30,3)
N1=NR
M1=NC
C
C   INITIALIZATION
C
N=N1
M=M1
DETERM = 0.0
DO 20 J=1,N
20 INDEX(J,3) = 0
DO 550 I=1,N
C
C   SEARCH FOR PIVOT ELEMENT
C
AMAX = 0.0
DO 105 J=1,N
IF(INDEX(J,3)-1) 60, 105, 60
60 DO 100 K=1,N
IF(INDEX(K,3)-1) 80, 100, 715
80 IF ( AMAX -ABS (A(J,K))) 85, 100, 100
85 IROW=J
ICOLUM =K
AMAX = ABS (A(J,K))
100 CONTINUE
105 CONTINUE
INDEX(ICOLUM,3) = INDEX(ICOLUM,3) +1
INDEX(I,1)=IROW
INDEX(I,2)=ICOLUM
C
C   INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
IF (IROW-ICOLUM) 140, 310, 140
140 DETERM=-DETERM
DO 200 L=1,N

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      SWAP=A(IPOW,L)
      A(IPOW,L)=A(ICOLUM,L)
200  A(ICOLUM,L)=SWAP
      IF(M) 310, 310, 210
210  DO 250 L=1, M
      SWAP=R(IPOW,L)
      R(IPOW,L)=R(ICOLUM,L)
250  R(ICOLUM,L)=SWAP
C
C   DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
210  PIVOT  =A(ICOLUM,ICOLUM)
      DETERM=DETERM*PIVOT
330  A(ICOLUM,ICOLUM)=1.0
      DO 350 L=1,N
350  A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
      IF(M) 380, 380, 360
360  DO 370 L=1,M
370  R(ICOLUM,L)=R(ICOLUM,L)/PIVOT
C
C   REDUCE NON-PIVOT ROWS
C
380  DO 550 L1=1,N
      IF(L1-ICOLUM) 400, 550, 400
400  T=A(L1,ICOLUM)
      A(L1,ICOLUM)=0.0
      DO 450 L=1,N
450  A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
      IF(M) 550, 550, 460
460  DO 500 L=1,M
500  R(L1,L)=R(L1,L)-R(ICOLUM,L)*T
550  CONTINUE
C
C   INTERCHANGE COLUMNS
C
      DO 710 I=1,N
      L=N+1-I
      IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
630  JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 705 K=1,N
      SWAP=A(K,JROW)
      A(K,JROW)=A(K,JCOLUM)
      A(K,JCOLUM)=SWAP
705  CONTINUE
710  CONTINUE
      DO 730 K = 1,N
      IF(INDEX(K,3) -1) 715,720,715
720  CONTINUE
730  CONTINUE
      ID = 1
810  RETURN
715  ID = 2
      GO TO 810
      END

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## KEY WORDS

Hydrofoil

Hullborne

Roll

Sway

Yaw

Seakeeping

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