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SWATH DYNAMIC SIMULATION MODEL.(U)

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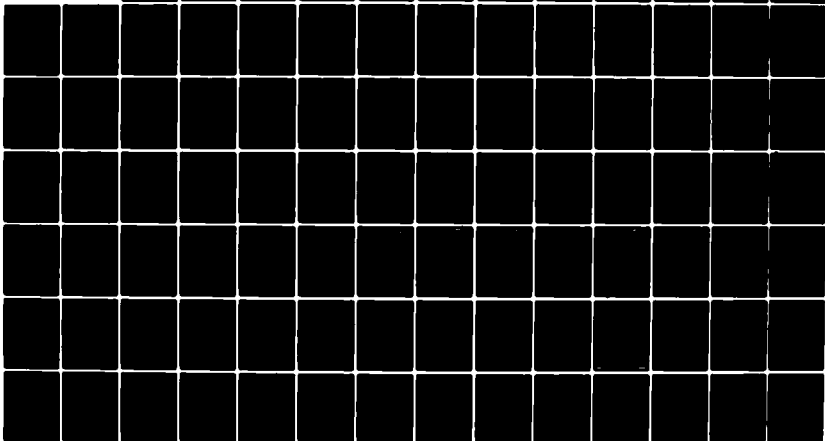
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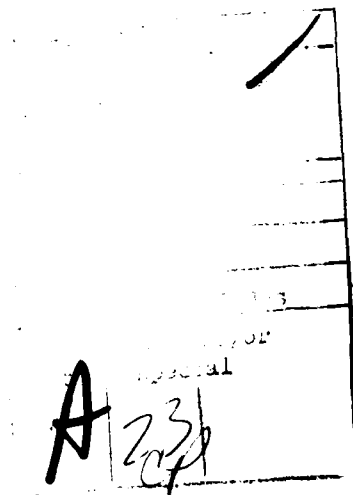
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ABSTRACT

A five degree of freedom (constant pitch) simulation model for a Small Waterplane Area Twin Hull (SWATH) ship has been developed. Complete descriptions of the mathematical models employed and a description of the corresponding digital simulation program are presented in this report. Performance predictions based on the mathematical model are also included. The mathematical models are based primarily on experimental model test data measured at the rotating arm facility at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC). The performance predictions generated in this study are appropriate for carrying out rudder configuration design evaluations. The results indicate that the spade rudder configuration is adequate for meeting turn diameter specifications.



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INTRODUCTION

The Navy is currently carrying out preliminary design and feasibility studies on various Small Waterplane Area Twin Hull (SWATH) ship configurations in the 2000 - 20,000 ton weight range. These ships have desirable performance properties due to their design. The SWATH ship basic configuration consists of two submerged hulls attached to two vertical struts. Propulsion is provided by propellers located at the end of the hulls. Since the waterplane is small, surface waves have a smaller effect on SWATH ship motion than on conventional craft which have larger waterplane areas. Also, SWATH ships can turn in a fairly small circle at low speed by applying a differential thrust. A sketch of the basic SWATH configuration is illustrated in Figure 1.

In order to carry out evaluation studies, the necessary tools must be developed. One such tool is a time domain simulation model suitable for predicting ship behavior during various maneuvers. The simulation model must be sufficiently flexible so that different SWATH configurations can be easily evaluated and compared. An appropriate simulation tool has been developed during the study reported here.

The general approach used in developing the SWATH simulation model involves the development of mathematical models based on experimental force and moment data. The experimental data is first processed to develop a sufficiently dense data base by interpolating and/or extrapolating for missing grid points. Also, symmetry properties are employed to generate a complete data base required to characterize the ship over all orientations and speeds. The force and moment values for a given ship state are obtained via multi-dimensional interpolation of the data base. Theoretical expressions are used whenever experimental model data is lacking.

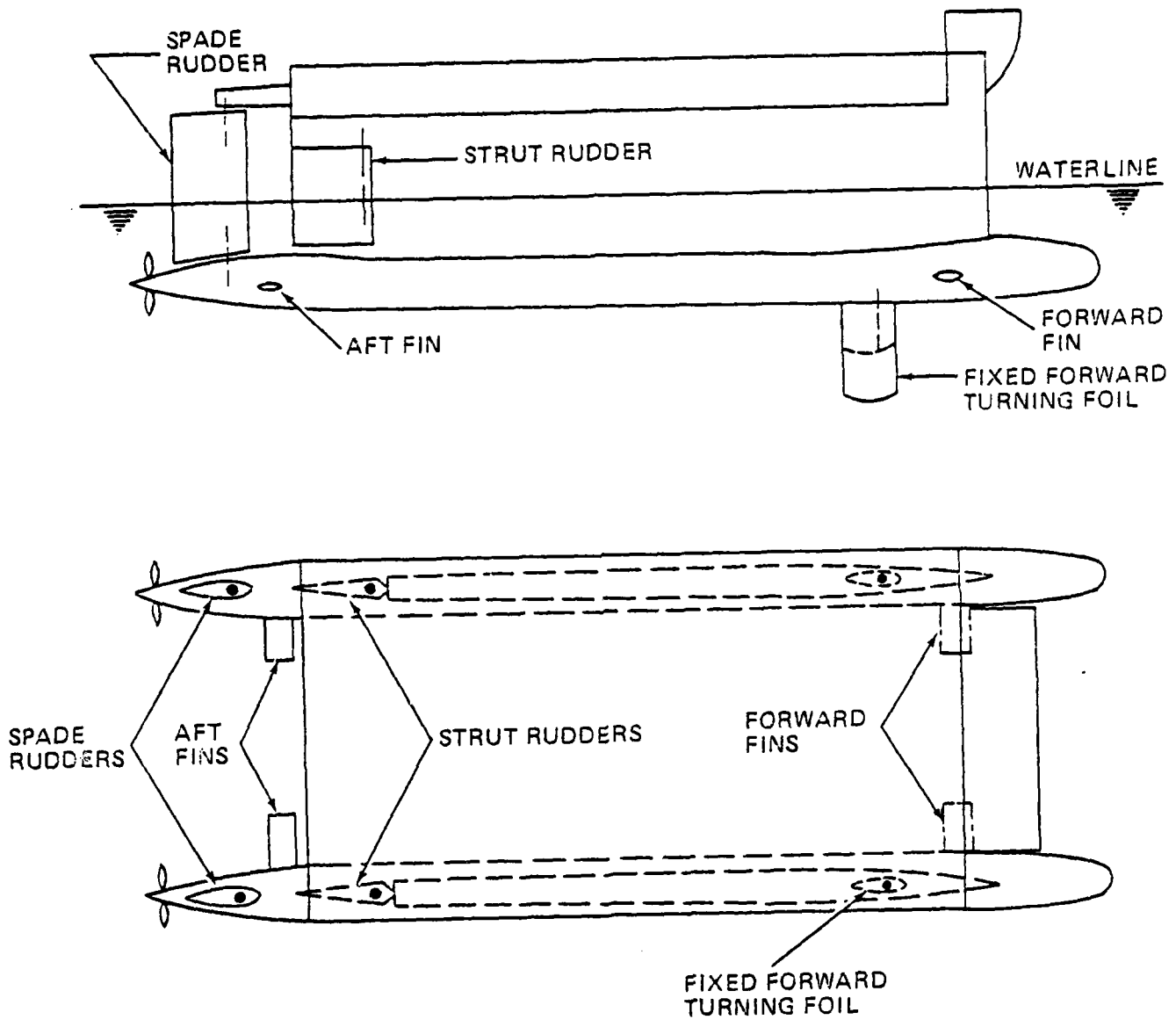


FIGURE 1 SCHEMATIC OF SWATH 6A CONFIGURATION

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The resulting force and moment models are used in the differential equations that describe the ship motion. These equations are solved numerically using standard integration procedures.

Various sets of experimental data are used in the present effort. These data characterize the hull, rudder, fin, and propulsion subsystems. These subsystems are modeled separately. However, some interference effects are taken into account. For example, the interference of a hull on its propeller is accounted for by a wake reduction factor based on experimental data. Other interference effects are assumed negligible. These assumptions are validated via an analysis of the experimental data in most cases.

The mathematical model development is presented in the next section. Subsequent sections present results and digital computer program documentation. Actual computer output and card images of various test runs are presented in the appendices.

MATHEMATICAL MODEL DEVELOPMENT

BASIC EQUATIONS OF MOTION

The equations governing the motion of the SWATH are extensions of Newton's second law, $F = Ma$, to the six degrees of freedom possible for ship motion. The SWATH simulation model is based on the standard equations of motion for a submarine outlined in NSRDC Report No. 2510. Minor changes have been made in converting the submarine equations to a set of equations appropriate for a surface ship. The predominate coordinate system used in the simulation model is a body fixed system as defined in reference #2510. All forces and moments are defined in terms of the body system. Unless otherwise specified all parameters are given in the MKS system of units.

The equations of motion presented in NSRDC Report No. 2510 can be written in the generalized form,

$$\dot{\vec{S}} = A^{-1} \vec{F}$$

where $\vec{S}$ is the state vector, A is a generalized mass/inertia matrix and $\vec{F}$ is a generalized force vector.

The generalized mass/inertia matrix appropriate for SWATH is presented in Table 1. All symbols used in Table 1 and in subsequent sections of this report are defined in the notation section. The generalized force vector, $\vec{F}$, contains kinematic terms plus contributions from the fin, hull, rudder, aerodynamic, buoyancy, propeller, and rate dependent forces and moments. The components of the generalized force vector are defined in Table 2.

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$\bar{M} - X_u$	0	0	0	$\bar{M} \cdot Z_g$	$-\bar{M} \cdot Y_g$
0	$\bar{M} - Y_v$	0	$-\bar{M} \cdot Z_g - Y_{\dot{p}}$	0	$\bar{M} \cdot X_g - Y_{\dot{r}}$
0	0	$\bar{M} - Z_{\dot{w}}$	$\bar{M} \cdot Y_g$	$-\bar{M} \cdot X_g - Z_{\dot{q}}$	0
0	$-\bar{M} \cdot Z_g - K_{\dot{v}}$	$\bar{M} \cdot Y_g$	$I_{xx} - K_{\dot{p}}$	$-I_{xy}$	$-I_{xz} - K_{\dot{r}}$
$\bar{M} \cdot Z_g$	0	$-\bar{M} \cdot X_g - M_{\dot{w}}$	$-I_{xy}$	$I_{yy} - M_{\dot{q}}$	$-I_{yz}$
$-\bar{M} \cdot Y_g$	$\bar{M} \cdot X_g - N_{\dot{v}}$	0	$-I_{xz} - N_{\dot{p}}$	$-I_{yz}$	$I_{zz} - N_{\dot{r}}$

Table 1 - GENERALIZED MASS/INERTIA MATRIX

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F_1	$X_{fin} + X_{rud} + X_{hull} + X_{air} + X_{buoy} + X_{prop} + X_{add} + (v \cdot r - w \cdot q) \bar{M} + \left[(q^2 + r^2) x_g - p q y_g - p r z_g \right]$
F_2	$Y_{fin} + Y_{rud} + Y_{hull} + Y_{air} + Y_{buoy} + Y_{prop} + X_{add} + (w p - u r) \bar{M} + \left[(r^2 + p^2) y_g - q r z_g - q p x_g \right] \bar{M}$
F_3	$Z_{fin} + Z_{rud} + Z_{hull} + Z_{air} + Z_{buoy} + Z_{prop} + Z_{add} + (u q - v p) \bar{M} + \left[(p^2 + q^2) z_g - r p x_g - r q y_g \right] \bar{M}$
F_4	$K_{fin} + K_{rud} + K_{hull} + K_{air} + K_{buoy} + K_{prop} + K_{add} + (I_{yy} - I_{zz}) q r + I_{xz} p q + (q^2 - r^2) I_{yz} - I_{xy} p r + \left[(u r - w p) z_g + (u_g - v p) y_g \right] \bar{M}$
F_5	$M_{fin} + M_{rud} + M_{hull} + M_{air} + M_{buoy} + M_{prop} + M_{add} + (I_{zz} - I_{xx}) r p + I_{xy} q r + (r^2 - p^2) I_{xz} - I_{yz} q p + \left[(v p - u q) x_g + (v r - w q) z_g \right] \bar{M}$
F_6	$N_{fin} + N_{rud} + N_{hull} + N_{air} + N_{buoy} + N_{prop} + N_{add} + (I_{xx} - I_{yy}) p q + I_{yz} r p + (p^2 - q^2) I_{xy} - I_{xz} r q + \left[(w q - v r) y_g + (w p - u r) x_g \right] \bar{M}$

Table 2 - GENERALIZED FORCE VECTOR

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The time rate of change of the roll, pitch, and yaw angles are obtained by solving the kinematic equations presented in Report No. 2510 for $\dot{\phi}$, $\dot{\theta}$, and $\dot{\psi}$. The results are,

$$\dot{\phi} = (q \sin\theta \sin\phi + r \sin\theta \cos\phi + p \cos\theta)/\cos\theta, \quad (2)$$

$$\dot{\theta} = q \cos\phi - r \sin\phi, \quad (3)$$

$$\dot{\psi} = (q \sin\phi + r \cos\phi)/\cos\theta. \quad (4)$$

Velocity components in the fixed or Earth coordinate system are obtained by transforming the body x, y, and z velocity components to the fixed system:

$$\begin{bmatrix} \dot{x}_E \\ \dot{y}_E \\ \dot{z}_E \end{bmatrix} = \overleftrightarrow{T} \begin{bmatrix} U \\ V \\ W \end{bmatrix} \quad (5)$$

The transformation matrix $\overleftrightarrow{T}$ is given in Table 3.

The above equations of motion are suitable for a full six degree of freedom simulation model. The SWATH ship considered in this report has four fins that can be used to provide a pitch moment such that the pitch angle remains constant, i.e., $\dot{\theta} = 0.0$. Rather than solve the extremely complicated problem of determining a fin angle of attack that would result in a value of $\dot{q}$ that would in turn result in a constant pitch, the kinematic equations can be used to obtain a differential equation for $\dot{q}$ such that the pitch remains constant.* When $\dot{\theta} = 0.0$, Equation (3) reduces to

* $\dot{\theta} = 0.0$ does not imply $q = 0.0$ unless $\phi = 0.0$ or $r = 0.0$.

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$$\begin{pmatrix} \cos\theta \cos\psi & -\cos\phi \sin\psi + \sin\phi \sin\theta \cos\psi & \sin\phi \sin\psi + \sin\theta \cos\phi \cos\psi \\ \cos\theta \sin\psi & \cos\phi \cos\psi + \sin\phi \sin\theta \sin\psi & -\sin\phi \cos\psi + \sin\theta \cos\phi \sin\psi \\ -\sin\theta & \sin\phi \cos\theta & \cos\theta \cos\phi \end{pmatrix}$$

$\vec{L}_T =$

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TABLE 3 BODY TO FIXED COORDINATE SYSTEM TRANSMISSION MATRIX

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$$q \cos\phi - r \sin\phi = 0.0. \quad (6)$$

A differential equation for q is obtained by taking the derivative of the above equation:

$$\dot{q} \cos\phi - \dot{r} \sin\phi = \dot{\phi} (q \sin\phi + r \cos\phi). \quad (7)$$

$\dot{\phi}$ can be eliminated in the above equation by using Equation (2). The constant pitch simulation model employs the above equation for $\dot{q}$ rather than the $\dot{q}$ equation given in Report No. 2510. Conceptually, the above approach is equivalent to including a fin pitch moment in the pitch equation such that $\dot{\theta} = 0.0$. In fact, if a strongly restoring pitch moment of the form

$$M = C\theta$$

is included in the differential equation for q in six degrees of freedom, the pitch moment remains at a value of zero degrees. Such a test was conducted in order to verify the five degree of freedom equations.

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HULL HYDRODYNAMIC FORCE AND MOMENT MODEL

The mathematical models used to represent hull forces and moments are based on experimental model data provided by DTNSRDC. The data supplied was obtained from experiments conducted on a 1/22.5 size scale model at the rotating arm facility located at DTNSRDC. Six different model configurations, as described in Table 4, were considered. The results of these experiments were supplied in the form of parametric curves for non-dimensional values of Y , K , and N versus non-dimensional turn rate for various drift angles. Measurements were not made for isolated grid points. These missing values were obtained by interpolation or extrapolation based on an inspection of various data trends. The final data bases used to characterize the hydrodynamic hull forces and moments are presented in Tables A1 - A4. A four variable table look-up or interpolation procedure is used in the digital simulation model to obtain values of Y , K , and N at given values of the speed, roll angle, drift angle, and non-dimensional yaw rate from the dimensional form of the data base. Interpolations were initially performed on the non-dimensional form of the data base. However, due to the fine sampling in speed (5 knot spacings) linear interpolation of the dimensional form of the data is sufficiently accurate and much more efficient. A comparison of both results is illustrated in Figures 2-4. The experimental data plotted in these figures are hand faired using French curves. The very close agreement between the interpolated values and the smooth curves indicate the high degree of accuracy possible by use of an interpolation procedure. Note that the data bases contain rudder contributions at zero rudder angle. Also, it is assumed that the force coefficients can be superimposed due to the strong linear nature of the forces and moments.

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Case	Rudder Configuration	Draft	Speed* knots	Roll deg	Drift deg	Yaw+ Rate
A	Strut rudders and fins at zero deflection	Design	5 - 28	0 - 4	-4 to 4	0.09 - 0.305
B	Same as above	Deep	5 - 28	0 - 4	-4 to 4	0.09 - 0.305
C	Strut rudders, spade rudder, fins at zero deflection	Design	5 - 28	0 - 4	-4 to 4	0.09 - 0.305
D	Same as above	Deep	5 - 28	0 - 4	-4 to 4	0.09 - 0.305
E	Strut rudders and fins at zero deflection. Fixed forward foil extended	Design	5 - 28	0 - 4	-4 to 4	0.09 - 0.305
F	Same as above	Deep	5 - 28	0 - 4	-4 to 4	0.09 - 0.305

* Full Scale

+ Non-dimensional: $\frac{v}{u}$

TABLE 4 DESCRIPTION OF TEST CASES A - F

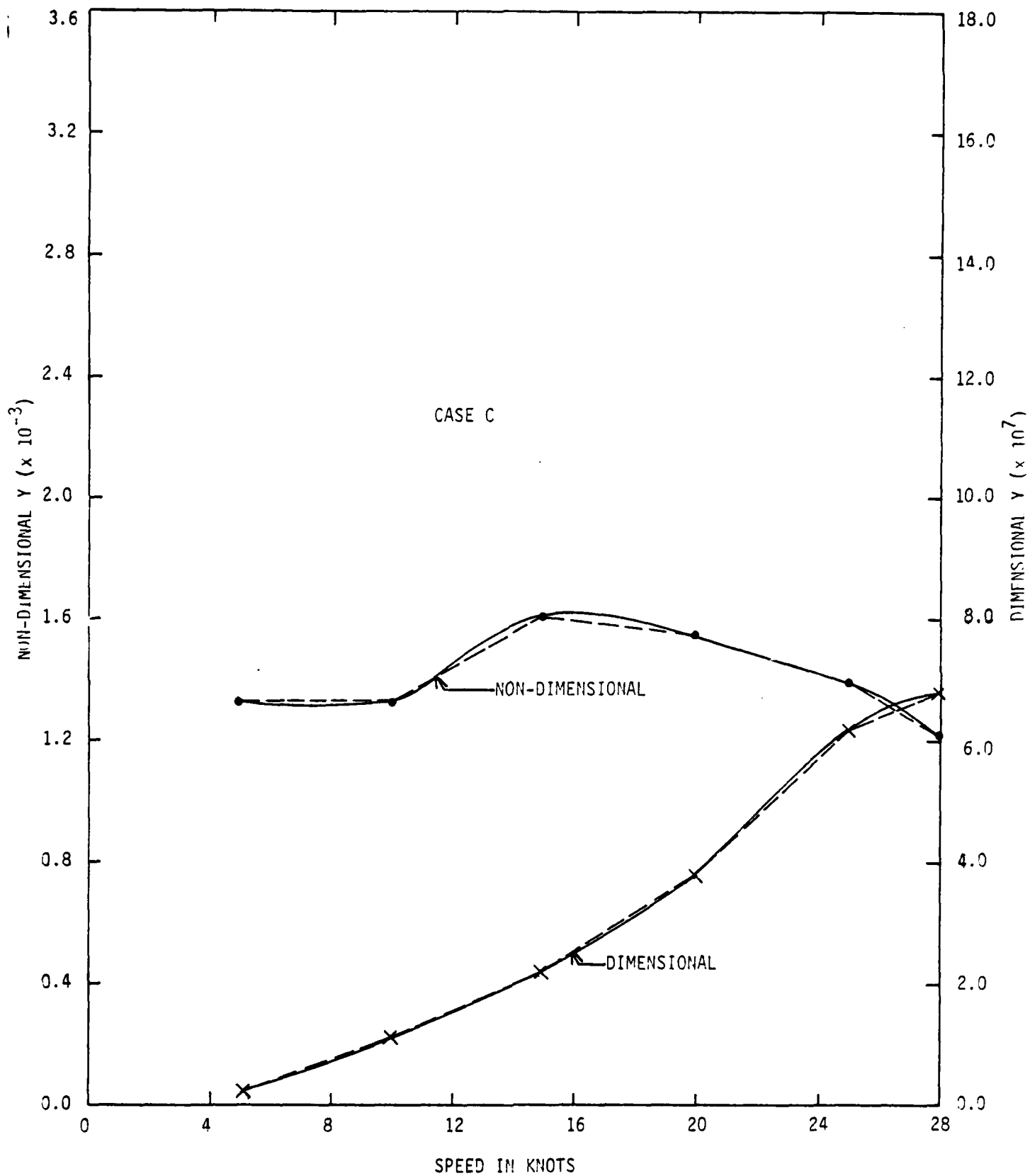


FIGURE 2 Y VS SPEED FOR ROLL = 6° , DRIFT = 4° , $r' = 0.3$

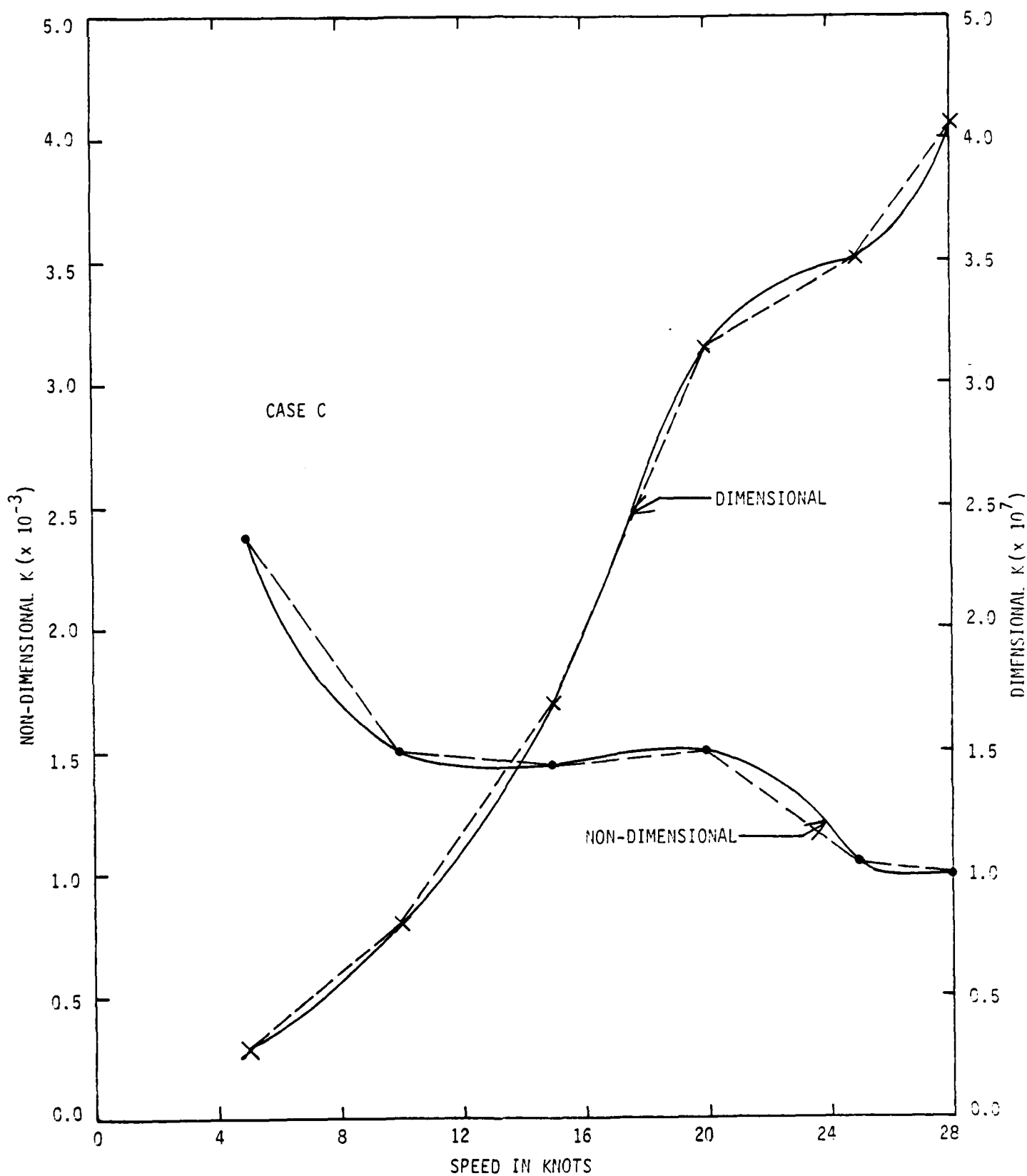


FIGURE 3 K VS SPEED FOR ROLL = -6° , DRIFT = -4° , $r' = -0.3$

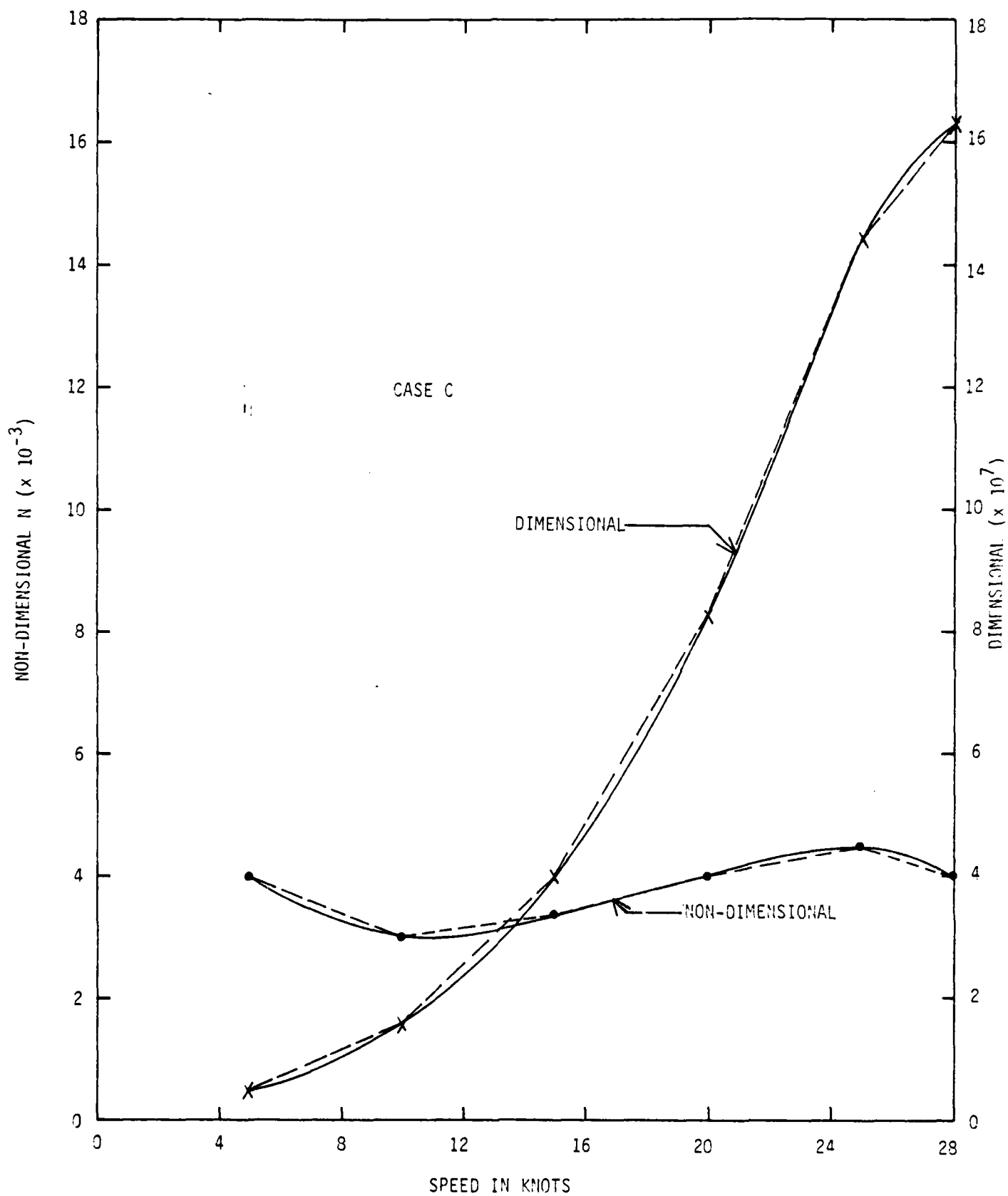


FIGURE 4 N VS SPEED FOR ROLL = DRIFT = 0^0 , $r' = -0.3$

The range of variables covered in the final data base used in the mathematical model proved adequate for all simulated maneuvers except for turns carried out by application of a differential thrust at 5 knots. For these cases, the non-dimensional turn rate ($r' \propto r/u$, $u \rightarrow 0$) can be as large as 1.5 and drift angles as large as 10.0° . However, a linear extrapolation of the available data should produce reasonable results since all low speed parametric curves examined show strong linearity.

The drag along the body x direction is calculated from EHP curves provided by DTNSRDC. For a given value of the EHP, the drag is obtained from the formula,

$$\text{Drag} = (\text{EHP} \cdot 326)/U,$$

where U is the speed in knots. This mathematical is strictly valid for straight ahead flight at zero trim. Effects of ship motion can be easily taken into account when more extensive EHP data becomes available. The effect of changes in drag due to changes in ship immersion is taken into account by computing the percent changes in frontal and wetted areas from ship geometrical factors. The resulting drag formula is given by,

$$R' = R(1.0 + 0.08(Z_0 + Z_E)),$$

where R is the nominal resistance that would be obtained for $Z_E = 0.0$, Z_0 is a reference heave in meters, and Z_E is the heave, which is assumed positive downward. Although the above formula is approximate, it should be sufficiently accurate for purposes of the present study since changes in drag will be small due to the small waterplane area, and due to the small changes of immersion encountered.

A vertical force model was developed based on data provided by DTNSRDC. Due to the wide scatter in the data, the only variable having a discernable effect on z appears to be the speed. An analysis of the data provided leads to the following model:

$$Z = (1.53 + 0.125U)\rho L^2 U^2 / 2000.$$

The magnitude of the above force results in only minor changes in heave. For example, at a speed of 25 knots, the vertical force will result in a change in heave of approximately 0.25 meters.

A hull pitch moment is estimated from the drag force times an appropriate moment arm. The moment arm is chosen such that the resulting pitch moment is zero during straight ahead flight at zero degree trim.

RUDDER FORCE AND MOMENT MODEL

Experimental data for the rudder X , Y , K and N forces were provided by DTNSRDC in a form similar to the hull force data. Only two parameters were varied, the rudder angle of attack and the speed. Since the hull data contained the effect of zero rudder angle, the rudder force described in this section represents the increment in force due to non-zero angle of attack on the rudder. From geometric considerations, the angle of attack on the rudder used in the rudder force model equals the rudder deflection angle. If, instead, the rudder forces had not been included in the hull, the appropriate rudder angle would be the actual inflow angle on the rudder, dependent not only on the deflection angle but also on the ship state variables, such as drift angle and yaw rate.

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For various rudder sizes, a combination of theory and empirical considerations yields the equation

$$F = F_0 \times \left(\frac{AR'}{AR_0} \right)^{\frac{1}{2}} \times \frac{Area'}{Area_0}$$

where F_0 is the force or moment for the design rudder, and AR = aspect ratio. From pure theory, at very high aspect ratios the rudder force is independent of small changes in the aspect ratio and is proportional only to the area change. At very low aspect ratios, the rudder force is proportional to both area change and the percent aspect ratio change. Since the curve is smooth between these two points, for a rudder between these two

extremes the rudder force is proportional to $\left(\frac{AR'}{AR_0} \right)^K$ where K lies between zero and one. Based on an examination of experimental data and theoretical considerations, a value of 0.5 is assigned to K . Through the use of this formula, changes in rudder forces due to pitch and immersion changes are included in the rudder force model. The rudder Z force is assumed to be zero, and the pitch moment is calculated as the X force times a moment arm equal to one half the submerged rudder draft plus the distance from the coordinate system origin to the waterline. The above formula is approximate. However, only small changes in aspect ratio and areas are considered in this study. Under these conditions, the above formula should be sufficiently accurate.

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Data was also supplied for the fixed forward rudder (Case E and F). By subtracting the Case A (no fixed forward rudder) forces from the Case E forces, one obtains a data base for the fixed forward rudder as a function of the three parameters: speed, drift angle and yaw rate. The drag data for the fixed rudder are quite scattered. Because of this, the theoretical approximations relating drag to lift is used: $\text{drag} = \text{lift}/7$. Since the additional drag of the rudder is but a small fraction of the total drag, this approximation is adequate.

A three dimensional interpolation procedure is used to obtain the appropriate non-dimensional fixed rudder forces. It should be noted that only one fixed rudder will be used at a time, the starboard one for starboard turns and vice versa. During the transition time of zero extension to full extension, the forces are assumed to be in direct proportion to the ratio of extended length/full length.

FIN FORCE AND MOMENT MODEL

The SWATH configurations considered in this study have four horizontal fins located on the inside of the hulls, two forward and two aft. The angle of attack of these fins can be individually changed to control pitch, induce roll, and control depth. The mathematical model used to characterize the fin lift is given by,

$$\text{Lift} = (1/2)\rho A U_f^2 \frac{\partial C_L}{\partial \alpha} \alpha$$

where

A = fin area or chord X span

U_f = local inflow velocity

$\frac{\partial C_L}{\partial \alpha}$ = lift coefficient slope.

α = fin angle of attack.

The value of the lift coefficient slope is obtained from data supplied by DTNSRDC. The values for the slope remain constant for fin angles of attack up to 15^0 , after which stall occurs resulting in a rapid decrease in lift. For fin angles of attack less than 15^0 , there is good correlation between the measured value of 1.19 and the theoretical value of 1.3. Since the slope of the lift coefficient agrees quite well with the theoretical prediction, it is assumed that the actual lift/drag ratio can be adequately approximated by the theoretical prediction for similar fins. The increment in drag due to non-zero fin angle of attack is obtained directly from the lift/drag ratio and the lift. The fin drag at zero angle of attack is contained in the hull force data base.

The fin angle of attack is dependent on the fin deflection angle and the ship velocities. The local velocities are given by

$$U_f = U - r \cdot Y_f + q \cdot Z_f,$$

$$W_f = W - p \cdot Z_f + r \cdot X_f,$$

where X_f , Y_f , and Z_f are the coordinate location of the fin. It is assumed that the fluid flow parallel to the fin span has a negligible effect on the fin lift and drag. Since the fin lift and drag are perpendicular and parallel to the stream flow, these values are transformed to the body coordinate system. The force along the body y axis is assumed to be zero. The roll, pitch, and yaw moments are obtained from the transformed forces by multiplying by appropriate moment arms. The center of pressure is assumed to be at the one quarter chord and one half span.

Note that the fin model is valid only up to angles of attack of approximately 15^0 . For larger angles of attack, the model overestimates the

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lift and under estimates the drag since stall effects are neglected. During normal maneuvers, fin angles of attack larger than 15° are rarely required. The results of work being conducted by Dr. C. M. Lee*, DTNSRDC, will be incorporated at a future date prior to carrying out simulation studies using the fins. This effort presents refined estimates appropriate for the fins.

*

C. M. Lee and Mr. Martin, "Determination of the Size of Stabilizing Fins for Small Waterplane Area Twin-Hull Ships", DTNSRDC Report 4495, Nov 1974.

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PROPELLER THRUST MODEL

The SWATH configurations considered in this study are driven by two submerged variable pitch propellers. The mathematical model used to represent the thrust is based on experimental data provided by DTNSRDC. These data were obtained for a single SWATH strut/hull/propeller configuration. The value for K_T and K_Q were measured for advance ratios values (J) ranging from -2.5 to 5.0 and for pitch/diameter ratios ranging from -4 to 4. Data were extracted from the curves and are used in a two dimensional interpolation procedure to obtain K_T values. The corresponding thrust is given by the formula,

$$T = K_T \rho n^2 D^4,$$

where

ρ = density of water,

n = rotational speed of the propeller in
revolutions per second.

D = propeller diameter.

The thrust is assumed to act along the thrust line used in the experimental testing, which was parallel to the body x axis. In the simulation model, each propeller is treated separately so that differential thrust can be applied.

The advance coefficient is given by

$$J = V_a / (nD),$$

where V_a is the speed of advance of the propeller. The value of V_a is less

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than the ship velocity due to hull interference effects. These hull interference effects are taken into account via a wake fraction. An average value of 0.82 is used in the mathematical model, i. e.,

$$V_a = 0.82 U.$$

The propeller forces along the body y and z axes and the roll moment are assumed negligible and not modeled. The pitch and yaw moments are calculated from the propeller thrust times the appropriate moment arms.

The propeller model neglects changes in thrust due to non-zero inflow angle. This effect is small during high speed turns but may become significant for low speed turns that result in large drift angles. The large changes in inflow angle can lead to non-zero values for the propeller forces along the y and z body axes. The effect would be largest for low speed turns (less than 5 knots) carried out by the application of a differential thrust. In these cases the ship transverse velocity can be a significant fraction of the forward speed. Including the effects of changing inflow angles is beyond the scope of the present effort. It is expected that these effects will have a small effect on the predictions presented in this report.

AERODYNAMIC FORCE MODEL

At this time, the forces and moments due to aerodynamic effects have been ignored and set equal to zero. A rough estimate of the magnitude of the aerodynamic forces and moments indicates that a 25 knot wind at 90° would result in a roll angle change of less than 0.25° . Based on this estimate, neglecting the aerodynamic forces and moments is a reasonable approximation.

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BUOYANCY FORCE AND MOMENT MODEL

The buoyancy forces and moments are determined from coefficients Z_θ , Z_z , M_θ , and M_z provided by DTNSRDC. The mathematical expressions for the forces and moments are given by,

$$Z_B = Z_\theta \theta + Z_z Z$$

$$M_B = M_\theta \theta + M_z Z$$

$$K_B = (\text{Beam}/2)^2 \tan \phi Z_z,$$

where Z_z is the combined value for both hulls. The drag, y axis force, and yaw moment due to buoyancy are assumed zero.

RATE DEPENDENT FORCES AND MOMENTS

Various first and second order rate dependent coefficients are contained in the equations of motion. These are of the form X_i and X_{ij} where X represents a force or moment and i and j represent u, v, w, p, q, r . The entire term is the local derivative of X with respect to $i(j)$ so the associated force or moment is equal to $X_{ij} \cdot \dot{i} \dot{j}$, where $\dot{i}$ and $\dot{j}$ represent the velocities of the ship. At the present time, experimental values have not been provided so all terms have been set to zero. Research, that should lead to theoretical estimates of these coefficients is currently underway at DTNSRDC by C. M. Lee, et al.

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SIMULATION PREDICTIONS

The digital simulation system developed during this study has the capability of simulating various maneuvers via simulated pilot actions or commands. The possible pilot actions consist of rudder deflections, propeller RPM changes, propeller pitch changes, fin angle changes, and changes in the position of the forward turning foil. All controlled elements can be independently moved; i. e., the starboard RPM can be set to 0.0 and the port RPM to a non-zero value simultaneously. The occurrence of a pilot action is governed by the value of time and/or state variables. The pilot actions were used to carry out turning maneuvers at high and low speeds, stopping at low speeds, and zigzag type of maneuvers. The results of the turning and stopping simulations are reported in this section.

Several different SWATH ships having various masses and slightly varying length/beam ratios were simulated. Minor modifications in the mathematical models were made to compensate for the dissimilarities between the experimental test model and the actual ship being considered. These modifications were discussed in detail with DTNSRDC personnel prior to generating final results. Results for one set of ship parameters, as listed in Table 5, are presented in this report.

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TABLE 5 -- Design Characteristics of Full Scale SWATH
Used for Sample Predictions

	<u>General Parameters</u>
Linear ratio full scale/model	22.5
Length	73.15m
Strut Length	52.5m
Strut Thickness	2.21m
Transverse Strut Separation	22.86m
Displacement, design draft	$2.9 \times 10^6 \text{kg}$
Displacement, deep draft	$3.015 \times 10^6 \text{kg}$
Design draft	8.13m
Deep draft	9.27m
Wetted surface, design draft	2847m ²
Wetted surface, deep draft	3088m ²
Longitudinal distance, nose to origin	35.14m
Vertical distance, baseline to origin	10.36m
Forward fins, each:	
Chord	2.61m
Span	2.903m
Aspect ratio	1.11
Longitudinal distance, origin to center of pressure	18.42m
Transverse distance, centerline to center of pressure	7.76m
Vertical distance, origin to center of pressure	8.06m
$\frac{\partial C_L}{\partial \alpha}$, per radian	1.9
Aft fins, each:	
Chord	4.5m
Span	5.0m
Aspect ratio	1.11
Longitudinal distance, origin to center of pressure	26.71m
Transverse distance, centerline to center of pressure	7.76m
Vertical distance, origin to center of pressure	8.06m
$\frac{\partial C_L}{\partial \alpha}$, per radian	1.19

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TABLE 5 -- Design Characteristics of Full Scale SWATH
Used for Sample Predictions (cont.)

	<u>General Parameters</u>
Propellers:	
Diameter	4.36m
Nominal Pitch/Diameter ratio	1.0775
Pitch/Diameter range	-0.6 to 1.2
Longitudinal distance, propeller to origin	39.72m
Transverse distance, propeller to centerline	11.43m
Vertical distance, propeller to origin	8.06m
Strut Rudder, each:	
Chord	5.72m
Span	7.32m
Thickness	1.71m
Span, to design waterline	3.0m
Area, to design waterline	21.96m
Longitudinal distance, origin to center of pressure	19.92m
Transverse distance, centerline to center of pressure	11.43m
Vertical distance, origin to center of pressure -- design waterline	3.73m
Spade Rudder, each:	
Chord	5.42m
Span, leading edge	10.82m
Span to design waterline, leading edge	3.85m
Thickness	0.813m
Area, to design waterline	21.9m
Longitudinal distance, origin to center of pressure	30.4m
Transverse distance, centerline to center of pressure	11.43m
Vertical distance, origin to center of pressure -- design waterline	4.1m
Fixed forward turning foil:	
Chord	3.49m
Span	6.98m
Aspect ratio	2.0
Area	24.34m ²
Thickness	0.15
Longitudinal distance, origin to center of pressure	18.42m
Transverse distance, centerline to center of pressure	11.43m
Vertical distance, origin to center of pressure	13.85
Fixed angle of attack	5°

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HIGH SPEED TURNS

High speed turn maneuvers are carried out by deflecting the aft rudders from zero degrees to the desired rudder angle at a rate of 5 deg/sec. The simulation is run for a sufficiently long time such that the heading angle changes by 180° .

The desired turn diameter at high speeds was specified to be less than seven ship lengths. A comparison of turn diameters versus rudder angle for strut and spade rudder configurations indicates that the specification can be met by the spade rudder configurations, but not by the strut rudder configurations. A comparison of turning performance at 20 kts for both configurations is presented in Figure 5. The turn diameter specification is met at speeds of 25 kts with the spade rudder configuration, as illustrated in Figure 6.

If turn maneuvers are performed at a draft deeper (1 meter) than the design draft, a significant reduction in turn diameter is achieved (see Figure 6). However, the speed reduction during the turn is greater for the deeper draft. At 25 kts, there is a 19 percent reduction in speed at the deeper draft compared with a 12 percent reduction at the design draft. The

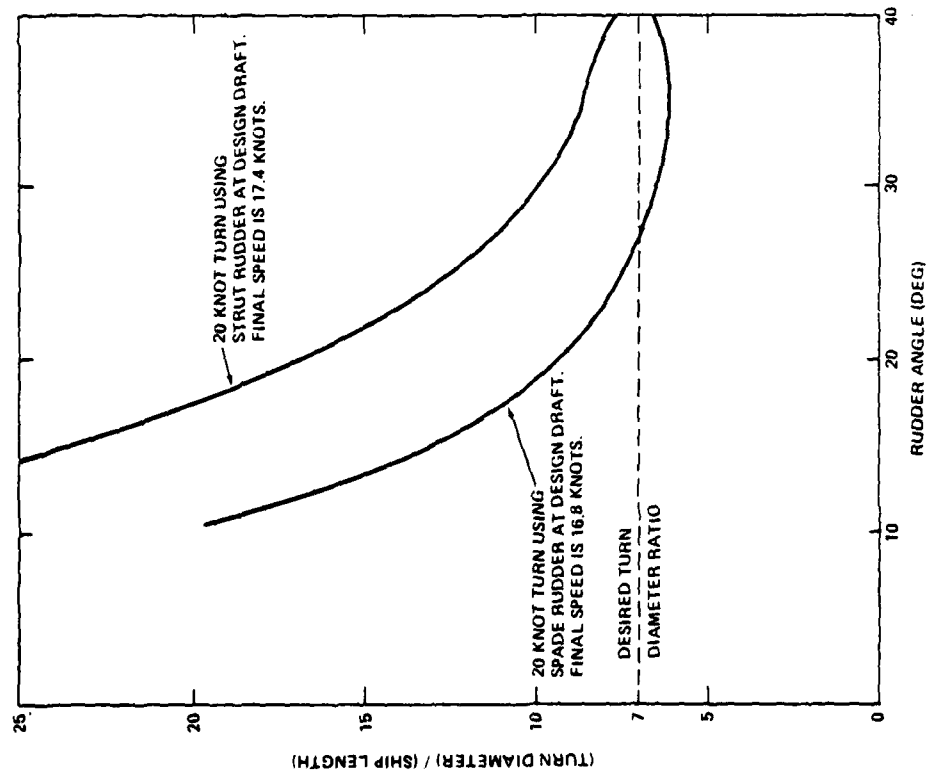


FIGURE 5 COMPARISON OF STRUT TURN DIAMETERS
WITH SPADE TURN DIAMETERS

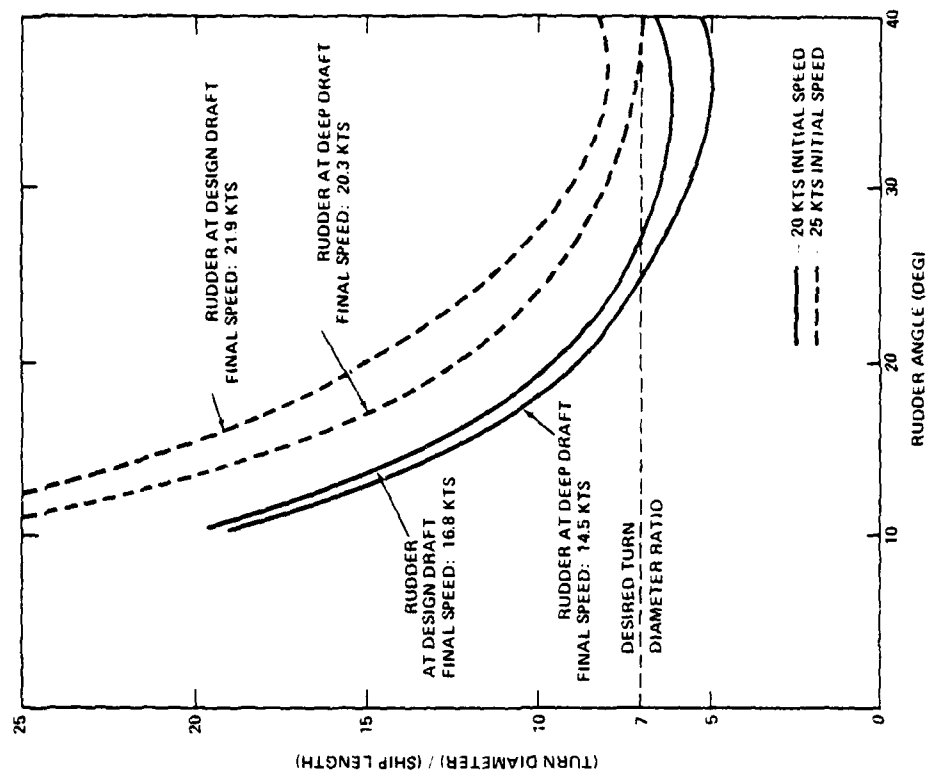


FIGURE 6 COMPARISON OF DESIGN DRAFT TURN
DIAMETERS FOR SPADE RUDDERS

percent reduction in speed is greater at the lower speeds, 27 percent for the deeper draft and 16 percent for the design draft. A deeper draft can be obtained by using the four fins to induce a net downward force.

An analysis of Figures 5 and 6 indicates that there is a small increase in turn diameter as the rudder angle increases beyond approximately 35° . This increase in turn diameter is attributed to rudder stall effects. Other factors associated with the fluid flow pattern may also contribute to this effect.

The excursions in roll angle and drift angle are minor in all cases simulated. For example, the steady state roll angle in a 20 Kt turn is less than 4° and the drift angle is less than 2.5° . Note that the ship rolls out during a turn.

The forward turn foils are not employed in the above simulation studies. The use of these rudders may induce a sufficient turning moment so that the strut rudders would be sufficient to turn the craft within seven boat lengths. A suitable mathematical model necessary to model these forward rudders or foils is currently under development. It is expected that the relative differences between the curves appearing in Figures 5 and 6 will remain the same when the forward turn foils are employed. The net effect should be to lower all of these curves by approximately the same amount.

A comparison of SWATH turn trajectories at 20 kts with a destroyer turn trajectory at approximately the same speed is illustrated in Figure 7. The SWATH transfer is approximately 25 percent greater than the transfer for the destroyer. The SWATH turn maneuver employed only the spade rudders at

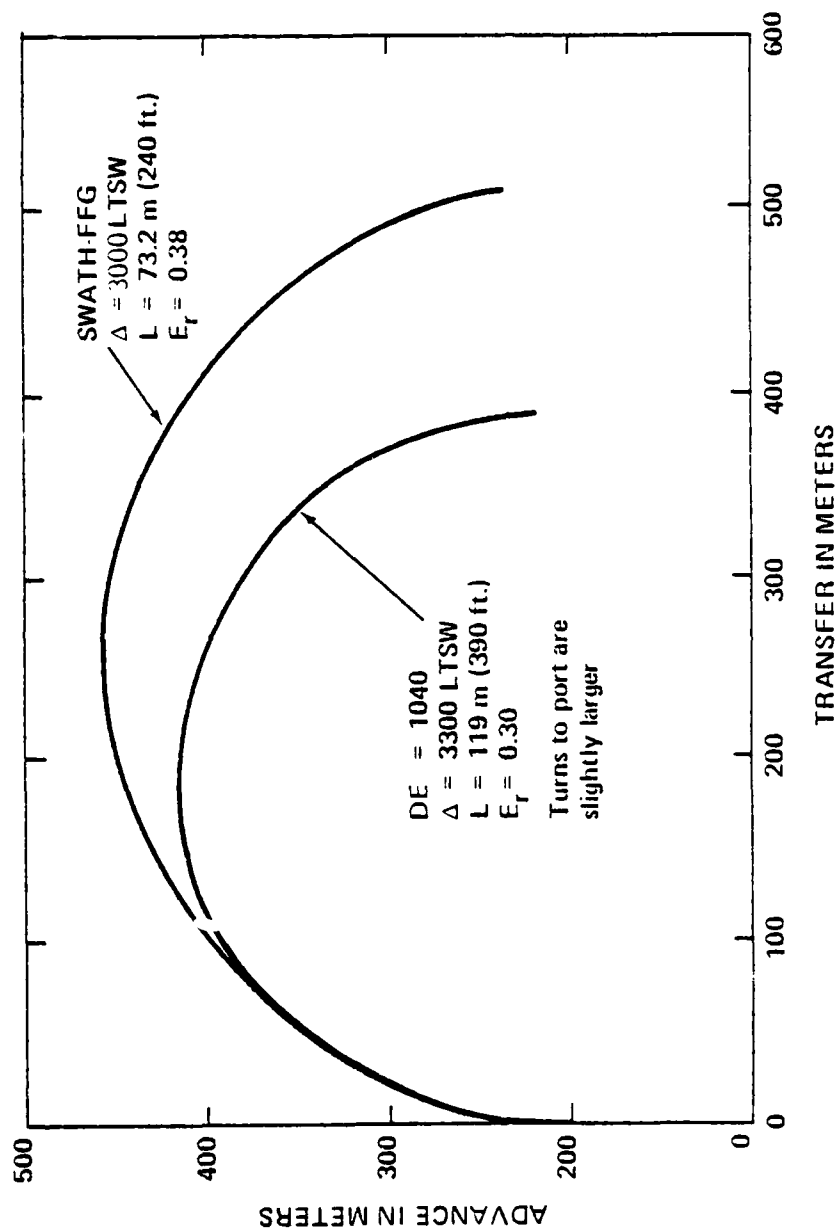


FIGURE 7 SWATH TURN TRAJECTORY COMPARED WITH A DESTROYER TURN TRAJECTORY

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design draft. The forward turn foils or differential thrust capabilities are not utilized.

The SWATH turning performance at low speeds is quite impressive. Low speed turn results are discussed in the next subsection.

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LOW SPEED TURNS

Low speed turns (5 and 10 kts) are accomplished by applying a differential thrust in addition to using the aft rudders. The objective of the simulation effort is to determine the proper combination of differential thrust and rudder angle such that the advance is a minimum for a 90° turn. Also, the horse power requirements are to remain less than a specified value. The desired performance can be accomplished by changing the propeller pitch/diameter ratio on one side of the ship to -0.6 and the opposite pitch/diameter ratio to 1.0. The resulting predicted advance is approximately 110 meters for a 5 kt turn. At the lower speeds, the rudders are not very effective in turning the ship. In fact, the predicted turn diameter achieved by applying only a differential thrust is about 15 meters larger at 5 kts.

During the low speed turns, both the drift angle and non-dimensional yaw rate exceed the range of the available data base. The drift angle may increase to 10° and the non-dimensional yaw rate to values up to 1.5. The reason for such large values is that the ship is turning at a high rate at a very low speed and is, in effect, pivoting about the propeller location. Extrapolation of the data should provide reasonable results due to the extreme

linearity of the data at low speeds. Further experimental tests would be necessary to fully determine the validity of the extrapolations.

The ship advance during low speed turns is only slightly larger than the ship length (75m). Hence, in obstacle avoidance maneuvers, it is of interest to examine the predicted path swept out by SWATH, in addition to the CG trajectory. The actual path swept out by SWATH during a low speed turn is illustrated in Figure 8. These results indicate that SWATH is capable of avoiding a point obstacle approximately 112 meters in front of the craft, by a turning maneuver. A better maneuver for avoiding point obstacles at low speeds involves stopping the ship. Stopping maneuvers are discussed in the following section.

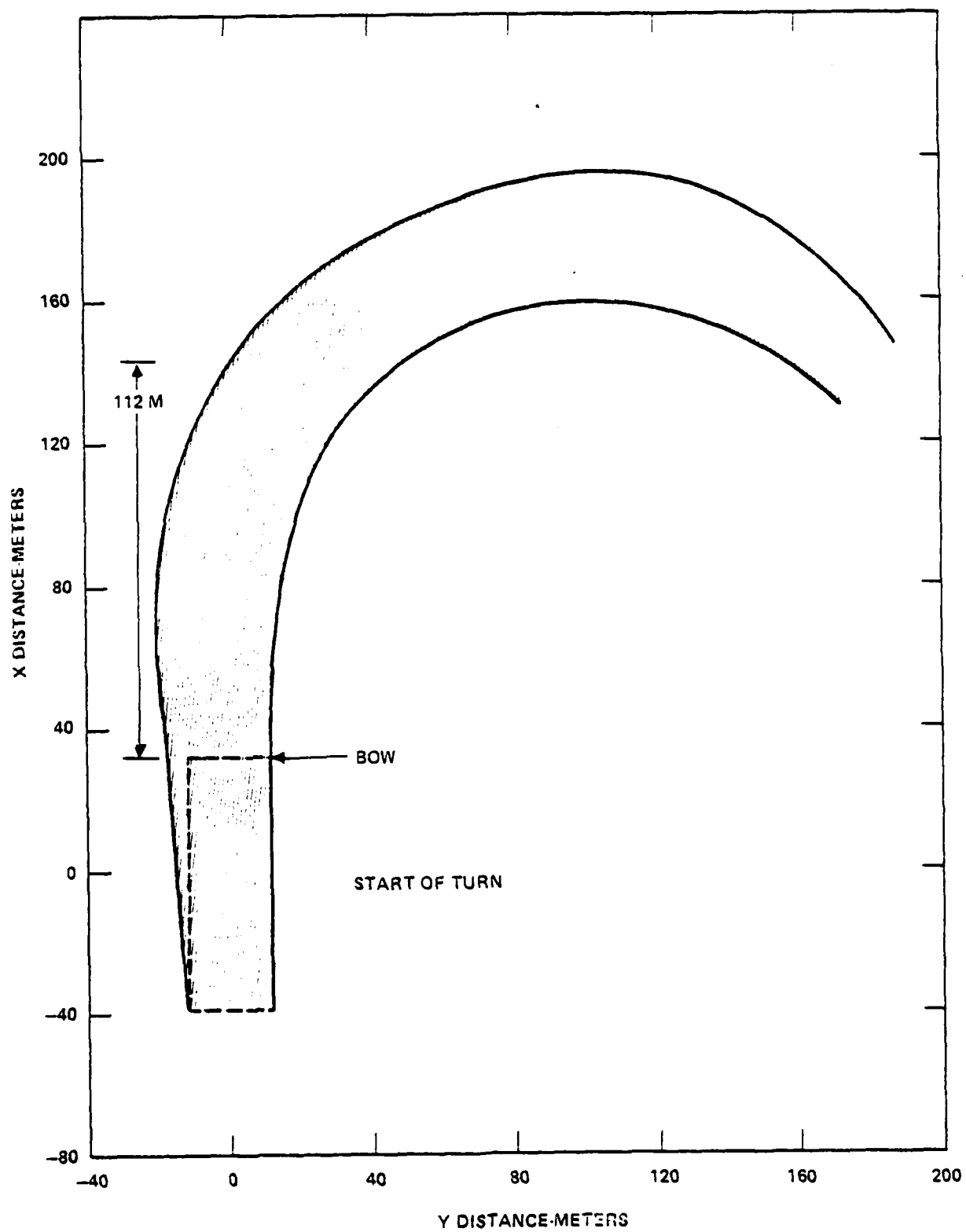


FIGURE 8 PATH SWEEPED OUT BY SWATH DURING A 5 KT TURN

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STOPPING

Stopping maneuvers were performed at 5 and 10 kts by changing the propeller pitch/diameter ratio to a value of -0.6 over a period of 5 seconds. Without deflecting the rudders to increase drag, the predicted stopping distances are 27m and 80m for speeds of 5 and 10 kts respectively. However, reducing the pitch/diameter ratio to a value of -0.6 over a 5 second period results in higher horsepower requirements than desired. In order to maintain horsepower requirements, the minimum pitch value is set to be -0.15 . The resulting stopping distances for 5 and 10 kts are 34m and 97m, respectively.

In order to improve stopping performance, the rudders can be deflected to their maximum values thereby increasing the drag. However, the net change in stopping distance is negligible. Such a maneuver may be more effective for high speed stopping.

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FIN EFFECTS ON TURNS

The fins can be employed to change the roll angle during turn. It was found that by forcing the ship to roll out more during a turn, the turning rate increased slightly, and vice versa. Because of stall effects, the fin angles were limited to values less than 15° during this investigation. At these angles, the fins have very little effect on the turn diameters. Based on the comparisons of predicted turn diameters for different drafts, it may be more beneficial to use the fins to produce a net downward force and thus increase the draft.

OVERVIEW

The digital simulation system used to implement the mathematical model for numerical solution is a FORTRAN computer program designed to operate on the CDC 6700 digital computer located at DTNSRDC, Carderock. The final code is based on a preliminary design developed using a "top down" approach. Many features of existing digital simulation programs for AALC are incorporated in the present system, such as, the pilot action strategy (Subroutine CONTRL), hydrodynamic table lookup procedure (Subroutines HYDINT, HYDPAR), and the Runge-Kutta-Merson integration algorithm (Subroutine KUTMER)*. Several of the modules employed have been previously developed and tested by ORI (TAB2V, TAB3V, NGHBR1). The highly modular structure of the digital simulation system with well defined interfaces allowed simultaneous and on schedule development and unit testing of all force and moment subroutines by several different analysts. Also, the modular design is extremely flexible allowing various SWATH configurations to be easily modeled.

A block diagram for the complete simulation system is illustrated in Figure 9. The order in which programs are called is in a downward fashion from left to right, except the block data module which is initialized at compile time. The main program serves as a driver for the system as illustrated by the Flowchart appearing in Figure 10. Brief descriptions of major subroutines and functions are presented in Table 6. More detailed descriptions of the subroutines are presented later in this report. A listing is presented in Appendix B.

*R.F. Messalle, "First Generation Dynamic Simulation Model for an Air Cushion Vehicle", ORI, Report #814, September 28, 1973, Contract No. N00167-73-C-0213

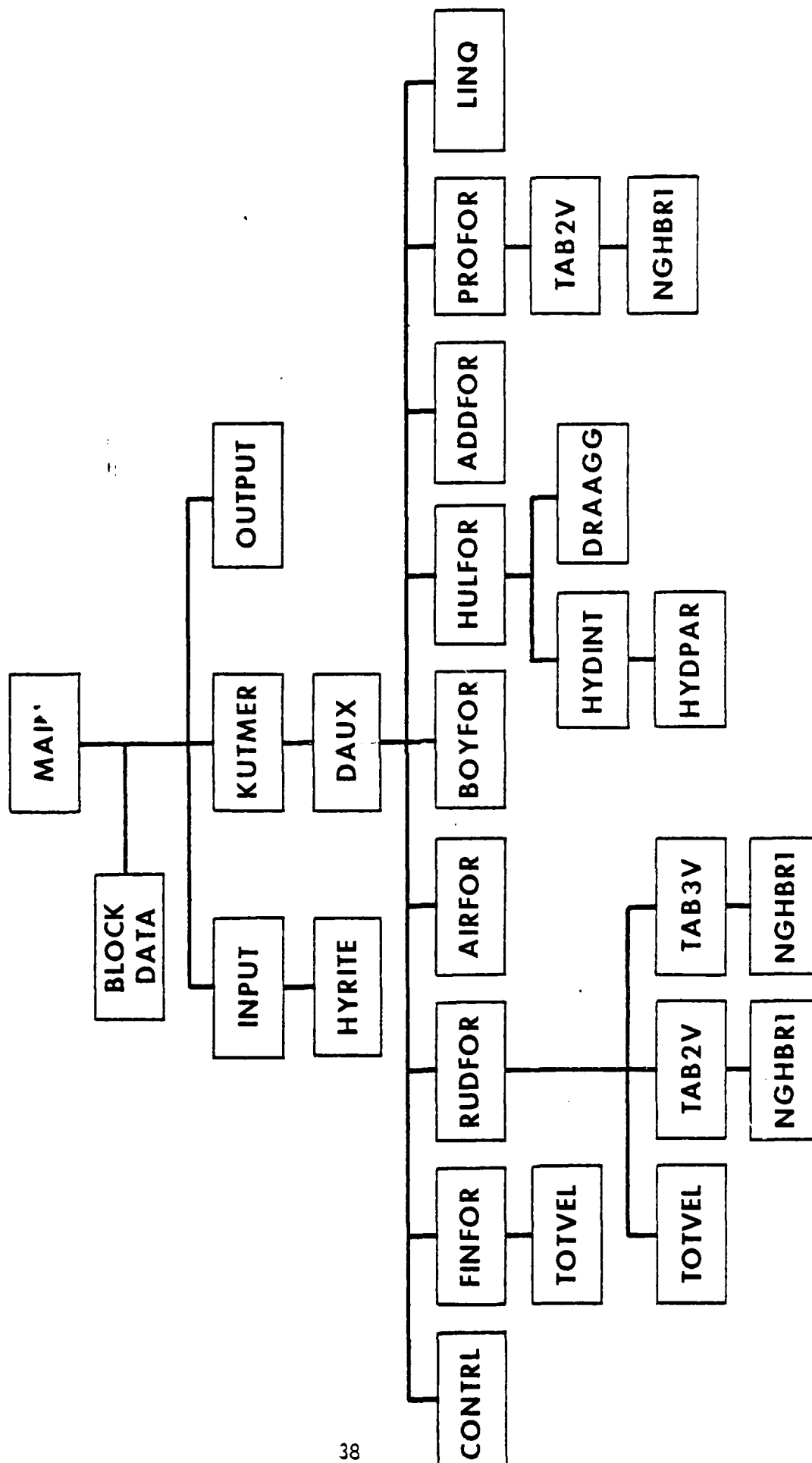


Figure 9 - SWATH Digital Simulation System Block Diagram

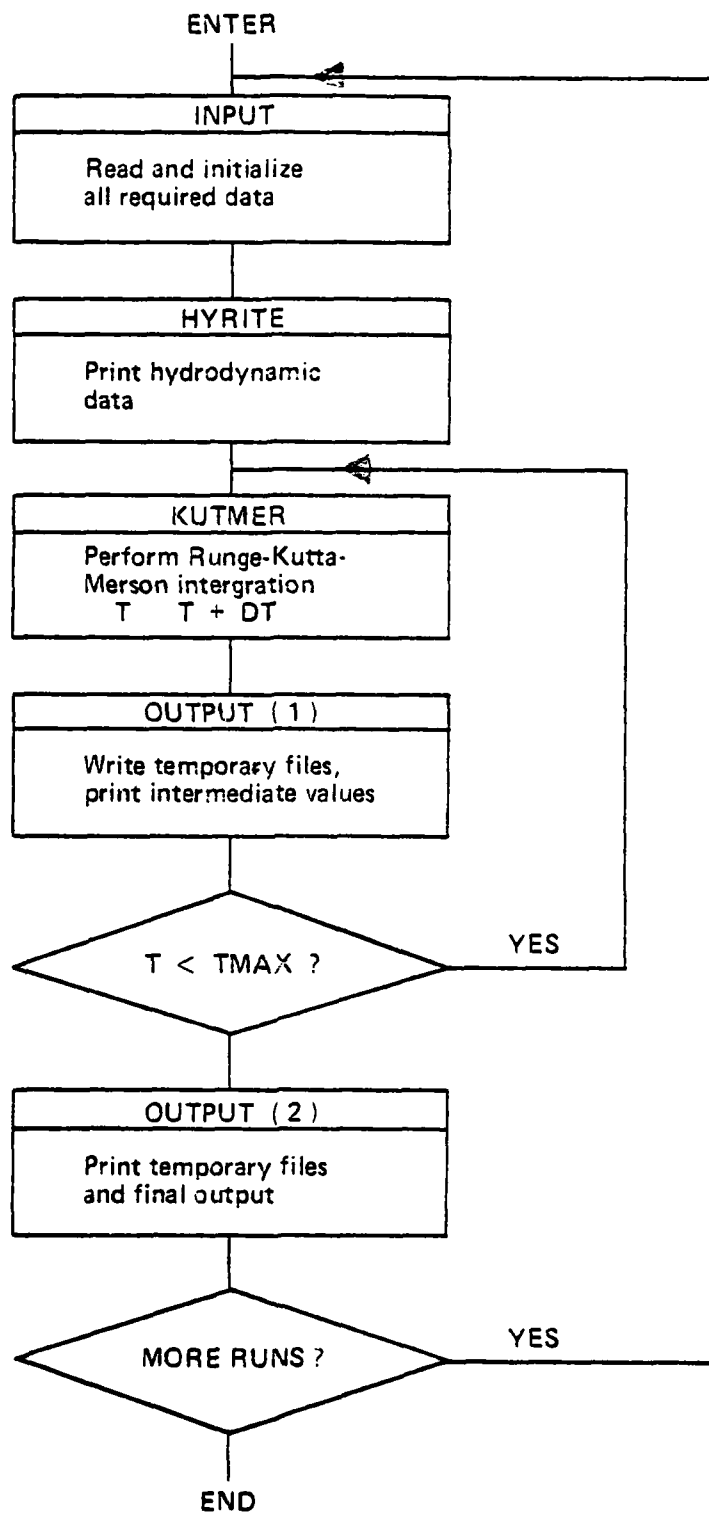


Figure 10 - Flowchart for Main Program

TABLE 6 - SUMMARY OF SUBROUTINE DESCRIPTIONS

SWATH	Main program. Serves as a driver for the entire system.
INPUT	Reads control data, NAMELIST input and hydrodynamic data. converts variables to internal MKS units and initializes state variables.
OUTPUT	Loads output data into page arrays and writes results on line printer.
CONTRL	Control system. Changes control surfaces according to pilot action data.
TURNON	Turns on all intermediate printout options used for de- bugging.
DAUX	Computes mass matrix, calls all force subroutines and com- putes total force vector. Calls LINQ to solve simultaneous equations for state acceleration vector.
BLOCKD	Block data. Initializes all pertinent parameters. Default values can be overridden by processing in subroutine INPUT.
ADDFOR	Computer forces and moments due to rate dependent terms in operations of motion (N_v , Y_v , etc.).
HYRITE	Prints out a table of the hull hydrodynamic Y, K and N forces and moments.
DRAAGG	Computes the drag (X force) on the hull.
HULFOR	Computes the hull hydrodynamic forces and moments by calling appropriate subroutines.
BOYFOR	Computes forces and moments due to buoyancy.
FINFOR	Computes all forces and moments due to the fins.

TABLE 6 - SUMMARY OF SUBROUTINE DESCRIPTIONS (continued)

TOTVEL	Calculates total inflow U, V, W velocities given the position vector and the ship motions.
RUDFOR	Calculates forces and moments due to aft movable rudders and fixed forward rudder.
AIRFOR	Calculates aerodynamic forces and moments.
PROFOR	Calculates propeller forces and moments.
LINQ	Solves for $\vec{X}$ where $\vec{A} \vec{X} = \vec{B}$. In this case, $\vec{X} = (\dot{u}, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r})$.
EULER	Performs Euler integration on state vector and updates time.
TAB2V	Subroutine to perform 2-dimensional interpolation on data.
NGHBR1	Finds nearest neighboring points in grid arrays used by interpolation subroutines TAB2V and TAB3V.
TAB3V	Subroutine to perform 3-dimensional interpolation on data.
HYDINT	4-way interpolation subroutine to calculate hydrodynamic hull forces based on speed, roll angle, drift angle and yaw rate.
HYDPAR	Computes interpolation coefficients for HYDINT.
KUTMER	Subroutine to perform Runge-Kutta-Merson integration.

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Communication between various subroutines is handled via named common blocks wherever possible. The FORTRAN symbols appearing in the common blocks are defined in a global sense. For example, the symbol U represents the ship velocity along the body x-axis in all subroutines. Definitions of all variables appearing in named common blocks are presented in Table 7. The table contains brief descriptions, the type of variable (Real, integer, etc.), and the units. Generally, descriptive notation is employed in defining the FORTRAN symbols. Some exceptions are (XC, YC, ZC) which represent (XG, YG, ZG), the CG location.

Core requirements are approximately 41,000 words base 10. Execution time is generally 5 times or more faster than real time.

A definition of required job control commands, a definition of all input data, and a user's guide are presented in the next section. Several test run setups are also presented.

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TABLE 7 DEFINITION OF FORTRAN SYMBOLS APPEARING IN NAMED COMMON BLOCKS

FORTRAN Symbol	Description	Type	Units
<u>COMMON /AIRVAR /</u>			
AIRFM (1-3)	Air resistance X, Y, Z forces along body axes	Real	nts
AIRFM (4-6)	Air K, M, N moments about body axes	Real	nt-m
<u>COMMON /ADDDVAR /</u>			
ADMTRX(6,6,6)	Matrix of rate dependent 2nd order terms for hull forces	Real	-
ADDFM (1-3)	Rate dependent X, Y, Z forces	Real	nts
ADDFM (4-6)	Rate dependent K, M, N moments	Real	nt-m
RTMTRX(6,6)	Matrix of 1st order rate dependent terms for hull forces	Real	-
<u>COMMON /BOYVAR /</u>			
MSUBZ	Restoring derivative M_z due to buoyancy	Real	nt-m/m
MSUBTH	Restoring derivative M_θ due to buoyancy	Real	nt-m/rad
ZSUBZ	Restoring derivative Z_z due to buoyancy	Real	nts/m
ZSUBTH	Restoring derivative Z_θ due to buoyancy	Real	nts/rad
BUOYFM (1-3)	Buoyancy X, Y, Z forces along body axes	Real	nts
BUOYFM (4-6)	Buoyancy K, M, N moments about body axes	Real	nt-m
<u>COMMON /CGMOVE /</u>			
XC,YC,ZC	X, Y, Z coordinates of center of gravity	Real	m
<u>COMMON /CRAFT /</u>			
SCFACT	Ship-Model scale factor	Real	-
LENGTH	Ship length	Real	m
MASS	Ship mass	Real	kg
IXX,IYY,IZZ	Ship moments of inertia	Real	kg-m ²
IXY, IYZ,IYZ	Ship products of inertia	Real	kg-m ²
<u>COMMON /CONST /</u>			
RADIAN	Number of degrees per radian, 57.29	Real	deg
RHOA	Density of air	Real	kg/m ³
RHOA2	$\frac{1}{2}$ of RHOA	Real	kg/m ³
RHOW	Density of water	Real	kg/m ³
RHOW2	$\frac{1}{2}$ of RHOW	Real	kg/m ³
FTTOM	Conversion feet to meters	Real	m/ft

TABLE 7 (Continued)

FORTRAN Symbol	Description	Type	Units
<u>COMMON /DOTCOE /</u>			
XUDOT	Dimensional coefficient X_u	Real	Kg
YVDOT	Dimensional coefficient Y_v	Real	Kg
YPDOT	Dimensional coefficient Y_p	Real	Kg-m ²
YRDOT	Dimensional coefficient Y_r	Real	Kg-m ²
ZWDOT	Dimensional coefficient Z_w	Real	Kg
ZQDOT	Dimensional coefficient Z_q	Real	Kg-m ²
KVDOT	Dimensional coefficient K_v	Real	Kg
KPDOT	Dimensional coefficient K_p	Real	Kg-m ²
KRDOT	Dimensional coefficient K_r	Real	Kg-m ²
MWDOT	Dimensional coefficient M_w	Real	Kg
MQDOT	Dimensional coefficient M_q	Real	Kg-m ²
NVDOT	Dimensional coefficient N_v	Real	Kg
NPDOT	Dimensional coefficient N_p	Real	Kg-m ²
NRDOT	Dimensional coefficient N_r	Real	kg-m ²
<u>COMMON /FINVAR /</u>			
XFIN(1-4) YFIN(1-4) ZFIN(1-4)	X, Y, Z coordinates of fin center of pressure 1 = bow starboard, 2 = bow port, 3 = aft starboard, 4 = aft port	Real	m
ARAFIN(1-4)	Areas of fins	Real	m ²
CLFIN(1-4)	Lift coefficient of fins	Real	/rad
DRFIN(1-4)	Lift/drag ratio of fins	Real	-
FINANG(1-4)	Fin angles	Real	rad
XFORFN(1-4) YFORFN(1-4) ZFORFN(1-4)	Fin X, Y, Z forces in body	Real	nts
ALIFT(1-4) DRAG(1-4)	Fin lift and drag	Real	nts
FFM(1-3)	Fin X, Y, Z forces in body system	Real	nts
FFM(4-6)	Fin K, M, N moments	Real	nt-m
FINANO(1-4)	Fin angles at time=0	Real	rad

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TABLE 7 (continued)

FORTTRAN Symbol	Description	Type	Units
<u>COMMON /HULVAR /</u>			
HULLFM (1-3)	Hull X, Y, Z forces along body axes	Real	nts
HULLFM (4-6)	Hull K, M, N moments about body axes	Real	nt-m
HULPIK	Difference in draft from design condition, deeper draft=positive	Real	m
<u>COMMON /HYDRO /</u>			
LG (4)	Number of grid points for HYDINT	Integer	-
LZ	Number of zero speed curves	Integer	-
HY (4,3213)	Data points for HYDINT array	Real	nt or nt-m
XG (4, 20)	Grid points for HYDINT array	Real	m/s, rad
IPOINT (4)	Pointer for HYDINT	Integer	-
<u>COMMON /INTGRL /</u>			
DT	Step size for integration procedure	Real	s
DTMIN	Minimum step size for KUTMER	Real	s
TMAX	Maximum time for run	Real	s
AE (15)	Absolute error criterion for KUTMER integration	Real	-
EPS (15)	Relative error criterion for KUTMER integration	Real	-
NSTATE	Number of state variables	Integer	-
<u>COMMON /OPTION /</u>			
IDOF	Degrees of freedom: 4, 5, 6	Integer	-
IOPTN(15)	IOPTN (2) = 0, Do not print pages 3-5 IOPTN (2) = 1, Print pages 3-5; rudder, fin, and propeller forces	Integer	-
<u>COMMON /PROPV R/</u>			
PDIA	Prop diameter	Real	m
PROARM (3)	Prop X, Y, Z coordinates	Real	m
PRPMS	Prop rpm starboard	Real	rpm
PRPMP	Prop rpm port	Real	rpm
PITCHS	Pitch/Diameter ratio - starboard	Real	-
PITCHP	Pitch/Diameter ratio - port	Real	-
PROPFM (1-3)	Prop X, Y, Z forces along body axes	Real	nts
PROPFM (4-6)	Prop K, M, N moments about body axes	Real	nt-m
PTCHSO	P/D ratio - starboard Time = 0	Real	-
PTCHPO	P/D ratio - port Time = 0	Real	-

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TABLE 7 (Continued)

FORTRAN Symbol	Description	Type	Units
<u>COMMON /RDPRT /</u>			
IR (1-5)	Read units	Integer	-
IP (1-10)	Print units, 6 = main output printer	Integer	-
PNT (15)	Optional-debugging output, 9 = hydro array 10 = intermediate force-moment time histories	Logical	-
<u>COMMON /RUDVAR /</u>			
RUDANG (2)	Aft rudder angles, 1 = starboard, 2 = port	Real	rad
UUVEL (10)	Grid velocity array for rudder forces	Real	m/s
RALFA (10)	Grid rudder angle array for rudder forces	Real	deg
AXRUD (100)	X rudder force array	Real	nts
AYRUD (100)	Y rudder force array	Real	nts
AKRUD (100)	K rudder moment array	Real	nt-m
ANRUD (100)	N rudder moment array	Real	nt-m
ARATIO	Rudder sizing ratio, to standard rudder	Real	-
RUDANO (2)	Rudder angles at time=0	Real	rad
NUMUUV	Number of data grid velocity points	Integer	-
NUMRAL	Number of data grid rudder angle points	Integer	-
BRUDAS	Starboard bow rudder position	Real	m
BRUDAP	Port bow rudder position	Real	m
RUDFM (1-3)	Rudder X, Y, Z forces in body system	Real	nts
RUDFM (4,6)	Rudder K, M, N moments about body axes	Real	nt-m
XRUD (2)	X coordinates of aft rudder center of pressure	Real	m
YRUD (2)	Y coordinates of aft rudder center of pressure	Real	m
ZRUD (2)	Z coordinates of aft rudder center of pressure	Real	m
RUDARM	Aft rudder pitch moment arm	Real	m
BRDAPM	Bow rudder pitch moment arm	Real	m
BRSPAN	Maximum bow rudder extended length	Real	m
<u>COMMON /STATE /</u>			
U,V,W	Ship velocity components in body coordinate system	Real	m/s
P,Q,R	Ship angular velocity about body axes	Real	rad/s
PHI	Roll angle	Real	rad
THETA	Pitch angle	Real	rad
PSI	Yaw angle	Real	rad
XE,YE,ZE	Ship position in fixed space coordinates	Real	m
S	Distance travelled	Real	m
SPEED	Ship speed	Real	rad
DRIFAN	Drift angle	Real	rad

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TABLE 7 (continued)

FORTRAN Symbol	Description	Type	Units
	<u>COMMON /STATE /</u> (Continued)		
COSPHI COSTHE COSPSI SINPHI SINTHE SINPSI	Cosines of PHI, THETA, PSI	Real	-
SINPHI SINTHE SINPSI	Sines of PHI, THETA, PSI	Real	-
TMTRX (3,3)	Transformation matrix from fixed system to body system	Real	-
TIME	Time	Real	s
	<u>COMMON /STATE0 /</u>		
TO UO VO WO PO QO RO PHIO THETAO PSIO	Initial time	Real	s
	Initial values of u, v w, P, Q, R, ϕ , θ , ψ	Real	-

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USER'S GUIDE

Examples of input run streams for Cases A - D are illustrated in Tables 8 - 11, respectively. Various temporary and permanent files are required. A summary of the files follows:

TAPE 8	}	Temporary files to store intermediate output
TAPE 10		
TAPE 12		
BINAR	-	Binary file for the system
TAPE 1	-	Data array for hull hydrodynamic Y force
TAPE 2	-	Data array for hull hydrodynamic K moment
TAPE 3	-	Data array for hull hydrodynamic N moment
HYDINT	-	Binary file containing subroutines HYDINT and HYDPAR

The asterisks appearing in the card images should be replaced by account numbers and ID designator appropriate for the user. Files will be copied to appropriate ID files upon request through Code 1572, DTNSRDC.

Four types of data are read from cards: a descriptive title, Namelist/SWATHD/, pilot action data, and rate dependent coefficients. Descriptions of the data sets follow.

Title Card

The first data card is a title card. A full 80 columns may be used.

Namelist/SWATHD/Data

Program control, except for pilot actions, are governed by data located in Namelist/SWATHD/. Namelist input is used to minimize data set up errors, and to relate directly data values with FORTRAN symbols. Many of the FORTRAN symbols are initialized in the BLOCK DATA program. The data cards merely override the values. A complete description of all symbols appearing in Namelist/SWATHD/ is presented in Table 12. Default values are set up for ship parameters presented in Table 5. A few points should be noted regarding

2. The second part of the document addresses the challenges faced by organizations in managing their resources effectively. It highlights the need for strategic planning and efficient allocation of funds. The author argues that without a clear vision and a well-defined strategy, organizations risk mismanaging their resources and failing to achieve their long-term goals.

3. The third part of the document focuses on the role of leadership in driving organizational success. It stresses that leaders must be proactive in identifying opportunities and challenges, and must take decisive action to address them. The text also discusses the importance of communication and collaboration within the organization, as these factors are crucial for fostering a positive work environment and achieving collective success.

4. The fourth part of the document explores the impact of external factors on organizational performance. It discusses how changes in the market, technology, and regulatory environment can influence an organization's operations and outcomes. The author suggests that organizations should remain vigilant and adaptable, constantly monitoring external trends and adjusting their strategies accordingly.

5. The fifth part of the document concludes by summarizing the key points discussed and offering final thoughts on the importance of continuous improvement and innovation. It encourages organizations to embrace change and seek out new ways to optimize their processes and services, ensuring they remain competitive in a rapidly evolving landscape.

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DRAFT

```

AKRUD= 9+0.0,
6.48E+06,6.08E+06,5.70E+06,4.54E+06,-4.74E+06,-5.70E+06,-6.08E+06,
-6.48E+06,
3.11E+06,2.80E+06,2.59E+06,2.37E+06,-2.07E+06,-1.59E+06,-2.81E+06,
-3.11E+06,
4.66E+06,4.55E+06,4.43E+06,3.50E+06,-3.50E+06,-4.43E+06,-4.55E+06,
-4.66E+06,
4.99E+06,4.70E+06,4.42E+06,3.30E+06,-3.30E+06,-4.42E+06,-4.70E+06,
-4.99E+06,
6.48E+06,5.67E+06,4.46E+06,3.24E+06,-3.24E+06,-4.46E+06,-5.67E+06,
-6.48E+06,
5.69E+06,5.60E+06,5.69E+06,4.17E+06,-4.17E+06,-5.69E+06,-5.69E+06,
-5.69E+06,
ANRUD= 9+0.0,
4.02E+06,3.82E+06,3.63E+06,3.48E+06,-3.48E+06,-3.63E+06,-3.82E+06,
-4.02E+06,
1.82E+07,1.74E+07,1.56E+07,1.40E+07,-1.40E+07,-1.56E+07,-1.74E+07,
-1.82E+07,
2.10E+07,2.04E+07,1.98E+07,1.87E+07,-1.87E+07,-1.98E+07,-2.04E+07,
-2.10E+07,
2.49E+07,2.29E+07,2.07E+07,1.97E+07,-1.97E+07,-2.07E+07,-2.29E+07,
-2.49E+07,
1.95E+07,1.74E+07,1.62E+07,1.30E+07,-1.30E+07,-1.62E+07,-1.74E+07,
-1.95E+07,
4+1.83E+07,4+-1.83E+07,
IMAX=120.,PTCHPR=1.07, PTCHSR=1.07,
PRPM50=150., PRPM20=150., DT=3.0, NPRINT=1, IFNC
      2 PILOT ACTIONS
      16      17.88      7      -35.0      5.0      1
      16      17.88      8      -35.0      5.0      1
-1000.5+00
-100000.0
SWATH TEST END
      3SWATHD NRUN=-4. *END
      2 PILOT ACTIONS
-1000.5+00
-100000.0
      END OF FILE

```

TABLE 8 - SAMPLE RUN STREAM FOR CASE A (CONTINUED)

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CASE B

```
JFCARD,CM120000,T200,P4.
CHARGE,NAME,*****.CC,X.
REQUEST,TAPE11,PF.
REQUEST,TAPE10,PF.
REQUEST,TAPE9,PF.
ATTACH,TAPE1,LAKHYDATA,CY=4,IO=
ATTACH,TAPE2,LAKHYDATA,CY=5,IO=
ATTACH,TAPE3,LAKHYDATA,CY=1,IO=
ATTACH,FINAR,JEVSEATH-1/4P,IO=
ATTACH,HYDINT,FINARY-AP,IO=
LOAD(HYDINT)
FINAR.
REWIND(TAPE10).
COPY(TAPE10,OUTPUT).
REWIND(TAPE11).
COPY(TAPE11,OUTPUT).
REWIND(TAPE9).
COPY(TAPE9,OUTPUT).
END OF FILE

SMATH TEST 5 CCF                               CASE B
16MATHO NMMV=1. IORT=5. IORTA(1)=0. IORTA(2)=1. N T(5)=T. OUT(10)=T.
AXRUD= R*0.0.
-3.74E+04,-9.32E+04,-6.73E+04,-4.07E+04,4.07E+04,6.73E+04,9.32E+04.
9.74E+04.
-3.40E+05,-2.76E+05,-2.13E+05,-1.27E+05,1.27E+05,2.13E+05,2.76E+05.
3.40E+05.
-6.37E+05,-5.10E+05,-3.32E+05,-2.07E+05,2.07E+05,3.40E+05,5.10E+05.
6.37E+05.
-9.35E+05,-7.64E+05,-5.60E+05,-2.83E+05,2.83E+05,5.64E+05,7.64E+05.
9.35E+05.
-9.74E+05,-7.50E+05,-5.75E+05,-2.66E+05,2.66E+05,5.75E+05,7.50E+05.
9.74E+05.
-9.44E+05,-6.66E+05,-5.55E+05,-2.77E+05,2.77E+05,5.55E+05,6.66E+05.
9.44E+05.
AYRUD= R*0.0.
-1.64E+05,-1.67E+05,-1.50E+05,-1.00E+05,1.20E+05,1.50E+05,1.67E+05.
1.64E+05.
-6.51E+05,-6.72E+05,-6.04E+05,-3.31E+05,3.31E+05,6.04E+05,6.72E+05.
6.51E+05.
-1.23E+06,-1.37E+06,-1.31E+06,-8.76E+05,8.76E+05,1.31E+06,1.37E+06.
1.23E+06.
-1.67E+06,-1.81E+06,-1.85E+06,-1.44E+06,1.44E+06,1.85E+06,1.81E+06.
1.67E+06.
-1.95E+06,-1.95E+06,-1.77E+06,-1.15E+06,1.15E+06,1.77E+06,2+1.95E+06.
-1.94E+06,-1.66E+06,-1.74E+06,-1.11E+06,1.11E+06,1.72E+06,1.66E+06.
1.94E+06.
```

TABLE 9 - SAMPLE RUN STREAM FOR CASE B

DRAFT

```

AKRUD= 5*0.0.
1.04E+06,0.04E+05,7.77E+05,5.16E+05,-5.18E+05,-7.77E+05,-3.06E+05,
-1.04E+06,
3.00E+06,3.11E+06,3.00E+06,0.59E+06,-0.73E+06,-1.00E+06,-3.11E+06,
-3.00E+06,
5.60E+06,6.18E+06,5.60E+06,4.43E+06,-4.43E+06,-5.60E+06,-6.18E+06,
-5.60E+06,
8.70E+06,9.74E+06,8.74E+06,7.80E+06,-7.80E+06,-8.74E+06,-9.74E+06,
-8.70E+06,
3*4.27E+06,4.44E+06,-6.44E+06,7*-1.07E+06,
4*6.80E+06,4*-6.80E+06,
AKRUD= 8*0.0,
3*4.27E+06,3.11E+06,-3.11E+06,3*-4.27E+06,
1.32E+07,2.00E+07,1.32E+07,1.55E+07,-1.55E+07,-1.32E+07,-2.00E+07,
-1.32E+07,
3.03E+07,3.51E+07,3.03E+07,2.80E+07,-2.80E+07,-3.03E+07,-3.51E+07,
-3.03E+07,
6.63E+07,7.25E+07,6.63E+07,4.14E+07,-4.14E+07,-6.63E+07,-7.25E+07,
-6.63E+07,
3*5.50E+07,3.24E+07,-3.24E+07,3*-5.50E+07,
3*4.26E+07,3.94E+07,-3.94E+07,3*-4.26E+07,
TMAX=120.,PTCHPRG=1.07, PITCHSC=1.07,
PRPMSO=150., PRPMPD=151., QTE=3.0, WPZINT=1, CEND
      2 PILOT ACTIONS
      16      17.93      7      -35.0      5.0      1
      16      17.94      8      -35.0      5.0      1
-1000.E+00
-100000.0
SMATH TEST END
      3 SMATHC NRUN=-4, 3END
      0 PILOT ACTIONS
-1000.E+00
-100000.0
      END OF FILE

```

TABLE 9 - SAMPLE RUN STREAM FOR CASE B (CONTINUED)

DRAFT

CASE C

JCRCARD,CM120000.T200.P4.
CHARGE.NAME,*****.CC.K.
REQUEST,TAPE11,*PF.
REQUEST,TAPE12,*PF.
REQUEST,TAPE8,*PF.

ATTACH,TAPE1,LAKHYDATA,CY=2,IDE .
ATTACH,TAPE2,LAKHYDATA,CY=3,IDE .
ATTACH,TAPE3,LAKHYDATA,CY=4,IDE .
ATTACH,BINAR,JEIDNATHYTHRE,IDE .
ATTACH,HYDINT,BILAPY1AR,IDE .
LOAD(HYDINT)

BINAR.
REWIND(TAPE12).
COPY(TAPE10,OUTPUT).
REWIND(TAPE11).
COPY(TAPE11,OUTPUT).
REWIND(TAPE8).
COPY(TAPE8,OUTPUT).

END OF FILE

SWATH TEST 5 DCF

CASE C

*SWATHD NRUN=1, INOF=5, IOPTH(1)=0, IOPTH(2)=1, PAT(9)=T, PNT(10)=T.

EXPND= 3*0.0,

-1.24E+05,-1.03E+05,-7.87E+04,-4.78E+04,4.72E+04,7.87E+04,1.03E+05,
1.24E+05,

-4.60E+05,-3.89E+05,-2.98E+05,-1.58E+05,1.54E+05,2.98E+05,3.89E+05,
4.60E+05,

-1.04E+06,-8.75E+05,-6.37E+05,-3.51E+05,3.51E+05,6.37E+05,8.75E+05,
1.04E+06,

-1.42E+06,-1.16E+06,-9.74E+05,-4.41E+05,4.41E+05,9.74E+05,1.16E+06,
1.42E+06,

-1.77E+06,-1.42E+06,-1.02E+06,-5.31E+05,5.31E+05,1.02E+06,1.42E+06,
1.77E+06,

-2.00E+06,-1.61E+06,-1.17E+06,-4.11E+05,4.11E+05,1.17E+06,1.61E+06,
2.00E+06,

AYRUI= 8*0.0,

-3.01E+05,-3.01E+05,-3.01E+05,-2.10E+05,2.10E+05,3.01E+05,3.01E+05,
3.01E+05,

-1.06E+06,-1.06E+06,-1.06E+06,-7.07E+05,7.07E+05,1.06E+06,1.06E+06,
1.06E+06,

-2.04E+06,-2.04E+06,-1.09E+06,-1.32E+06,1.32E+06,1.99E+06,2.04E+06,
2.04E+06,

-3.23E+06,-3.23E+06,-3.10E+06,-2.26E+06,2.26E+06,3.10E+06,3.23E+06,
3.23E+06,

-2.64E+06,-2.79E+06,-2.70E+06,-1.92E+06,1.91E+06,2.79E+06,2.79E+06,
2.64E+06,

-2.30E+06,-2.51E+06,-2.51E+06,-1.71E+06,1.71E+06,2.51E+06,2.51E+06,
2.30E+06.

TABLE 10 - SAMPLE RUN STREAM FOR CASE C

DRAFT

```

AKRUD= 0+0.0.
2.03E+05, 2.12E+05, 7.36E+05, 7.33E+05, -2.77E+05, -2.36E+05, -2.12E+05,
-2.03E+05,
7.11E+06, 3.21E+06, 2.42E+06, 2.97E+06, -2.67E+06, -2.99E+06, -3.21E+06,
-7.11E+06,
6.70E+06, 7.00E+06, 6.60E+06, 4.00E+06, -4.00E+06, -6.00E+06, -7.00E+06,
-6.70E+06,
1.16E+07, 1.00E+07, 1.04E+07, 7.84E+06, -7.98E+06, -1.04E+07, -1.20E+07,
-1.16E+07,
1.55E+07, 1.62E+07, 1.36E+07, 1.04E+07, -1.04E+07, -1.36E+07, -1.62E+07,
-1.55E+07,
1.70E+07, 1.79E+07, 1.64E+07, 1.14E+07, -1.14E+07, -1.64E+07, -1.79E+07,
-1.70E+07,
AMRUD= 0+0.0.
5.13E+06, 6.00E+06, 7.09E+06, 4.01E+06, -4.01E+06, -7.09E+06, -6.00E+06,
-5.13E+06,
2.40E+07, 2.64E+07, 2.74E+07, 2.38E+07, -2.38E+07, -2.74E+07, -2.64E+07,
-2.40E+07,
4.66E+07, 4.01E+07, 5.13E+07, 3.73E+07, -3.73E+07, -5.13E+07, -4.01E+07,
-4.66E+07,
7.87E+07, 7.67E+07, 7.46E+07, 5.60E+07, -5.60E+07, -7.46E+07, -7.67E+07,
-7.87E+07,
7.45E+07, 7.45E+07, 7.45E+07, 5.83E+07, -5.83E+07, -7.45E+07, -7.45E+07,
-7.45E+07,
6.69E+07, 6.69E+07, 6.69E+07, 5.24E+07, -5.24E+07, -6.69E+07, -6.69E+07,
-6.69E+07,
TVAX=120., PITCHPO=1.07, PITCHSO=1.07,
PRPMSO=150., PRPMPD=150., DT=3.0, NPRINT=1, IEND
      2 PILOT ACTIONS
      16      17.74      7      -35.0      5.0      1
      16      17.80      0      -35.0      5.0      1
-1000.E+00
-100000.0
SWATH TEST END
      ISWATHD NRUM=-4. 5END
      0 PILOT ACTIONS
-1000.E+00
-100000.0
      END OF FILE

```

TABLE 10 - SAMPLE RUN STREAM FOR CASE C (CONTINUED)

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CASE D

JRCARD,CY120000,T200,P4.
CHARGE,NAME,*****.CC.Y.
REQUEST,TAPE11,*PF.
REQUEST,TAPE10,*PF.
REQUEST,TAPE9,*PF.
ATTACH,TAPE1,LAKHYDATA,CY=9,IDE .
ATTACH,TAPE2,LAKHYDATA,CY=1,IDE .
ATTACH,TAPE3,LAKHYDATA,CY=0,IDE .
ATTACH,BINAR,UE,SWATHBINUM,IDE .
ATTACH,HYDINT,BINARY1AP,IDE .
LEAD(HYDINT)
BINAR.
REWIND(TAPE10).
COPY(TAPE10,OUTPUT).
REWIND(TAPE11).
COPY(TAPE11,OUTPUT).
REWIND(TAPE9).
COPY(TAPE9,OUTPUT).
END OF FILE

SWATH TEST 5 DOF CASE D
ISWATHD ARM=1. IDOF=5. IORTN(1)=0. IORTN(2)=1. INT(9)=T. INT(10)=T.
AXRUD= 8+0.0.
-1.56E+05,-1.28E+05,-1.01E+05,-4.73E+05,6.73E+05,1.01E+05,1.28E+05,
1.56E+05,
-5.46E+05,-4.00E+05,-3.54E+05,-2.13E+05,2.13E+05,3.54E+05,4.00E+05,
5.46E+05,
-1.04E+06,-8.30E+05,-6.02E+05,-3.13E+05,3.13E+05,6.02E+05,8.30E+05,
1.04E+06,
-1.53E+06,-1.12E+06,-7.04E+05,-4.25E+05,4.25E+05,7.04E+05,1.12E+06,
1.53E+06,
-1.77E+06,-1.31E+06,-9.41E+05,-4.43E+05,4.43E+05,9.41E+05,1.31E+06,
1.77E+06,
-1.67E+06,-1.18E+06,-7.20E+05,-3.85E+05,3.85E+05,7.20E+05,1.18E+06,
1.67E+06,
AYRUD= 8+0.0.
-4.25E+05,-3.90E+05,-3.54E+05,-3.00E+05,3.00E+05,3.54E+05,3.90E+05,
4.25E+05,
-1.30E+06,-1.21E+06,-1.13E+06,-0.30E+05,0.30E+05,1.13E+06,1.21E+06,
1.30E+06,
-2.07E+06,-1.01E+06,-1.75E+05,-1.30E+05,1.30E+05,1.75E+05,1.01E+06,
2.07E+06,
-2.62E+06,-2.48E+06,-2.21E+06,-1.74E+05,1.74E+05,2.21E+06,2.48E+06,
2.62E+06,
-2.17E+06,-1.00E+06,-1.64E+05,-1.15E+05,1.15E+05,1.64E+05,1.00E+06,
2.17E+06,
-1.39E+06,-1.31E+06,-1.00E+05,-0.38E+05,0.38E+05,1.00E+05,1.31E+06,
1.39E+06,

TABLE 11 - SAMPLE RUN STREAM FOR CASE D

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```

AKRUL= 2*0.0,
5.44E+05,5.12E+05,4.57E+05,3.59E+05,-3.54E+05,-4.57E+05,-5.14E+05,
-5.66E+05,
2.70E+04,2.44E+04,2.18E+04,1.71E+04,-1.71E+04,-2.18E+04,-2.44E+04,
-2.70E+04,
2.05E+04,7.23E+04,6.01E+04,4.66E+04,-4.66E+04,-6.01E+04,-7.23E+04,
-8.05E+04,
2.35E+04,4.02E+04,3.02E+04,6.22E+04,-6.22E+04,-3.02E+04,-9.02E+04,
-9.35E+04,
2.75E+04,7.24E+04,7.13E+04,6.51E+04,-5.51E+04,-7.13E+04,-7.24E+04,
-8.75E+04,
6.13E+06,5.56E+06,4.23E+06,3.65E+06,-3.65E+06,-4.23E+06,-5.56E+06,
-6.13E+06,
ANRUC= 3*0.0,
5.91E+06,5.57E+06,5.22E+06,7.82E+06,-3.92E+06,-5.22E+06,-5.57E+06,
-5.91E+06,
2.95E+07,2.72E+07,2.48E+07,1.97E+07,-1.97E+07,-2.48E+07,-2.72E+07,
-2.95E+07,
4.55E+07,4.22E+07,3.61E+07,3.03E+07,-3.03E+07,-3.61E+07,-4.22E+07,
-4.55E+07,
4.77E+07,4.44E+07,4.13E+07,3.32E+07,-3.32E+07,-4.13E+07,-4.44E+07,
-4.77E+07,
4.54E+07,4.25E+07,3.66E+07,2.82E+07,-2.82E+07,-3.66E+07,-4.25E+07,
-4.54E+07,
4.27E+07,3.81E+07,3.35E+07,2.74E+07,-2.74E+07,-3.35E+07,-3.81E+07,
-4.27E+07,
TMAX=120.,PTCHREF=1.07,PTCHGO=1.07,
PRPMSO=150.,PRPMRO=150.,DT=3.0,MPRINT=1,SEND
  0 PILOT ACTIONS
      14      17.88      7      -35.0      5.0      1
      16      17.88      8      -35.0      5.0      1
-1000.E+00
-100000.0
SWATH TEST END
  0 SWATHD ARUN=-4,SEND
  0 PILOT ACTIONS
-1000.E+00
-100000.0
END OF FILE

```

TABLE 11 - SAMPLE RUN STREAM FOR CASE D (CONTINUED)

TABLE 12-DEFINITION OF FORTRAN SYMBOLS APPEARING IN NAMELIST /SWATHD/

FORTRAN Symbol	Description	Type	Units
AE	Absolute error criterion for range-KUTMER integration	Real	-
AKRUD	K rudder moment array	Real	nt-m
ANRUD	N rudder moment array	Real	nt-m
ARAFIN	Areas of fins	Real	m ²
ARATIO	Rudder sizing ratio, to standard rudder	Real	-
AXRUD	X rudder force array	Real	nts
AYRUD	Y rudder force array	Real	nts
BRDARM	Aft rudder pitch moment arm	Real	m
BRSPAN	Maximum bow rudder extended length	Real	m
BRUDPO	Port bow rudder position, initial time		
BRUDSO	Starboard bow rudder position, initial time		
CLFIN	Lift coefficient of fins	Real	/rad
DT	Step size for integration procedure	Real	s
DTMIN	Minimum step size for KUTMER	Real	s
EPS	Relative error criterion for KUTMER integration	Real	-
FINANO	Fin angles at initial time	Real	rad
HULPIK	Difference in draft from design condition, deeper draft=positive	Real	m
IDOF	Degrees of freedom	Integer	-
IOPTN	Integration technique and optional pages 3-5	Integer	-
IXX	Ship moments of inertia	Real	kg-m ²
IXY	Ship products of inertia	Real	kg-m ²
IXZ	Ship products of inertia	Real	kg-m ²
IYY	Ship moments of inertia	Real	kg-m ²
IYZ	Ship products of inertia	Real	kg-m ²
IZZ	Ship moments of inertia	Real	kg-m ²
KPDOT	Dimensional coefficient K_p	Real	kg-m ²
KRDOT	Dimensional coefficient K_r	Real	kg-m ²
KVDOT	Dimensional coefficient K_v	Real	kg
LENGTH	Ship length	Real	m
MASS	Ship mass	Real	kg
MQDOT	Dimensional coefficient M_q	Real	kg-m ²
MSUBTH	Restoring derivative M_{θ} due to buoyancy	Real	nt-m/rad
MSUBZ	Restoring derivative M_z due to buoyancy	Real	nt-m/m
MWDOT	Dimensional coefficient M_w	Real	kg
NPDOT	Dimensional coefficient N_p	Real	kg-m ²
NPRINT	Number of DT increments in print loop	Integer	-
NRDOT	Dimensional coefficient N_r	Real	kg-m ²

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TABLE 12 (continued)

FORTRAN Symbol	Description	Type	Units
NRUN	Simulation run number	Integer	-
NUMRAL	Number of data grid rudder angle points	Integer	-
NUMUUV	Number of data grid velocity points	Integer	-
NVDOT	Dimensional coefficient N_v	Real	kg
PDIA	Prop diameter	Real	m
PHIO	Initial ϕ value	Real	-
PNT	Optional-debugging output, 9 = hydro array 10 = intermediate force-moment time histories	Logical	-
PO	Initial P value	Real	-
PROARM	Prop X, Y, Z coordinates	Real	m
PRPMPO	Initial port propeller rpm's	Real	rpm
PRPMSO	Initial starboard propeller rpm's	Real	rpm
PSIO	Initial ψ value	Real	-
PTCHPO	P/D ratio - port at T=0	Real	-
PTCHSO	P/D ratio - starboard at T=0	Real	-
QO	Initial Q value	Real	-
RALFA	Grid rudder angle array for rudder forces	Real	deg
RO	Initial R value	Real	-
RUDANO	Rudder angles at initial time	Real	rad
RUDARM	Aft rudder pitch moment arm	Real	m
SCFACT	Ship-Model scale factor	Real	-
THETAO	Initial θ value	Real	-
TITLE	Title of run		
TMAX	Maximum time for run	Real	s
TO	Initial time	Real	s
UO	Initial U value	Real	-
UUVEL	Grid velocity array for rudder forces	Real	m/s
VO	Initial V value	Real	-
XC	X coordinate of center of gravity	Real	m
XFIN	X coordinate of fin center of pressure 1 = bow starboard, 2 = bow port, 3 = aft starboard, 4 = aft port	Real	m
XRUD	X coordinate of aft rudder center of pressure	Real	m
XUDOT	Dimensional coefficient X_u	Real	kg
YC	Y coordinates of center of gravity	Real	m
YFIN	Y coordinates of fin center of pressure	Real	m
YPDOT	Dimensional coefficient Y_p	Real	kg-m ²
YRDOT	Dimensional coefficient Y_r	Real	kg-m ²
YRUD	Y coordinates of aft rudder center of pressure	Real	m

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TABLE 12 (continued)

FORTRAN Symbol	Description	Type	Units
YV DOT	Dimensional coefficient Y_v	Real	kg
ZC	Z coordinates of center of gravity	Real	m
ZFIN	Z coordinates of fin center of pressure 1 = bow starboard, 2 = bow port, 3 = aft starboard, 4 = aft port	Real	m
ZQ DOT	Dimensional coefficient Z_q	Real	kg-m ²
ZRUD	Z coordinates of aft rudder center of pressure	Real	m
ZSUBTH	Restoring derivative Z_{θ} due to buoyancy	Real	nts/rad
ZSUBZ	Restoring derivative Z_z due to buoyancy	Real	nts/m
ZW DOT	Dimensional coefficient Z_w	Real	kg

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the Namelist input data. The FORTRAN variable NRUN should be assigned a unique value for all runs to be submitted at one time. Only IDOF=5, and IDOF=6 modes of operation have been tested. During the course of this study, several values of DT were used. A value of 3.0 results in a very few interval halving operations in KUTMER, and, hence, can be considered optimum. A smaller value of DT may be desirable due to print out considerations. Currently, state variable time histories are printed at integer multiples of DT, every NPRINT*DT seconds. If a sampling interval of 3.0 seconds is undesirable, DT should be changed.

Pilot Action Data

The control system allows the programmer to read in up to ten control actions via pilot action data cards. The system is designed so that the programmer can choose from twelve controlled items and sixteen state controlling variables. The system allows for both single instance or constant monitoring of the controlling variables. For example, assume the aft rudder is to be turned to -20° if $\psi < 10^{\circ}$. If single instance is chosen, this action will be performed the first time $\psi < 10^{\circ}$. Under constant monitoring, however, this action will be performed every time $\psi < 10^{\circ}$.

In the present system, the controlled item must have a numerical end value read in. There is no provision for reducing a variable by ten percent, for example. All pilot action data items are in 10 column fields right justified*. The first card of data indicates how many pilot action cards are to be read. The pilot action cards have the following format:

*Floating point numbers need not be right justified provided the decimal point appears explicitly.

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	J1	CV1(I)	J2	CV2(I)	CV3(I)	JACT(I)
Columns	1-10	11-20	21-30	31-40	41-50	51-60

where

J1 = index of state vector controlling variable

CV1 = numerical value of J1 when control is to be activated

J2 = controlled item

CV2 = final value of controlled item

CV3 = rate of change of controlled item

JACT = 1 = single instance, 0 = constant monitoring.

The definitions of possible values for J1 and J2 are given in Table 13.

The units for CV1, CV2, and CV3 are MKS units. Angles are in degrees. If a controlling variable condition is to be less than some CV1 value, e.g. If YE < - 100 m, the index of the controlling variable should be assigned a negative value. CONTRL is called during each call to DAUX. CONTRL checks to see whether the controlled item needs to be changed, and if so performs the changes at the desired rate. When the control item reaches its final value, CONTRL checks JACT and if JACT=1, the control item is turned off. Otherwise, that controlled item is continuously monitored for possible further actions. If multiple actions have been programmed for a controlled item, an error message will be printed out and the last action performed.

Rate Dependent Coefficients

The pilot action data is followed by rate coefficients. Currently, values are not available. The values -1000.E + 00 and - 100000. indicate to the subroutine INPUT that rate coefficients are not to be read.

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TABLE 13 PILOT ACTION DATA DESCRIPTIONS

INDEX	STATE VECTOR CONTROLLING VARIABLE	CONTROLLED ITEM
1	u	Starboard propeller RPM
2	v	Port propeller RPM
3	w	Starboard propeller P/D ratio
4	p	Port propeller P/D ratio
5	q	Forward starboard rudder position
6	r	Forward port rudder position
7	Roll angle	Aft starboard rudder angle
8	Pitch angle	Aft port rudder angle
9	Yaw angle	Bow starboard fin angle
10	XE	Bow port fin angle
11	YE	Aft starboard fin angle
12	ZE	Aft port fin angle
13	Distance travelled	
14	Speed	
15	Drift angle	
16	Time	

DESCRIPTION OF OUTPUT

An example of printout is presented in Appendix C. A brief description of the output follows. The title card and all data read via Namelist is printed at the beginning of the output. This output appears as the FORTRAN symbol followed by the assigned value. After the Namelist is printed the requested pilot actions are listed. The hull hydrodynamic data are next printed if PNT(9)=.TRUE..

Following the above output, up to 5 pages of time histories are printed. These contain time histories of the state variables and time histories of the control surface deflections. Pages 2-4 are printed if IOPTN(2) is set to 1. These pages consist of time histories associated with the rudder, fin, and propulsion subsystems. The printout starting with the Namelist and ending with page five is repeated for each run.

Intermediate forces and moments are printed following the paged output for all runs (if PNT(10)=.TRUE.). These data contain a time history of each force component computed in DAUX. A complete table of X, Y, Z, K, M, N forces and moments is given at each time step. This option is useful for debugging purposes, as unrealistic ship motions are often caused by improper programming of a specific force subroutine.

A time history of time steps used by KUTMER is printed at the end of each computer job submitted if PNT(10)=.TRUE.. Optimum integration time steps can be selected based on an examination of this output.

The next section contains descriptions of various subroutines. Sufficient detail is presented so that new force and moment models can be easily developed.

SUBROUTINE DESCRIPTIONS

This section contains a short description of the main program and the associated subroutines. Each description contains the purpose of the subroutine, how to call it, parameter descriptions and clarifying remarks. Except for the main program, the subroutines are listed in alphabetical order.

Program SWATH

Purpose - Main driver for simulation. Calls INPUT to initialize variables, calls KUTMER in integration loop, calls OUTPUT, and checks to see if all runs have been completed.

Subroutines called - INPUT, KUTMER, OUTPUT

Remarks -

- 1) SWATH calls INPUT to initialize variables
- 2) SWATH calls KUTMER in a do-loop of order NPRINT, thus obtaining output values in increments of $DT \times NPRINT$, e.g., $DT = 1$, $NPRINT = 3$, output is in 3 sec intervals
- 3) SWATH automatically terminates the run when $time > TMAX$
- 4) Each run must have a different NRUN value, a repeated value or a negative value stops the program and starts intermediate printout.
- 5) SWATH calls OUTPUT in the integration loop to load values into output arrays. OUTPUT is also called outside the loop at the end of a run to print out the last page of output that will not necessarily be a full forty lines.
- 6) Output is printed one page (40 line) at a time. The data is loaded into page arrays

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Subroutine ADDFOR

Purpose. To calculate the hull forces due to first and second order rate dependent terms

Usage. CALL ADDFOR

Remarks. 1) The first order equation used is
$$ADDFM(J) = RTMRX(J,K) \cdot \text{Variable}(K) \cdot \text{dimensionalizing factor}$$

2) The second order equation used is
$$ADDFM(J) = ADMTRX(J,K,L) \cdot \text{Variable}(K) \cdot \text{Variable}(L) \cdot \text{dimensionalizing factor}$$

3) RTMTDX and ADMTRX are the derivatives of the forces and moments with respect to the velocities, e.g. N_v , X_u , K_{pr} .

4) The dimensionalizing factors are:
 $\frac{1}{2}\rho(\text{ship length})^2$ for $J=1,2,3$ (X,Y,Z)
 $\frac{1}{2}\rho(\text{length})^3$ for $J=4,5,6$ (K,M,N)

Subroutine AIRFOR

Purpose. To calculate the aerodynamic forces and moments

Usage. Call AIRFOR

Remarks. 1) Estimates show that the aerodynamic forces can be neglected and all forces and moments are set equal zero.

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Subroutine BOYFOR

Purpose. to calculate forces and moments due to bouyancy and gravitation

Usage. CALL BOYFOR

Remarks. 1) Equations used for buoyancy are

$$Z = Z_h h + Z_\theta \theta$$

$$K = \frac{\text{beam}^2}{2} \cdot \tan \phi \cdot Z_z$$

$$M = M_h h + M_\theta \theta$$

- 2) $Z_h, Z_\theta, M_h, M_\theta$ are assumed constant for small motions and given in the body coordinate system
- 3) The gravitational moments are calculated as weight $\cdot$ moment arm, where the moment arm is dependent on the distance X_G, Y_G , or Z_G and the ship orientation.

Program BLOCKD

Purpose. Initializes all constants and ship state variables appearing in named common blocks

Remarks. 1) All variables have been initialized to perform straight ahead flight at 20 knots.

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Subroutine CONTRL

Purpose. to determine whether a pilot action is necessary and if so, to perform the operation at a specified rate.

Usage. CALL CONTRL (T,Y)

Description of Parameters.

T = time

Y = state vector, see INPUT for description

- Remarks.
- 1) Control actions are read in on cards. See users guide section description of parameters and Table 13.
 - 2) Controlled items are fin and rudder angles, bow rudder position, and propeller pitch and rpm.

Subroutine DAUX

Purpose. to compute the right hand side of the differential equations of motion. (See Figure 11 for Flow Chart).

Usage. CALL DAUX(T,Y,F)

Description of Parameters.

- T - time
- Y(1) - U, velocity along body x axis (m/sec)
- Y(2) - V, velocity along body y axis (m/sec)
- Y(3) - W, velocity along body z axis (m/sec)
- Y(4) - P, angular velocity about body x axis (rad/sec)
- Y(5) - Q, angular velocity about body y axis (rad/sec)
- Y(6) - R, angular velocity about body z axis (rad/sec)
- Y(7) - ϕ , roll angle (rad)
- Y(8) - θ , pitch angle (rad)
- Y(9) - ψ , yaw angle (rad)
- Y(10) - X_E , x position in fixed coordinate systems (m)
- Y(11) - Y_E , y position in fixed coordinate systems (m)
- Y(12) - Z_E , z position in fixed coordinate systems (m)
- Y(13) - S, distance traveled (m)

F(1-13) - derivatives corresponding to the above variables

Subroutines Called. CONTRL, FINFOR, RUDFOR, HULFOR, AIRFOR, BOYFOR, PROFOR, ADDFOR, LINQ

Remarks. 1) The 6x6 mass/inertia matrix is computed from the ship mass, moments and products of inertia, and added mass-inertia terms.

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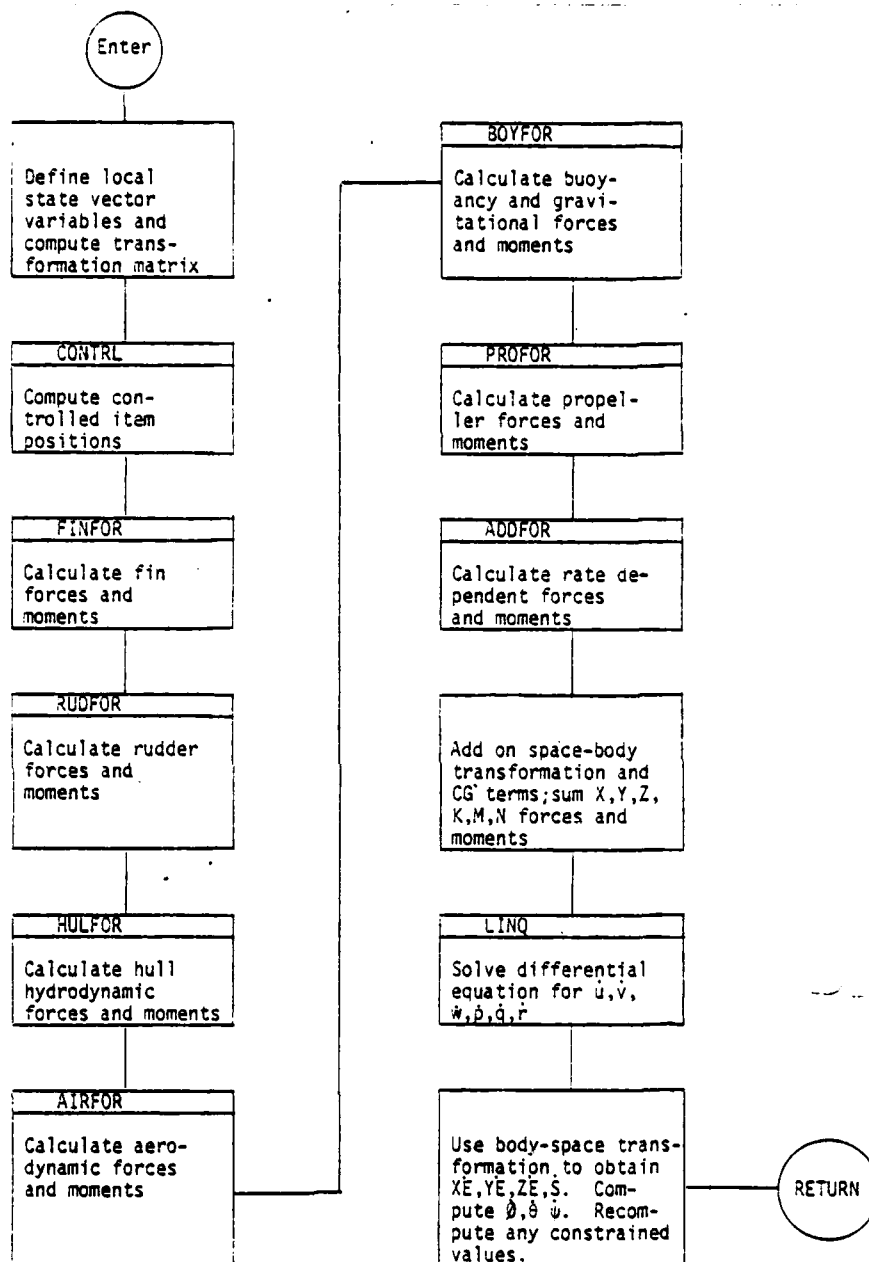


FIGURE 11 FLOWCHART FOR SUBROUTINE DAUX

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- 2) The force vector is determined by
 - A - calling the separate force subroutines
 - B - calculating the terms due to space-body transformation
 - C - calculating terms due to center of gravity not origin
 - D - summing all forces
- 3) DAUX computes the space-body transformation matrix based on the ship orientation. This matrix is used to calculate the fixed space acceleration terms from the body axis acceleration terms returned from LINQ.
- 4) If degrees of freedom are less than 6, DAUX uses a constraint equation to evaluate the appropriate terms.

Function DRAAGG

Purpose. calculates hull drag at a given speed

Usage. DRAAGG(V)

Description of Parameters.

V - Speed (m/s)

Remarks. 1) Drag is calculated as $\frac{EHP \times 1450.1}{V(m/s)}$

- 2) EHP is computed by interpolating a data base of EHP values for speeds from 0 to 28 knots with grid points at integer values of speed.

Subroutine EULER

Purpose. performs EULER integration on state vector Y

Usage. CALL EULER (T,DT,Y,NSTATE)

Subroutines Called. DAUX

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Description of Parameters.

T - time
DT - step size
Y - state vector (See INPUT)
NSTATE - number of variables in Y

Remarks. 1) DAUX is called to obtain the time derivatives of state vector Y
2) $Y_{\text{new}} = Y_{\text{old}} + DT \cdot F$ where F is the time derivative vector
3) EULER has no error check and is a purely mechanical subroutine.
If too large a DT is used, there will be major errors in the integration after many time steps.

Subroutine FINFOR

Purpose. to calculate the total fin forces and moments

Usage. CALL FINFOR

Subroutines Called. TOTVEL

Remarks. 1) TOTVEL is used to calculate the total inflow velocity at each fin
2) Fin lift is calculated theoretically as $\text{Lift} = \frac{1}{2} \rho A U^2 C_L$
where ρ = density of water
A = fin chord · span
U = total inflow velocity $\sqrt{u^2 + w^2}$
 C_L = lift coefficient
3) Fin drag approximated as Lift/7
4) Center of pressure assumed at quarter chord and half span.
5) Effects of side flow (v) have been ignored

Subroutine HULFOR

Purpose. to calculate the hydrodynamic Y,K,N hull forces as a function of speed, roll angle, yaw rate, and drift angle.

Usage. CALL HULFOR

Subroutines called. DRAAGG, HYDINT

Remarks. 1) Equations used, at a given speed

$$Y = Y_{\beta}\beta + Y_{r'}r' + Y_{\phi}\phi$$

$$K = K_{\beta}\beta + K_{r'}r' + K_{\phi}\phi$$

$$N = N_{\beta}\beta + N_{r'}r' + N_{\phi}\phi$$

2) HYDINT and HYDPAR perform a four-dimensional interpolation to obtain the Y,K,N forces as a function of speed, drift angle, yaw rate, and roll angle.

3) DRAAGG calculates the X force

Subroutine HYDINT

Purpose. performs a 4 dimensional interpolation for hull hydrodynamic forces based on data curves. Independent variables are speed, drift angle, yaw rate, and roll angle.

Usage. CALL HYDINT

Subroutine Called. HYDPAR

Remarks. 1) Hydrodynamic values must be stored in array HY(4,3213) in a linear fashion. The first index represents the X,Y,K,N data. Array XG(4,20) contains the data base grid values. The first index represents the four independent variables: 1 = roll angle, 2 = drift angle, 3 = yaw rate, 4 = speed. Array LG(4) contains the number of base grid values for

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each parameter. The indexing of HY(Y,3213) is as follows:
for Array HY(I,J), the Jth value corresponds to the I force
at the location

$$J = IR + LG(1) \left[ID-1 + LG(2) \{ IY-1 + LG(3)(IS-1) \} \right]$$

where IR, ID, IY, and IS represent the grid point index in the
XG array for roll, drift, yaw and speed, respectively and LG(k)
equals the number of grid points for that parameter.

Subroutine HYDPAR

Purpose. to recompute the interpolation coefficients for HYDINT if the
data cell is not entered when HYDINT is called

Usage. CALL HYDPAR

Remarks. 1) HYDINT will call HYDPAR automatically if necessary.
2) The coefficients calculated by HYDPAR are based on the cell grid
points and the data base grid points need not be uniformly spaced.

Subroutine HYRITE

Purpose. optional listing of hydrodynamic hull coefficients in tabular
form

Usage. CALL HYRITE

Remarks. 1) Called from INPUT if PNT(9) = .TRUE.

Subroutine INPUT

Purpose. Reads in NAMELIST data, hydrodynamic hull data, pilot control
data and rate dependent terms and converts initial conditions to MKS units.

Call CALL INPUT(Y, TIMEE)

Definition of Parameters.

1 - Ship state vector

2 - Velocity along body x axis (m/sec)

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- 2 = V, velocity along body y axis (m/sec)
- 3 = W, velocity along body z axis (m/sec)
- 4 = P, angular velocity about body x axis (rad/sec)
- 5 = Q, angular velocity about body y axis (rad/sec)
- 6 = R, angular velocity about body z axis (rad/sec)
- 7 = ϕ , roll angle (rad)
- 8 = θ , pitch angle (rad)
- 9 = ψ , yaw angle (rad)
- 10 = XE, X coordinate in fixed space
- 11 = YE, Y coordinate in fixed space
- 12 = ZE, Z coordinate in fixed space
- 13 = S - distance travelled

TIMEE = time

- Remarks.
- 1) All initial conditions and values that may change due to configuration changes can be read in via NAMELIST.
 - 2) Hull data read in from tapes. These must be attached in the following manner. Tape 1 = Y data, Tape 2 = K data, Tape 3 = N data.
 - 3) Pilot action data is described in the User's Guide section and Table 13.
 - 4) Rate dependent terms are read in as follows

Example - for first order terms

$$N_v = \text{RTMTRX}(6,2), K_p = \text{RTMTRX}(4,4) \cdots 1 = X, U \quad 2 = Y, V$$

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3 = Z,W 4 = K,p 5 = M,q 6 = N,r

for second order terms

N_{vr} = ADMTRX (6,2,6) and (6,6,2) as in the above
correspondence

Subroutine KUTMER

Purpose. Performs Runge-Kutta-Merson integration.

Usage. CALL KUTMER (ND, T, H, Y0, EPSE, A, HCX, FIRST)

Subroutines Called. DAUX

Description of Parameters.

- ND - number of variables in Y0
- T - time
- H - step size
- Y0 - state vector, enter with initial values at T, returns
values at T + H
- EPSE - relative error criterion for Y0 components
- A - absolute error criterion for Y0 components
- HCX - smallest step size to be used by KUTMER
- FIRST = 0. when KUTMER is entered for first time or with changed
step size
- = 1. when entered with same H to continue integration in a
sequence
- = 2. When error criterion cannot be met and $H < HCX$

Remarks. 1) KUTMER calls DAUX five times to predict endpoint value of Y
2) If error criteria are not met KUTMER automatically halves the
interval and repeats. If halved interval becomes less than

H/32, KUTMER stops and prints out error message

Subroutine LINQ

Purpose. Solves for X where $AX = B$

Usage. CALL LINQ (A,B,N,KS)

Description of Parameters.

A,B = input matrix, LINQ solves for X and replaces B by X

N - number of equations, dimension of B

KS - error code, 1 = singular matrix, 0 = normal

Remarks. 1) X represents the acceleration matrix used by KUTMER

2) A = mass-inertia matrix obtained from DAUX

3) B = force matrix obtained from DAUX

Subroutine NGHBR1

Purpose. To find the nearer neighbor less than or equal to the desired value in the Array V

Usage. CALL NGHBR1 (V, ARG, II, N, IER, RATIO)

Description of parameters.

V - variable array

ARG - search argument

II - Location such that $V(II) \leq ARG \leq V(II+1)$

N - number of points in V

IER - 0 in range, otherwise out of range

RATIO = $(ARG - V(II)) / (V(II+1) - V(II))$

Remarks. RATIO will be used in the interpolation in TAB2V or TAB3V

Subroutine OUTPUT

Purpose. prints out paged output

Usage. call OUTPUT (IOPT)

Description of parameters.

IOPT - SWATH sets = 2 when the run terminates. If IOPT = 1, the pages

are printed out even if not full, which may happen if run terminates. Otherwise, OUTPUT does not print until a full page of 40 lines is reached.

- Remarks.
- 1) Page 1 contains a time history of some ship state values and the position in fixed space
Page 2 contains a time history of the control surface values
Page 3 contains a detailed time history of propeller forces and moments
Page 4 contains a detailed time history of rudder forces and moments
Page 5 contains a detailed time history of fin forces and moments
 - 2) IOPTN (2) controls pages 3-5. If 1, pages are printed. If 0, they are not
 - 3) Output is in MKS system with angles in degrees
 - 4) Time history values are loaded into page arrays and printed out one page (40 lines) at a time.
 - 5) See sample run for page listings

Subroutine PROFOR

Purpose. to calculate propeller thrust, pitch, and yaw moments.

Usage. CALL PROFOR

Subroutines Called. TAB2V

Remarks. 1) $\text{Thrust} = K_T \rho n^2 D^4$

where K_T = thrust coefficient obtained through table
look up

n = revolutions/sec

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D = propeller diameter

- 2) K_T is obtained through interpolation using TAB2V and propeller K_T vs. J curves as data
- 3) Propeller Y and Z forces have been neglected.
- 4) Propellers are operated independently so that differential thrust can be applied for low speed turns.

Subroutine RUDFOR

Purpose. to calculate the rudder forces and moments

Usage. Call RUDFOR

Subroutines called. TAB2V, TAB3V

- Remarks.
- 1) RUDFOR first calculates the aft rudder contribution, and then the fixed forward rudder contribution
 - 2) The aft rudder data is read in as four linear arrays AXRUD, AYRUD, AKRUD, ANRUD. These arrays contain rudder force data based on rudder deflection angle and speed.
 - 3) TAB2V performs a two-way interpolation on the rudder data to obtain the aft rudder X, Y, K, and N forces. The M moment is calculated as the X force times the moment arm.
 - 4) For the fixed forward rudder, an array BYRUD has been constructed that contains the rudder Y force based on speed, drift angle, and yaw rate. TAB3V performs a 3-way interpolation to obtain the rudder Y force. The X force is approximated as Y/7 and K, M, N moments are calculated using the X and Y forces times the appropriate moment arms. This portion of modeling is still under development.

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- 5) Different aft rudder sizes are handled by an ARATIO term in the aft rudder equations. ARATIO is a ratio of actual rudder size to a standard size rudder used in the model tests.

Subroutine TAB2V

Purpose. performs a two-dimensional interpolation on a given data base.

Usage. CALL TAB2V (V1, V2, OB, N1, N2, ARG1, ARG2, ID, KEY, II, JJ,) VAL, IER)

Subroutines Called. NGHBR2

Description of Parameters.

V1, V2	- variable arrays starting with smallest and increasing monotonically. Values must be unique	
OB	- observed function values stored columnwise according to V1, V2	
N1, N2	- number of V1's and V2's	
ARG1, ARG2	- arguments 1 and 2	
ID	- unit for printout	
KEY	- if = 0, do not perform search, use previous V's and ratios	
II	- closest point to ARG1 S.T. V(II).L E. ARG1	determined by NGHBR1
JJ	- closest point to ARG2 S.T. V(JJ).L E. ARG2	
VAL	- interpolated value	
IER	- 0 - in range, otherwise out of range	

Subroutine TAB3V

Purpose. performs a 3-dimensional interpolation on a given data base.

Usage. CALL TAB3V (V1, V2, V3, OB, N1, N2, N3, ARG1, ARG2, ARG3, ID, KEY,

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II, JJ, KK, VAL, IER)

Subroutines Called. NGHBR2

Description of parameters

V1, V2, V3	- Variable data arrays starting with smallest and increasing monotonically. Values must be unique.
OB	- Observed function values stored columnwise according to V1, V2, V3
N1, N2, N3	- number of V1's, V2's, V3's
ARG1, ARG2, ARG3	- arguments 1, 2, and 3
ID	- unit for printout
KEY	- if = 0, do not perform search, use previous v's and ratios
II	- closest point in V1 to ARG1 S.T. V(II).LE. ARG1
JJ	- closest point in V2 to ARG2 S.T. V(JJ).LE. ARG2
KK	- closest point in V3 to ARG3 S.T. V(KK).LE. ARG3
VAL	- Interpolated value
IER	- 0, in range, otherwise out of range

Subroutine TOTVEL

Purpose. to calculate inflow velocity at a given point based on the radius vector and the ship velocities.

Usage. CALL TOTVEL (UU, VV, WW, PP, QQ, RR, XDV, YDV, ZDV, UTOT, VTOT, WTOT)

Description of Parameters.

UU, VV, WW	- ship U, V, W velocities
PP, QQ, RR	- ship P, Q, R angular velocities (radius/sec)
SDV, YDV, ZDV	- X, Y, Z coordinates of point in question

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UTOT, VTOT, WTOT - U, V, W inflow velocities at that point

Remarks. 1) All velocities are in the body system

2) $UTOT = UU - RR \cdot YDV + QQ \cdot ZDV$

$$VTOT = VV - PP \cdot ZDV + RR \cdot XDV$$

$$WTOT = WW - QQ \cdot XDV + PP \cdot YDV$$

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RECOMMENDATIONS

The current digital simulation can be used to develop optimum maneuvering strategies for various missions to be performed by SWATH. The results of such studies if they are conducted may provide useful information to the Navy allowing a complete evaluation of SWATH potential capabilities.

Another major area of mathematical modeling that should be pursued is the modeling of sea way effects. Due to the small waterplane area, it is expected that seaway effects would have a relatively mild influence on craft dynamics as compared with conventional craft. Taking these effects into account would lead to a more meaningful comparison of SWATH performance with conventional craft performance.

There are many minor refinements that can be made regarding the mathematical model. The mathematical model and digital simulation program are designed to accept refined data bases and improved theoretical estimates when they become available.

It is recommended that the basic data base approach employed in this study be extended to other high performance craft that are currently employing theoretical models. These theoretical models are usually very complex and require extensive computational efforts. However, one could limit these computational efforts by using the theoretical expressions offline to generate a data base, a one time effort, that could then be used in the approach presented in this paper to carry out many different simulated maneuvers.

CONCLUSIONS

This study represents a fairly extensive dynamic simulation model development based primarily on experimental model data. The

final product has proved to be a useful evaluation tool in studying SWATH performance during a variety of maneuvers for several different configurations. The success of the approach used is based on a well planned program of model experiments that provided a sufficient data base for mathematical model development.

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The results of the predictions indicate that significant improvements in performance can be achieved when the spade rudder configuration are considered or when a deeper draft is used during turn maneuvers. The results also indicate that the SWATH has very good turning performance characteristics at low speeds when differential thrust is used.

ACKNOWLEDGEMENTS

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NOTATION

$\vec{S}$	State vector
A	Generalized mass/inertia matrix
$\dot{\vec{F}}$	Time rate of change of state vector
$\bar{M}$	Ship mass
X_u	Coefficient used in representing X as a function of $\dot{u}$
Y_v	Coefficient used in representing Y as a function of $\dot{v}$
Z_w	Coefficient used in representing Z as a function of $\dot{w}$
K_p	Coefficient used in representing K as a function of $\dot{p}$
M_q	Coefficient used in representing M as a function of $\dot{q}$
N_r	Coefficient used in representing N as a function of $\dot{r}$
X_G	Location of CG along body x axis
Y_G	Location of CG along body y axis
Z_G	Location of CG along body z axis
Y_p	Coefficient used in representing Y as a function of $\dot{p}$
Y_r	Coefficient used in representing Y as a function of $\dot{r}$
Z_q	Coefficient used in representing Z as a function of $\dot{q}$
K_v	Coefficient used in representing K as a function of $\dot{v}$
K_r	Coefficient used in representing K as a function of $\dot{r}$
M_w	Coefficient used in representing M as a function of $\dot{w}$
N_v	Coefficient used in representing N as a function of $\dot{v}$
N_p	Coefficient used in representing N as a function of $\dot{p}$
I_{xx}	Moment of inertia about x axis.
I_{yy}	Moment of inertia about y axis
I_{zz}	Moment of inertia about z axis

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I_{xy}	Product of inertia about xy axis
I_{xz}	Product of inertia about xz axis
I_{yz}	Product of inertia about yz axis
p	Angular velocity about x axis
q	Angular velocity about y axis
r	Angular velocity about z axis
u	Velocity along body x axis
v	Velocity along body y axis
w	Velocity along body z axis
ϕ	Roll angle
θ	Pitch angle
ψ	Yaw angle
X_E	Displacement along fixed x axis
Y_E	Displacement along fixed y axis
Z_E	Displacement along fixed z axis
T	Transformation matrix from body to fixed coordinate system
EHP	Effective horsepower
X	Total force along body x axis
Y	Total force along body y axis
Z	Total force along body z axis
K	Total moment about body x axis
M	Total moment about body y axis
N	Total moment about body z axis
ρ	Density of water
L	Ship length

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F	Fin force or moment
AR	Fin aspect ratio
V_f	Inflow velocity at fin
C_L	Fin lift coefficient
α	Fin angle of attach
A	Fin area
X_f	Fin x position
Y_f	Fin y position
Z_f	Fin z position
K_T	Thrust coefficient
n	Propeller revolutions per second
D	Propeller diameter
J	Advance coefficient
V_a	Propeller speed of advance
Z_θ	Coefficient to represent buoyancy Z as a function of θ
Z_z	Coefficient to represent buoyancy Z as a function of z
M_θ	Coefficient to represent buoyancy Z moment as a function of θ
M_z	Coefficient to represent buoyancy Z moment as a function of z

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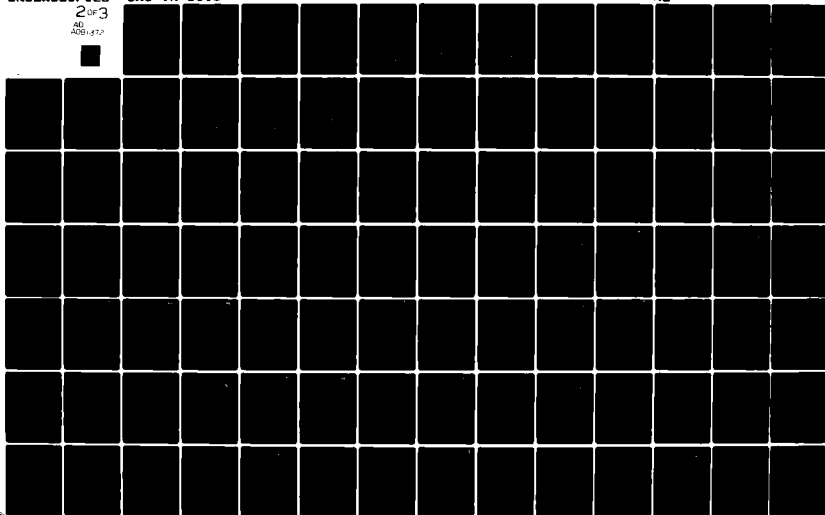
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F	Fin force or moment
AR	Fin aspect ratio
V_f	Inflow velocity at fin
C_L	Fin lift coefficient
α	Fin angle of attach
A	Fin area
X_f	Fin x position
Y_f	Fin y position
Z_f	Fin z position
K_T	Thrust coefficient
n	Propeller revolutions per second
D	Propeller diameter
J	Advance coefficient
V_a	Propeller speed of advance
Z_θ	Coefficient to represent buoyancy Z as a function of θ
Z_z	Coefficient to represent buoyancy Z as a function of z
M_θ	Coefficient to represent buoyancy Z moment as a function of θ
M_z	Coefficient to represent buoyancy Z moment as a function of z

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APPENDIX A

DATA BASES USED IN THE SIMULATION MODEL

ROLL ANGLE DEG	PITCH ANGLE DEG	VELOCITY NON-DIMENSIONAL	SPEED KTS	Y FORCE MTS	X MOMENT MT-M	Y MOMENT MT-M
-5.00	-4.00	-0.30	5.00	-.244244E+06	.323669E+07	.155360E+07
0.00	-4.00	-0.30	5.00	-.244244E+06	.297774E+07	.129467E+07
5.00	-4.00	-0.30	5.00	-.244244E+06	.271921E+07	.103574E+07
-5.00	0.00	-0.30	5.00	-.134511E+06	.259034E+07	.414295E+07
0.00	0.00	-0.30	5.00	-.134511E+06	.233241E+07	.332401E+07
5.00	0.00	-0.30	5.00	-.134511E+06	.207147E+07	.342509E+07
-5.00	4.00	-0.30	5.00	-.247794E+05	.194201E+07	.673229E+07
0.00	4.00	-0.30	5.00	-.247794E+05	.169307E+07	.647335E+07
5.00	4.00	-0.30	5.00	-.247794E+05	.142414E+07	.621442E+07
-5.00	-4.00	0.00	5.00	-.109733E+06	.906262E+06	-.233041E+07
0.00	-4.00	0.00	5.00	-.109733E+06	.647335E+06	-.256034E+07
5.00	-4.00	0.00	5.00	-.109733E+06	.389401E+06	-.294908E+07
-5.00	0.00	0.00	5.00	0.	.258934E+06	.253934E+06
0.00	0.00	0.00	5.00	0.	0.	0.
5.00	0.00	0.00	5.00	0.	0.	0.
-5.00	4.00	0.00	5.00	.109733E+06	-.348401E+06	-.258934E+06
0.00	4.00	0.00	5.00	.109733E+06	-.647335E+06	-.256034E+07
5.00	4.00	0.00	5.00	.109733E+06	-.906262E+06	-.233041E+07
-5.00	-4.00	.30	5.00	.247794E+05	-.142414E+07	-.621442E+07
0.00	-4.00	.30	5.00	.247794E+05	-.169307E+07	-.647335E+07
5.00	-4.00	.30	5.00	.247794E+05	-.194201E+07	-.673229E+07
-5.00	0.00	.30	5.00	.134511E+06	-.207147E+07	-.342509E+07
0.00	0.00	.30	5.00	.134511E+06	-.233241E+07	-.332401E+07
5.00	0.00	.30	5.00	.134511E+06	-.259034E+07	-.414295E+07
-5.00	4.00	.30	5.00	.244244E+06	-.271921E+07	-.103574E+07
0.00	4.00	.30	5.00	.244244E+06	-.297774E+07	-.129467E+07
5.00	4.00	.30	5.00	.244244E+06	-.323669E+07	-.155360E+07
-5.00	-4.00	-0.30	10.00	-.101237E+07	.321078E+07	.414295E+07
0.00	-4.00	-0.30	10.00	-.101237E+07	.279649E+07	.517868E+07
5.00	-4.00	-0.30	10.00	-.101237E+07	.232212E+07	.621442E+07
-5.00	0.00	-0.30	10.00	-.516906E+06	.932163E+06	.145033E+08
0.00	0.00	-0.30	10.00	-.516906E+06	.517868E+06	.155360E+08
5.00	0.00	-0.30	10.00	-.516906E+06	.103574E+06	.165713E+08
-5.00	4.00	-0.30	10.00	-.212386E+05	-.134446E+07	.249577E+06
0.00	4.00	-0.30	10.00	-.212386E+05	-.176275E+07	.259234E+08
5.00	4.00	-0.30	10.00	-.212386E+05	-.217585E+07	.269221E+08
-5.00	-4.00	0.00	10.00	-.495568E+06	.269221E+07	-.117271E+08
0.00	-4.00	0.00	10.00	-.495568E+06	.227862E+07	-.103574E+08
5.00	-4.00	0.00	10.00	-.495568E+06	.186433E+07	-.932163E+07
-5.00	0.00	0.00	10.00	0.	.414295E+06	-.103574E+07
0.00	0.00	0.00	10.00	0.	0.	0.
5.00	0.00	0.00	10.00	0.	0.	0.
-5.00	4.00	0.00	10.00	.495568E+06	-.414295E+06	.103574E+07
0.00	4.00	0.00	10.00	.495568E+06	-.186433E+07	.932163E+07
5.00	4.00	0.00	10.00	.495568E+06	-.227862E+07	.103574E+08
-5.00	-4.00	0.00	10.00	.212386E+05	-.269221E+07	.117271E+08
0.00	-4.00	0.00	10.00	.212386E+05	-.259234E+08	.269221E+08

TABLE A1 Hydrodynamic Hull Data for Strut Rudder Configuration at Design Dfart

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ROLL ANGLE DEG	PITCH ANGLE DEG	YAW RATE HOUR-DIMENSIONAL	SPEED KTS	Y FORCE LBS	Y MOMENT LBS-FT	Y MOMENT LBS-FT
0.00	-4.00	.70	10.00	.212786E+05	.176075E+07	-.259934E+08
0.00	-4.00	.70	10.00	.212786E+05	.176075E+07	-.259934E+08
-0.00	0.00	.70	10.00	.516006E+06	-.103574E+06	-.145718E+08
0.00	0.00	.70	10.00	.516006E+06	-.517369E+07	-.155369E+08
0.00	0.00	.70	10.00	.516006E+06	-.032163E+06	-.145003E+08
-0.00	4.00	.70	10.00	.101133E+07	-.238019E+07	-.621442E+07
0.00	4.00	.70	10.00	.101133E+07	-.270649E+07	-.517069E+07
0.00	4.00	.70	10.00	.101133E+07	-.321037E+07	-.414285E+07
-0.00	-4.00	-.70	15.00	-.278034E+07	.170120E+08	.915642E+07
0.00	-4.00	-.70	15.00	-.210262E+07	.160709E+08	.915642E+07
0.00	-4.00	-.70	15.00	-.191500E+07	.151476E+08	.915642E+07
-0.00	0.00	-.70	15.00	-.124244E+07	.114170E+08	.314605E+08
0.00	0.00	-.70	15.00	-.355738E+06	.104268E+08	.314605E+08
0.00	0.00	-.70	15.00	-.669016E+06	.955467E+07	.314605E+08
-0.00	4.00	-.70	15.00	-.127432E+06	.582602E+07	.547646E+08
0.00	4.00	-.70	15.00	.153200E+06	.487385E+07	.547646E+08
0.00	4.00	-.70	15.00	.446011E+06	.396169E+07	.547646E+08
-0.00	-4.00	0.00	15.00	-.143761E+07	.652514E+07	-.237041E+08
0.00	-4.00	0.00	15.00	-.114680E+07	.559299E+07	-.237041E+08
0.00	-4.00	0.00	15.00	-.869164E+06	.466081E+07	-.237041E+08
-0.00	0.00	0.00	15.00	-.236721E+06	.332163E+06	0.
0.00	0.00	0.00	15.00	0.	0.	0.
0.00	0.00	0.00	15.00	.286721E+06	-.332163E+06	0.
-0.00	4.00	0.00	15.00	.869164E+06	-.466081E+07	.237041E+08
0.00	4.00	0.00	15.00	.114680E+07	-.559299E+07	.237041E+08
0.00	4.00	0.00	15.00	.143761E+07	-.652514E+07	.237041E+08
-0.00	-4.00	.70	15.00	-.446011E+06	-.126169E+07	-.547646E+08
0.00	-4.00	.70	15.00	-.159299E+06	-.487385E+07	-.547646E+08
0.00	-4.00	.70	15.00	.127432E+06	-.582602E+07	-.547646E+08
-0.00	0.00	.70	15.00	.669016E+06	-.955467E+07	-.314605E+08
0.00	0.00	.70	15.00	.355738E+06	-.104268E+08	-.314605E+08
0.00	0.00	.70	15.00	.124244E+07	-.114170E+08	-.314605E+08
-0.00	4.00	.70	15.00	.191500E+07	-.151476E+08	-.915642E+07
0.00	4.00	.70	15.00	.210262E+07	-.160709E+08	-.915642E+07
0.00	4.00	.70	15.00	.278034E+07	-.170120E+08	-.915642E+07
-0.00	-4.00	-.70	20.00	-.410617E+07	.295863E+08	.176075E+08
0.00	-4.00	-.70	20.00	-.410617E+07	.310721E+08	.331436E+08
0.00	-4.00	-.70	20.00	-.410617E+07	.335579E+08	.486796E+08
-0.00	0.00	-.70	20.00	-.297741E+07	.294142E+08	.130538E+08
0.00	0.00	-.70	20.00	-.297741E+07	.269291E+08	.870019E+08
0.00	0.00	-.70	20.00	-.297741E+07	.244434E+08	.714658E+08
-0.00	4.00	-.70	20.00	-.194068E+07	.252720E+08	.156332E+08
0.00	4.00	-.70	20.00	-.194068E+07	.277577E+08	.171532E+08
0.00	4.00	-.70	20.00	-.194068E+07	.302435E+08	.197469E+08
-0.00	-4.00	0.00	20.00	-.113273E+07	.165718E+07	-.603043E+08
0.00	-4.00	0.00	20.00	-.113273E+07	.414295E+07	-.535583E+08

TABLE A1 (Continued)

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SOIL SAMPLE NO.	DEPTH, INCHES DFT	WAVE RATE NON-DIMENSIONAL	SPEED KTS	X FORCE LBS	Y MOMENT IN-LB	Z MOMENT IN-LB
4.00	-4.00	0.00	20.00	-.113073E+07	.662971E+07	-.593222E+08
-4.00	0.00	0.00	20.00	0.	-.248577E+17	-.155367E+08
0.00	0.00	0.00	20.00	0.	0.	0.
0.00	0.00	0.00	20.00	0.	.248577E+07	.155367E+08
-4.00	4.00	0.00	20.00	.113273E+07	-.662971E+07	.593222E+08
0.00	4.00	0.00	20.00	.113273E+07	-.414295E+07	.539593E+08
4.00	4.00	0.00	20.00	.113273E+07	-.165719E+07	.693643E+09
-4.00	-4.00	.30	20.00	.184769E+07	-.302435E+08	-.127469E+09
0.00	-4.00	.30	20.00	.184769E+07	-.277577E+08	-.171232E+09
4.00	-4.00	.30	20.00	.184769E+07	-.252720E+08	-.150796E+09
-4.00	0.00	.30	20.00	.297741E+07	-.244474E+09	-.714659E+09
0.00	0.00	.30	20.00	.297741E+07	-.269291E+08	-.470019E+18
4.00	0.00	.30	20.00	.297741E+07	-.294149E+08	-.102538E+09
-4.00	4.00	.30	20.00	.410613E+07	-.335672E+09	-.484796E+09
0.00	4.00	.30	20.00	.410613E+07	-.310721E+09	-.331436E+09
4.00	4.00	.30	20.00	.410613E+07	-.285867E+09	-.176975E+09
-4.00	-4.00	-.30	25.00	-.641587E+07	.291301E+08	.339815E+09
0.00	-4.00	-.30	25.00	-.577637E+07	.271281E+08	.485501E+08
4.00	-4.00	-.30	25.00	-.517621E+07	.252461E+08	.631152E+09
-4.00	0.00	-.30	25.00	-.352402E+07	.278354E+08	.111665E+09
0.00	0.00	-.30	25.00	-.296456E+07	.258874E+08	.126270E+09
4.00	0.00	-.30	25.00	-.234510E+07	.232514E+08	.140755E+09
-4.00	4.00	-.30	25.00	-.752201E+06	.265407E+08	.219476E+09
0.00	4.00	-.30	25.00	-.132741E+06	.245927E+08	.233041E+09
4.00	4.00	-.30	25.00	.486718E+06	.226567E+08	.247666E+09
-4.00	-4.00	0.00	25.00	-.345127E+07	.323649E+07	-.322463E+08
0.00	-4.00	0.00	25.00	-.283192E+07	.129467E+07	-.776802E+08
4.00	-4.00	0.00	25.00	-.221736E+07	-.647335E+06	-.631152E+08
-4.00	0.00	0.00	25.00	-.619460E+06	.194201E+07	-.145633E+08
0.00	0.00	0.00	25.00	0.	0.	0.
4.00	0.00	0.00	25.00	.619460E+06	-.194201E+07	.145633E+08
-4.00	4.00	0.00	25.00	.221236E+07	.647335E+06	.631152E+08
0.00	4.00	0.00	25.00	.283192E+07	-.129467E+07	.776802E+08
4.00	4.00	0.00	25.00	.345127E+07	-.323649E+07	.322463E+08
-4.00	-4.00	.30	25.00	-.486718E+06	-.226567E+08	-.247666E+09
0.00	-4.00	.30	25.00	-.132741E+06	-.245927E+08	-.233041E+09
4.00	-4.00	.30	25.00	.752201E+06	-.265407E+08	-.219476E+09
-4.00	0.00	.30	25.00	.234510E+07	-.232514E+08	-.140755E+09
0.00	0.00	.30	25.00	.296456E+07	-.258874E+08	-.126270E+09
4.00	0.00	.30	25.00	.352402E+07	-.278354E+08	-.111665E+09
-4.00	4.00	.30	25.00	.517621E+07	-.252461E+08	-.631152E+08
0.00	4.00	.30	25.00	.577637E+07	-.271281E+08	-.485501E+08
4.00	4.00	.30	25.00	.641587E+07	-.291301E+08	-.339815E+08
-4.00	-4.00	-.30	28.00	-.715994E+07	.341147E+08	.207004E+09
0.00	-4.00	-.30	28.00	-.689744E+07	.316627E+08	.486009E+08
4.00	-4.00	-.30	28.00	-.467493E+07	.292726E+08	.602017E+08

TABLE A1 (Continued)

DRAFT

ROLL ANGLE DEG	HEAVE ANGLE DEG	YAW RATE NON-DIMENSIONAL	COEFF KTC	Y SPACE KTC	X MOMENT MT-M	Y MOMENT MT-M
-4.00	0.00	-0.70	28.00	-.705270E+07	.322667E+08	.117743E+08
-4.00	0.00	-0.70	28.00	-.277518E+07	.304507E+08	.132843E+08
-4.00	0.00	-0.70	28.00	-.249766E+07	.280146E+08	.150343E+08
-4.00	0.00	-0.70	28.00	.105457E+07	.316697E+08	.215155E+08
-4.00	0.00	-0.70	28.00	.133209E+07	.292126E+08	.235425E+08
-4.00	0.00	-0.70	28.00	.160560E+07	.267766E+08	.255785E+08
-4.00	-4.00	0.00	28.00	-.438478E+07	.365408E+07	-.117743E+08
-4.00	-4.00	0.00	28.00	-.415726E+07	.121903E+07	-.974421E+08
-4.00	-4.00	0.00	28.00	-.382275E+07	-.121903E+07	-.771416E+08
-4.00	0.00	0.00	28.00	-.277518E+06	.243605E+07	-.223224E+07
-4.00	0.00	0.00	28.00	0.	0.	0.
-4.00	0.00	0.00	28.00	.277518E+06	-.243605E+07	.223224E+07
-4.00	4.00	0.00	28.00	.392975E+07	.121903E+07	.771416E+08
-4.00	4.00	0.00	28.00	.415726E+07	-.121903E+07	.974421E+08
-4.00	4.00	0.00	28.00	.438478E+07	-.365408E+07	.117743E+08
-4.00	-4.00	.70	28.00	-.160560E+07	-.267766E+08	-.255785E+08
-4.00	-4.00	.70	28.00	-.133209E+07	-.292126E+08	-.235425E+08
-4.00	-4.00	.70	28.00	-.105457E+07	-.316697E+08	-.215155E+08
-4.00	0.00	.70	28.00	.249766E+07	-.280146E+08	-.150343E+08
-4.00	0.00	.70	28.00	.277518E+07	-.304507E+08	-.132843E+08
-4.00	0.00	.70	28.00	.705270E+07	-.322667E+08	-.117743E+08
-4.00	4.00	.70	28.00	.667493E+07	-.282726E+08	-.622013E+08
-4.00	4.00	.70	28.00	.689244E+07	-.316697E+08	-.406229E+08
-4.00	4.00	.70	28.00	.715996E+07	-.341347E+08	-.283224E+08

TABLE A1 (Continued)

DRAFT

ROLL ANGLE DEG	DRAFT FT	YAW RATE DEG/SEC	DEPTH FT	Y POS FT	K MOMENT MT-LB	N MOMENT MT-LB
-4.00	-4.00	-0.30	5.00	-.002031E+06	.415640E+06	.647335E+06
-4.00	-4.00	-0.30	5.00	-.002318E+06	.310721E+07	.194201E+07
-4.00	-4.00	-0.30	5.00	-.002743E+06	.510076E+07	.327668E+07
-4.00	-4.00	-0.30	5.00	-.00150440E+06	.308401E+05	.308401E+07
-4.00	-4.00	-0.30	5.00	-.00141591E+06	.233041E+07	.517848E+07
-4.00	-4.00	-0.30	5.00	-.00132741E+06	.462197E+07	.647335E+07
-4.00	-4.00	-0.30	5.00	-.0084042E+04	-.647335E+06	.710069E+07
-4.00	-4.00	-0.30	5.00	0.	.155360E+07	.241536E+07
-4.00	-4.00	-0.30	5.00	-.0084042E+04	.304517E+07	.971603E+07
-4.00	-4.00	0.00	5.00	-.00150440E+06	-.151476E+07	-.453135E+07
-4.00	-4.00	0.00	5.00	-.00141591E+06	.776802E+06	-.327668E+07
-4.00	-4.00	0.00	5.00	-.00132741E+06	.306637E+07	-.194201E+07
-4.00	-4.00	0.00	5.00	-.0084042E+04	-.229157E+07	-.124467E+07
-4.00	-4.00	0.00	5.00	0.	0.	0.
-4.00	-4.00	0.00	5.00	.0084042E+04	.229157E+07	.124467E+07
-4.00	-4.00	0.00	5.00	.00132741E+06	-.306637E+07	.194201E+07
-4.00	-4.00	0.00	5.00	.00141591E+06	-.776802E+06	.327668E+07
-4.00	-4.00	0.00	5.00	.00150440E+06	.151476E+07	.453135E+07
-4.00	-4.00	0.30	5.00	-.0084042E+04	-.304517E+07	-.971603E+07
-4.00	-4.00	0.30	5.00	0.	-.155360E+07	-.241536E+07
-4.00	-4.00	0.30	5.00	.0084042E+04	.647335E+06	-.710069E+07
-4.00	-4.00	0.30	5.00	.00132741E+06	-.462197E+07	-.647335E+07
-4.00	-4.00	0.30	5.00	.00141591E+06	-.233041E+07	-.517848E+07
-4.00	-4.00	0.30	5.00	.00150440E+06	-.308401E+05	-.308401E+07
-4.00	-4.00	0.30	5.00	.002743E+06	-.510076E+07	-.327668E+07
-4.00	-4.00	0.30	5.00	.0028318E+06	-.310721E+07	-.194201E+07
-4.00	-4.00	0.30	5.00	.002031E+06	-.415640E+06	-.647335E+06
-4.00	-4.00	-0.30	10.00	-.0057344E+06	.621442E+07	.517848E+06
-4.00	-4.00	-0.30	10.00	-.0066363E+06	.776802E+07	.310721E+07
-4.00	-4.00	-0.30	10.00	-.00553294E+07	.932163E+07	.569655E+07
-4.00	-4.00	-0.30	10.00	-.0063715E+06	.362508E+07	.107467E+08
-4.00	-4.00	-0.30	10.00	-.0066363E+06	.517848E+07	.155360E+08
-4.00	-4.00	-0.30	10.00	-.0049556E+06	.673229E+07	.121254E+08
-4.00	-4.00	-0.30	10.00	.00446011E+07	.103574E+07	.253755E+08
-4.00	-4.00	-0.30	10.00	.00453090E+07	.258034E+07	.279649E+08
-4.00	-4.00	-0.30	10.00	.00469170E+07	.414295E+07	.305540E+08
-4.00	-4.00	0.00	10.00	-.00516806E+07	.103574E+07	-.151420E+08
-4.00	-4.00	0.00	10.00	-.00509727E+07	.252234E+07	-.124099E+08
-4.00	-4.00	0.00	10.00	-.00502647E+07	.414295E+07	-.993050E+07
-4.00	-4.00	0.00	10.00	-.00707954E+05	-.155360E+07	-.254934E+07
-4.00	-4.00	0.00	10.00	0.	0.	0.
-4.00	-4.00	0.00	10.00	.00707954E+05	.155360E+07	.254934E+07
-4.00	-4.00	0.00	10.00	.002647E+07	-.414295E+07	.723050E+07
-4.00	-4.00	0.00	10.00	.009727E+07	-.258034E+07	.124099E+08
-4.00	-4.00	0.00	10.00	.0016806E+07	-.103574E+07	.150182E+08
-4.00	-4.00	0.30	10.00	-.00469170E+07	-.414295E+07	-.305540E+08

TABLE A2 Hydrodynamic Hull Data for Strut Rudder Configuration at Deep Draft

DRAFT

ROLL ANGLE DEG	PITCH ANGLE DEG	YAW RATE NON-DIMENSIONAL	SPEED KTS	Y FORCE LBS	X MOMENT LBS-FT	Y MOMENT LBS-FT
0.00	-4.00	.30	10.00	-.453090E+07	-.254834E+07	-.276449E+09
4.00	-4.00	.30	10.00	-.446011E+07	-.103574E+07	-.253755E+09
-4.00	0.00	.30	10.00	.495566E+06	-.673220E+07	-.121254E+09
0.00	0.00	.30	10.00	.566763E+06	-.517868E+07	-.155763E+09
0.00	0.00	.30	10.00	.677158E+06	-.362560E+07	-.129447E+09
-4.00	4.00	.30	10.00	.559384E+07	-.932163E+07	-.554655E+07
0.00	4.00	.30	10.00	.566763E+07	-.776402E+07	-.310721E+07
4.00	4.00	.30	10.00	.577444E+07	-.621442E+07	-.517969E+06
-4.00	-4.00	-.30	15.00	-.238934E+07	.179441E+08	0.
0.00	-4.00	-.30	15.00	-.238934E+07	.102250E+08	.932163E+07
4.00	-4.00	-.30	15.00	-.238934E+07	.219058E+08	.104433E+09
-4.00	0.00	-.30	15.00	-.055739E+06	.104964E+09	.254834E+07
0.00	0.00	-.30	15.00	-.055739E+06	.174677E+09	.340561E+09
0.00	0.00	-.30	15.00	-.055739E+06	.144448E+09	.440777E+09
-4.00	4.00	-.30	15.00	.477069E+06	.302553E+07	.517868E+09
0.00	4.00	-.30	15.00	.477069E+06	.501133E+07	.605066E+09
4.00	4.00	-.30	15.00	.477069E+06	.692122E+07	.694120E+09
-4.00	-4.00	.30	15.00	-.143761E+07	.547646E+07	-.340561E+09
0.00	-4.00	.30	15.00	-.143761E+07	.745730E+07	-.254834E+07
4.00	-4.00	.30	15.00	-.143761E+07	.943815E+07	-.143761E+07
-4.00	0.00	.30	15.00	0.	-.199085E+07	-.932163E+07
0.00	0.00	.30	15.00	0.	0.	0.
4.00	0.00	.30	15.00	0.	.199085E+07	.932163E+07
-4.00	4.00	.30	15.00	.143761E+07	-.943815E+07	.143761E+07
0.00	4.00	.30	15.00	.143761E+07	-.745730E+07	.254834E+07
4.00	4.00	.30	15.00	.143761E+07	-.547646E+07	.340561E+09
-4.00	-4.00	.30	15.00	-.477069E+06	-.692122E+07	-.694120E+09
0.00	-4.00	.30	15.00	-.477069E+06	-.501133E+07	-.605066E+09
4.00	-4.00	.30	15.00	-.477069E+06	-.302553E+07	-.517868E+09
-4.00	0.00	.30	15.00	.055739E+06	-.104964E+09	-.254834E+07
0.00	0.00	.30	15.00	.055739E+06	-.174677E+09	-.340561E+09
4.00	0.00	.30	15.00	.055739E+06	-.144448E+09	.440777E+09
-4.00	4.00	.30	15.00	.238934E+07	-.179441E+08	.253755E+09
0.00	4.00	.30	15.00	.238934E+07	-.103574E+07	.253755E+09
4.00	4.00	.30	15.00	.238934E+07	-.254834E+07	.253755E+09
-4.00	-4.00	-.30	20.00	-.509727E+07	.377450E+08	.220166E+09
0.00	-4.00	-.30	20.00	-.509727E+07	.379050E+08	.455724E+09
4.00	-4.00	-.30	20.00	-.509727E+07	.402522E+08	.601442E+09
-4.00	0.00	-.30	20.00	-.737818E+07	.275064E+08	.270017E+09
0.00	0.00	-.30	20.00	-.832518E+07	.316035E+08	.101574E+09
4.00	0.00	-.30	20.00	-.832518E+07	.350755E+08	.120145E+09
-4.00	4.00	-.30	20.00	-.169009E+07	.213362E+08	.161577E+09
0.00	4.00	-.30	20.00	-.167109E+07	.254721E+08	.171477E+09
4.00	4.00	-.30	20.00	-.167109E+07	.296221E+08	.194719E+09
-4.00	-4.00	.30	20.00	-.169009E+07	.207147E+07	-.311442E+09
0.00	-4.00	.30	20.00	-.169009E+07	.621442E+07	-.745730E+09

TABLE A2 (Continued)

ROLL ANGLE DEG	DRIFT ANGLE DEG	YAW RATE DIMENSIONAL	SPEED KTS	Y FORCE NTE	K MOMENT NTE-M	N MOMENT NTE-M
0.00	-4.00	0.00	20.00	-.169905E+07	.103574E+08	-.590012E+09
-5.00	0.00	0.00	20.00	0.	-.414295E+07	-.165718E+08
0.00	0.00	0.00	20.00	0.	0.	0.
5.00	0.00	0.00	20.00	0.	.414295E+07	.165718E+08
-10.00	4.00	0.00	20.00	.169905E+07	-.103574E+08	.590012E+09
0.00	4.00	0.00	20.00	.169905E+07	-.421442E+07	.745730E+08
5.00	4.00	0.00	20.00	.169905E+07	-.207147E+07	.911440E+08
-15.00	-4.00	.30	20.00	.169905E+07	-.294221E+08	-.124712E+09
0.00	-4.00	.30	20.00	.169905E+07	-.254791E+08	-.176147E+09
5.00	-4.00	.30	20.00	.169905E+07	-.217362E+08	-.161575E+09
-20.00	0.00	.30	20.00	.339818E+07	-.358365E+08	-.102145E+09
0.00	0.00	.30	20.00	.339818E+07	-.316935E+08	-.103574E+09
5.00	0.00	.30	20.00	.339818E+07	-.275526E+08	-.102006E+09
-25.00	4.00	.30	20.00	.509727E+07	-.420508E+08	-.601442E+09
0.00	4.00	.30	20.00	.509727E+07	-.379090E+08	-.455724E+09
5.00	4.00	.30	20.00	.509727E+07	-.337650E+08	-.290006E+09
-30.00	-4.00	-.30	25.00	-.769905E+07	.420768E+08	.398401E+09
0.00	-4.00	-.30	25.00	-.636070E+07	.420768E+08	.552602E+09
5.00	-4.00	-.30	25.00	-.502641E+07	.420768E+08	.776902E+09
-35.00	0.00	-.30	25.00	-.399224E+07	.271301E+08	.115240E+09
0.00	0.00	-.30	25.00	-.331953E+07	.271301E+08	.155340E+09
5.00	0.00	-.30	25.00	-.265483E+07	.271301E+08	.174791E+09
-40.00	4.00	-.30	25.00	-.265483E+06	.161934E+08	.273241E+09
0.00	4.00	-.30	25.00	.398224E+06	.161934E+08	.252461E+09
5.00	4.00	-.30	25.00	.106123E+07	.161934E+08	.271301E+09
-45.00	-4.00	0.00	25.00	-.439046E+07	.129467E+08	-.115240E+09
0.00	-4.00	0.00	25.00	-.371576E+07	.129467E+08	-.071003E+09
5.00	-4.00	0.00	25.00	-.305305E+07	.129467E+08	-.774902E+09
-50.00	0.00	0.00	25.00	0.	0.	0.
0.00	0.00	0.00	25.00	0.	0.	0.
5.00	0.00	0.00	25.00	.663707E+06	0.	-.194201E+09
-55.00	4.00	0.00	25.00	.663707E+06	0.	0.
0.00	4.00	0.00	25.00	.305305E+07	-.129467E+08	.164701E+09
5.00	4.00	0.00	25.00	.371576E+07	-.129467E+08	.774902E+09
-60.00	4.00	1.00	25.00	.439046E+07	-.129467E+08	.115240E+09
0.00	-4.00	.30	25.00	-.106123E+07	-.161934E+08	-.071003E+09
5.00	-4.00	.30	25.00	-.398224E+06	-.161934E+08	-.252461E+09
-65.00	-4.00	.30	25.00	.265483E+06	-.161934E+08	-.233041E+09
0.00	0.00	.30	25.00	.265483E+07	-.291301E+08	-.174791E+09
5.00	0.00	.30	25.00	.331953E+07	-.291301E+08	-.155340E+09
-70.00	0.00	.30	25.00	.399224E+07	-.291301E+08	-.115240E+09
0.00	4.00	.30	25.00	.502641E+07	-.420768E+08	-.776902E+09
5.00	4.00	.30	25.00	.636070E+07	-.420768E+08	-.552602E+09
-75.00	4.00	.30	25.00	.769905E+07	-.420768E+08	-.398401E+09
0.00	-4.00	-.30	28.00	-.113782E+08	.439499E+08	.324907E+09
5.00	-4.00	-.30	28.00	-.125457E+08	.439499E+08	.568412E+09
-80.00	-4.00	-.30	28.00	-.071313E+07	.439499E+08	.910017E+09

TABLE A2 (Continued)

DRAFT

ROLL ANGLE DEG	DEFT. ANGLE DEG	VAL. RATE NON-DIMENSIONAL	COEFF KTC	Y FORCE LBS	X MOMENT IN-LB	Y MOMENT IN-LB
-1.00	0.00	-0.70	28.00	-0.438091E+07	.251705E+09	.146163E+09
-1.00	0.00	-0.70	28.00	-0.555036E+07	.251705E+09	.179524E+09
-1.00	0.00	-0.70	28.00	-0.471780E+07	.251705E+09	.194924E+09
-1.00	0.00	-0.70	28.00	-0.138759E+07	.251705E+09	.250944E+09
-1.00	0.00	-0.70	28.00	-0.555036E+06	.812017E+07	.284286E+07
-1.00	0.00	-0.70	28.00	.277519E+06	.812017E+07	.300567E+07
-1.00	0.00	-0.70	28.00	-0.582788E+07	.170524E+09	-0.138043E+09
-1.00	0.00	-0.70	28.00	-0.499532E+07	.170524E+09	-0.117482E+09
-1.00	0.00	-0.70	28.00	-0.416277E+07	.170524E+09	-0.093213E+09
-1.00	0.00	-0.70	28.00	-0.832554E+06	0.	-0.243605E+09
-1.00	0.00	-0.70	28.00	0.	0.	0.
-1.00	0.00	-0.70	28.00	.832554E+06	0.	.243605E+09
-1.00	0.00	-0.70	28.00	.416277E+07	-0.170524E+09	.893012E+09
-1.00	0.00	-0.70	28.00	.499532E+07	-0.170524E+09	.117482E+09
-1.00	0.00	-0.70	28.00	.582788E+07	-0.170524E+09	.138043E+09
-1.00	0.00	-0.70	28.00	-0.277519E+06	-0.812017E+07	-0.300567E+07
-1.00	0.00	-0.70	28.00	-0.555036E+06	-0.812017E+07	-0.284286E+07
-1.00	0.00	-0.70	28.00	.138759E+07	-0.812017E+07	-0.250944E+07
-1.00	0.00	-0.70	28.00	.471780E+07	-0.251705E+09	-0.194924E+09
-1.00	0.00	-0.70	28.00	.555036E+07	-0.251705E+09	-0.179524E+09
-1.00	0.00	-0.70	28.00	.639291E+07	-0.251705E+09	-0.146163E+09
-1.00	0.00	-0.70	28.00	.971717E+07	-0.438091E+09	-0.093213E+09
-1.00	0.00	-0.70	28.00	.105457E+09	-0.438091E+09	-0.049412E+09
-1.00	0.00	-0.70	28.00	.113782E+09	-0.438091E+09	-0.037460E+09

TABLE A2 (Continued)

DRAFT

YAW ANGLE DEG	DRAFT ANGLE DEG	YAW RATE DEG/SEC	SPEED KTS	Y FORCE LBS	Y MOMENT FT-LB	Z MOMENT FT-LB
-1.00	-4.00	-1.00	5.00	-.046721E+06	.304048E+07	.033741E+07
-1.00	-4.00	-1.00	5.00	-.046721E+06	.304048E+07	.033741E+07
-1.00	-4.00	-1.00	5.00	-.046721E+06	.304048E+07	.033741E+07
-1.00	0.00	-1.00	5.00	-.176088E+06	.245087E+07	.517968E+07
-1.00	0.00	-1.00	5.00	-.176088E+06	.245087E+07	.517968E+07
-1.00	0.00	-1.00	5.00	-.176088E+06	.245087E+07	.517968E+07
-1.00	4.00	-1.00	5.00	-.670556E+06	.197727E+07	.000606E+07
-1.00	4.00	-1.00	5.00	-.670556E+06	.197727E+07	.000606E+07
-1.00	4.00	-1.00	5.00	-.670556E+06	.197727E+07	.000606E+07
-1.00	-4.00	0.00	5.00	-.109733E+06	.592602E+06	-.004928E+07
-1.00	-4.00	0.00	5.00	-.109733E+06	.592602E+06	-.004928E+07
-1.00	-4.00	0.00	5.00	-.109733E+06	.592602E+06	-.004928E+07
-1.00	0.00	0.00	5.00	0.	0.	0.
-1.00	0.00	0.00	5.00	0.	0.	0.
-1.00	0.00	0.00	5.00	0.	0.	0.
-1.00	4.00	0.00	5.00	.109733E+06	-.592602E+06	.004928E+07
-1.00	4.00	0.00	5.00	.109733E+06	-.592602E+06	.004928E+07
-1.00	4.00	0.00	5.00	.109733E+06	-.592602E+06	.004928E+07
-1.00	-4.00	1.00	5.00	-.670556E+06	-.197727E+07	-.000606E+07
-1.00	-4.00	1.00	5.00	-.670556E+06	-.197727E+07	-.000606E+07
-1.00	-4.00	1.00	5.00	-.670556E+06	-.197727E+07	-.000606E+07
-1.00	-4.00	1.00	5.00	-.670556E+06	-.197727E+07	-.000606E+07
-1.00	0.00	1.00	5.00	-.176088E+06	-.245087E+07	-.517968E+07
-1.00	0.00	1.00	5.00	-.176088E+06	-.245087E+07	-.517968E+07
-1.00	0.00	1.00	5.00	-.176088E+06	-.245087E+07	-.517968E+07
-1.00	4.00	1.00	5.00	-.046721E+06	-.304048E+07	-.033741E+07
-1.00	4.00	1.00	5.00	-.046721E+06	-.304048E+07	-.033741E+07
-1.00	-4.00	-1.00	10.00	-.109733E+07	.776002E+07	.517968E+07
-1.00	-4.00	-1.00	10.00	-.109733E+07	.776002E+07	.517968E+07
-1.00	-4.00	-1.00	10.00	-.109733E+07	.776002E+07	.517968E+07
-1.00	0.00	-1.00	10.00	-.670556E+06	.560655E+07	.155360E+08
-1.00	0.00	-1.00	10.00	-.670556E+06	.560655E+07	.155360E+08
-1.00	0.00	-1.00	10.00	-.670556E+06	.560655E+07	.155360E+08
-1.00	4.00	-1.00	10.00	-.247784E+06	.362508E+07	.050345E+08
-1.00	4.00	-1.00	10.00	-.247784E+06	.362508E+07	.050345E+08
-1.00	4.00	-1.00	10.00	-.247784E+06	.362508E+07	.050345E+08
-1.00	-4.00	0.00	10.00	-.424772E+06	.207147E+07	-.103574E+08
-1.00	-4.00	0.00	10.00	-.424772E+06	.207147E+07	-.103574E+08
-1.00	-4.00	0.00	10.00	-.424772E+06	.207147E+07	-.103574E+08
-1.00	0.00	0.00	10.00	0.	0.	0.
-1.00	0.00	0.00	10.00	0.	0.	0.
-1.00	0.00	0.00	10.00	0.	0.	0.
-1.00	4.00	0.00	10.00	.424772E+06	-.207147E+07	.103574E+08
-1.00	4.00	0.00	10.00	.424772E+06	-.207147E+07	.103574E+08
-1.00	4.00	0.00	10.00	.424772E+06	-.207147E+07	.103574E+08
-1.00	-4.00	1.00	10.00	-.247784E+06	-.362508E+07	-.050345E+08

TABLE A3 Hydrodynamic Hull Data for Spade Rudder Configuration at Design Draft

DRAFT

FILE NO.	DATE	TIME	COORD	X COORD	Y COORD	Z COORD
FILE NO.	DATE	TIME	COORD	X COORD	Y COORD	Z COORD
1001	10/10	10:00	10.00	10.00	10.00	10.00
1002	10/10	10:01	10.00	10.00	10.00	10.00
1003	10/10	10:02	10.00	10.00	10.00	10.00
1004	10/10	10:03	10.00	10.00	10.00	10.00
1005	10/10	10:04	10.00	10.00	10.00	10.00
1006	10/10	10:05	10.00	10.00	10.00	10.00
1007	10/10	10:06	10.00	10.00	10.00	10.00
1008	10/10	10:07	10.00	10.00	10.00	10.00
1009	10/10	10:08	10.00	10.00	10.00	10.00
1010	10/10	10:09	10.00	10.00	10.00	10.00
1011	10/10	10:10	10.00	10.00	10.00	10.00
1012	10/10	10:11	10.00	10.00	10.00	10.00
1013	10/10	10:12	10.00	10.00	10.00	10.00
1014	10/10	10:13	10.00	10.00	10.00	10.00
1015	10/10	10:14	10.00	10.00	10.00	10.00
1016	10/10	10:15	10.00	10.00	10.00	10.00
1017	10/10	10:16	10.00	10.00	10.00	10.00
1018	10/10	10:17	10.00	10.00	10.00	10.00
1019	10/10	10:18	10.00	10.00	10.00	10.00
1020	10/10	10:19	10.00	10.00	10.00	10.00
1021	10/10	10:20	10.00	10.00	10.00	10.00
1022	10/10	10:21	10.00	10.00	10.00	10.00
1023	10/10	10:22	10.00	10.00	10.00	10.00
1024	10/10	10:23	10.00	10.00	10.00	10.00
1025	10/10	10:24	10.00	10.00	10.00	10.00
1026	10/10	10:25	10.00	10.00	10.00	10.00
1027	10/10	10:26	10.00	10.00	10.00	10.00
1028	10/10	10:27	10.00	10.00	10.00	10.00
1029	10/10	10:28	10.00	10.00	10.00	10.00
1030	10/10	10:29	10.00	10.00	10.00	10.00
1031	10/10	10:30	10.00	10.00	10.00	10.00
1032	10/10	10:31	10.00	10.00	10.00	10.00
1033	10/10	10:32	10.00	10.00	10.00	10.00
1034	10/10	10:33	10.00	10.00	10.00	10.00
1035	10/10	10:34	10.00	10.00	10.00	10.00
1036	10/10	10:35	10.00	10.00	10.00	10.00
1037	10/10	10:36	10.00	10.00	10.00	10.00
1038	10/10	10:37	10.00	10.00	10.00	10.00
1039	10/10	10:38	10.00	10.00	10.00	10.00
1040	10/10	10:39	10.00	10.00	10.00	10.00
1041	10/10	10:40	10.00	10.00	10.00	10.00
1042	10/10	10:41	10.00	10.00	10.00	10.00
1043	10/10	10:42	10.00	10.00	10.00	10.00
1044	10/10	10:43	10.00	10.00	10.00	10.00
1045	10/10	10:44	10.00	10.00	10.00	10.00
1046	10/10	10:45	10.00	10.00	10.00	10.00
1047	10/10	10:46	10.00	10.00	10.00	10.00
1048	10/10	10:47	10.00	10.00	10.00	10.00
1049	10/10	10:48	10.00	10.00	10.00	10.00
1050	10/10	10:49	10.00	10.00	10.00	10.00
1051	10/10	10:50	10.00	10.00	10.00	10.00
1052	10/10	10:51	10.00	10.00	10.00	10.00
1053	10/10	10:52	10.00	10.00	10.00	10.00
1054	10/10	10:53	10.00	10.00	10.00	10.00
1055	10/10	10:54	10.00	10.00	10.00	10.00

ROLL ANGLE DEG	PITCH ANGLE DEG	YAW RATE DEG/SEC	SPED KTS	X FORCE LBS	X MOMENT IN-LB	Y MOMENT IN-LB
-4.00	0.00	-0.30	28.00	-.344122E+07	.324807E+09	.155747E+09
-4.00	0.00	-0.30	28.00	-.333021E+07	.365408E+09	.162403E+09
-4.00	0.00	-0.30	28.00	-.321921E+07	.406009E+09	.169444E+09
-4.00	0.00	-0.30	28.00	-.311007E+06	.243605E+09	.220146E+09
-4.00	0.00	-0.30	28.00	0.	.224206E+09	.224206E+09
-4.00	0.00	-0.30	28.00	.111007E+06	.324807E+09	.224206E+09
-4.00	0.00	-0.30	28.00	-.344122E+07	.406009E+09	-.125463E+09
-4.00	0.00	-0.30	28.00	-.333021E+07	.365408E+09	-.125463E+09
-4.00	0.00	-0.30	28.00	-.321921E+07	.406009E+09	-.117743E+09
-4.00	0.00	-0.30	28.00	-.311007E+06	.243605E+09	-.406009E+09
-4.00	0.00	-0.30	28.00	0.	.224206E+09	0.
-4.00	0.00	-0.30	28.00	.111007E+06	.324807E+09	.406009E+09
-4.00	0.00	-0.30	28.00	.321921E+07	-.406009E+09	.117743E+09
-4.00	0.00	-0.30	28.00	.333021E+07	-.365408E+09	.125463E+09
-4.00	0.00	-0.30	28.00	.344122E+07	-.406009E+09	.125463E+09
-4.00	0.00	-0.30	28.00	.111007E+06	-.324807E+09	-.224206E+09
-4.00	0.00	-0.30	28.00	0.	-.224206E+09	-.224206E+09
-4.00	0.00	-0.30	28.00	-.111007E+06	-.324807E+09	-.406009E+09
-4.00	0.00	-0.30	28.00	-.321921E+07	-.406009E+09	-.169444E+09
-4.00	0.00	-0.30	28.00	-.333021E+07	-.365408E+09	-.169444E+09
-4.00	0.00	-0.30	28.00	-.344122E+07	-.406009E+09	-.155747E+09
-4.00	0.00	-0.30	28.00	.654342E+07	-.427210E+09	-.447413E+09
-4.00	0.00	-0.30	28.00	.666043E+07	-.446610E+09	-.466009E+09
-4.00	0.00	-0.30	28.00	.677144E+07	-.406009E+09	-.365408E+09

TABLE A3 (Continued)

DRAFT

ROLL ANGLE DEG	HEAVE FT	YAW RATE DEG/SEC	SPIN RPS	Y FORCE LBS	K MOMENT FT-LB	H MOMENT FT-LB
-4.00	-4.00	-0.70	5.00	-.334503E+06	.233041E+07	.310721E+07
0.00	-4.00	-0.70	5.00	-.752707E+06	.245797E+07	.440188E+07
4.00	-4.00	-0.70	5.00	-.369706E+06	.258934E+07	.567655E+07
-4.00	0.00	-0.70	5.00	-.125033E+06	.245047E+07	.517260E+07
0.00	0.00	-0.70	5.00	-.003337E+06	.254934E+07	.647335E+07
4.00	0.00	-0.70	5.00	-.021036E+06	.271881E+07	.776802E+07
-4.00	4.00	-0.70	5.00	-.371676E+06	.142414E+07	.725015E+07
0.00	4.00	-0.70	5.00	-.548664E+06	.155760E+07	.854493E+07
4.00	4.00	-0.70	5.00	-.706657E+06	.164107E+07	.987353E+07
-4.00	-4.00	0.00	5.00	-.130971E+06	.906269E+06	-.336614E+07
0.00	-4.00	0.00	5.00	-.149673E+06	.103574E+07	-.207147E+07
4.00	-4.00	0.00	5.00	-.166768E+06	.116520E+07	-.776025E+06
-4.00	0.00	0.00	5.00	-.175988E+06	-.123467E+06	-.123467E+07
0.00	0.00	0.00	5.00	0.	0.	0.
4.00	0.00	0.00	5.00	-.175728E+06	.129467E+06	.129467E+07
-4.00	4.00	0.00	5.00	.166768E+06	-.116520E+07	.776025E+06
0.00	4.00	0.00	5.00	.149673E+06	-.103574E+07	.207147E+07
4.00	4.00	0.00	5.00	.130971E+06	-.906269E+06	.336614E+07
-4.00	-4.00	.70	5.00	.726653E+06	-.168175E+07	-.297955E+07
0.00	-4.00	.70	5.00	.548664E+06	-.155760E+07	-.854493E+07
4.00	-4.00	.70	5.00	.371676E+06	-.142414E+07	-.725015E+07
-4.00	0.00	.70	5.00	.021036E+06	-.271881E+07	-.776802E+07
0.00	0.00	.70	5.00	.003337E+06	-.254934E+07	-.647335E+07
4.00	0.00	.70	5.00	.125033E+06	-.245047E+07	-.517260E+07
-4.00	4.00	.70	5.00	.369706E+06	-.258934E+07	-.567655E+07
0.00	4.00	.70	5.00	.752707E+06	-.245797E+07	-.440188E+07
4.00	4.00	.70	5.00	.334503E+06	-.233041E+07	-.310721E+07
-4.00	-4.00	-0.70	10.00	-.127430E+07	.100344E+08	.677225E+07
0.00	-4.00	-0.70	10.00	-.134511E+07	.126163E+08	.113112E+08
4.00	-4.00	-0.70	10.00	-.141592E+07	.111742E+08	.130297E+08
-4.00	0.00	-0.70	10.00	-.707954E+06	.621442E+07	.145003E+08
0.00	0.00	-0.70	10.00	-.778749E+06	.673223E+07	.185790E+08
4.00	0.00	-0.70	10.00	-.849545E+06	.725015E+07	.249577E+08
-4.00	4.00	-0.70	10.00	-.141591E+06	.033341E+07	.020603E+08
0.00	4.00	-0.70	10.00	-.212386E+06	.284928E+07	.274479E+08
4.00	4.00	-0.70	10.00	-.283182E+06	.336614E+07	.320257E+08
-4.00	-4.00	0.00	10.00	-.495569E+06	.336614E+07	-.123467E+08
0.00	-4.00	0.00	10.00	-.566363E+07	.388401E+07	-.776802E+07
4.00	-4.00	0.00	10.00	-.637158E+06	.440188E+07	-.207147E+07
-4.00	0.00	0.00	10.00	.767954E+06	-.517968E+06	-.517968E+07
0.00	0.00	0.00	10.00	0.	0.	0.
4.00	0.00	0.00	10.00	-.707954E+06	.517968E+06	.517968E+07
-4.00	4.00	0.00	10.00	.637158E+06	-.440188E+07	.207147E+07
0.00	4.00	0.00	10.00	.566363E+06	-.388401E+07	.776802E+07
4.00	4.00	0.00	10.00	.495569E+06	-.336614E+07	.123467E+08
-4.00	-4.00	.70	10.00	.283182E+06	-.336614E+07	-.320257E+08

TABLE A4 Hydrodynamic Hull Data for Spade Rudder Configuration at Deep Draft

DRAFT

ROLL ANGLE DEG	DRIFT ANGLE DEG	MAX DATA NO. DIMENSIONAL	SPIN MTC	Y FORCE MTC	K MOMENT MT-M	H MOMENT MT-M
0.00	-4.00	.30	10.00	.212196E+06	-.244909E+07	-.274479E+08
0.00	-4.00	.30	15.00	.141551E+06	-.231104E+07	-.202665E+08
-4.00	0.00	.30	10.00	.649545E+06	-.725015E+07	-.242577E+08
0.00	0.00	.30	10.00	.775749E+06	-.673029E+07	-.186700E+08
0.00	0.00	.30	10.00	.707054E+06	-.621442E+07	-.145003E+08
-4.00	4.00	.30	10.00	.141551E+07	-.111302E+08	-.170907E+08
0.00	4.00	.30	10.00	.134511E+07	-.106167E+08	-.114110E+08
0.00	4.00	.30	10.00	.127430E+07	-.100984E+08	-.673200E+07
-4.00	-4.00	-.30	15.00	-.261203E+07	.139085E+08	.815642E+07
0.00	-4.00	-.30	15.00	-.277164E+07	.209737E+08	.183095E+08
0.00	-4.00	-.30	15.00	-.293003E+07	.221389E+08	.314605E+08
-4.00	0.00	-.30	15.00	-.127430E+07	.116520E+08	.314605E+08
0.00	0.00	-.30	15.00	-.143361E+07	.129172E+08	.431125E+08
0.00	0.00	-.30	15.00	-.159280E+07	.139974E+08	.547646E+08
-4.00	4.00	-.30	15.00	-.637159E+05	.349561E+07	.547646E+08
0.00	4.00	-.30	15.00	-.955732E+05	.446081E+07	.547646E+08
0.00	4.00	-.30	15.00	-.254862E+06	.582602E+07	.780686E+08
-4.00	-4.00	.30	15.00	-.117274E+07	.699122E+07	-.349561E+08
0.00	-4.00	.30	15.00	-.133903E+07	.815642E+07	-.233041E+08
0.00	-4.00	.30	15.00	-.147732E+07	.932163E+07	-.114520E+08
-4.00	0.00	.30	15.00	-.159280E+06	-.116520E+07	-.114520E+08
0.00	0.00	.30	15.00	0.	0.	0.
0.00	0.00	.30	15.00	-.159280E+06	.116520E+07	.116520E+08
-4.00	4.00	.30	15.00	-.149732E+07	-.332163E+07	.116520E+08
0.00	4.00	.30	15.00	.133903E+07	-.815642E+07	.233041E+08
0.00	4.00	.30	15.00	.117274E+07	-.699122E+07	.349561E+08
-4.00	-4.00	.30	15.00	.254862E+06	-.582602E+07	-.780686E+08
0.00	-4.00	.30	15.00	.955732E+05	-.446081E+07	-.547646E+08
0.00	-4.00	.30	15.00	.637159E+05	-.349561E+07	-.547646E+08
-4.00	0.00	.30	15.00	.159280E+07	-.139974E+08	-.547646E+08
0.00	0.00	.30	15.00	.143361E+07	-.129172E+08	-.431125E+08
0.00	0.00	.30	15.00	.127430E+07	-.116520E+08	-.314605E+08
-4.00	4.00	.30	15.00	.293003E+07	-.221389E+08	-.314605E+08
0.00	4.00	.30	15.00	.277164E+07	-.209737E+08	-.183095E+08
0.00	4.00	.30	15.00	.261203E+07	-.199085E+08	-.815642E+07
-4.00	-4.00	-.30	20.00	-.504063E+07	.352150E+08	.145003E+08
0.00	-4.00	-.30	20.00	-.532381E+07	.372865E+08	.350150E+08
0.00	-4.00	-.30	20.00	-.560609E+07	.393580E+08	.559228E+08
-4.00	0.00	-.30	20.00	-.339418E+07	.269291E+08	.766445E+08
0.00	0.00	-.30	20.00	-.368136E+07	.290006E+08	.973530E+08
0.00	0.00	-.30	20.00	-.396454E+07	.310721E+08	.117974E+08
-4.00	4.00	-.30	20.00	-.175573E+07	.186433E+08	.132769E+08
0.00	4.00	-.30	20.00	-.203891E+07	.207147E+08	.153503E+08
0.00	4.00	-.30	20.00	-.232209E+07	.227862E+08	.173218E+08
-4.00	-4.00	.30	20.00	-.135527E+07	.601442E+07	-.928599E+08
0.00	-4.00	.30	20.00	-.164245E+07	.823589E+07	-.621442E+08

TABLE A4 (Continued)

DRAFT

ROLL ANGLE DEG	PITCH ANGLE DEG	YAW RATE 1/G-DIMENSIONAL M/S	HEIGHT M/S	V. SPEED M/S	ACCELERATION M/S ²	ANGULAR M/S ²
4.00	-4.00	0.00	20.00	-.102563E+07	.103574E+08	-.414005E+08
-4.00	0.00	0.00	20.00	.281130E+06	-.207147E+07	-.207147E+07
0.00	0.00	0.00	20.00	0.	0.	0.
0.00	0.00	0.00	20.00	-.281130E+06	.207147E+07	.207147E+07
-4.00	4.00	0.00	20.00	.102563E+07	-.103574E+08	.414005E+08
0.00	4.00	0.00	20.00	.164245E+07	-.222589E+07	.621442E+08
4.00	4.00	0.00	20.00	.135327E+07	-.621442E+07	.820540E+08
4.00	4.00	0.00	20.00	.232300E+07	-.227862E+08	-.100019E+09
-4.00	-4.00	0.00	20.00	.203101E+07	-.207147E+07	-.159507E+08
0.00	-4.00	0.00	20.00	.175977E+07	-.186433E+08	-.134760E+08
4.00	-4.00	0.00	20.00	.294454E+07	-.310721E+08	-.110074E+09
-4.00	0.00	0.00	20.00	.358136E+07	-.290006E+08	-.277502E+08
0.00	0.00	0.00	20.00	.239810E+07	-.269291E+08	-.766445E+08
-4.00	4.00	0.00	20.00	.560600E+07	-.303660E+08	-.560000E+08
0.00	4.00	0.00	20.00	.532381E+07	-.372865E+08	-.750150E+08
4.00	4.00	0.00	20.00	.504063E+07	-.352150E+08	-.145003E+09
-4.00	-4.00	0.00	20.00	-.710007E+07	.568455E+08	.356034E+08
0.00	-4.00	0.00	20.00	-.672556E+07	.674380E+08	.679700E+08
4.00	-4.00	0.00	20.00	-.628309E+07	.602122E+08	.100337E+09
-4.00	0.00	0.00	20.00	-.442471E+07	.453135E+08	.150104E+09
0.00	0.00	0.00	20.00	-.398024E+07	.517869E+08	.144615E+09
4.00	0.00	0.00	20.00	-.353977E+07	.582602E+08	.216575E+09
-4.00	4.00	0.00	20.00	-.163139E+07	.336614E+08	.266444E+08
0.00	4.00	0.00	20.00	-.103690E+07	.401349E+08	.301011E+09
4.00	4.00	0.00	20.00	-.796448E+06	.446191E+08	.333370E+09
-4.00	-4.00	0.00	20.00	-.318570E+07	.517869E+08	-.140227E+09
0.00	-4.00	0.00	20.00	-.274332E+07	.116520E+09	-.116520E+09
4.00	-4.00	0.00	20.00	-.230005E+07	.121054E+09	-.141834E+09
-4.00	0.00	0.00	20.00	-.442471E+06	-.647335E+07	-.323668E+08
0.00	0.00	0.00	20.00	0.	0.	0.
4.00	0.00	0.00	20.00	.442471E+06	.647335E+07	.323668E+08
-4.00	4.00	0.00	20.00	.230005E+07	-.101054E+09	.141834E+09
0.00	4.00	0.00	20.00	.274332E+07	-.116520E+09	.116520E+09
4.00	4.00	0.00	20.00	.318570E+07	-.517869E+08	.140227E+09
-4.00	-4.00	0.00	20.00	.796448E+06	-.446191E+08	.333370E+09
0.00	-4.00	0.00	20.00	.163139E+07	-.401349E+08	.301011E+09
4.00	-4.00	0.00	20.00	.103690E+07	-.336614E+08	.266444E+08
-4.00	0.00	0.00	20.00	.753277E+07	-.582602E+08	-.216575E+09
0.00	0.00	0.00	20.00	.798224E+07	-.517869E+08	-.140227E+09
4.00	0.00	0.00	20.00	.442471E+07	-.453135E+08	-.150104E+09
-4.00	4.00	0.00	20.00	.628309E+07	-.602122E+08	-.100337E+09
0.00	4.00	0.00	20.00	.672556E+07	-.674380E+08	-.679700E+08
4.00	4.00	0.00	20.00	.710007E+07	-.766445E+08	-.750150E+08
-4.00	-4.00	0.00	20.00	-.974902E+07	.649614E+09	.401011E+09
0.00	-4.00	0.00	20.00	-.777050E+07	.730816E+08	.560412E+08
4.00	-4.00	0.00	20.00	-.749099E+07	.812017E+08	.640414E+08

TABLE A4 (Continued)

DRAFT

ROLL ANGLE DEG	PITCH ANGLE DEG	WIND RATE PERCENT DIMENSIONAL	SPEED KTS	Y FORCE LBS	K MOMENT FT-LB	M MOMENT FT-LB
-6.00	0.00	-0.30	28.00	-.4162775+07	.5274115+09	.1042245+09
0.00	0.00	-0.30	28.00	-.3824255+07	.6090135+09	.2030045+09
6.00	0.00	-0.30	28.00	-.3407735+07	.6900155+09	.2111255+09
-6.00	4.00	-0.30	28.00	-.2775135+06	.4061005+08	.3410475+09
0.00	4.00	-0.30	28.00	0.	.4970105+08	.3401475+09
6.00	4.00	-0.30	28.00	.2775195+06	.5684125+08	.3572085+09
-6.00	-4.00	-0.30	28.00	-.4162775+07	.4060005+07	-.1541235+09
0.00	-4.00	-0.30	28.00	-.3985255+07	.1010035+08	-.1461435+09
6.00	-4.00	-0.30	28.00	-.3607735+07	.2030045+08	-.1380435+09
-6.00	0.00	0.00	28.00	-.2775135+06	-.8120175+07	-.0120175+07
0.00	0.00	0.00	28.00	0.	0.	0.
6.00	0.00	0.00	28.00	.2775195+06	.8120175+07	.8120175+07
-6.00	4.00	0.00	28.00	.3607735+07	-.2030045+08	.1380435+09
0.00	4.00	0.00	28.00	.3985255+07	-.1010035+08	.1461435+09
6.00	4.00	0.00	28.00	.4162775+07	-.4060005+07	.1541235+09
-6.00	-4.00	0.30	28.00	-.2775180+06	-.5684125+08	-.3572085+09
0.00	-4.00	0.30	28.00	0.	-.4970105+08	-.3401475+09
6.00	-4.00	0.30	28.00	.2775195+06	-.4061005+08	-.3410475+09
-6.00	0.00	0.30	28.00	.3607735+07	-.6090135+09	-.2111255+09
0.00	0.00	0.30	28.00	.3824255+07	-.6900155+09	-.2030045+09
6.00	0.00	0.30	28.00	.4162775+07	-.5274115+09	-.1042245+09
-6.00	4.00	0.30	28.00	.7490685+07	-.8120175+08	-.6420145+08
0.00	4.00	0.30	28.00	.7770505+07	-.7300165+08	-.5684125+08
6.00	4.00	0.30	28.00	.8040005+07	-.6490145+08	-.4970105+08

TABLE A4 (Continued)

DRAFT

CASE A

TABLE OF RUDDER Y VALUES

		RUDDER ANGLE - DEG									
		-40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	-5.0	0.0	40.0
SPEED KTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	-.1740E+06	-.1010E+06	-.9570E+05	-.7540E+05	-.5560E+05	-.4560E+05	-.3560E+05	-.2560E+05	-.1560E+05	-.1240E+06
	10.0	-.3890E+06	-.2360E+06	-.2830E+06	-.1420E+06	-.1420E+06	-.2830E+06	-.2830E+06	-.3360E+06	-.3890E+06	
	15.0	-.4780E+06	-.4220E+06	-.3670E+06	-.1590E+06	-.1590E+06	-.3670E+06	-.4220E+06	-.4780E+06	-.5670E+06	
	20.0	-.5670E+06	-.4960E+06	-.4250E+06	-.2830E+06	-.2830E+06	-.4250E+06	-.4960E+06	-.5670E+06	-.670E+06	
	25.0	-.4430E+06	-.3760E+06	-.3100E+06	-.2210E+06	-.2210E+06	-.3100E+06	-.3760E+06	-.4430E+06	-.530E+06	
	25.0	-.3890E+06	-.3330E+06	-.2760E+06	-.2210E+06	-.2210E+06	-.2760E+06	-.3330E+06	-.3890E+06	-.4740E+06	

TABLE A5 Hydrodynamic Data for Strut Rudder at Design Draft

CASE A

TABLE OF RUDDER Y VALUES

	RUDDER ANGLE - DEG									
	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	35.0	40.0	P.
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5.0	-0.2300E+06	-0.2300E+06	-0.2300E+06	-0.1770E+06	-0.1770E+06	-0.1770E+06	-0.2300E+06	-0.2300E+06	-0.2300E+06	-0.2300E+06
10.0	-0.7080E+06	-0.6570E+06	-0.6070E+06	-0.5310E+06	-0.5310E+06	-0.5310E+06	-0.6870E+06	-0.6870E+06	-0.7080E+06	-0.7080E+06
15.0	-0.1140E+07	-0.1080E+07	-0.1020E+07	-0.7970E+06	-0.7970E+06	-0.7970E+06	-0.1020E+07	-0.1020E+07	-0.1140E+07	-0.1140E+07
20.0	-0.2010E+07	-0.1800E+07	-0.1590E+07	-0.8790E+06	-0.8790E+06	-0.8790E+06	-0.1590E+07	-0.1800E+07	-0.2010E+07	-0.2010E+07
25.0	-0.1630E+07	-0.1240E+07	-0.9300E+06	-0.6200E+06	-0.6200E+06	-0.6200E+06	-0.9300E+06	-0.1240E+07	-0.1630E+07	-0.1630E+07
28.0	-0.9990E+06	-0.9440E+06	-0.8800E+06	-0.6110E+06	-0.6110E+06	-0.6110E+06	-0.8800E+06	-0.9440E+06	-0.9990E+06	-0.9990E+06

TABLE A5 (Continued)

CASE A

TABLE OF RUDDER K VALUES

RUDDER ANGLE - DEG									
	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	35.0	40.0
SPEED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	.6480E+06	.6090E+06	.5700E+06	.4540E+06	-.4540E+06	-.5700E+06	-.6090E+06	-.6480E+06	
10.0	.3110E+07	.2800E+07	.2500E+07	.2070E+07	-.2070E+07	-.2590E+07	-.2800E+07	-.3110E+07	
15.0	.4660E+07	.4550E+07	.4430E+07	.3500E+07	-.3500E+07	-.4430E+07	-.4660E+07		
20.0	.4980E+07	.4700E+07	.4420E+07	.3320E+07	-.3320E+07	-.4420E+07	-.4980E+07		
25.0	.6480E+07	.5670E+07	.4960E+07	.3240E+07	-.3240E+07	-.4860E+07	-.5670E+07	-.6480E+07	
28.0	.5690E+07	.5690E+07	.5690E+07	.4070E+07	-.4070E+07	-.5690E+07	-.5690E+07	-.5690E+07	

A-20

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TABLE A5 (Continued)

CASE A

TABLE OF BODDER A. VALUES

		BODDER ANGLE - DEG							
		-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	40.0
SPEED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	.4020E+07	.3820E+07	.3630E+07	.2980E+07	.2980E+07	.3630E+07	.3820E+07	.4020E+07
	10.0	.1920E+08	.1740E+08	.1560E+08	.1400E+08	.1400E+08	.1560E+08	.1740E+08	.1920E+08
	15.0	.2100E+08	.2040E+08	.1980E+08	.1870E+08	.1870E+08	.1980E+08	.2040E+08	.2100E+08
	20.0	.2490E+08	.2280E+08	.2070E+08	.1870E+08	.1870E+08	.2070E+08	.2280E+08	.2490E+08
KTS	25.0	.1950E+08	.1740E+08	.1620E+08	.1300E+08	.1300E+08	.1620E+08	.1740E+08	.1950E+08
	28.0	.1830E+08	.1830E+08	.1830E+08	.1830E+08	.1830E+08	.1830E+08	.1830E+08	.1830E+08

TABLE A5 (Continued)

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TABLE OF RUDDER X VALUES

	RUDDER ANGLE - DEG									
	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	45.0	40.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	-0.1560E+06	-0.1280E+06	-0.1010E+06	-0.6730E+06	-0.6730E+06	-0.6730E+06	-0.1010E+06	-0.1280E+06	-0.1560E+06	0.0
10.0	-0.5460E+06	-0.4000E+06	-0.3540E+06	-0.2130E+06	-0.2130E+06	-0.2130E+06	-0.3540E+06	-0.4000E+06	-0.5460E+06	0.0
15.0	-0.1040E+07	-0.8300E+06	-0.6220E+06	-0.3190E+06	-0.3190E+06	-0.3190E+06	-0.6220E+06	-0.8300E+06	-0.1040E+07	0.0
20.0	-0.1530E+07	-0.1120E+07	-0.7680E+06	-0.4250E+06	-0.4250E+06	-0.4250E+06	-0.7680E+06	-0.1120E+07	-0.1530E+07	0.0
25.0	-0.1770E+07	-0.1310E+07	-0.8410E+06	-0.4430E+06	-0.4430E+06	-0.4430E+06	-0.8410E+06	-0.1310E+07	-0.1770E+07	0.0
30.0	-0.1670E+07	-0.1150E+07	-0.7220E+06	-0.3890E+06	-0.3890E+06	-0.3890E+06	-0.7220E+06	-0.1150E+07	-0.1670E+07	0.0

TABLE A6 Hydrodynamic Data for Strut Rudder at Deep Draft

CASE I

TABLE OF RUDDER Y VALUES

		RUDDER P. ANGLE - DEG									
		-40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	-5.0	0.0	40.0
SPEED KTS	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	5.0	-4250E+06	-3900E+06	-3540E+06	-3000E+06	-3000E+06	-3540E+06	-3900E+06	-4250E+06	-3900E+06	-4250E+06
	10.0	-1300E+07	-1210E+07	-1130E+07	-890E+06	-890E+06	-1130E+07	-1210E+07	-1300E+07	-1210E+07	-1300E+07
	15.0	-2070E+07	-1910E+07	-1750E+07	-1390E+07	-1390E+07	-1750E+07	-1910E+07	-2070E+07	-1750E+07	-2070E+07
	20.0	-2690E+07	-2480E+07	-2270E+07	-1760E+07	-1760E+07	-2270E+07	-2480E+07	-2690E+07	-2270E+07	-2690E+07
	25.0	-2170E+07	-1900E+07	-1640E+07	-1150E+07	-1150E+07	-1640E+07	-1900E+07	-2170E+07	-1640E+07	-2170E+07
	28.0	-1390E+07	-1310E+07	-1220E+07	-8380E+06	-8380E+06	-1220E+07	-1310E+07	-1390E+07	-1220E+07	-1390E+07

TABLE A6 (Continued)

TABLE OF PHOTON K VALUES

		SCATTER ANGLE - DEG							
		-40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	0.0
SAMPLE	0.0	0.	0.	0.	0.	0.	0.	0.	0.
	5.0	.5660E+06	.5120E+06	.4570E+06	.4020E+06	.3590E+06	.3170E+06	.2760E+06	.2360E+06
	10.0	.2700E+07	.2440E+07	.2180E+07	.1910E+07	.1710E+07	.1500E+07	.1290E+07	.1080E+07
NTS	15.0	.8050E+07	.7230E+07	.6410E+07	.5600E+07	.4860E+07	.4190E+07	.3590E+07	.3050E+07
	20.0	.9950E+07	.5020E+07	.4090E+07	.3220E+07	.2400E+07	.1640E+07	.9090E+07	.5050E+07
	25.0	.8750E+07	.7940E+07	.7130E+07	.6310E+07	.5510E+07	.4730E+07	.3940E+07	.3150E+07
	28.0	.6130E+07	.5560E+07	.4990E+07	.4450E+07	.3850E+07	.3290E+07	.2760E+07	.2200E+07

TABLE A6 (Continued)

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TABLE A6 (Continued)

CASE 1

TABLE OF RUDDER Y VALUES

RUDDER ANGLE - 10°

	-40.0	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0
SPEED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	-0.9740E+05	-0.8120E+05	-0.6720E+05	-0.5070E+05	-0.4070E+05	-0.330E+05	-0.320E+05	-0.320E+05	-0.320E+05
10.0	-0.3400E+06	-0.2760E+06	-0.2190E+06	-0.1270E+06	-0.1270E+06	-0.2190E+06	-0.2760E+06	-0.3400E+06	-0.3400E+06
15.0	-0.6370E+06	-0.5100E+06	-0.3420E+06	-0.2070E+06	-0.2070E+06	-0.3420E+06	-0.5100E+06	-0.6370E+06	-0.6370E+06
20.0	-0.9350E+06	-0.7640E+06	-0.560E+06	-0.2830E+06	-0.2830E+06	-0.560E+06	-0.7640E+06	-0.9350E+06	-0.9350E+06
25.0	-0.9740E+06	-0.7520E+06	-0.5750E+06	-0.2660E+06	-0.2660E+06	-0.5750E+06	-0.7520E+06	-0.9740E+06	-0.9740E+06
28.0	-0.9440E+06	-0.660E+06	-0.5550E+06	-0.2770E+06	-0.2770E+06	-0.5550E+06	-0.660E+06	-0.9440E+06	-0.9440E+06

TABLE A7 Hydrodynamic Data for Spade Rudder at Design Draft

CASE C

TABLE OF RUDDER Y VALUES

		RUDDER ANGLE - DEG									
		-40.0	-35.0	-30.0	-20.0	0.	20.0	30.0	35.0	40.0	
SPEED	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	
	5.0	-.1840E+06	-.1670E+06	-.1500E+06	-.1200E+06	-.1000E+06	.1200E+06	.1500E+06	.1670E+06	.1840E+06	
	10.0	-.6510E+06	-.6720E+06	-.6940E+06	-.5310E+06	-.510E+06	.5310E+06	.6940E+06	.6720E+06	.6510E+06	
	15.0	-.1230E+07	-.1370E+07	-.1310E+07	-.8760E+06	-.8760E+06	.8760E+06	.1310E+07	.1370E+07	.1230E+07	
KTS	20.0	-.1670E+07	-.1810E+07	-.1950E+07	-.1440E+07	-.1440E+07	.1440E+07	.1950E+07	.1810E+07	.1670E+07	
	25.0	-.1950E+07	-.1950E+07	-.1770E+07	-.1150E+07	-.1150E+07	.1150E+07	.1770E+07	.1950E+07	.1950E+07	
	28.0	-.1940E+07	-.1660E+07	-.1380E+07	-.1110E+07	-.1110E+07	.1110E+07	.1380E+07	.1660E+07	.1940E+07	

TABLE A7 (Continued)

KUDDEH ANGLE - FIG

TABLE A7 (Continued)

CASE 1

TABLE OF RUBBER R VALUES

RUBBER ANGLE - DEG										
	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	35.0	40.0	
SPFFD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	5.0	.4270E+07	.4270E+07	.4270E+07	.3110E+07	-.4270E+07	-.4270E+07	-.4270E+07	-.4270E+07	
	10.0	.1020E+08	.2620E+08	.1020E+08	.1550E+08	-.1520E+08	-.1520E+08	-.2020E+08	-.1020E+08	
	15.0	.3030E+08	.3500E+08	.3300E+08	.2800E+08	-.3380E+08	-.3500E+08	-.3030E+08	-.1020E+08	
KTS	20.0	.6630E+08	.7250E+08	.6610E+08	.4140E+08	-.4140E+08	-.6020E+08	-.7250E+08	-.6630E+08	
	25.0	.5080E+08	.5500E+08	.5500E+08	.3240E+08	-.3240E+08	-.5500E+08	-.5500E+08	-.5080E+08	
	28.0	.4260E+08	.4260E+08	.4260E+08	.3940E+08	-.3940E+08	-.4260E+08	-.4260E+08	-.4260E+08	

TABLE A7 (Continued)

CASE 11

TABLE OF EQUIPPED X VALUES

RUDDER AREA - 146

	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	35.0	40.0
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.
5.0	-0.1240E+06	-0.1030E+06	-0.7470E+05	-0.4780E+05	0.	0.	0.	0.	0.
10.0	-0.4600E+06	-0.3800E+06	-0.2470E+06	-0.1560E+06	0.	0.	0.	0.	0.
15.0	-0.1040E+07	-0.8750E+06	-0.6370E+06	-0.3510E+06	0.	0.	0.	0.	0.
20.0	-0.1420E+07	-0.1160E+07	-0.8780E+06	-0.4810E+06	0.	0.	0.	0.	0.
25.0	-0.1770E+07	-0.1420E+07	-0.1020E+07	-0.5310E+06	0.	0.	0.	0.	0.
28.0	-0.2000E+07	-0.1610E+07	-0.1170E+07	-0.6110E+06	0.	0.	0.	0.	0.

TABLE A8 Hydrodynamic Data for Spade Rudder at Deep Draft

CASE II

TABLE OF BUDDER Y VALUES

BUDDER ANGLE - DEG

	-40.0	-35.0	-30.0	-20.0	0.0	20.0	30.0	35.0	40.0
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.
5.0	-0.3010E+06	-0.3010E+06	-0.3010E+06	-0.2100E+06	-0.2100E+06	-0.2100E+06	-0.3010E+06	-0.3010E+06	-0.3010E+06
10.0	-0.1060E+07	-0.1060E+07	-0.1060E+07	-0.8070E+06	-0.8070E+06	-0.8070E+06	-0.1060E+07	-0.1060E+07	-0.1060E+07
15.0	-0.2040E+07	-0.2040E+07	-0.1950E+07	-0.1320E+07	-0.1320E+07	-0.1320E+07	-0.1990E+07	-0.2040E+07	-0.2040E+07
20.0	-0.3230E+07	-0.3230E+07	-0.3120E+07	-0.2260E+07	-0.2260E+07	-0.2260E+07	-0.3120E+07	-0.3230E+07	-0.3230E+07
25.0	-0.2660E+07	-0.2790E+07	-0.2790E+07	-0.1900E+07	-0.1900E+07	-0.1900E+07	-0.2790E+07	-0.2790E+07	-0.2660E+07
28.0	-0.2390E+07	-0.2510E+07	-0.2510E+07	-0.1710E+07	-0.1710E+07	-0.1710E+07	-0.2510E+07	-0.2510E+07	-0.2390E+07

TABLE A8 (Continued)

CALCUL

TABLE OF RUDIMENTARY VALUES

		WINDSPEED ANGLE - DEG									
		-45.0	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	45.0	60.0
SPFEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	.8030E+06	.6120E+06	.7360E+06	.5330E+06	.5330E+06	-.5330E+06	-.7360E+06	-.9120E+06	-.6030E+06	0.0
	10.0	.3110E+07	.3210E+07	.2400E+07	.2070E+07	.2070E+07	-.2070E+07	-.2900E+07	-.3210E+07	-.3110E+07	0.0
KTS	15.0	.6760E+07	.7000E+07	.6000E+07	.4000E+07	.4000E+07	-.4000E+07	-.6000E+07	-.7000E+07	-.6760E+07	0.0
	20.0	.1160E+08	.1200E+08	.1040E+08	.7880E+07	.7880E+07	-.7880E+07	-.1040E+08	-.1200E+08	-.1160E+08	0.0
	25.0	.1550E+08	.1620E+08	.1360E+08	.1040E+08	.1040E+08	-.1040E+08	-.1360E+08	-.1620E+08	-.1550E+08	0.0
	28.0	.1700E+08	.1790E+08	.1540E+08	.1140E+08	.1140E+08	-.1140E+08	-.1540E+08	-.1790E+08	-.1700E+08	0.0

TABLE A8 (Continued)

CASE D

TABLE A6 ROCKET P-1 VALUES

		ROCKET ANGLE - DEG							
		-40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	0.0
SPEED KTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	.5130E+07	.6200E+07	.7290E+07	.8410E+07	.9510E+07	.1.0620E+08	.1.1720E+08	.1.2830E+08
	10.0	.2490E+08	.2640E+08	.2740E+08	.2860E+08	.2930E+08	.3000E+08	.3070E+08	.3140E+08
	15.0	.4660E+08	.4900E+08	.5130E+08	.5350E+08	.5570E+08	.5790E+08	.6010E+08	.6230E+08
	20.0	.7870E+08	.7670E+08	.7460E+08	.7250E+08	.7040E+08	.6830E+08	.6620E+08	.6410E+08
A-33	25.0	.7450E+08	.7450E+08	.7450E+08	.7450E+08	.7450E+08	.7450E+08	.7450E+08	.7450E+08
	26.0	.6690E+08	.6690E+08	.6690E+08	.6690E+08	.6690E+08	.6690E+08	.6690E+08	.6690E+08

TABLE A8 (Continued)

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APPENDIX B

PROGRAM LISTING

```

PROGRAM CVATH(INPUT,OUTPUT,TAPPE=INPUT,TAPPE=OUTPUT,TAPPE2=510,
TAPPE3=510,TAPPE4=510,TAPPE5=510,TAPPE11=510,TAPPE1=510,TAPPE12=510

```

```

COMMON /INITPL/ DT,DTMIN,TMAX,AF(15),EPS(15),NOTATE

```

```

COMMON /OUTV/ IFC(5),IPOINT(5),JSL,NRM,NPRINT
LOGICAL INT,ERRORS

```

```

COMMON /ADPRAT/ IP1,IP2,IP3,IP4,IP5,IP1,IP2,IP3,IP4,IP5,IP6,IP7,
IP8,IP9,IP10,PAT(15)

```

```

COMMON /SPITIM/ ICF,ICRTM(20)

```

```

DIMENSION F(13),Y(20)

```

```

IRUNS = -1000

```

```

CONTINUE

```

```

CALL INPUT(Y,TIME)

```

```

IF(NRM.EQ.0) GO TO 300

```

```

IF(NRM.LE.0) GO TO 500

```

```

NOTATE = 17

```

```

NRM = 1000

```

```

FIRST = 0.0

```

```

HGX = DT

```

```

IRUN(1) = 0

```

```

DAUXS=PAT(10)

```

```

BEGIN INTEGRATION LOOP

```

```

CONTINUE

```

```

PAT(10)=DAUXS

```

```

WRITE(150,640) TIME,HGX

```

```

640 FORMAT(F10.2,F10.8)

```

```

INTEGRATE FROM TIME TO TIME + DPRINT*DT

```

```

DO 210 I=1,NPRINT

```

```

IF(ICRTM(1).EQ.0) CALL KUTTER(INSTATE,TIME,DT,Y,EPS,AF,HGX,FIRST

```

```

IF(ICRTM(1).EQ.1) CALL EULER(TIME,DT,Y,INSTATE)

```

```

IF(SICST.EQ.0) IBUS(1)=1

```

```

IF(TIME.DT.TMAX) IBUS(1) = 1

```

```

IF(IBUS(1).EQ.1) GO TO 210

```

```

CONTINUE

```

```

PRINT OUTPUT AT INTERVALS OF DT*POINT

```

```

CALL OUTPUT(1)

```

```

IF(ICRTM(1).EQ.1) GO TO 210

```

```

GO TO 100

```

```

CONTINUE

```

```

PAT(10)=DAUXS

```

```

CALL OUTPUT(2)

```

```

COMPLETION OF RUN

```

```

GO TO 1

```

```

CONTINUE

```

```

WRITE(150,640)

```

```

FORMAT(47H ALL RUNS COMPLETED INTERMEDIATE PRINT FOLLOWS.)

```

```

STOP

```

```

END

```

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()

١٠٠

2

...

()

()

()

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[illegible]

SPS(1-15) - RELATIVE ERROR CRITERIA FOR X(1-15)

COMMON /X(1) / ACOST,IC1(10),IC2(10),IAC1(10),IAC2(10),CV1(10),
 CV2(10),CV3(10),CV4(10),CPI1(10),CPI2(10),
 CCI1(10),CCIN2(10),CCIN3(10),FELAB(2),CHECK(2),
 SATF(10),KACT(10)
 COMMON /Y(1) / HOUT(2),HPRINT(2),JST,LEIS,LEPRINT
 COMMON /PAGE(1) / TITLE(10)
 DATA BRN,BS/0.,/TRUAP/0./
 DATA XENF/0+11.7427/,YELC/11.43,-11.47/,ZFNF/2+3.15+5/
 DATA (TITLE(1),I=1,10) /10+14/, HPRINT/1/
 DATA SCFAC1/22.5/,LENGT1/73.15/,ACD/2.9E+06/,IYY/8.4984E+08/
 IYY/4.274E/,IYZ/4.274E+07/
 IYY/0.0 /, IYZ/0.0 /, IYZ/0.0/
 DATA DADIA1/57.2,57751/,RHOA/1.05/,RHOA2/0.645/,RHO/1000./
 RHO/450./,FITCH/7.704E/
 DATA H/20.0/,V,4.P,0.2,PHI,THETA,PSI,YE,YE,ZF,BRIFAN/12+0.0/,
 CSETH/11.0/,COSPHI,COSTHE,COSPSI/3+1.0/,TIME/0.0/,
 S1,PHI,SIN THE,SINPSI/3+0.0/,TIPY/1.0..0..0..0..1..0..0..0..
 1./
 DATA T/20./,UG/20./,VC/2./,PC/0./,CC/0./,FM/2./,VO/0./,
 PHI/0./,THETA/0./,PSI/0./
 DATA KRCOT/1.344E+06/
 DATA YV,CT,LRJCT,YR,CT,MVJCT,YR,CT,KVJCT,I,RECT,KR,CT/
 A-1.214E+07,-2.844E+08.3+-2.1E4E+06.0+-4.139E+07,
 0+-5.777E+08/
 DATA AX,RY/4+0.0/,G/0.0/
 DATA X,LOCT,750CT,261CT,740CT,400CT/5+0.0/
 DATA H,AX/1.0/,L7/0/
 DATA D,CI1/4.34/,PR,CI1/1-32.72,11.43,-.06/,CH,MSQ/150./,
 VOR,MSQ/150./,PTCH,SC/1.07/,PTCH,PO/1.07/
 DATA XE1/2+19.421E+0+-26.632E/,YE1/7.7627,-7.7627,7.7627,
 -7.7627/
 ZE1/4+2.061E/,LE,AT,IN/2+7.544.2+22.50E7/,CLE,IN/4+1.13/
 DATA Z,OL,ST,Z,OL,TH,ICURZ,M,URTH/-2001086.,2+434374.-0761917./
 DATA RU,APR/4.0/
 DATA RE,PR/13.25/,-200AN/6.58/
 DATA MU,VL/0.,0.572,5.144,7.716,10.022,13.26,14.407/
 DATA R,ALTA/-1.7,-.611,-.504,-.346,-.346,-.611,-.7/
 DATA VC/0.0/,YC/0.0/,ZC/0.0/
 DATA AX,YS/100+0.0/,Y,PR/100+0.0/,X,BS/100+0.0/,Y,BS/100+0.0/
 DATA MU,VAL/0.,MU,UV/77,AR,STIO/1.0/,H,LSIK/0./
 DATA I-1,I-2,I-3,I-4,I-5/5/,I-1/6/,I-2/9/.

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1 184/67, 184/67, 187/67, 187/67, 187/67, 187/67, 187/67,
2 1810/107

DATA 187/67, 187/67, 187/67

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DATA 187/67, 187/67

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
1 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
2 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
1 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
2 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
1 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
2 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
1 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,
2 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DATA 187/67, 187/67, 187/67, 187/67, 187/67, 187/67, 187/67,

DEFINITION OF FOOTPRINT SYMBOLS
DESCRIPTION OF VARIABLES APPEARING IN NAME COMMON

COMMON /AIRVAR /

AIRFX(1-3) - AIR RESISTANCE X,Y,Z FORCES ALONG BODY AXES
AIRFY(4-6) - AIR X,Y,Z MOMENTS ABOUT BODY AXES

COMMON /ADDERVAR /

ADDERX(6,6,6) - MATRIX OF RATE DEPENDENT 2ND ORDER TERMS FOR
FULL FOOTPRINT

ADDERX(1-3) - RATE DEPENDENT X,Y,Z FORCES

ADDERX(4-6) - RATE DEPENDENT X,Y,Z MOMENTS

ADDERX(6,6,6) - MATRIX OF 1ST ORDER RATE DEPENDENT TERMS FOR
FULL FOOTPRINT

COMMON /BOYVAR /

BOYFX(1-3) - RESTORING DERIVATIVE XZ DUE TO BUOYANCY

BOYFY(4-6) - RESTORING DERIVATIVE YZ DUE TO BUOYANCY

BOYFX(1-3) - RESTORING DERIVATIVE XZ DUE TO BUOYANCY

BOYFY(4-6) - RESTORING DERIVATIVE YZ DUE TO BUOYANCY

BOYFX(1-3) - RESTORING DERIVATIVE XZ DUE TO BUOYANCY

BOYFY(4-6) - RESTORING DERIVATIVE YZ DUE TO BUOYANCY

COMMON /BOYVAR /

BOYFX(1-3) - RESTORING DERIVATIVE XZ DUE TO BUOYANCY

BOYFY(4-6) - RESTORING DERIVATIVE YZ DUE TO BUOYANCY

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COMMON /ACRAFT /

COEFAC1 - SHIP-MODEL SCALE FACTOR
LENGTH - SHIP LENGTH
MASS - SHIP MASS
INX,INY,IZ - SHIP MOMENTS OF INERTIA
IYZ,IYZ,IZZ - SHIP PRODUCTS OF INERTIA

COMMON /ACONST /

RADIAN - NUMBER OF DEGREES PER RADIAN, 57.30
RHOA - DENSITY OF AIR
RHOA1 - 1/2 OF RHOA
RHO1 - DENSITY OF WATER
RHO11 - 1/2 OF RHO1
RTIO1 - CONVERSION FEET TO METERS

COMMON /AOTOCF /

XUCST - DIMENSIONAL COEFFICIENT XU
YUCST - DIMENSIONAL COEFFICIENT YU
YUCST - DIMENSIONAL COEFFICIENT YU
YUCST - DIMENSIONAL COEFFICIENT YU
ZUCST - DIMENSIONAL COEFFICIENT ZU
XUCST - DIMENSIONAL COEFFICIENT XU
YUCST - DIMENSIONAL COEFFICIENT YU
YUCST - DIMENSIONAL COEFFICIENT YU
ZUCST - DIMENSIONAL COEFFICIENT ZU
XUCST - DIMENSIONAL COEFFICIENT XU
YUCST - DIMENSIONAL COEFFICIENT YU
YUCST - DIMENSIONAL COEFFICIENT YU
ZUCST - DIMENSIONAL COEFFICIENT ZU
XUCST - DIMENSIONAL COEFFICIENT XU
YUCST - DIMENSIONAL COEFFICIENT YU
YUCST - DIMENSIONAL COEFFICIENT YU
ZUCST - DIMENSIONAL COEFFICIENT ZU

COMMON /FINVAR /

YFIN(1-4) - X,Y,Z COORDINATES OF FIN CENTER OF
YFIN(1-4) - PRESSURE 1 = PORT STAFFORD, 2 = PORT PORT,
ZFIN(1-4) - 3 = AFT STAFFORD, 4 = AFT PORT
ARFIN(1-4) - AREA OF FIN
CLFIN(1-4) - LIFT COEFFICIENT OF FIN
CDFIN(1-4) - LIFT/DRAG RATIO OF FIN
FINANG(1-4) - FIN ANGLES
YFORF(1-4) - FIN X,Y,Z FORCES IN BODY
YFORF(1-4) - FIN X,Y,Z FORCES IN BODY
ZFORF(1-4) - FIN X,Y,Z FORCES IN BODY
ALIFT(1-4) - FIN LIFT AND DRAG
DRAG(1-4) - FIN LIFT AND DRAG
FFM(1-3) - FIN X,Y,Z FORCES IN BODY SYSTEM
FFM(4-6) - FIN X,Y,Z MOMENTS
FINANG(1-4) - INITIAL FIN ANGLES

COMMON /HULLVAR /

HULLF(1-3) - HULL X,Y,Z FORCES ALONG BODY AXES
HULLM(4-6) - HULL X,Y,Z MOMENTS ABOUT BODY AXES
HULLF1 - DIFFERENCE IN CRAFT FROM DESIGN CONDITION,
VELOCITY POSITIVE

COMMON /HYDRO /

L1(4) - NUMBER OF GRID POINTS FOR HYDINT
L2 - NUMBER OF ZERO SPEED CURVES
HY(4,0213) - DATA POINTS FOR HYDINT ARRAY

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YDATA(20) - GRID POINTS FOR HYDRO ARRAY
 XDATA(1000) - GRID POINTS FOR HYDRO ARRAY

COMMON /CONTROL /
 DT - STEP SIZE FOR INTEGRATION PROCEDURE
 NMIN - MINIMUM STEP SIZE FOR KUTMER
 NMAX - MAXIMUM TIME FOR RUN
 ACRITER - ABSOLUTE ERROR CRITERION FOR KUTMER
 RCRITER - RELATIVE ERROR CRITERION FOR KUTMER
 NSTATE - NUMBER OF STATE VARIABLES

COMMON /PORTION /
 NMODE - DEGREES OF FREEDOM
 IPORT(1-15) - IPORT(1)=0, KUTMER INTEGRATION
 IPORT(1)=1, EULER INTEGRATION
 IPORT(2)=0, DO NOT PRINT PAGES 2-5
 IPORT(2)=1, PRINT PAGES 2-5, RUDDER, PRCP, FIN FORCES

COMMON /GEOMETRY /
 RCDIA - RUDDER DIAMETER
 RCOORD(1-3) - RUDDER X,Y,Z COORDINATES
 RSRNS - RUDDER SOW STARBOARD
 RPRNS - RUDDER SOW PORT
 RITCHS - RITCH/DIAMETER RATIO - STARBOARD
 RITCHP - RITCH/DIAMETER RATIO - PORT
 RCOORD(1-3) - RUDDER X,Y,Z FORCES ALONG BODY AXES
 RMOM(4-6) - RUDDER X,Y,M,MOMENTS ABOUT BODY AXES
 RITCHS - R/D RATIO - STARBOARD, INITIAL
 RITCHP - R/D RATIO - PORT, INITIAL

IF(1-5) - REAR UNITS
 IF(1-10) PRINT UNITS 4 = MAIN OUTPUT PRINTER
 IPRINT - OPTIONAL-DEBUGGING OUTPUT, 2 = HYDRO ARRAY
 10 = INTERMEDIATE FORCE-MOMENT TIME HISTORIES

COMMON /RESULTS /
 RUDDANG(10) - ACT RUDDER ANGLE, 1=STARBOARD, 2=PORT
 RUVEL(10) - GRID VELOCITY ARRAY FOR RUDDER FORCES
 RUANG(10) - GRID RUDDER ANGLE ARRAY FOR RUDDER FORCES
 RUVELX(100) - X RUDDER FORCE ARRAY
 RUVELY(100) - Y RUDDER FORCE ARRAY
 RUVELZ(100) - Z RUDDER FORCE ARRAY
 RUVELX - X RUDDER MOMENT ARRAY
 RUVELY - Y RUDDER MOMENT ARRAY
 RUVELZ - Z RUDDER MOMENT ARRAY
 RUANG - RUDDER SIZING RATIO, 10 STANDARD RUDDER
 RUANG(2) - RUDDER ANGLES AT INITIAL TIME
 NRUVEL - NUMBER OF DATA GRID VELOCITY POINTS
 NRUANG - NUMBER OF DATA GRID RUDDER ANGLE POINTS
 RUANGS - STARBOARD RUDDER POSITION
 RUANGP - PORT RUDDER POSITION
 RUDEL(1-3) - RUDDER X,Y,Z FORCES IN BODY SYSTEM
 RUDEL(4-6) - RUDDER X,Y,M,MOMENTS ABOUT BODY AXES

[illegible]

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```

SUBROUTINE ROYER-
  ROYER- COMPUTES FORCES AND MOMENTS DUE TO BUOYANCY
  REAL XCURTH,XSURZ
  COMMON /STATE/ U,V,W,P,C,P,PHI,THETA,POI,YE,YE,ZE,SPEED,C,DRIFAM,
  COSCHI,COSIHE,COSPSI,SINPHI,CINHE,SINPOI,TOTR(3,3),TIME
  COMMON /PARAM/ MSU Z,XSURTH,ZSURZ,ZSURTH,BUOYEX(6)
  COMMON /FORM/ IA,PCAT(3),PRNO,PRPV,PITCHS,PITCHP,PRDFW(6)
  XCURZ = DIMENSIONALIZED COEFFICIENT * CUR ZE
  XCURTH = DIMENSIONALIZED COEFFICIENT * CUR THETA
  ZCURZ = DIMENSIONALIZED COEFFICIENT * FORCE SUR ZE
  ZSURTH = DIMENSIONALIZED COEFFICIENT * FORCE SUR THETA
  BUOYEX(1-3) = BUOYANCY FORCES ALONG BODY X,Y,Z AXES
  BUOYEX(4-6) = BUOYANCY MOMENTS ABOUT BODY AXES
  XFIX = ZSURZ*ZE+ZSURTH*THETA
  XFIX=(COSCAR(2)**2.)*TAN(CHI)*ZSURZ
  XFIX = ENCLPZ*ZE+XCURTH*THETA
  BUOYEX(1)=0.0
  BUOYEX(2)=0.0
  BUOYEX(3)=XFIX
  BUOYEX(4)=XFIX
  BUOYEX(5)=XFIX
  BUOYEX(6)=0.0
  RETURN
END
```

CURRENT TIME CONTROL (T.Y.)

```

- INFLST = STAT(12),CUMV(16),AC(18,16),Y(17)
- INFLST = COLACT(11)

```

CONV - CONVERSION FACTORS TO CONVERT INTERNAL UNITS TO UNITS
AS SHOWN (APPLIED TO STATE METHOD)

```
REAL LENGTH, MASS, IXX, IXY, IXZ, IYY, IYZ, IZZ, KXDOT, KYDOT, KZDOT,
      MXDOT, MYDOT, MZDOT, XDOT, YDOT, ZDOT, XDOT2, YDOT2, ZDOT2,
      XDOT3, YDOT3, ZDOT3, LENGTH, MASS, IXX, IYY, IXZ, IYY, IYZ, IZZ
```

COMMON ACCTG / RADIAN. PH01, PH0A2. PH01, PH0W2, FIT0W

```
COMMON /STATE / U,V,W,P,C,P,RHT,THETA,PSI,YX,YZ,ZF,S,SPEED,  
ORIFAN,COSPHI,COSTHE,COSST,CSINPHI,CSINTHE,ST,PSI,  
IMTX(3,3),TIME
```

```

COMMON/XYINVAR/XYIN(4),YFIN(4),ZFIN(4),XCFIN(4),ZCFIN(4),
COPFIN(4),FINANG(4),XFORFIN(4),YFORFIN(4),ZFORFIN(4),ALIST(4),
IPD(4),CFIN(4)
4,FINANG(4)

```

```

COP(4) = ANYORD / LG(4).LG.HY(4,3213).FF(4,16).C(4,20).IPRINT(4).
IMAX.HYREF(4).ICNT

```

```
COMMON /FLOWER/ ZRUF AND (2), JUVTEL (10), SALE (10), AXRPU (100), AYRPU (100),
1. AXRPU (100), AMRPU (100), AKRATC, RUDAND (2), RUDUDY, RUDFAL,
1. RUDFSN, RUDDAC, RUDAP, RUDSEN, RUDEN (6)
1. YRUE (2), YRUE (2), ZRUE (2)
1. RUDAP"
1. RUDAP", RUDSEN
```

COMMON PROPERTY/ POLA. PROPER(3), PROPS. PROPS, PITCHS, PITCHS,
PROPER(4)

COMMON AIRPORT AIRFIELD

01W 40N/01L 145R/01U 150R (4) . 01U 150R

COMMON/POVVAE/MSUEZ,MSUPTH,ZSUEZ,ZSUPTH,EUOYEM(6)

COMMON/ADCOMAR/ADENTRY(6,6,6),ADCEX(6),RTENTRY(6,6)
COMMON/ADTGC6/XYDOT,YVDOT,YEDOT,YBDOT,ZVDOT,ZODOT,KYDOT,XBDOT,
KBDOT,NVDOT,XODOT,NVBOT,NEDOT,NBDOTCOMMON/COROVE/XC.YC.PC
LOGICAL ENT

```
COMMON /COPDATA/ IP1,IP2,IP3,IP4,IP5,IP1,IP2,IP3,IP4,IP5,IP4,IP7,
1 IP1,IP2,IP10,PNT(15)
```

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COMMON /CONTROL/ ICOR,ICOR1(20)

COMMON /STATE/ TO,UO,VO,XO,RO,CO,PO,PHIO,THETAO,PSIO

COMMON /INTELS/ DT,DTMIN,IMAX,AE(15),ERR(15),NSTATE

DT - STEP SIZE FOR CALLS TO KUTMER, SEC
DTMIN - MINIMUM STEP SIZE TO BE USED BY KUTMER, SEC
IMAX - SIMULATION STOP TIME
AE(1-15) - ABSOLUTE INTEGRATION ERROR CRITERIA FOR STATE
VECTORS, Y(1-15)
ERR(1-15) - RELATIVE ERROR CRITERIA FOR Y(1-15)

COMMON /CONTRL/ ACCNT,IC1(10),IC2(10),IACT(10),JACT(10),CV1(10),
CV2(10),CV3(10),CV4(10),COIN1(10),COIN2(10),
COIN3(10),COIN4(10),COIN5(10),REFLAG(0),CHECK(2),
PATE(12),%ACT(12)

COMMON /OUTP / IPUR(5),IPRINT(5),JF,ASUM,IPRINT

COMMON /HEADER/ TITLE(10)

DATA CONV/3+1.,6+57.0957705,5+1.,57.0957705,1./

IF(ACNT.EQ.0) RETURN
CONVERT CONTROL SURFACE POSITIONS TO PROPER UNITS. INITIALIZE
ARRAY CNT.

CNT(1) = PRPNC
CNT(2) = PRPXP
CNT(3) = FITCHS
CNT(4) = FITCHP
CNT(5) = PRUDAS
CNT(6) = PRULCAP
CNT(7) = PRIDIAN + PRUDANG(1)
CNT(8) = PRADIAN + PRUDANG(2)
CNT(9) = SINANG(1) + RADIAN
CNT(10) = SINANG(2) + RADIAN
CNT(11) = SINANG(3) + RADIAN
CNT(12) = SINANG(4) + RADIAN

DO 50 I=1,ACCNT
IF(IACT(I).NE.0) GO TO 50
J1 = IC1(I)
IF(J1.EQ.10) XW = T
IF(J1.EQ.14) XW = SPEED + CONV(J1)*CV4(I)
IF(J1.EQ.15) XW = DRIFAN + CONV(J1)*CV4(I)
IF(J1.LT.14) XW = Y(J1)*CONV(J1)*CV4(I)
CHECK TO SEE IF ACTION IS REQUIRED
IF((XW-CV1(I)).LT.1.0E-05) GO TO 50

IF CURRENT VALUE IS EQUAL TO ORDERED VALUE, TAKE NO ACTION

J2=IC2(I)
XW = CV2(I)-CNT(J2)
IF(ABS(XW).LT.0.00001) GO TO 50

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      IF (KACT(J2).EQ.0) GO TO 15
      MULTIPLE COMMANDS
      WRITE(IP6,499) J2
      FORMAT(41H MULTIPLE COMMANDS FOR CONTROLLED SURFACE,14)
      CONTINUE
      ACTIVATE COMMANDS
      IACT(I) = 1
      KACT(J2) = 1
      COMPUTE CONSTANTS REQUIRED FOR LINEAR MODEL-INITIALIZATION
      A(I,1) = SIGN(CV3(I),X)
      A(I,2) = -T*A(I,1)+CONT(J2)
      A(I,3) = XV/A(I,1) + T
      A(I,4) = T
      CONACT(I)=CONT(J2)
      WRITE(IP6,715) T,CPIN1(J1),XV,CPIN2(J1),COIN1(J2),
      CV2(I),COIN2(J2),A(I,1),COIN3(J2),A(I,2),A(I,3)
715  FORMAT(3X,59.3,2X,410.5,2X,410.1X,412,F15.5,2X,49.2X,
      F10.5,1X,49.2F12.5,4H SEC. 1)
      CONTINUE
      COMPUTE KEY VALUES
      DO 100 I=1,NCONT
      IF (IACT(I).LE.0) GO TO 100
      J2 = ICR(I)
      CONT(J2) = A(I,1)*T + A(I,2)
      IF (T.GE.A(I,4)) GO TO 80
      CONT(J2)=CONACT(I)
80  CONTINUE
      IF (T.LT.A(I,4)) GO TO 100
      CONTROL ACTION COMPLETED.
      IACT(I) = 0
      IF (KACT(I).EQ.1) IACT(I) = -1
      KACT(J2) = 0
      CONT(J2) = CV2(I)
100  CONTINUE
      ORPMS=CONT(1)
      RPPMS=CONT(2)
      PITCHS=CONT(3)
      PITCHR=CONT(4)
      RUCCAS=CONT(5)
      RUCCAR=CONT(6)
      RUANG(1)=CONT(7)/RADIANS
      RUANG(2)=CONT(8)/RADIANS
      RUANG(3)=CONT(9)/RADIANS
      RUANG(4)=CONT(10)/RADIANS
      RUANG(5)=CONT(11)/RADIANS
      RUANG(6)=CONT(12)/RADIANS
      RETURN
      END

```

[illegible]

```

C      EPS(1-15)      - RELATIVE ERROR CRITERIA FOR Y(1-15)
C
COMMON /XCONTL/ NCONT,IC1(10),IC2(10),IAC1(10),JAC1(10),CV1(10),
1      CV2(10),CV3(10),CV4(10),CPIN1(16),CRIN2(16),
2      COIN1(12),COIN2(12),COIN3(12),RELAB(2),CHECK(2),
3      RATE(12),KACT(12)
COMMON /OUTX / IBUG(5),TPRINT(5),JRA,NRUN,NPRINT
C
COMMON /HEADER/ TITLE(10)
DIMENSION Y(13),A(6,6),F(13)
C      F      - GENERALIZED FORCE VECTOR
C      A      - GENERALIZED MASS/INERTIA MATRIX
C
DEFINE LOCAL VARIABLES
U      = Y(1 )
V      = Y(2 )
W      = Y(3 )
P      = Y(4 )
Q      = Y(5 )
R      = Y(6 )
PHI    = Y(7 )
THETA  = Y(8 )
PSI    = Y(9 )
YE     = Y(10)
VE     = Y(11)
ZE     = Y(12)
S      = Y(13)
TIME=T
C
C      COMPUTE SPEED AND OTHER REQUIRED VALUES
C
U2     = U*U + V*V + W*W
SPEED= SGRT(U2)
DRIFAN = -ASIN(V/SPEED)
COSPHI = COS(PHI)
COSTHE = COS(THETA)
COSPSI = COS(PSI)
SINPHI = SIN(PHI)
SINTHE = SIN(THETA)
SINPSI = SIN(PSI)
C
C      COMPUTE FIXED TO BODY TRANSFORMATION MATRIX
C
TMTRX(1,1) = COSTHE*COSPSI
TMTRX(1,2) = COSTHE*SINPSI
TMTRX(1,3) = -SINTHE
C
TMTRY(2,1) = -COSPHI*SINPSI + SINTHE*SINPHI*COSPSI
TMTRY(2,2) = COSPHI*COSPSI + SINTHE*SINPHI*SINPSI
TMTRY(2,3) = COSTHE*SINPHI
C
TMTRX(3,1) = SINPHI*SINPSI + SINTHE*COSPHI*COSPSI
TMTRY(3,2) = -SINPHI*COSPSI + SINTHE*COSPHI*SINPSI
TMTRX(3,3) = COSTHE*COSPHI
C
C      COMPUTE CONTROLLER ENVIRONMENTAL FACTORS SUCH AS WIND GUSTS,
C      COMPUTE PILOT ACTIONS. MAJOR LINK IS VIA COMMON
C

```

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```
C      CALL CONTRL(T,Y)
C
C      COMPUTE TOTAL FIN FORCES AND MOMENTS.
C
C      CALL FINFOR
C
C      COMPUTE TOTAL RUDDER FORCES AND MOMENTS.
C
C      CALL RUDEFOR
C
C      COMPUTE BARE HULL FORCES AND MOMENTS
C
C      CALL HULFOR
C
C      COMPUTE AERODYNAMIC FORCES AND MOMENTS
C
C      CALL AIRFOR
C
C      COMPUTE BUOYANCY FORCES AND MOMENTS
C
C      CALL BOYFOR
C
C      COMPUTE PROPELLER FORCES AND MOMENTS
C
C      CALL PROFOR
C
C      COMPUTE ACCELERATION AND ADDITIONAL RATE DEPENDENT FORCES AND MOMENTS
C
C      CALL ADDFOR
C
C      SUM TOTAL FORCES AND MOMENTS
C
C      DO 1 I= 1, 6
C          F(I) = FFM(I)+RUDEFM(I)+HULFM(I)+AIRFM(I)+BUOYFM(I)
C          + PROPFM(I) + ADDFM(I)
1      CONTINUE
C
C      ADD ON TERMS DUE TO CENTER OF GRAVITY NOT AT ORIGIN
C      F(1)=F(1)      +MASS*(XC*(Q*Q+R*R)-YC*P*Q-ZC*P*R)
C      F(2)=F(2)      +MASS*(YC*(R*R+P*P)-ZC*Q*R-XC*Q*P)
C      F(3)=F(3)      +MASS*(ZC*(P*P+Q*Q)-XC*R*P-YC*R*Q)
C      F(4)=F(4)      +MASS*(ZC*(U*R-W*P)+YC*(U*Q-V*P))
C      F(5)=F(5)      +MASS*(XC*(V*P-U*Q)+ZC*(V*R-W*Q))
C      F(6)=F(6)      +MASS*(YC*(W*Q-V*P)+XC*(W*P-U*Q))
C
C      ADD ON ADDITIONAL TERMS ARISING FROM SPACE/EODY TRANSFORMATION
C
C      F(1)= F(1)+(V*R - W*Q)*MASS
C      F(2)= F(2)+(W*P - U*R)*MASS
C      F(3)= F(3)+(U*Q - V*P)*MASS
C
C      F(4) = (IYY-IZZ)*Q*R + IXZ*P*Q + F(4) + (Q*C-R*R)*IYZ - IXY*P*R
C      F(5) = (IZZ-IXY)*R*P + IXY*Q*P + F(5) + (R*P-P*P)*IXZ - IYZ*Q*P
C      F(6) = (IXX-IYY)*P*Q + IYZ*R*P + F(6) + (P*P-Q*Q)*IXY - IXZ*P*Q
C
C      LOAD INERTIA/MASS MATRIX
```

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```
C
DO 10 I=1,6
  DO 10 J=1,6
    A(I,J)= 0.0
10 CONTINUE
A(1,1)=MASS-XUDOT
A(1,5)=MASS*ZC
A(1,6)=-MASS*YC
A(2,2)=MASS-YVDOT
A(2,4)=-MASS*ZC-YPDOT
A(2,6)=-YRDOT+MASS*XC
A(3,3)=MASS-ZWDOT
A(3,4)=MASS*YC
A(3,5)=-MASS*XC-ZQDOT
A(4,2)=-MASS*ZC-KVDOT
A(4,3)=MASS*YC
A(4,4)=IXX-KPDOT
A(4,5)=-IXY
A(4,6)=-IXZ-KQDOT
A(5,1)=MASS*ZC
A(5,3)=-MASS*XC-MWDOT
A(5,4)=-IXY
A(5,5)=IYY-MQDOT
A(5,6)=-IYZ
A(6,1)=-MASS*YC
A(6,2)=+MASS*XC-NVDOT
A(6,4)=-IXZ-NPDOT
A(6,5)=-IYZ
A(6,6)=IZZ-NRDOT
IF(IDOF.NE.6)GO TO 100
SOLVE FOR (DOT) VECTOR
C
C
CALL LINQ(A,F,6,IERR)
IF(IERR.NE.0) GO TO 1999
C
C
PHIDOT, THETADOT, PSIDOT, UE, VF, WE, SPEED
C
C
F(7) = (Q*SIN THE*SIN PHI + R*SIN THE*COS PHI + P*COS THE)/COS THE
F(8) = (Q*COS PHI - R*SIN PHI
F(9) = (R*COS PHI + Q*SIN PHI)/COS THE
C
DO 30 I=1,3
  SS = 0.0
  DO 29 J = 1,3
    SS = SS + TMTRX(J,I)*Y(J)
29 CONTINUE
  F(9+I) = SS
30 CONTINUE
C
F(13) = SQRT(F(10)**2+F(11)**2+F(12)**2)
C
GO TO 999
C
100 CONTINUE
C
C
DEGREES OF FREEDOM ARE LESS THAN 5
C
```

C PITCH ANGLE FIXED. THDOT= 0.0 IMPLIES $0=Q*\text{COSPHI}-R*\text{SINPHI}$. HENCE
C $\text{COSPHI}+Q\text{DOT}-\text{SINPHI}*R\text{DOT}=\text{PHIDOT}*(Q*\text{SINPHI}+R*\text{COSPHI})$. PHIDOT IS
C USED FOR CONVENIENCE. EQUIVALENT NON (DOT) EXPRESSION COULD BE
C USED FOR PHIDOT.

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C A(5,1)=0.0
C A(5,2)=0.0
C A(1,5)=0.0
C A(3,5)=0.0
C A(4,5)=0.0
C A(6,5)=0.0
C A(5,3)=0.0
C A(5,4)=0.0
C A(5,5)=COSPHI
C A(5,6)=-SINPHI
C COMPUTE PHIDOT
C F(7) = (Q*SIN THE*SINPHI + R*SIN THE*COSPHI + P*COSTHE)/COSTHE
C F(5) = F(7)*(Q*SINPHI+R*COSPHI)
C IF(IDOF.LT.5) GO TO 300
C CALL LING(A,F,6,IERR)
C IF(IERR.NE.0) GO TO 1999
C F(8) = 0.
C F(9) = (R*COSPHI + Q*SINPHI)/COSTHE
C DO 130 I = 1,3
C SS = 0.0
C DO 129 J = 1,3
C SS = SS + TMTRX(J,I)*Y(J)
129 CONTINUE
C F(9+I) = SS
130 CONTINUE
C F(13) = SQRT(F(10)**2+F(11)**2+F(12)**2)
C GO TO 999
C
C CONTINUE
C
C IF(IDOF.LT.4) GO TO 400
C
C 4 DOF NO PITCH, NO HEAVE. IMPLIES THETA DOT=0., WE=0., WEDOT=0.0.
C $0=-U*\text{SIN THE}+V*\text{COSTHE}*\text{SINPHI} + W*\text{COSTHE}*\text{COSPHI}$ IMPLIES
C $U\text{DOT}*\text{SIN THE}-V\text{DOT}*\text{COSTHE}*\text{SINPHI}-W\text{DOT}*\text{COSTHE}*\text{COSPHI} =$
C $\text{PHIDOT}*(V*\text{COSTHE}*\text{COSPHI}-\text{PHIDOT}*(W*\text{COSTHE}*\text{SINPHI})$
C
C A(3,1)= SIN THE
C A(3,2)=-COSTHE*SINPHI
C A(3,3)=-COSTHE*COSPHI
C A(3,5)= 0.0
C A(3,4)=0.0
C A(3,6)=0.0
C A(4,3)=0.0
C A(5,3)=0.0
C
C F(3) = F(7)*COSTHE*(V*COSPHI-W*SINPHI)
C
C CALL LING(A,F,6,IERR)
C IF(IERR.NE.0) GO TO 1999
C F(8) = 0.0

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```
F(3) = (8+COSPHI + 0+SINPHI)/COSTHE
DO 330 I=1,3
  SS = 0.0
  DO 329 J=1,3
    SS = SS + T*TRX(J,I)*Y(J)
329  CONTINUE
  F(3+I) = SS
330  CONTINUE
  F(12) = 0.0
  F(13) = SQRT(F(10)**2+F(11)**2)
  GO TO 599
400  CONTINUE
  WRITE(6,601) IDOF
601  FORMAT(24H MODEL NOT AVAILABLE FOR I4,10H DEGREES OF FREEDOM.//)
C
  STOP 6
CC
599  CONTINUE
  IF(PNT(10)) GO TO 1000
  RETURN
C
  *** INTERMEDIATE DEBUG OUTPUT ***
C
1000 WRITE(IP10,603) T,U,V,W,PHI,THETA,DRIFAN, (FFM(K),RUDEM(K),HULLFM
1(K),AIRFM(K),BUOYFM(K),DCFM(K),PROPFM(K),K=1,6)
  PNT(10)=.FALSE.
  RETURN
1399 CONTINUE
C
  NO INVERSE FOR MASS/INEPTIA MATRIX.
  WRITE(IP6,600)
  WRITE(IP6,602) (F(I),I=1,6),((A(I,J),J=1,6),I=1,6)
  WRITE(IP6,602) IXX,IYY,IZZ,IXY,IYZ,IYZ,XUDOT,YVDOT,YPDOT,YROCT,
1 ZWDOT,ZQDOT,KVDOT,KPDOT,KFODT,MWDOT,MQDOT,NVODT,
2 NPDOT,NRDOT
600  FORMAT(52H INVERSE OF MASS/INEPTIA MATRIX DOES NOT EXIST. STOP/)
602  FORMAT(5H DALX,10E12.4)
603  FORMAT(T3,4HTIME,T10,1HU,T16,1HV,T22,1HW,T27,3HPHI,T32,
  A5HTHETA,T39,4HRETA,T51,3HFIN,T59,4HRUDDER,T71,4HHULL,
  BT82,4HAERO,T92,8HBUOYANCY,T105,4HRAE,T113,10HPROPULSION.//,
  C1H ,F5.1,6F6.2,T45,1HX,7E11.4,/,T45,1HY,7E11.4,/,
  T45,1HZ,7E11.4,/,T45,1HK,7E11.4,/,T45,1HV,7E11.4,/,T45,1HN,7E11.4
  C.//)
  STOP 5
  END
```

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```
C  FUNCTION DRAAGG(V)
    PERFORMS INTERPOLATION FOR DRAG FOR SWATH
    DIMENSION SPEED(25),EHP(25)
    DATA SPEED/0.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,
      19.,20.,21.,22.,23.,24.,25.,26.,27.,28., /
    DATA EHP/0.,100.,200.,400.,800.,1200.,1600.,2300.,3300.,4200.,
      1 5000.,5500.,6000.,6700.,7300.,8500.,12000.,15200.,18600.,
      1 21900.,24700.,27600.,30000.,32000.,33800./
    VMS=V
    V=VMS*1.544
    IF(V.LT.0.)GO TO 99
    DO 10 I=2,25
    IF(V.LE.SPEED(I))GO TO 15
10  CONTINUE
15  RATIO = (V-SPEED(I-1))/(SPEED(I)-SPEED(I-1))
    EHPV = (EHP(I)-EHP(I-1))*RATIO+EHP(I-1)
    DRAAGG = (EHPV*1450.1)/V
    V=VMS
    RETURN
99  WRITE(6,20)V
20  FORMAT(* SPEED EXCEEDS RANGE *,F10.4)
    RETURN
    END
```

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```
C      SUBROUTINE EULER(T,DT,Y,NSTATE)
C      FULLER INTEGRATION ROUTINE.
C      DIMENSION Y(NSTATE),F(50)
C      COMPUTE RHS OF DIFFERENTIAL EQUATIONS.
C      CALL DAXX(T,Y,F)
C      INTEGRATE FROM T TO T + DT
C      DO 1 I=1,NSTATE
C         Y(I) = Y(I) + F(I)*DT
1      CONTINUE
C      UPDATE TIME
C      T = T + DT
C      RETURN
C      END
```

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```
C
SUBROUTINE FINFOR
PROGRAM TO COMPUTE FIN FORCES AND MOMENTS
COMMON /CONST/ RHOA,RHOA2,RHOW,RHOW2,RTTOM
COMMON /STATE/ U,V,W,P,Q,R,PHI,THETA,PSI,XE,YE,ZE,SPEED,S,DRIFAN,
1 COSPHI,COSTHE,COSPSI,SINPHI,SINTHE,SINPSI,T,TRX(7,3),TIME
COMMON /FINVAR / XFIN(4),YFIN(4),ZFIN(4),ARAFIN(4),CLFIN(4),CRFIN
1(4),FINANG(4),XFOREN(4),YFOREN(4),ZFOREN(4),ALIFT(4),DRAG(4),FFM
1(6),FINNO(2)
DO 1 N=1,4
CALL TOTVEL(U,V,W,P,Q,R,XFIN(N),YFIN(N),ZFIN(N),UTOTAL,VTOTAL,
1 WTOTAL)
GAM=ATAN(WTOTAL/UTOTAL)
ALFA= GAM+FINANG(N)
TRFOR= GAM
ALIFT(N)=RHOW2*ARAFIN(N)* (UTOT **2+WTOTAL**2)*CLFIN(N)*ALFA
DRAG(N)=ABS(ALIFT(N))/7.
XFOREN(N)=ALIFT(N)*SIN(TRFOR)-DRAG(N)*COS(TRFOR)
ZFOREN(N)=- (ALIFT(N)*COS(TRFOR)+DRAG(N)*SIN(TRFOR))
1 CONTINUE
DO 2 N=1,6
2 FFM(N)=0.
DO 3 N=1,4
FFM(1)=FFM(1)+XFOREN(N)
3 FFM(3)=FFM(3)+ZFOREN(N)
DO 4 N=1,4
FFM(4)=FFM(4)+ZFOREN(N)*YFIN(N)-YFOREN(N)*ZFIN(N)
FFM(5)=FFM(5)+XFOREN(N)*ZFIN(N)-ZFOREN(N)*XFIN(N)
4 FFM(6)=FFM(6)+YFOREN(N)*XFIN(N)-XFOREN(N)*YFIN(N)
RETURN
END
```

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```
SUBROUTINE HULLFOR
REAL LENGTH
REAL MASS, IXX, IXY, IXZ, IYY, IYZ, IZZ
COMMON /STATE / U, V, W, P, Q, R, PHI, THETA, PSI, XE, YE, ZE, SPEED, S,
1      DRIFAN, COSPHI, COSTHE, COSPSI, SINPHI, SINTHE, SINPSI,
2      TMTRX(3,3), TIME
COMMON /CONST/ RADIAN, RHOA, RHOA2, RHOV, RHOV2, FTTOM
COMMON /COMOVE/ XC, YC, ZC
COMMON /VARBLE/ E(4), DUMMY(44)
COMMON /HYDRO/ LG(4), LZ, HY(4,3213), F(4,16), XG(4,20), IPOINT(4),
1UMAX, HYDRFM(4), ICNT
COMMON /CRAFT/ SCFACT, LENGTH, MASS, IXX, IXY, IXZ, IYY, IYZ, IZZ
COMMON /HULVAR/ HULFM(6), HULPIK
DO 45 KU=2,4
45 HULFM(KU)=9999.
H(1)=PHI*RADIAN
H(2)=DRIFAN*RADIAN
H(3)=R*LENGTH/U
H(4)=U*1.844
CALL HYDINT
SSS=SQRT(U*U+V*V)
FORCE=-DRAAGG(SSS)
HULFM(1)=FORCE*(1.+(.02*(HULPIK+ZE)))
HULFM(2)=HYDRFM(2)
HULFM(3)=(.5+.125*U)*RHOV2*LENGTH*LENGTH*.001*U*U
HULFM(4)=HYDRFM(3)
HULFM(5)=HULFM(1)*(8.06-((HULPIK+ZE)/6.))
HULFM(6)=HYDRFM(4)
C
C TERMS DUE TO CENTER OF GRAVITY NOT AT ORIGIN
HULFM(4)=HULFM(4)+MASS*9.81*(YC*TMTRX(3,3)-ZC*TMTRX(2,3))
HULFM(5)=HULFM(5)+MASS*9.81*(XC*TMTRX(3,3)-ZC*TMTRX(1,3))
HULFM(6)=HULFM(6)+MASS*9.81*(XC*TMTRX(2,3)-YC*TMTRX(1,3))
RETURN
END
```

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```

SUBROUTINE HYDINT
C   SUBROUTINE TO LINEARLY INTERPOLATE HYDRODYNAMIC FUNCTION
C   VALUES USING 16 STORED COEFFICIENTS.
C   COMMON / VARBLE/ H(4),I,DT,DUMMY(42)
C   COMMON / HYDRO/ LG(4),L7,X(4,3213),Y(4,161),YG(4,201),IPPOINT(4),
C   L12,-HYDHE(4),ICNT
C   COMMON / IOUT/ I5,IPRINT(6),JUT,IPRIN,APRINT
C   DIMENSION D(4)
C   DITE(4,100)
C 700 FORMAT(*,HYDINT--I INTERPOLATION - - - -*)
C   - - - - -
C   X(I,0)=0-TH GRID POINT OF I-TH INDEPENDENT VARIABLE.
C   H= INDEPENDENT VARIABLE (NONDIMENSIONAL)
C   ROLL ANGLE=H(1), DRIFT VEL=H(2), YAW RATE=H(3), SPEED=H(4)
C   HY(I,0)=TABLE OF HYDRODYNAMIC FUNCTION VALUES
C   X(I=1), Y(I=2), H(I=3), K(I=4)
C   IPOINTER=INTER FOR GRID SET--TO COMPARE LAST ENTRY.
C   LG(I)=NO. OF GRID POINTS FOR I-TH VARIABLE.
C   L7=NO. OF POINTS FOR ZERO SPEED (750 VALUES NOT STORED)
C   - - - - -
C   CHECK 1-DIMENSIONAL SPEED. IF GREATER THAN MAX
C   VALUE SET SPEED TO ALMOST MAX VALUE( TO AVOID NO DATA CELL).
C   LG4=LG(4)
C   IF( X(4,0).GT. YG(4,LG4) ) H(4)=YG(4,LG4)+0.0000001
C   - - - - - CHECK IF CURRENT VALUE OF INDEPENDENT VARIABLES (H)
C   ARE IN THE CURRENT CELL ( 4-DIMENSIONAL INTERVAL )
C   INDICATED BY VALUES OF IPOINT. IF NOT FIND NEW CELL.
C
C   ISW=0
C 10 20 I=1,4
C   I=H(I)
C   I=IPPOINT(I)
C 10 IF( XG(I,0).GT.Z ) GO TO 15
C   IF( XG(I,N+1).GT.Z ) GO TO 20
C   SEARCH UPWARD TO FIND NEW GRID POINT.
C
C   ISW=1
C   I=Y+1
C   IPOINT(I)=N
C   IF(N.EQ.LG(I)) IPOINT(I)=N-1
C   IF(N.EQ.LG(I)) GO TO 20
C   GO TO 10
C   SEARCH DOWNWARD TO FIND NEW GRID POINT.
C
C 15 ISW=1
C   I=Y-1
C   IPOINT(I)=N
C   IF(N.EQ.0) IPOINT(I)=1
C   IF(N.EQ.0) GO TO 20
C   GO TO 1
C 20 CONTINUE
C   WRITE(6,100) (IPOINT(I),I=1,4)
C 710 FORMAT(*,HINTER +.4I4)
C
C   - - - - - IF ISW=1 NEW COEFFICIENTS MUST BE COMPUTED.
C   IF( ISW.EQ.1 ) CALL HYDHEP
C
C   - - - - - COMPUTE DISTANCE TO GRID POINT.
C 20 30 I=1,4
C   I=IPPOINT(I)

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30  D(I)=P(I)-C(I,1)
C  - - - - - INTERPOLATION USING COEFFICIENTS.
      DO 50 I=1,4
      F0=P(I,1)
      F1=P(I,2)*C(1)+P(I,3)*C(2)+P(I,4)*C(3)+P(I,7)*C(4)
      F2=P(I,5)*C(1,6)+P(I,6)*C(2)+P(I,7)*C(3)+P(I,8)*C(4)+
      + C(2)*C(3)+P(I,9)*C(3)+P(I,10)*C(4) + P(I,11)*C(3)*C(4)
      F3=P(I,1)*C(2)*C(3)+P(I,10)*C(3)+P(I,13)*C(4) + C(3)*C(4)+
      + C(3)*P(I,14)*C(11)+P(I,15)*C(2)
      F4=P(I,15)*P(I,1)*P(2)*C(3)+C(4)
      HYDYMFI=F0+F1+F2+F3+F4
C  WRITE(6,720) I,F0,F1,F2,F3,F4,HYDYMFI
C 720  FORMAT(/ * PARTS OF FORCE*,I2,5E14.5, * TOTAL=*,E15.8 )
      50 CONTINUE
      RETURN

C  - - - - - NONDIMENSIONAL VALUES OUT OF BOUNDS---ERROR-----
C 000  WRITE(6,750) I,(H(I),I=1,4)
      IRUG(1)=1
C 750  FORMAT(/// * VARIABLE NO. *, I4, * OUT OF BOUNDS IN HYDRO-*,
      + * DYNAMIC INTERPOLATION */
      + * *, * COLL AND *11X, * * PRIEST VEL *, 10X, * Y15 RATE *, 15X, * CORREC *
      + /4E20.1 // 5H STOP )
C  - - - - - POINTER DESTROYED --REINITIALIZE AND GET
C  - - - - - CORRESPONDING COEFFICIENTS FOR NEXT RUN.
      DO 210 I=1,4
      210  IPOINT(I)=L(I)/2
      CALL HYDRAP
      RETURN
      END

```

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SUBROUTINE HYDRAE
      SUBROUTINE TO COMPUTE LINEAR INTERPOLATION COEFFICIENTS
      FOR A FUNCTION OF 4 INDEPENDENT VARIABLES. FUNCTION
      VALUES ARE STORED IN A TABLE.

      COMMON /HYDRAE/ LL1,LL2,LL3,LL4,LL5, HY(4,3017),P(4,14),XC(4,20),
      1  YPOINT(4),UNAV, -HYDRAE(4),ICNT
      DIMENSION P(4,14), UNAV

      C - - - - - FUNCTION TO COMPUTE SUBSCRIPT
      C 1000 SUBROUTINE (X,Y,IS)= 1+LL1*( X-1+LL2*( Y-1+LL3*(IS-1) ) )-L7
      C 1001 COUNT CALLS TO THIS ROUTINE.
      C 1002
      ICNT=ICNT+1
      WRITE(6,7100)
      C 7100 FORMAT('** HYDRAE - - - - - **')
      C - - - - - GET FUNCTION VALUES AT SURROUNDING GRID POINTS.
      C 1003
      I1=1
      DO 20 I1=1,2
      I2=IPNT(I1)+I1-1
      DO 20 I2=1,2
      I3=IPNT(I2)+I2-1
      DO 20 I3=1,2
      I4=IPNT(I3)+I3-1
      DO 20 I4=1,2
      I5=IPNT(I4)+I4-1
      DO 20 I5=1,2
      I6=IPNT(I5)+I5-1
      I7=IPNT(I6)+I6-1
      I8=IPNT(I7)+I7-1
      I9=IPNT(I8)+I8-1
      I10=IPNT(I9)+I9-1
      I11=IPNT(I10)+I10-1
      I12=IPNT(I11)+I11-1
      I13=IPNT(I12)+I12-1
      I14=IPNT(I13)+I13-1
      I15=IPNT(I14)+I14-1
      I16=IPNT(I15)+I15-1
      I17=IPNT(I16)+I16-1
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      I19=IPNT(I18)+I18-1
      I20=IPNT(I19)+I19-1
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      I437=IPNT(I436)+I436-1
      I438=IPNT(I437)+I437-1
      I439=IPNT(I438)+I438-1
      I440=IPNT(I439)+I439-1
      I441=IPNT(I440)+I440-1
      I442=IPNT(I441)+I441-1
      I443=IPNT(I442)+I442-1
      I444=IPNT(I443)+I443-1
      I445=IPNT(I444)+I444-1
      I446=IPNT(I445)+I445-1
      I447=IPNT(I446)+I446-1
      I448=IPNT(I447)+I447-1
      I449=IPNT(I448)+I448-1
      I450=IPNT(I449)+I449-1
      I451=IPNT(I450)+I450-1
      I452=IPNT(I451)+I451-1
      I453=IPNT(I452)+I452-1
      I454=IPNT(I453)+I453-1
      I455=IPNT(I454)+I454-1
      I456=IPNT(I455)+I455-1
      I457=IPNT(I456)+I456-1
      I458=IPNT(I457)+I457-1
      I459=IPNT(I458)+I458-1
      I460=IPNT(I459)+I459-1
      I461=IPNT(I460)+I460-1
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      I463=IPNT(I462)+I462-1
      I464=IPNT(I463)+I463-1
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      I472=IPNT(I471)+I471-1
      I473=IPNT(I472)+I472-1
      I474=IPNT(I473)+I473-1
      I475=IPNT(I474)+I474-1
      I476=IPNT(I475)+I475-1
      I477=IPNT(I476)+I476-1
      I478=IPNT(I477)+I477-1
      I479=IPNT(I478)+I478-1
      I480=IPNT(I479)+I479-1
      I481=IPNT(I480)+I480-1
      I482=IPNT(I481)+I481-1
      I483=IPNT(I482)+I482-1
      I484=IPNT(I483)+I483-1
      I485=IPNT(I484)+I484-1
      I486=IPNT(I485)+I485-1
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      I488=IPNT(I487)+I487-1
      I489=IPNT(I488)+I488-1
      I490=IPNT(I489)+I489-1
      I491=IPNT(I490)+I490-1
      I492=IPNT(I491)+I491-1
      I493=IPNT(I492)+I492-1
      I494=IPNT(I493)+I493-1
      I495=IPNT(I494)+I494-1
      I496=IPNT(I495)+I495-1
      I497=IPNT(I496)+I496-1
      I498=IPNT(I497)+I497-1
      I499=IPNT(I498)+I498-1
      I500=IPNT(I499)+I499-1
      I501=IPNT(I500)+I500-1
      I502=IPNT(I501)+I501-1
      I503=IPNT(I502)+I502-1
      I504=IPNT(I503)+I503-1
      I505=IPNT(I504)+I504-1
      I506=IPNT(I505)+I505-1
      I507=IPNT(I506)+I506-1
      I508=IPNT(I507)+I507-1
      I509=IPNT(I508)+I508-1
      I510=IPNT(I509)+I509-1
      I511=IPNT(I510)+I510-1
      I512=IPNT(I511)+I511-1
      I513=IPNT(I512)+I512-1
      I514=IPNT(I513)+I513-1
      I515=IPNT(I514)+I514-1
      I516=IPNT(I515)+I515-1
      I517=IPNT(I516)+I516-1
      I518=IPNT(I517)+I517-1
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      I520=IPNT(I519)+I519-1
      I521=IPNT(I520)+I520-1
      I522=IPNT(I521)+I521-1
      I523=IPNT(I522)+I522-1
      I524=IPNT(I523)+I523-1
      I525=IPNT(I524)+I524-1
      I526=IPNT(I525)+I525-1
      I527=IPNT(I526)+I526-1
      I528=IPNT(I527)+I527-1
      I529=IPNT(I528)+I528-1
      I530=IPNT(I529)+I529-1
      I531=IPNT(I530)+I530-1
      I532=IPNT(I531)+I531-1
      I533=IPNT(I532)+I532-1
      I534=IPNT(I533)+I533-1
      I535=IPNT(I534)+I534-1
      I536=IPNT(I535)+I535-1
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      I538=IPNT(I537)+I537-1
      I539=IPNT(I538)+I538-1
      I540=IPNT(I539)+I539-1
      I541=IPNT(I540)+I540-1
      I542=IPNT(I541)+I541-1
      I543=IPNT(I542)+I542-1
      I544=IPNT(I543)+I543-1
      I545=IPNT(I544)+I544-1
      I546=IPNT(I545)+I545-1
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      I553=IPNT(I552)+I552-1
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      I560=IPNT(I559)+I559-1
      I561=IPNT(I560)+I560-1
      I562=IPNT(I561)+I561-1
      I563=IPNT(I562)+I562-1
      I564=IPNT(I563)+I563-1
      I565=IPNT(I564)+I564-1
      I566=IPNT(I565)+I565-1
      I567=IPNT(I566)+I566-1
      I568=IPNT(I567)+I567-1
      I569=IPNT(I568)+I568-1
      I570=IPNT(I569)+I569-1
      I571=IPNT(I570)+I570-1
      I572=IPNT(I571)+I571-1
      I573=IPNT(I572)+I572-1
      I574=IPNT(I573)+I573-1
      I575=IPNT(I574)+I574-1
      I576=IPNT(I575)+I575-1
      I577=IPNT(I576)+I576-1
      I578=IPNT(I577)+I577-1
      I579=IPNT(I578)+I578-1
      I580=IPNT(I579)+I579-1
      I581=IPNT(I580)+I580-1
      I582=IPNT(I581)+I581-1
      I583=IPNT(I582)+I582-1
      I584=IPNT(I583)+I583-1
      I585=IPNT(I584)+I584-1
      I586=IPNT(I585)+I585-1
      I587=IPNT(I586)+I586-1
      I588=IPNT(I587)+I587-1
      I589=IPNT(I588)+I588-1
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      I601=IPNT(I600)+I600-1
      I602=IPNT(I601)+I601-1
      I603=IPNT(I602)+I602-1
      I604=IPNT(I603)+I603-1
      I605=IPNT(I604)+I604-1
      I606=IPNT(I605)+I605-1
      I607=IPNT(I606)+I606-1
      I608=IPNT(I607)+I607-1
      I609=IPNT(I608)+I608-1
      I610=IPNT(I609)+I609-1
      I611=IPNT(I610)+I610-1
      I612=IPNT(I611)+I611-1
      I613=IPNT(I612)+I612-1
      I614=IPNT(I613)+I613-1
      I615=IPNT(I614)+I614-1
      I616=IPNT(I615)+I6
```

$P(I,6) = (A(I,2) - Y) / D(6)$

SECOND DEGREE TERMS

$P(I,6) = (A(I,13) - A(I,9) - A(I,5) + Y) / (D(1) + D(2))$

$P(I,7) = (A(I,11) - A(I,9) - A(I,7) + Y) / (D(1) + D(3))$

$P(I,8) = (A(I,13) - A(I,9) - A(I,7) + Y) / (D(1) + D(4))$

$P(I,9) = (A(I,7) - A(I,5) - A(I,3) + Y) / (D(2) + D(3))$

$P(I,10) = (A(I,9) - A(I,5) - A(I,3) + Y) / (D(2) + D(4))$

$P(I,11) = (A(I,4) - A(I,3) - A(I,2) + Y) / (D(3) + D(4))$

CUBIC TERMS

$Y = A(I,15) - (A(I,13) + A(I,11) + A(I,7)) + (A(I,9) + A(I,5) + A(I,3)) - Y$

$P(I,12) = Y / (D(1) + D(2) + D(3))$

$Y = A(I,14) - (A(I,13) + A(I,10) + A(I,6)) + (A(I,9) + A(I,5) + A(I,2)) - Y$

$P(I,13) = Y / (D(1) + D(2) + D(4))$

$Y = A(I,10) - (A(I,11) + A(I,10) + A(I,4)) + (A(I,7) + A(I,5) + A(I,2)) - Y$

$P(I,14) = Y / (D(1) + D(3) + D(4))$

$Y = A(I,8) - (A(I,7) + A(I,4) + A(I,4)) + (A(I,9) + A(I,3) + A(I,2)) - Y$

$P(I,15) = Y / (D(2) + D(3) + D(4))$

FOURTH DEGREE TERM

$Y = A(I,15) - (A(I,16) + A(I,14) + A(I,12) + A(I,8)) +$

$(A(I,13) + A(I,11) + A(I,10) + A(I,7) + A(I,6) + A(I,4)) -$

$(A(I,9) + A(I,5) + A(I,3) + A(I,2)) + Y$

$P(I,16) = Y / (D(1) + D(2) + D(3) + D(4))$

WRITE(6,72) 1,(P(I,J),J=1,16)

C 700 COEFFICIENTS COEFFICIENT IS FOR INTERPOLATION-FUNCTION 4,14/

C 700 7/4720.5/4720.5/4720.5/4720.5

C 100 CONTINUE

RETURN

END

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COMMON/RYXDC/LR(4),LF,RY(4,3013),F(4,10),XG(4,00),I(4,1),
LMAX,RYDC=RY(4),ICNT
SITE(0,0010)

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[illegible]

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1 20001, 20002, 20003, 20004, 20005, 20006, 20007, 20008

COMMON ACOST / EASTIAN, PHOI, PHOAI, PHOI, PHONG, FTON

```
COMMON /STATE / U,V,W,P,Q,R,PHI,THETA,POI,YE,YF,ZE,S,SPEED,  
DRIFAN,COSPHI,COSTH,COSPHI,SINPHI,SINTH,CINPHI,  
TIME(3,3),TIME
```

```
COMMON/PSI/VAR/PSIN(4),YPSIN(4),ZPSIN(4),APSPIN(4),CLPSIN(4),
  ZPSPIN(4),EPSIN(4),XEQSPIN(4),YEQSPIN(4),ZEQSPIN(4),ALIFIN(4),
  RPSIN(4),EPS(4)
4,FINANC(4)
```

COMMON /HYPERC / I6(4),L7,RY(4,3013),FF(4,14),Y5(4,20),IPDINT(4),
RYAX,RYTREN(4),TOUT

```

1  CCAMIN,ABDOMAR,ZUCAN(100),HUVEL(100),PALEA(100),AXEUD(100),AYRUD(100),
2      AKRUD(100),ANRUD(100),ACATIG,ZUCAN(2),NUMUDV,NUMRAL,
3      RUCRDN,ERLIDIS,ERHAR,ERECER,RUFER(6)
4  YRUD(3),YRUD(2),ZRUD(2)
5  RUDIR*
6  PROIRY,ERGRIN

```

COMMON, PROPER, EDIS, PROPER(3), PROPS, LREYS, RITCHS, RITCHS,
REUREM(2)

COMMON AIRWAY / AIRWAY (C)

COMMON/PULVAF/BULLEN (4), HULBTR

COM 40N 250YMAR 140000Z, 200000Z, 250000Z, 300000Z, 010000Z (6)

```
COMMON/ADDMVAR/ALMTRX(6,6,6),ALFEM(6),RTMTRY(6,6)
COMMON/STATCOF/XYRDOT,XYRDOT,XYRDOT,XYRDOT,ZXRDOT,ZXRDOT,KXRDOT,KXRDOT,
KXRDOT,KXRDOT,XYRDOT,XYRDOT,XYRDOT,XYRDOT,XYRDOT,XYRDOT
```

COMMON APPROVE /YC.YC.7C
LOGICAL ENT

```
COMMON /PDEPRAT/ IR1,IR2,IR3,IR4,IR5,IR1,IR2,IR3,IR4,IR5,IR6,IR7,
IR8,IR9,IR10,END(15)
```

COMMUN. SECTION / ID#F, JONAS (20)

COMMON ACCTG/ TC,UC,MC,MO,PO,CC,BO,PHIC,THETAQ,PSID

COMMON INTEREST/ DT, CTWJ, TWAY, AF (15), FFS (15), HSTATE

BT - STEP SIZE FOR CALLS TO KUTHER. SEC

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C DIMIN - MINIMUM STEP SIZE TO BE USED BY KUTTER, SEC
 C TMAX - SIMULATION STOP TIME
 C 1E(1-15) - ABSOLUTE INTEGRATION ERROR CRITERIA FOR STATE
 C VECTOR, Y(1-15)
 C EPS(1-15) - RELATIVE ERROR CRITERIA FOR Y(1-15)

COMMON /XCH/ TLX, ICONF, ICF(10), ICF2(10), IACT(10), IACT2(10), CV1(10),
 1 CV2(10), CV3(10), CV4(10), CFH1(14), CRIN2(14),
 2 COIN1(12), COIN2(12), COIN3(12), RELAR(2), CHECK(2),
 3 RATE(12), KACT(12)

COMMON /OUTY / IOUT(5), IPRINT(5), JSA, IPRN, APRINT

COMMON /HEADER/ TITLE(10)

DIMENSION Y(20)

DATA PRDYSO/200./, PRDMPD/200./, DTCHSO/0./, DTCHPD/0./,
 1 FINAND/4*0./,
 2 BRUDSO/0./, BRUDPD/0./, PUTAND/2*0./

NAMELIST /SWATHD/ TL, UC, VC, PC, CO, PO, PHIN, THETAO, PSIO,
 1 XC, YC, ZC.

1 SGEACT, LENGTH, XASS, IXV, IYV, IZZ, IXY, IYZ, IYZ,
 2 POTA, POCAP, PRDUSO, PRDMPD, DTCHSO, DTCHPD,
 3 FINAND, ARAFIN, XFIN, YFIN, ZFIN, PUTAND, ARATIC,
 4 BRUDSO, BRUDPD,

1 BRSPAL, BRDARM,

1 XPDOT, YPDOT, ZPDOT, XPDOT, YPDOT, XPDOT, YPDOT, XPDOT, YPDOT,
 2 ZPDOT, ZPDOT, XPDOT, XPDOT, CLFIN, ZSURZ, ZSURTH, "SURZ, "SURTH.

1 NUMBAL, NUMDUV,

1 GULR2K.

1 IDOE, ENT, DT, DTMIN, TMAX, AF, EPS, IPRN
 2 . IACT, TITLE, IPRINT
 3 . UNVEL, PALEA, AXRUD, AYRUD, AKRUD, /VRUD
 4 . XPRD, YPRD, ZPRD, PUTARM

1 READ(155,500) (TITLE(I), I=1,10)

1 500 FORMAT(10A10)

1 400 FORMAT(21H10,4TH SIMULATION RUN. I4,10X,10A10//)

1 READ(155,SWATHD)

1 WRITE(155,SWATHD)

1 CONVERT INITIAL CONDITIONS TO PROPER INTERNAL UNITS

1 = UC*1.480*FTTOY

1 = VC*1.480*FTTOY

1 = PC*1.480*FTTOY

1 = PC/30.48

1 = PC/30.48

1 = PC/30.48

1 TIME = 0

1 TIME=TIME

1 SPEED = SQRT(U*U+V*V+W*W)

1 C=0.0

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```

CDEF=U*1.440+RTIC
PIFAN=0.0
VE=0.0
VF=0.0
WF=0.0
C=0.0
THI = THIC/RADIAN
THETA = THETA/RADIAN
SI = SCIO/RADIAN
RPPMS = RPPMSJ
RPPMP = RPPMPJ
RITCHS=RITCHSC
RITCHP=RITCHPC
C0 R240 IPP=1.4
6010 FINANG(IPP) = FINANG(IPP)/RADIAN
RUDANG(1)=RUDANG(1)/RADIAN
RUDANG(2)=RUDANG(2)/RADIAN
RUDAS=RUDSC
RUDIP=RUDSC
C
V(1)=U
V(2)=V
V(3)=W
V(4)=P
V(5)=Q
V(6)=R
V(7)=PXY
V(8)=THETA
V(9)=RST
V(10)=XF
V(11)=YL
V(12)=ZF
V(13)=C
C INITIALIZE LINE COUNTER FOR OUTPUT RECORD
ISA = 0
C ADJUST IMAX TO ASSURE PROPER INEQUALITY CHECK IN SUBSEQUENT CODE
IMAX = IMAX-ST/100.
C
C *** ACNTL INPUT ***
C
C READ(IP5,510) ACNT
610 FORMAT(I10,F10.2,I10,F10.2,I10)
IF(ACNT.LT.0) GO TO 200
IF(ACNT.EQ.0) GO TO 170
C READ IN PILOT ACTION COMMAND DATA
C
C WRITE(IP6,602) ACNT
610 FORMAT(7,14H THERE ARE TO BE 14.0H ACTIONS)
C
C WRITE(IP6,603)
610 FORMAT(4X,19H CONTROL CONDITION,70X,14HCOMMAND CHANGES,4X,2HTO,
17X,4HPAGE,/)
C
C READ COMMANDS
C
C GO 102 I=1,ACNT

```

```

      READ(15,510) J1,CV1(I),J2,CV2(I),CV3(I),IAC1(I)
      CV4(I)=SIGN(1.,FLCOT(J1))
      IF(J1.LT.0) X=0
      IF(J1.GT.0) X=1
      IF(IAC1(I).LE.0) X=0
      IF(IAC1(I).GT.0) X=1
      IF(J1.LT.0) J1=-J1
      IF(J1.EQ.1) IACT(I)=1
      IF(J1.EQ.1) X=1

```

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```

      IC1(I) = 11
      IC2(I) = J2

```

```

      IF(J1.EQ.0.OR.J1.EQ.17.OR.J2.LE.1.OR.J2.EQ.14) GO TO 221

```

```

      SET ACTIVITY INDICATOR TO ZERO
      IACT(I) = 0
      USE DEFAULT RATES IF COMMANDED RATE IS ZERO
      IF(CV3(I).LT.0.001) CV3(I)=RATE(J2)

```

```

      PRINT OUT COMMANDS

```

```

      WRITE(15,600) CR1(I),RELAT(I),CV1(I),CR2(I),
     1 CR1(J2),CV2(I),CR2(J2),CV3(I),CR3(J2),CHECK(I)
      FORMAT(4X,A10,F4.3,F10.2,2X,A11,1X,F10.2,2X,A5,2X,F10.2,
     1 2X,47.3X,A10)

```

```

      CONVERT RATES TO PROPER SIGNS

```

```

      CV1(I)=CV1(I)*CV4(I)

```

```

      CONTINUE
      INIT KACT TO ZERO

```

```

      DO 103 I=1,12
      KACT(I) = 0

```

```

      CONTINUE

```

```

      **          ** READ HYDRO DATA          **

```

```

      DO 6682 LKU=1,6
      DO 6683 LYM=1,6
      6682 DTIMEX(LKU,LYM)=0.0
      DO 6681 COAR1=1,70
      READ(15,600) IJ,JY,COEFF
      6681 FORMAT(2I2,F10.4)
      IF(IJ.LT.0) GO TO 6700
      DTIMEX(IJ,JY)=COEFF
      6681 CONTINUE
      6700 CONTINUE
      DO 6050 ILE=1,6
      DO 6050 IJE=1,6
      DO 6050 IJM=1,6
      6050 DTIMEX(IJE,ILE,IJM)=0.0
      DO 6051 ICARF=1,31
      READ(15,6050) IJ,JY,KM,COEF

```

[illegible]

```

SUBROUTINE KUTYER(NQ,T,H,YO,ERSE,A,HGX,FIRST)
DIMENSION YO(20),Y1(20),Y2(20),F0(20),F1(20),F2(20)
DIMENSION ERSE(20),A(20)
COMMON/CTV/IRUS(5),IPRINT(5),JDA,NRUM,NPRINT
DATA NAR1,NAR2 /DHY1,2HY2/

```

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```

C
C ALGORITHM OF: FROM DEC 1967 COMMUNICATION OF ACM.
C ERROR INFORMATION AND STEP SIZE WRITTEN TO TAPE 2.
C NQ= NUMBER OF EQUATIONS, NO. OF COMPONENTS OF YO
C T= INDEPENDENT VARIABLE
C H=INCREMENT FOR WHICH SOLN IS TO BE RETURNED + OR-
C YO IS THE VECTOR OF DEPENDENT VARIABLES. ENTER WITH INITIAL
C VALUES AT T AND RETURNS WITH VALUES AT T+H
C ERSE=RELATIVE ERROR CRITERION FOR COMPONENTS OF YO .GT. APS(A)
C A=ABSOLUTE ERROR CRITERIA FOR COMPONENTS OF YO .LT. APS(A)
C NOTE-- ERSE AND A MUST BE SPECIFIED FOR EACH COMPONENT OF THE SYSTEM
C HGX = THE SMALLEST STEP SIZE USED IN THE INTEGRATION
C DAUX(T,Y,F) RETURNS THE VECTOR F(T,Y)
C FIRST -- SHOULD BE =0. WHEN (1) KUTYER IS ENTERED FOR THE FIRST
C TIME OR (2) ENTERED WITH A CHANGED H.
C FIRST SHOULD BE = 1.0 WHEN ENTERED WITH THE SAME H TO
C CONTINUE INTEGRATION IN A SEQUENCE.
C FIRST WILL =2.0 WHEN THE ERROR CRITERIA CANNOT BE MET AND
C STEP SIZE IS REDUCED TO H/128.
C
IF(YO(1).LT.0.) FIRST=2.
IF(YO(1).LT.0.) GO TO 300
IF(FIRST)20,10,20
C - - - - - FIRST ENTRY
10 HC=H
IFLOC=1
FIRST=1.
C - - - - - OTHER ENTRY
20 LOC=0
HGX=HC
IF(HC.LE.0.) GO TO 300
WRITE(6,*)00
200 FORMAT(5X,'KUTYER ENTERED WITH ZERO INTEGRATION INTERVAL+ ')
FIRST=2.
RETURN
C - - - - - 5 CALLS TO DAUX
C
30 CALL DAUX(T,YO,F0),RETURNS(300)
IPRINT(1)=0
70 40 I=1,NQ
40 Y1(I) =YO(I) +(HC/3.)*F0(I)
C
CALL DAUX(T+HC/3., Y1,F1),RETURNS(320)
50 50 I=1,NQ
50 Y1(I) =YO(I) +(HC/6.)*F0(I)+(HC/6.)*F1(I)
C
CALL DAUX(T+HC/3., Y1,F1),RETURNS(320)
60 60 I=1,NQ
60 Y1(I) =YO(I) +HC/8.*F0(I)+.375*HC*F1(I)
C
CALL DAUX(T+HC/2., Y1,F2),RETURNS(320)
70 70 I=1,NQ

```

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```

70 Y1(I) = Y0(I) + HC/2. * F0(I) - 1.5 * HC * F1(I) + 2. * HC * F2(I)
C
    CALL DUMX( T+HC, Y1, F1), RETURNS(300)
    DO 90 I=1, 10
80 Y0(I) = Y1(I) + HC/6. * F0(I) + ( 2./3. ) * HC * F2(I) + (HC/6.) * F1(I)
    INC=1
C - - - - - CHECK ERROR CRITERIA
    DO 110 I=1, 10
    F0I=ABS(Y1(I))-A(I)
    IF (F0I) 95, 97, 97
C
    95 ERROR=ABS(.2*(Y1(I) - Y0(I)))
    IF( ERROR-A(I) ) 100, 100, 98
C
    97 ERROR=ABS(.2-.2*Y2(I)/Y1(I) )
    IF( ERROR-ERSE(I) ) 100, 100, 99
C - - - - - -SINCE ERROR, GT. ERROR CRITERIA CHECK IF HC, GT. 4/128.
C - - - - - -IF YES THEN HALVE INTERVAL. OTHERWISE STOP.
    99 K= 128.+(ABS(HC))-ABS(H)
    IF(K) 91, 95, 95
C
    91 WRITE(6, 42) T, I, ERROR, HC
    92 FORMAT( / 19H FOR EQUATION NO. 10, 27H THE RELATIVE ERROR AT T = .
    93 15.0, 4H IS . 15.0, 2H STEP SIZE = ., 515.0 )
    FIRST = 2.
    RETURN
C
    95 WRITE(6, 43)
    95 WRITE(11, 710) T, I, ERROR, HC
    710 FORMAT( / 41H TIME=*, F10.3, 2X, HALVE INTERVAL. EQUATION *, I3,
    711 41H ERROR=*, E10.6, 2X, STEP SIZE NOW = *, E15.4 )
    WRITE(11, 720) NAX2, (Y2(J), J=1, ND)
    WRITE(11, 720) NAX1, (Y1(J), J=1, ND)
    720 FORMAT( 2X, 40 / 3(10F13.5 /) )
    721 TO 72
C - - - - - -TEST IF INTERVAL LENGTH CAN BE DOUBLED.
    100 IF( ERROR*64.-ERSE(I) ) 110, 110, 101
    101 INC=1
    110 CONTINUE
C - - - - - -UPDATE T AND SOLUTION.
    111 T=T+HC
    DO 112 I=1, 10
    112 Y0(I) = Y1(I)
C - - - - - - SET SOLUTION ON NEXT INTERVAL
    LCC=LCC+1
    IF (LCC-IFLCC) 120, 210, 210
    120 IF( INC ) 130, 130, 210
    130 IF( LCC-(LCC/2) ) 210, 140, 210
    140 IF( IFLCC-1 ) 210, 210, 210
C - - - - - -DOUBLE INTERVAL LENGTH.
    210 HC=2.*HC
    LCC=LCC/2
    IFLCC=IFLCC/2
    210 IF( IFLCC-LCC ) 30, 329, 70
    300 RETURN
    END

```

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SUBROUTINE WGNHR1 (I,ARG,II,N,IER,RATIO)

```

0-----
0  WGNHR1 FINDS THE NEAREST NEIGHBOR .LE. TO ARG IN ARRAY V
0      V      - VARIABLE ARRAYS
0      ARG    - SEARCH ARGUMENT
0      II     - LOCATION C.T. V(II).LE.ARG.LE.V(II+1)
0      N      - NUMBER OF POINTS IN V
0      IER    - 0 IN RANGE, IF NOT OUT OF RANGE
0      RATIO  - (ARG-V(II))/(V(II+1)-V(II))
0-----

```

```

      DIMENSION V(1)
      I=II
      IER = 0
      IC = 0
1    CONTINUE
      IF(ARG.GE.V(I))GO TO 2
      I=I-1
      IF(I.LE.1)GO TO 1
      IER=0
      I=1
      IC = 4
2    IF(I+1.NE.N) GO TO 3
      IF(ARG.LE.V(I+1))GO TO 4
      I= I+1
      GO TO 2
3    N = N-1
      IER=0
4    II = I
      RATIO = (ARG-V(I))/(V(I+1)-V(I))
      GO(IEO,NE,1) RETURN
      WRITE(II,600) II,N,V(I),V(I+1),ARG,RATIO
600  FORMAT(* OUT OF RANGE IN WGNHR1. II= *.I4.* N= *.I4.* V(I)= *.
      . F10.3.* V(I+1)= *.F10.3.* ARG= *.F10.3.* RATIO = *.F10.3.
      . /.* ERROR *.)
      RETURN
      END

```

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THESE ARE THE OUTPUTS (PRINTS)

THIS ROUTINE PRINTS FIVE PAGES OF OUTPUT

PAGE 1 T,SPEED,U,V,W,P,PHI,ORIST,HEADINC,YE,YE,DISTANCE

PAGE 2 T,SPEED,W,P,THETA,ZE

PAGE 3 T,SPEED,PITCHES,ITCHP,PPMS,PPMS,PPRPFY(1-4)

PAGE 4 T,SPEED,FRUAS,FRUAP,PHUAS,PHUAP,PHUAF,PHUAFY(1-4)

PAGE 5 T,SPEED,FRUANG,FRUANG,FRUANG,FRUANG,FRUAFY(1-4)

COMMON /PAGE(4,40,14),PAGE(13)

REAL LENGTH,MASS,IXX,IXY,IXZ,IVX,IVY,IVZ,IYZ,KRODT,KRODT,KVRODT,

1 KRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT

COMMON /ACRAFT / SCFACT, LENGTH, MASS, IXX,IXY,IXZ, IVX,IVY,IVZ, IYZ

COMMON /CONST / RADIAN, PHO1, PHO2, PHO3, PHO4, PHO5, PHO6

COMMON /STATE / U,V,W,P,Q,R,PHI,THETA,PST,YE,YE,ZE,S,SPEED,

1 DRIFAN,COSPHI,COSTHE,COSFI,SINPHI,SINHE,SINFI,

1 INTX(3,3),TIME

COMMON /XIMVAR / XFI(4),YFI(4),ZFI(4),XFI(4),YFI(4),

1 XFI(4),YFI(4),ZFI(4),XFI(4),YFI(4),ZFI(4),XFI(4),

1 XFI(4),YFI(4)

1 XFI(4),YFI(4)

COMMON /YDOP / LG(4),L7,MY(4,3213),FF(4,16),Y(4,20),IPRINT(4),

1 UYAX,MYDOP(4),ICNT

COMMON /RUDVAR / RUDANC(2),UNVEL(10),RUDLEA(10),AXRUD(100),AYRUD(100),

1 AMRUD(100),AMRUD(100),ARATIC,RUDANC(2),NUMRUD,NUMRUD,

1 RUDANC,FRUDAP,FRUDAP,FRUDAP,FRUDAP,FRUDAP(4)

1,VRUD(2),VRUD(2),ZVRUD(2)

1,VRUD(2)

1,VRUD(2),VRUD(2)

COMMON /RUDVAR / RUD1, RUDAR(3), RUDMS, RUDMS, RUDMS, RUDMS,

1 RUDMS, RUDMS, RUDMS, RUDMS, RUDMS, RUDMS, RUDMS, RUDMS,

COMMON /AIRVAR / AIRFX(6)

COMMON /HULLVAR / HULLFX(4),HULLIK

COMMON /RCYVAR / XSUBZ,"SUBTH,ZSUBZ,ZSUBTH,FRUAFY(4)

COMMON /AIRVAR / AIRTRX(6,6,6),AIRDF(4),AIRTRX(6,6)

COMMON /RUDVAR / XRODT,YRODT,YRODT,YRODT,ZRODT,ZRODT,KVRODT,KVRODT,

1 KRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT,MBRODT

COMMON /COMVAR / XC,YC,ZC

COMMON /COMVAR / XC,YC,ZC

COMMON /RUDVAR / IR1,IR2,IR3,IR4,IR5,IR6,IR7,IR8,IR9,IR10,IR11,IR12,

1 IR13,IR14,IR15,IR16,IR17,IR18,IR19,IR20,IR21,IR22,IR23,IR24,IR25,

COMMON /RUDVAR / IR26,IR27,IR28,IR29,IR30,IR31,IR32,IR33,IR34,IR35,

1 IR36,IR37,IR38,IR39,IR40,IR41,IR42,IR43,IR44,IR45,IR46,IR47,IR48,

1 IR49,IR50,IR51,IR52,IR53,IR54,IR55,IR56,IR57,IR58,IR59,IR60,IR61,

1 IR62,IR63,IR64,IR65,IR66,IR67,IR68,IR69,IR70,IR71,IR72,IR73,IR74,

1 IR75,IR76,IR77,IR78,IR79,IR80,IR81,IR82,IR83,IR84,IR85,IR86,IR87,

1 IR88,IR89,IR90,IR91,IR92,IR93,IR94,IR95,IR96,IR97,IR98,IR99,IR100,

1 IR101,IR102,IR103,IR104,IR105,IR106,IR107,IR108,IR109,IR110,IR111,

1 IR112,IR113,IR114,IR115,IR116,IR117,IR118,IR119,IR120,IR121,IR122,

1 IR123,IR124,IR125,IR126,IR127,IR128,IR129,IR130,IR131,IR132,IR133,

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1 IR167,IR168,IR169,IR170,IR171,IR172,IR173,IR174,IR175,IR176,IR177,

1 IR178,IR179,IR180,IR181,IR182,IR183,IR184,IR185,IR186,IR187,IR188,

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1 IR200,IR201,IR202,IR203,IR204,IR205,IR206,IR207,IR208,IR209,IR210,

1 IR211,IR212,IR213,IR214,IR215,IR216,IR217,IR218,IR219,IR220,IR221,

1 IR222,IR223,IR224,IR225,IR226,IR227,IR228,IR229,IR230,IR231,IR232,

1 IR233,IR234,IR235,IR236,IR237,IR238,IR239,IR240,IR241,IR242,IR243,

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1 IR1103,IR1104,IR1105,IR1106,IR1107,IR1108,IR1109,IR1110,IR1111,IR1112,

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1 IR1123,IR1124,IR1125,IR1126,IR1127,IR1128,IR1129,IR1130,IR1131,IR1132,

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1 IR1193,IR1194,IR1195,IR1196,IR1197,IR1198,IR1199,IR1200,IR1201,IR1202,

1 IR1203,IR1204,IR1205,IR1206,IR1207,IR1208,IR1209,IR1210,IR1211,IR1212,

1 IR1213,IR1214,IR1215,IR1216,IR1217,IR1218,IR1219,IR1220,IR1221,IR1222,

1 IR1223,IR1224,IR1225,IR1226,IR1227,IR1228,IR1229,IR1230,IR1231,IR1232,

1 IR1233,IR1234,IR1235

COMMON /STATE/ T0, W0, V0, A0, P0, Q0, R0, P010, THETA0, PSI0

COMMON /INTERL/ DT, DTIM, TRAY, AE(15), EPS(15), STATE

DT - STEP SIZE FOR CALLS TO KUTTER, SEC
DTIM - KUTTER STEP SIZE TO BE USED BY KUTTER, SEC
TRAY - SIMULATION STOP TIME
AE(1-15) - ABSOLUTE INTEGRATION ERROR CRITERIA FOR STATE
VECTORS, Y(1-15)
EPS(1-15) - RELATIVE ERROR CRITERIA FOR Y(1-15)

COMMON /CONST/ AC01(10), AC02(10), JAC0(10), JAC1(10), CV1(10),
CV2(10), CV3(10), CV4(10), CRIN1(10), CRIN2(10),
COIN1(10), COIN2(10), COIN3(10), RELAP(2), CHECK(2),
RATE(12), KACT(12)

COMMON /OUT/ IOUT(5), TPRINT(5), JRA, ASUM, PRINT

COMMON /HEADER/ TITLE(1)

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POINT PAGE 1

IF(JRA.EQ.1) WRITE(IPC,600) ASUM, (TITLE(I), I=1,10)

JRA = JRA + 1

LOAD LINE FOR PAGE 1.

PAGE1(1) = TIME

PAGE1(2) = (SPEED/FTON)/1.680

PAGE1(3) = W

PAGE1(4) = V

PAGE1(5) = R*RADIAN

PAGE1(6) = PHI*RADIAN

PAGE1(7) = THETA*RADIAN

PAGE1(8) = CRIFAN*RADIAN

PAGE1(9) = PSI*RADIAN

PAGE1(10) = YF

PAGE1(11) = YF

PAGE1(12) = PE

PAGE1(13) = C

PRINT JRA-TH LINE ON PAGE1

WRITE(IPC,601) (PAGE1(I), I=1,13)

LOAD PAGES 2-5 INTO PAGE(1-4, I, J)

DO 1 J=1,4

PAGE(I, JPA, 1) = TIME

PAGE(I, JPA, 2) = (SPEED/FTON)/1.680

CONTINUE

PAGE(1, JPA, 3) = PITCHS

PAGE(1, JPA, 4) = PITCHP

PAGE(1, JPA, 5) = PRPAC

PAGE(1, JPA, 6) = PRPYR

PAGE(2, JPA, 3) = PITCHS

PAGE(2, JPA, 4) = PITCHP

PAGE(2, JPA, 5) = PRPAC

PAGE(2, JPA, 6) = PRPYR

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C 101 I=1,4
101 PAGE(1,URA,I+1) = FINANG(I)*RADIANG
PAGE(1,URA,11) = RUDANG(1)*RADIANG
PAGE(1,URA,12)=RUDANG(2)*RADIANG
PAGE(1,URA,13)=RUDANG
PAGE(1,URA,14)=RUDANG
PAGE(3,URA,3)=RUDANG
PAGE(3,URA,4)=RUDANG
PAGE(3,URA,5) = RADIANG*RUDANG(1)
PAGE(3,URA,6) = RADIANG*RUDANG(2)

C
PAGE(4,URA,3) = RADIANG*FINANG(1)
PAGE(4,URA,4) = RADIANG*FINANG(2)
PAGE(4,URA,5) = RADIANG*FINANG(3)
PAGE(4,URA,6) = RADIANG*FINANG(4)
PAGE(4,URA,3) = FINANG(1)*RADIANG
PAGE(4,URA,4) = FINANG(2)*RADIANG
PAGE(4,URA,5) = FINANG(3)*RADIANG
PAGE(4,URA,6) = FINANG(4)*RADIANG

C
C 102 K=1,6
PAGE(2,URA,K+1) = PRODEF(K)
PAGE(7,URA,6+1) = PRODEF(1)
PAGE(4,URA,6+1) = PRODEF(1)
C
C CONTINUE
C RETURN IF FULL PAGE NOT REACHED
IF(URA.LT.40.AND.IORT.NE.2) RETURN
C
C PRINT PAGES 2-4.
C
C PAGE 2
WRITE(IP6,602) NRUN,(TITLE(I),I=1,10)
WRITE(IP6,603) ((PAGE(1,J,K),K=1,14),J=1,URA)
C
C PAGE 3
IF(IORT(2).EQ.0) GO TO 608
WRITE(IP6,604) NRUN,(TITLE(I),I=1,10)
WRITE(IP6,605) ((PAGE(2,J,K),K=1,12),J=1,URA)
C
C PAGE 4
WRITE(IP6,606) NRUN,(TITLE(I),I=1,10)
WRITE(IP6,607) ((PAGE(3,J,K),K=1,12),J=1,URA)
C
C PAGE 5
WRITE(IP6,608) NRUN,(TITLE(I),I=1,10)
WRITE(IP6,609) ((PAGE(4,J,K),K=1,12),J=1,URA)
C
C
C CONTINUE
URA = 0
C
C PAGE 1 FORMAT
400 FORMAT(1=1,///,2A5,SWATH SIMULATION,NUMBER,1A,10X,10A3,/,1H,
1H,4H TIME,T12,4H SPEED,T21,1H,1H,T22,1H,1H,T23,4H TURN,
1H,4H COLL,1H,4H FITCH,T20,4H PRIET,T21,7H READING,T24,1H,1H,

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T753,1HY,T100,1H3,T113,5H DISTANCE,/.
T14,CHIN,T14,2HIN,T21,CHIN,T23,CHIN,T37,4H RATE,T44,5H ANGLE,
T754,5H ANGLE,T62,5H ANGLE,T71,5H ANGLE,T84,CHIN,T87,2HIN,
T100,2HIN,T100,4H RATE,/.
T74,5H SEC,T10,5H KNOTS,T17,5H M/SEC,T26,5H M/SEC,T35,7H M/SEC,
T46,4HIN,SEC,T55,4HIN,SEC,T62,4HIN,SEC,T71,6HIN,SEC,T80,
4H METER,T81,6H METER,T100,4H METER,T100,6H METER,/.
C
C
C
C

611 FORMAT(1H,56.2,F10.0,277.0,F11.3,F11.2,55.2,53.1,F11.1,359.1)

PAGE 2 FORMATS

612 FORMAT(1H1,///,24H SWATH SIMULATION NUMBER,14,10Y,1048,/,/
113H TIME SPED PROPELLER PROPELLER SIN ANGLE
22 IN DEGREES RUDDER ANGLE IN DEG RUDDER POSITION IN METE
335.7,113H IN IN PITCH IN DEG RRM ROR
4 304 AFT AFT AFT AFT ROR ROR,/
5100H SEC KNOTS SIDE PORT STAR PORT STAR PORT
17 STAR PORT STAR PORT STAR PORT STAR PORT,/
613 FORMAT(1H,57.2,57.0,53.0,57.2,359.1,57.0,53.1,56.1,512.1,
1713.0,51.2)

PAGE 3 FORMATS

614 FORMAT(1H1,///,24H SWATH SIMULATION NUMBER,14,10Y,1048,/,/
1 T7,4H TIME,T16,5H SPEED,T26,16H PROPELLER PITCH,T47,4H ROR,T57,
2 4H ROR,T65,6H ROR Y,T77,4H ROR Y,T85,6H ROR Z,T101,6H ROR K,
3 T113,4H ROR Y,T125,6H ROR N,/.1H,
4 T9,2HIN,T19,2HIN,T29,11HIN DEGREES,T49,3H ROR,T59,3H ROR,T64,
5 6H ROR IN,T74,6H ROR IN,T89,6H ROR IN,T101,6H ROR IN,T113,
6 6H ROR IN,T125,6H ROR IN,/.1H,
7 T8,3H SEC,T16,5H KNOTS,T27,4H STAR,T37,4H PORT,T47,4H STAR,T57,
8 4H PORT,T65,6H ROR IN,T77,6H ROR IN,T89,6H ROR IN,T101,6H ROR IN,T114,
9 4H ROR IN,T126,4H ROR IN,/.1H

615 FORMAT(1H,59.2,3510.2,2510.1,3510.4)

PAGE 4 FORMATS

616 FORMAT(1H1,///,24H SWATH SIMULATION NUMBER,14,10Y,1048,/,/
1 T7,4H TIME,T16,5H SPEED,T24,10H ROR RUDDER POSITION,T44,
2 174H ROR ANGLE,T64,6H ROR Y,T74,6H ROR Y,T84,
3 6H ROR Z,T100,6H ROR K,T110,6H ROR Y,T124,6H ROR Y,/.1H,
4 T9,2HIN,T19,2HIN,T29,10HIN DEGREES,T49,11HIN DEGREES,T64,
5 6H ROR IN,T74,6H ROR IN,T89,6H ROR IN,T101,6H ROR IN,T113,
6 6H ROR IN,T125,6H ROR IN,/.1H,
7 T8,3H SEC,T16,5H KNOTS,T27,4H STAR,T37,4H PORT,T47,4H STAR,T57,
8 4H PORT,T65,6H ROR IN,T77,6H ROR IN,T89,6H ROR IN,T101,6H ROR IN,T114,
9 4H ROR IN,T126,4H ROR IN,/.1H

617 FORMAT(1H,53.2,5510.2,6510.4)

PAGE 5 FORMATS

618 FORMAT(1H1,///,24H SWATH SIMULATION NUMBER,14,10Y,1048,/,/
1 T7,4H TIME,T16,5H SPEED,T27,14H ROR SIN ANGLE,T47,
2 144H ROR ANGLE,T66,6H ROR Y,T78,6H ROR Y,T90,6H ROR Z,T100,
3 6H ROR K,T114,6H ROR Y,T126,6H ROR N,/.1H,
4 T9,2HIN,T19,2HIN,T29,10HIN DEGREES,T49,10HIN DEGREES,T64,
5 6H ROR IN,T74,6H ROR IN,T89,6H ROR IN,T101,6H ROR IN,T113,

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CMMN 1  /STATEC/  TU,MO,MC,MD,PE,CE,SC,PHIC,THETAC,PSIC
CMMN 2  /ANCPYR/  EDIA, PRCARM(4), PRPOS, PRPNE, PITCHC, PITCHD,
                PRORF(4)

```

NAME(S): PORTO(13), PUJIC(11), PUJIC(5), PUJO(4), VALHI(45), VALLO(52)
1, VALLO(5), 143)

DATA: PUNIT/ -1.0, -.8, -.6, -.4, -.2, 0.0, .2, .4, .6, .8, 1.0/

[illegible]

DATA DELTA-1.-.8,-.6,-.4/

DATA VAL=1 3*-20.,-17.,-16.,2*-15.,3*-10.,-7.,-2.,5.,-1.,

$$-2.7, -2.5, -4.3, -2.7, -3.7, -2.9, -2.4, -2.5, -2.1, -1.16, -.5, .28, .41.$$

$-1.2, -1.4, -2.4, -2.5, -2.9, -1.55, -1.25, -1.05, -.6, -.26, .13, .55, .72,$

0-1, .5, -2.97, -2.97, -1.45, -1.5, -1.1, -.77, -.52, -.12, .11, .39, .72, .24

-1.5, -1.1, -1.7, -1.42, -1.2, -.94, -.49, -.26, -.14, -.27, .53, .23, .88/

DATA VALLOZ-.82,-.85,-.64,-.39,-.1..16,.74,.86,.74,1.13,1.5,1.52.

1.6, -.95, -.2, -.40, -.2, .09, .7, .55, .06, 1.10, 1.52, 1.9, 1.9, 0.

$\gamma = .74, .64, .51, .45, .46, .41, .39, .31, .75, .2, .23, .25, .2, .$

0-.35.0...64...95.1.2.1.6.0.5.3.0.3.5.3.5.4.0.4.0.3.7.1

ATA V-L 137-.82,-.86,-.64,-.79,-.1,.16,.34,.65,.94,1.17,1.5,1.72.

1.6, -.6, -.24, -.72, -.52, -.24, .34, .21, .52, .72, 1.64, 1.1, 1.12.

4 - .2 , - .6 , - .75 , - .4 , - .35 , - .27 , .1 , .24 , .44 , .56 , .78 , .2 , .94 ,

0-.81,-.74,-.72,-.62,-.43,-.15,.24,.26,.56,.67,.2,.06,1.07,

-.62,-.76,-.67,-.56,-.44,-.3,.37,.32,.62,.75,.35,1.0,1.0,

5 - .84, -.4, -.44, -.55, -.4, -.22, 0, .3, .6, .77, .9, .75, .98,

$= -.89, -.3, -.77, -.66, -.4, -.24, -.64, .23, .5, .71, .87, .98, .26.$

3-.27,-1.01,-.23,-.76,-.6,-.35,-.1,.14,.30,.40,.01,.96,.94,

-1.17, -1.17, -1.12, -.95, -.69, -.52, -.2, .37, .27, .51, .74, .74, .82.

-1.5, -1.5, -1.20, -1.10, -1., -.74, -.33, -.1., .10, .4., .64, .90, .9.

$-1.65, -1.6, -1.7, -1.49, -1.2, -.94, -.49, -.24, .24, .27, .53, .23, .12 /$

$$PQ = (.82 * \text{SQRT}((U+U+V+V) * 60.)) / (PBP * P + PQIA)$$
$$CJ = (.32 * \text{SQRT}(U * U + V * V) * 60.) / (\text{DEBMS} * \text{DZTA})$$
$$\frac{1}{2} \frac{1}{2} = \frac{1}{4}$$
$$J = 1$$

15 (PJ.LT.-1.)60 TO 1

REF ID: A66102

CALL TAPVIAVERTIC.FOXID,VALVID,13.11.81TCHD.FJ.6,1,11.00,PKT.189

$$2J = 1.75J$$

CALL TACUCCERIO, PULC. VALLO, 17.4, PITCHER, RJ. 4.1, II, JJ, RYT, IES)

— 1 —

[illegible]

CALL TACVAFBRT12, RUMI, WILHI, 13, 5, DITCHES, RJ, 6, 1, II, JN, RKT, 153)

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      I=1
      JU=1
      IF(SU.LT.-1.) GO TO 4
      IF(SU.GT.1.) GO TO 5
      CALL TAPV(PERTIC,PJHI,VALVD,13,11,PITCHS,SJ,6,1,II,JU,SKT,IF2)
      GO TO 4
4     SU=1./SU
      CALL TAPV(PERTIC,PJLD,VALLD,13,4,PITCHS,SJ,6,1,II,JU,SKT,IF2)
      GO TO 4
5     SU=1./SU
      CALL TAPV(PERTIC,PJHI,VALHI,13,5,PITCHS,SJ,6,1,II,JU,SKT,IF2)
6     CONTINUE
      X=SKT+R-5MG+PRPVG+R-OW*(PDIA**4.)/7400.
      Y=PKT+R-5MP+PRPVB+R-OU*(PDIA**4.)/7400.
      PROPM(1)=A+B
      PROPM(2)=C.
      PROPM(3)=0.
      PROPM(4)=0.
      PROPM(5)=PROPM(1)+PROPM(3)
      PROPM(6)=(5-11)*PROPM(2)
      RETURN
      END

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XVR3=AXR2/2.
XVR1=AXR1/2.
XVR2=AXR3/2.
XVR1=AXR1/2.
XVR2=AXR2/2.
RUDFM(1)=(XVR1+XVR2)*ARATIO
RUDFM(2)=(XVR1+XVR2)*ARATIO
RUDFM(3)=0.0
RUDFM(4)=(XVR1+XVR2)*ARATIO
RUDFM(5)=(XVR1+XVR2)*(RUDARM-(ZF-SINTHE*XVR1)/2.0)*ARATIO
RUDFM(6)=(XVR1+XVR2)*ARATIO
DO 3 K=1,4
RUDFM(K)=RUDFM(K)*SQRT(1.0+((ZF-SINTHE*XVR1)/2.0))

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FIXED FORWARD BUDDER

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VAR1=0.015708 *RADIANS
VAR2=2*LENGTH*U
VAR3=U/.5144
IF (RUDAS,ST,0.) 60 TO 70
VAR1=-VAR1
VAR2=-VAR2
70 CONTINUE
CALL T4=TV(VV1,VV2,VV3,XVRD,2,2,5,VAR1,VAR2,VAR3,10,1,1,1,1,PYP,
*STR)
FFF=(RUDAS-RUDAP)/RRSRAM
ROWY=5*LENGTH*LENGTH*U*U*PYP+FFF*.1
ROWX=-FOS/ROWY)/7.
ROWK=-((20.70+RRUDAS+RUDAP)+.5*ROWY
*ROWY=14.42+ROWY-11.43*ROWY*STG(1.,FFF)
RUDFM(1)=RUDFM(1)+ROWY
RUDFM(2)=RUDFM(2)+ROWY
RUDFM(4)=RUDFM(4)+ROWK
RUDFM(6)=RUDFM(6)+ROWK
RUDFM(5)=RUDFM(5)+ROWY+RRDARM
RETURN
END

```

SUBROUTINE TO CV(V1,V2,IT,M1,M2,APG1,APG2,IT,KEY,II,JJ,VAL,ITER)
 DIMENSION V1(1),V2(1),O(1)
 REAL M1,M2,M1M2

TABLE LOOKUP FOR 2 VARIABLES

100 - OBSERVED VALUES STORED COLUMN WISE ACCORDING TO V1,V2
 11 - NO. OF V1-C
 12 - NO. OF V2-C
 13 - 0 IN RANGE OTHERWISE OUT OF RANGE
 14 - UNIT FOR INTERPOLATED PRINTOUT
 15 - 0 DO NOT PERFORM SEARCH, USE PREVIOUS POINTS
 V1 - CLOSEST POINT TO APG1 S.T. V1(II).LE.APG1.
 V2 - CLOSEST POINT TO APG2 S.T. V2(JJ).LE.APG2
 VAL - RESULTING INTERPOLATED VALUE.
 M1,M2 - FIRST AND SECOND VARIABLE ARRAYS. THEY SHOULD BE
 STORED IN MONOTONICALLY INCREASING ORDER STARTING
 WITH MOST NEGATIVE VALUE. ALL V1 OR V2 VALUES
 MUST BE UNIQUE

IF KEY.EQ.0 GO TO 100

CALL NCH21(V1,APG1,II,1,ITER,M1)

CALL NCH22(V2,APG2,JJ,1,ITER,M2)

ITER=ITER+10*ITER

M1M2=M1*M2

100 = 1.-M1-M2+M1M2

M10 = M1-M1M2

M01 = M2-M1M2

M11 = M1M2

100 = 100+1

101 = 100+M1

111 = 100+1+M1

100 VAL = OF(100)*APG + OF(110)*M10

+ OF(101)*M01 + OF(111)*M11

TESTING

RETURN

END

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      NAME=NAME TAB3/V1,V2,V3,02,M1,M2,M3,ARG1,ARG2,ARG3,IO,KEY,
      II,III,KK,VAL,IER)
      TABLE LINK FOR 7 VARIABLES, V1,V2,V3.
      02 - OBSERVATIONS STORED COLUMN WISE ACCORDING TO V1,V2,V3.
      M1 - 02 OF V1=0
      M2 - 02 OF V2=0
      M3 - 02 OF V3=0
      IER - 0 - IN RANGE
      1 - OUT OF RANGE
      IO - INTERMEDIATE PRINTOUT UNIT.
      KEY - 0 - DO NOT PERFORM SEARCH, USE PREVIOUS POINTS.
      II - CLOSEST POINT TO ARG1 S.T. V1(II).LE.ARG1.
      JJ - CLOSEST POINT TO ARG2 S.T. V2(JJ).LE.ARG2.
      KK - CLOSEST POINT TO ARG3 S.T. V3(KK).LE.ARG3.
      VAL - RESULTING INTERPOLATED VALUE.
      V1,V2,V3 FIRST,SECOND,AND THIRD VARIABLE ARRAYS.
      V1-V3 SHOULD EACH BE STORED IN MONOTONICALLY
      INCREASING ORDER STARTING WITH MOST NEGATIVE VALUE.
      ALL V1,V2,OR V3 VALUES MUST BE UNIQUE

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      DIMENSION V1(1),V2(1),V3(1),02(1)
      REAL V1,V2,V3,M1M2,M1M3,M2M3,M1M2M3
      IF(KEY.EQ.0) GO TO 100

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      C-----
      C PERFORM SEARCH
      C-----
      CALL NCHTRI(V1,ARG1,II,M1,IER1,M1)
      CALL NCHTRI(V2,ARG2,JJ,M2,IER2,M2)
      CALL NCHTRI(V3,ARG3,KK,M3,IER3,M3)
      IER= IER1+10*IER2+100*IER3
      M1M2 = M1*M2
      M1M3 = M1*M3
      M2M3 = M2*M3
      M1M2M3 = M1*M2*M3
      I000 = 1.-M1-M2-M3+M1M2+M1M3+M2M3-M1M2M3
      I000 = M1-M1M2-M1M3+M1M2M3
      A001 = M3-M1M3-M2M3+M1M2M3
      A010 = M2-M1M2-M2M3+M1M2M3
      A110 = M1M2-M1M2M3
      A101 = M1M3-M1M2M3
      A011 = M2M3-M1M2M3
      A111 = M1M2M3
      I000 = II*M1*(JJ-1)+M1*M2*(KK-1)
      I100 = I000 + 1
      I010 = I000 + M1
      I001 = I000 + M1*M2
      I110 = I000 + 1 + M1
      I101 = I000 + 1 + M1*M2
      I011 = I000 + M1*(1+M2)
      I111 = I001 + M1
      100 VAL = 02(I000)*A001 + 02(I100)*A100
      1 + 02(I010)*A010 + 02(I001)*A001
      2 + 02(I110)*A110 + 02(I101)*A101
      3 + 02(I011)*A011 + 02(I111)*A111
      RETURN
      END

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CURR TIME TEND

C THIS PROGRAM TURNS ON ALL PRINT OUT SWITCHES AND SETS TMAX, THE
C SIMULATION END TIME TO ZERO SO THAT RUN TERMINATES
C LOGICAL END

C COMMON /COMMON/ IFILL(15),PNT(15)

C COMMON /INTERL/ IT,RTMIN,TMAX,A(15),EPS(15),NSTATE

C TMAX = 0.0

C DO 1 I=1,15

C PNT(I) = .TRUE.

C CONTINUE

C RETURN

C END

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APPENDIX C

SAMPLE OUTPUT FOR A TURN MANEUVER PREDICTION

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$$A_{\text{eff}} = \frac{1}{\pi} \int_0^{2\pi} A(\theta) d\theta$$

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[illegible]

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THE UNIVERSITY OF CHICAGO

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1. The first step is to identify the problem or question that needs to be addressed. This involves understanding the context and the specific requirements of the task.

10

DRAFT

PERCENTAGE OF

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CONTROL POINTS

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DRAFT

ROLL ANGLE DEG	TRIFT ANGLE DEG	YAW RATE DEG/SEC	SPD KTS	Y FT	K FT/SEC	N FT/SEC
-6.00	-4.00	-1.0	5.00	-26.701F+06	366.948F+07	335.041F+07
0.00	-4.00	-1.0	5.00	-26.721F+06	366.948F+07	335.041F+07
6.00	-4.00	-1.0	5.00	-26.741F+06	366.948F+07	335.041F+07
-6.00	0.00	-1.0	5.00	-176.008F+06	245.987F+07	51.784F+07
0.00	0.00	-1.0	5.00	-176.008F+06	245.987F+07	51.784F+07
6.00	0.00	-1.0	5.00	-176.008F+06	245.987F+07	51.784F+07
-6.00	4.00	-1.0	5.00	-672.561F+06	187.727F+07	366.948F+07
0.00	4.00	-1.0	5.00	-672.561F+06	187.727F+07	366.948F+07
6.00	4.00	-1.0	5.00	-672.561F+06	187.727F+07	366.948F+07
-6.00	-4.00	0.00	5.00	-10.733F+06	582.602F+06	284.084F+07
0.00	-4.00	0.00	5.00	-10.733F+06	582.602F+06	284.084F+07
6.00	-4.00	0.00	5.00	-10.733F+06	582.602F+06	284.084F+07
-6.00	0.00	0.00	5.00	0.00	0.00	0.00
0.00	0.00	0.00	5.00	0.00	0.00	0.00
6.00	0.00	0.00	5.00	0.00	0.00	0.00
-6.00	4.00	0.00	5.00	10.733F+06	-582.602F+06	-284.084F+07
0.00	4.00	0.00	5.00	10.733F+06	-582.602F+06	-284.084F+07
6.00	4.00	0.00	5.00	10.733F+06	-582.602F+06	-284.084F+07
-6.00	-4.00	0.00	5.00	672.561F+06	-187.727F+07	-366.948F+07
0.00	-4.00	0.00	5.00	672.561F+06	-187.727F+07	-366.948F+07
6.00	-4.00	0.00	5.00	672.561F+06	-187.727F+07	-366.948F+07
-6.00	0.00	0.00	5.00	116.981F+06	-245.987F+07	-51.784F+07
0.00	0.00	0.00	5.00	116.981F+06	-245.987F+07	-51.784F+07
6.00	0.00	0.00	5.00	116.981F+06	-245.987F+07	-51.784F+07
-6.00	4.00	0.00	5.00	286.721F+06	-304.248F+07	-233.041F+07
0.00	4.00	0.00	5.00	286.721F+06	-304.248F+07	-233.041F+07
6.00	4.00	0.00	5.00	286.721F+06	-304.248F+07	-233.041F+07
-6.00	-4.00	0.00	5.00	-10.733F+06	776.802F+07	51.784F+07
0.00	-4.00	0.00	5.00	-10.733F+06	776.802F+07	51.784F+07
6.00	-4.00	0.00	5.00	-10.733F+06	776.802F+07	51.784F+07
-6.00	0.00	0.00	5.00	672.561F+06	-569.551F+07	155.360F+08
0.00	0.00	0.00	5.00	672.561F+06	-569.551F+07	155.360F+08
6.00	0.00	0.00	5.00	672.561F+06	-569.551F+07	155.360F+08
-6.00	4.00	0.00	5.00	-247.784F+06	362.508F+07	258.934F+08
0.00	4.00	0.00	5.00	-247.784F+06	362.508F+07	258.934F+08
6.00	4.00	0.00	5.00	-247.784F+06	362.508F+07	258.934F+08
-6.00	-4.00	0.00	5.00	-424.772F+06	-207.147F+07	-103.574F+08
0.00	-4.00	0.00	5.00	-424.772F+06	-207.147F+07	-103.574F+08
6.00	-4.00	0.00	5.00	-424.772F+06	-207.147F+07	-103.574F+08
-6.00	0.00	0.00	5.00	0.00	0.00	0.00
0.00	0.00	0.00	5.00	0.00	0.00	0.00
6.00	0.00	0.00	5.00	0.00	0.00	0.00
-6.00	4.00	0.00	5.00	424.772F+06	-207.147F+07	103.574F+08
0.00	4.00	0.00	5.00	424.772F+06	-207.147F+07	103.574F+08
6.00	4.00	0.00	5.00	424.772F+06	-207.147F+07	103.574F+08
-6.00	-4.00	0.00	5.00	247.784F+06	-362.508F+07	-258.934F+08

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OPERATIONS RESEARCH INC SILVER SPRING MD

F/G 13/10

SWATH DYNAMIC SIMULATION MODEL.(U)

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DRAFT

ALL RUNS COMPLETED INTERMEDIATE PRINT FOLLOWING

TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AFRO	BUOYANCY	RATE	PROPULSION
0.0	10.30	0.00	0.00	0.00	0.00	-0.00	X 0.	-.9313F-04	-.8703F+06	0.	0.	0.	-.7708F+06
							Y 0.	.3725F-0F	0.	0.	0.	0.	0.
							Z 0.	0.	-.5068E+06	0.	0.	0.	0.
							K 0.	-.2960F-07	0.	0.	0.	0.	0.
							M 0.	-.3725F-0F	-.7037F+07	0.	0.	0.	-.6213F+07
							N 0.	-.2384E-06	0.	0.	0.	0.	0.
TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AFRO	BUOYANCY	RATE	PROPULSION
3.0	10.20	-0.00	.12	.00	0.00	.00	X -.5918E+04	-.4554E-10	-.6684E+06	0.	0.	0.	-.7892E+06
							Y 0.	-.9716F-09	.1672F-07	0.	0.	0.	0.
							Z -.4537E+05	0.	.4938F+06	0.	0.	0.	0.
							K -.1118F-07	.4858F-08	-.0113F-07	0.	0.	0.	0.
							M -.7451E+06	-.1745F-04	-.6951F+07	0.	0.	0.	-.6361E+07
							N .1307E-08	.4664E-07	.6076F-07	0.	0.	0.	0.
TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AFRO	BUOYANCY	RATE	PROPULSION
6.0	10.13	.00	-.10	.00	0.00	-0.00	X -.4853F+04	-.1815E-09	-.8472F+06	0.	0.	0.	-.8019E+06
							Y 0.	.1694F-0F	-.6519E-08	0.	0.	0.	0.
							Z .3557E+05	0.	.4850F+06	0.	0.	0.	0.
							K .1723F-07	.2903F-0F	.3725F-07	0.	0.	0.	0.
							M .5230E+06	-.6883E-05	-.6786F+07	0.	0.	0.	-.6463F+07
							N .2154E-08	-.3484E-07	-.4768E-06	0.	0.	0.	0.
TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AFRO	BUOYANCY	RATE	PROPULSION
9.0	10.10	-0.00	.01	.00	0.00	.00	X -.4013F+03	-.2313F-04	-.8275F+06	0.	0.	0.	-.8081E+06
							Y 0.	-.1186F-0F	-.7451E-08	0.	0.	0.	0.
							Z -.4537E+05	0.	.4806F+06	0.	0.	0.	0.
							K .6365E-08	-.7541E-0F	.1192F-06	0.	0.	0.	0.
							M .7466E+05	-.9317E-04	-.6495F+07	0.	0.	0.	-.6518F+07
							N .8477E-09	-.5695F-07	.9537F-04	0.	0.	0.	0.
TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AFRO	BUOYANCY	RATE	PROPULSION
12.0	10.60	-0.00	.04	.00	0.00	.00	X -.2086E+04	-.6032E-1F	-.4301F+06	0.	0.	0.	-.8122E+06
							Y 0.	.1706F-0F	-.1490F-07	0.	0.	0.	0.
							Z -.1475E+05	0.	.4771F+06	0.	0.	0.	0.

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TIME	U	V	W	PHI	THETA	ETA	FIN	RUDDER	HULL	AERO	HUAVANCY	RATE	PROPULSION
15.0	10.00	-0.00	-0.00	-0.00	-0.00	-0.00	X	-0.1020E+04	-0.2110E+04	-0.7930E+06	0.00	0.00	0.00
							Y	0.00	-0.1050E+07	-0.7100E+06	0.00	0.00	0.00
							Z	-0.3070E+04	0.00	-0.4620E+06	0.00	0.00	0.00
							K	-0.5050E+05	-0.5750E+07	-0.7020E+07	0.00	0.00	0.00
							M	-0.7050E+05	-0.8190E+06	-0.6360E+07	0.00	0.00	0.00
							N	-0.2740E+04	-0.3070E+08	-0.1240E+08	0.00	0.00	0.00
TIME	U	V	W	PHI	THETA	ETA	X	-0.3060E+04	-0.5370E+06	-0.7220E+06	0.00	0.00	0.00
24.0	9.00	-0.00	-0.00	-0.00	-0.00	-0.00	Y	0.00	-0.1840E+07	-0.1840E+07	0.00	0.00	0.00
							Z	-0.2780E+04	0.00	-0.2840E+06	0.00	0.00	0.00
							K	-0.2780E+06	-0.9010E+07	-0.1890E+08	0.00	0.00	0.00
							M	-0.1090E+06	-0.2080E+07	-0.5790E+07	0.00	0.00	0.00
							N	-0.7910E+04	-0.5540E+08	-0.3740E+08	0.00	0.00	0.00
TIME	U	V	W	PHI	THETA	ETA	X	-0.7120E+04	-0.6710E+06	-0.6390E+06	0.00	0.00	0.00
27.0	9.00	-0.25	-0.03	-0.07	-0.00	-0.03	Y	0.00	-0.1660E+07	-0.2400E+07	0.00	0.00	0.00
							Z	-0.2150E+05	0.00	-0.3750E+06	0.00	0.00	0.00
							K	-0.4700E+06	-0.8430E+07	-0.2560E+08	0.00	0.00	0.00
							M	-0.5670E+06	-0.2630E+07	-0.5130E+07	0.00	0.00	0.00
							N	-0.1070E+05	-0.6800E+08	-0.5720E+08	0.00	0.00	0.00
TIME	U	V	W	PHI	THETA	ETA	X	-0.4750E+04	-0.6380E+06	-0.5990E+06	0.00	0.00	0.00
30.0	8.00	-0.56	-0.04	-0.11	-0.00	-0.04	Y	0.00	-0.1600E+07	-0.2450E+07	0.00	0.00	0.00
							Z	-0.1740E+05	0.00	-0.3410E+06	0.00	0.00	0.00
							K	-0.6050E+05	-0.7960E+07	-0.2530E+08	0.00	0.00	0.00
							M	-0.9360E+06	-0.2010E+07	-0.4910E+07	0.00	0.00	0.00
							N	-0.2020E+04	-0.5330E+08	-0.5310E+08	0.00	0.00	0.00
TIME	U	V	W	PHI	THETA	ETA	X	-0.6000E+04	-0.6170E+06	-0.5750E+06	0.00	0.00	0.00
33.0	8.00	-0.42	-0.03	-0.06	-0.00	-0.00	Y	0.00	-0.1560E+07	-0.2590E+07	0.00	0.00	0.00
							Z	-0.2100E+05	0.00	-0.3190E+06	0.00	0.00	0.00
							K	-0.9060E+06	-0.7660E+07	-0.2490E+08	0.00	0.00	0.00
							M	-0.5410E+06	-0.2870E+07	-0.6020E+07	0.00	0.00	0.00
							N	-0.1070E+05	-0.5010E+08	-0.4600E+08	0.00	0.00	0.00
TIME	U	V	W	PHI	THETA	ETA	X	-0.1720E+04	-0.6020E+06	-0.6730E+06	0.00	0.00	0.00
36.0	8.00	-0.35	-0.03	-0.03	-0.00	-0.04	Y	0.00	-0.1530E+07	-0.2520E+07	0.00	0.00	0.00
							Z	-0.6100E+04	0.00	-0.5020E+06	0.00	0.00	0.00
							K	-0.5000E+05	-0.7450E+07	-0.2410E+08	0.00	0.00	0.00
							M	-0.2000E+06	-0.2360E+07	-0.5590E+07	0.00	0.00	0.00
							N	-0.2000E+06	-0.2360E+07	-0.5590E+07	0.00	0.00	0.00

