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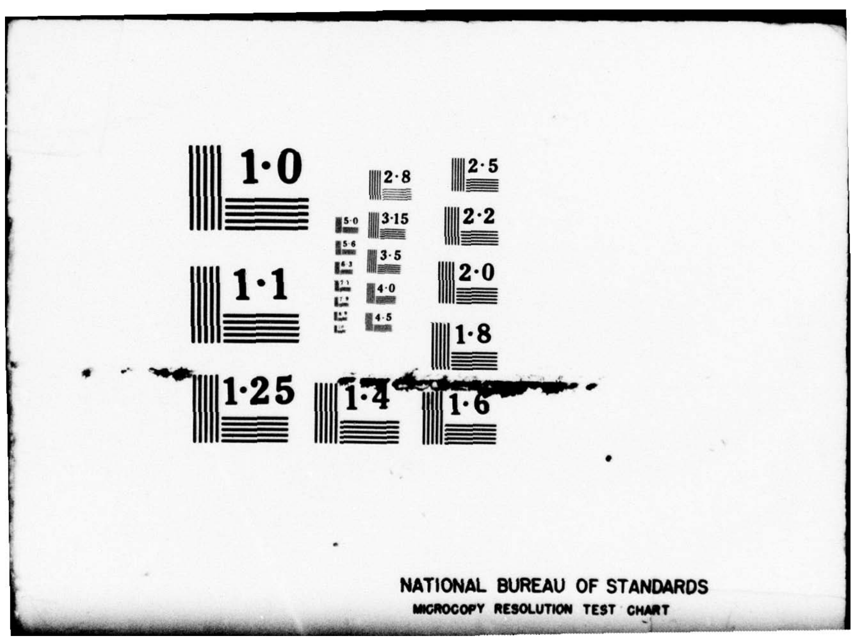
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FINAL REPORT

VULNERABILITY OF SURFACE EFFECT VEHICLES TO EXPLOSION GENERATED WATER WAVES

PREPARED FOR:
OFFICE OF NAVAL RESEARCH
ARLINGTON, VIRGINIA

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CONTRACT NO. N-00014-76-C-0261
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives of the study are: to develop a mathematical model appropriate for analysis of the behavior of surface effect vehicles (SEV) in unusually large waves; and to subsequently apply this model to investigate the vulnerability of these vehicles to explosion generated wave environments. The generation of surface waves due to an explosion is modeled mathematically as a function of the explosive yield, detonation depth and water depth. Further, the dynamic property of the propagated waves is treated to vary with the local

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water depth. The SEV dynamics are modeled mathematically by considering the vehicle as a rigid body having six degrees of freedom in space subject to an appropriate constraint derived from the cushion air dynamics as well as to the environmental excitations due to waves. Non-linear contributions including effects due to large motions, viscous flows, and control logics are considered and vehicle responses are solved numerically through time domain simulations. Analyses have been conducted using this analytical model to examine the potential threat of underwater explosions to a typical 2000-ton class SES, and the operational envelopes for such a vehicle in explosion generated wave environments are ~~have been~~ developed and discussed in this report.

SUMMARY

This report was prepared to fulfill the requirements under contract N00014-76-C-0261, supported by the Office of Naval Research, U. S. Navy. The objectives of the study were to develop a mathematical model appropriate for analysis of the behavior of surface effect vehicles (SEV) in unusually large waves and to subsequently apply this model to investigate the vulnerability of these vehicles to explosion generated wave environments.

The model was formulated in a very general structure applicable both to surface effect ships (SES) and to air cushion vehicles (ACV). Specific features of this model include heave alleviation ride control, thrust control, and various schemes for turning and maneuvering. The model provides time domain solutions of SEV in six degrees of freedom over any prescribed sea state, appropriate for both seakeeping and maneuvering analyses. Specifically worth mentioning is the fact that the model is efficient and can be quickly executed on high speed digital computers. Typically, a 100-second real-time simulation can be accomplished in 19 seconds of computer time on a CDC 7600 computer.

Another specific feature of the present model is its ability to simulate vehicle response to large excitations. This feature was specially incorporated for the purpose of analyzing vehicle behaviors in an explosion generated wave environment. Analyses of vessel response of a typical 2000-ton class SES to various initial conditions of explosion were conducted. Operational envelopes defining the required stand-off distance and vessel heading for safe maneuvers of this vehicle are also presented in this report. It must be noted that, in this study, the vehicle dimensions and characteristics were treated only in general terms in order to represent a typical SES. It should also be emphasized that only a number of vehicle speeds, control parameters, and weapon sizes have been

considered in this study. Therefore, further studies are warranted for more comprehensive parametric examinations as well as for investigations of a specific vehicle of interest. Nevertheless, the present mathematical model provides a valuable foundation for analyzing these problems.

In the following, several major findings from the present study are summarized:

- Depending on yield and craft heading, a critical standoff distance can be defined for a typical SES within which craft survival is questionable.

- Reaction time to a blast is critical. If sufficient time is available, outrunning the waves is possible. If sufficient reaction time does not exist, best option is to head into the waves and maintain a hovering mode.

- In relatively shallow water the critical parameter affect craft survival is wave height to water depth ratio rather than standoff distance as in the case of deep water.

- Heave compensation devices help provide substantial improvement to craft survival as evidenced by a limited number of cases investigated.

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1.0 INTRODUCTION

Currently, there is a concerted effort being made by the Navy and other Governmental agencies in exploring the feasibility of using alternate concepts to present day naval ship design for the Navy of the future. These investigations have led to the consideration of Air Cushion Vehicles (ACV) and Surface Effects Ships (SES) as viable candidates. These vehicles offer the potential for much greater versatility and higher operational speeds than hithertofore possible with conventional ship design. The ACV with its totally flexible skirt system presents an amphibious capability most attractive for coastal and nearshore operations, assault landing operations, and for arctic environmental use. The SES, on the otherhand, while not of an amphibious nature, provides an ocean going vehicle capable of very high speed performance in reasonable sea states and weather conditions.

Interest in these concepts has led the Navy into a development program in which two air cushion assault vehicles are presently being evaluated. Additionally, two 100-ton surface effect ships have been built and tested, under Navy contract, with sufficiently encouraging results that the Navy is currently conducting a detail design of a 3000-ton class SES. It is apparent from this activity that more than just casual interest is being given to these vehicles and indeed, dependent on the results of the above programs, they may prove to be the forerunners of a completely new class of fighting ship for the Navy of tomorrow.

The advent of the Surface Effect Vehicle as a serious contender for Naval applications has led to the need for an evaluation of the vulnerability of this type of craft under typical tactical situations. As presently envisaged the role these vehicles are to play in naval operations is one of antisubmarine warfare (ASW), escort duties and near or offshore patrol and rescue, which operations require a dash or high speed capability coupled with maneuverability, a feature characteristic of air cushion vehicles (ACV) and surface effect ships (SES) alike.

Due to this mounting interest it is appropriate, at this time, to obtain an assessment of the vulnerability of such craft to possible threats. In identifying possible threat areas one outstanding possibility is that due to explosion generated waves. Past experience in this field, [1] and [2],has shown the great damage potential such a phenomenon can have on submarines and conventional ships. The effects on ACV's and SES are expected to be of greater significance since the unique features of these vehicles make them particularly susceptible to sudden and anomalous changes in sea surface topography, such as are known to be produced by nuclear detonations.

Past studies have been primarily concerned with the behavior of ships and submarines within the transient surf zone produced by high yield explosions at the continental margins (Van Dorn Effect). However, because of their dynamic response we expect that the damage potential on SES and ACV's cannot only be restricted to these conditions but must be extended to include the effects of small and moderate yield devices and operations in deep water. It is evident that even under these latter conditions waves can be produced that are capable of limiting the performance of these craft.

The radical differences between the design of these craft and those of present naval ships makes it impossible to extrapolate the results obtained in past studies to the present case. It is only by conducting an investigation, wherein the features of these vehicles are faithfully modeled, that the vulnerability of these craft can be determined.

In light of the above discussion, it is deemed imperative that such a study be conducted with the objective of defining the operational limits of ACV's and SES under explosion generated waves, and to ascertain, where possible, the survival potential of these vehicles when subjected to tactical situations of this nature.

The criteria used in defining the structural design and stability characteristics of SES are derived principally from the desired operational envelopes. The envelope defines the speed-wave height domain over which the craft will operate. Typically, such an envelope is shown in Figure 1.

Two factors which greatly affect the basic structural design of the SES are the highest wave environment to be encountered when operating on-cushion and the maximum impact loading to be seen by the hull during operation. The former factor is of prime importance in selecting the height of the flexible skirt system and thus impacts hull design. The latter determines plating thickness and consequently weight. From Figure 1 it will be seen that point A on the chart determines maximum wave height on cushion. The worst combination of sea state and speed will be determined by line AB along which maximum impact loads are likely to occur. If such an operating envelope is determined without due consideration for potential threats as outlined above grave consequences can arise. It is easily conceivable that a wave environment outside the typical boundaries now being considered in the SES field can be generated by low to moderate yield devices. Such circumstances could cause structural and operational failures.

In addition to the above impacts the question of craft stability and survival are of equal importance. The response of an SES to a typical explosion generated wave profile could lead to conditions of craft plow-in, pitch poling and capsizing. Such

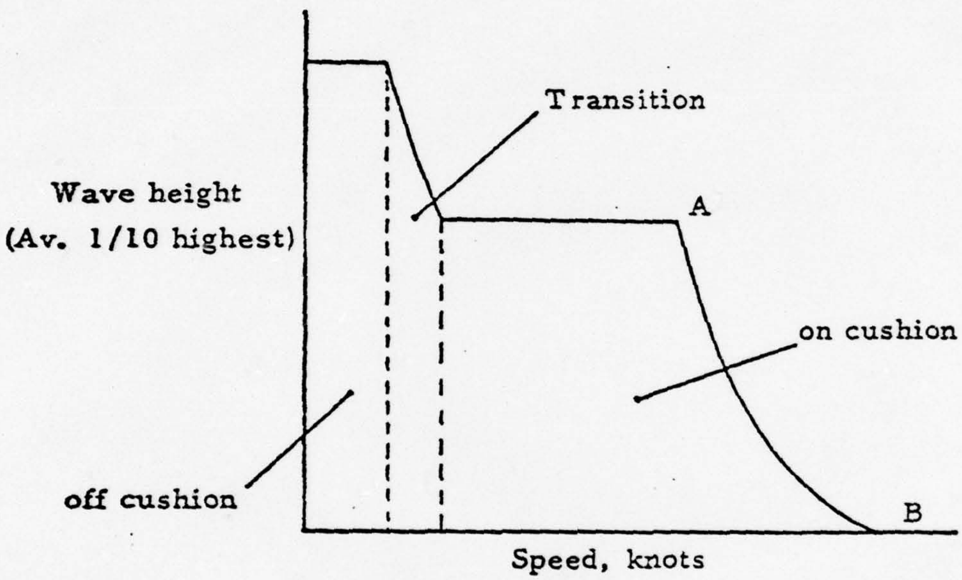

Figure 1: Typical SES operational envelope.

extreme motions are indeed possible under certain conditions of speed, water depth and yield. This aspect of vulnerability is therefore of equal importance in analyzing SES operational characteristics.

The problem at hand can be divided into two basic sub tasks:

(a) The analytical description and modeling of explosion generated water waves, and

(b) The analytical treatment of the craft dynamics and motions when subjected to a disturbing functions as defined in (a) above.

Whereas previously conducted work by Tetra Tech, References 1 and 2, is directly applicable to the first of these areas, the second provides a new and added dimension due to the radical difference between ACV and SES and conventional ships. Analytical modeling of SES motions and maneuvering however, have also been conducted by Tetra Tech [3] and has been used as a basis of departure for the present program.

The present report deals with the investigation of the response of a typical SES to an explosion wave environment. This study has been directed to the formulation and development of the analytical model describing the dynamics of a surface effect vehicle, the description of the explosion generated wave environment and the investigation of such a craft under various scenarios. Exercise of the program in this area has been concentrated on various parameters of the problem such as the effects of yield, standoff distance, water depth and tactical maneuvers to enhance survival.

In order to fully exercise the analytic program and ensure its validity several cases of sinusoidal waves and solitary waves were also run. These latter waves are representative of waves in the shallow water environment and consequently are worthy of investigation in their own right.

The work described in this report was conducted for the Office of Naval Research under contract N00014-76-C-0261. This report, covers all work performed under this contract and is submitted in fulfillment of the requirements of the contract.

2.0 FORMULATION OF PROBLEM

2.1 Coordinate System

The motion of the craft is described in terms of the relationship between a body fixed reference frame and a coordinate system fixed in space. The initial coordinates (x_o, y_o, z_o) and the body coordinates (x,y,z) are both designated according to a right hand convention with z_o and z positive downward. The origin of the body frame is kept fixed at the center of gravity of the craft with the x-axis parallel to the baseline of the craft, positive forward, and y positive starboard. The two coordinate systems coincide initially at time zero. At time t, there are three linear displacements and three angular displacements to describe the six degrees of freedom craft motions.

As a body moves in a fluid domain, various forces and moments act on the body. For the convenience of analysis, the total force is resolved into three components along the body axes. Definitions and symbols of the six components of force/moment, displacement and velocity are given by Table 1 and illustrated in Figure 2.

Table 1 Definition of Force/Motion Variables

Motion	Force or Moment	Displacement	Velocity
Longitudinal	X	ξ	u
Lateral	Y	η	v
Vertical	Z	ζ	w
Roll	K	ϕ	p
Pitch	M	θ	q
Yaw	N	ψ	r

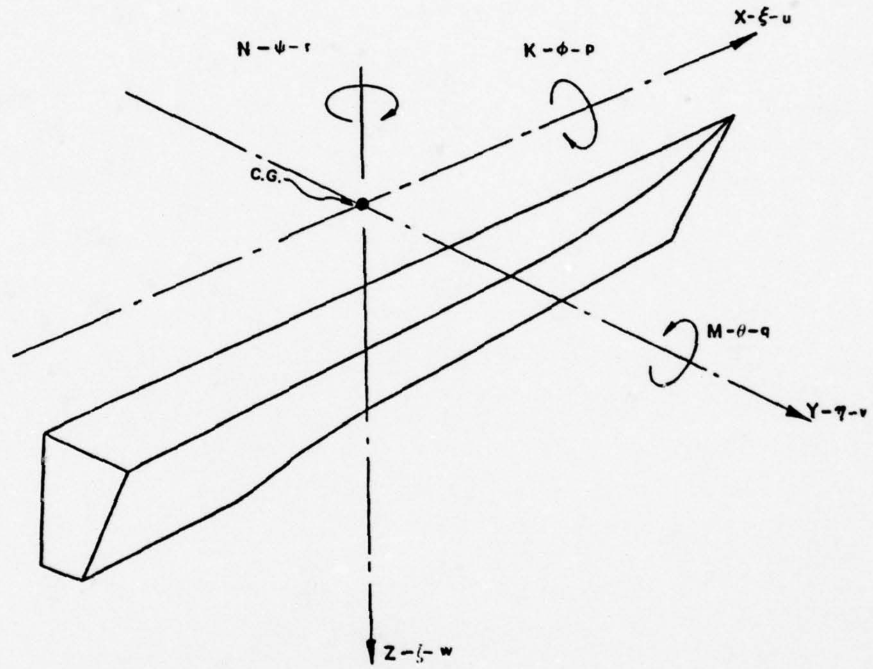

FIGURE 2 - COORDINATE SYSTEM AND NOTATIONS

2.2 Equations of Motion

The equations of motion for a craft in six degrees of freedom can be written as:

$$
\begin{aligned}
\overline{m}\,(\dot{u} + qw - rv) &= X \\
\overline{m}\,(\dot{v} + ru - pw) &= Y \\
\overline{m}\,(\dot{w} + pv - qu) &= Z \\
I_x\,\dot{p} + (I_z - I_y)\,qr &= K \\
I_y\,\dot{q} + (I_x - I_z)\,rp &= M \\
I_z\,\dot{r} + (I_y - I_x)\,pq &= N
\end{aligned}
\qquad (1)
$$

Where $\overline{m}$ is the mass and I_x, I_y and I_z are the moments of inertia of the craft about the respective axes. Terms on the lefthand side represent the rigid body inertial reactions and the centrifugal effects acting at the origin with respect to the moving coordinate system. The terms on the righthand side refer to the total forces and moments applied to the craft, including the hydrodynamic effects arising from the overall motions of the craft as well as the results of propulsion, control and environmental forces which may affect the craft motions and maneuvers. In a functional form, these components can be expressed generally as:

$$
\left.\begin{matrix} X \\ Y \\ Z \\ K \\ M \\ N \end{matrix}\right\} = f\,(\dot{u},\dot{v},\dot{w},\dot{p},\dot{q},\dot{r},u,v,w,p,q,r,x_o,y_o,z_o,\phi,\theta,\psi,\delta,\varepsilon) \qquad (2)
$$

In the above equation, x_o, y_o, and z_o are the position components or the linear displacements of the craft and ϕ,θ, and ψ are the angular displacements. The parameter δ represents a general description of the effect of various propulsion and control schemes, and the parameter ε represents the effect due to environmental disturbances such as waves. This functional form equation shows clearly the dependence of the external force and moment on the various variables. To reduce this functional relationship into a useful mathematical form, a Taylor expansion is usually applied provided that the non-dimensional proportionality constants are known or determinable. By keeping a sufficient number of terms for each variable, forces and moments can be expressed in a desired order of these variables to account for non-linear effects.

The determination of the proportionality constants, or the hydrodynamic derivaties, by analytical methods is generally limited only to the linear terms. The non-linear coefficients are normally determined experimentally by means of captive model tests. In the present analysis external forces and moments are determined analytically on the basis of physical concepts. By this approach various non-linear features can be included without the backup of experimental information. The general representation of the total force (or moment) acting on an SES is assumed to be composed of various components as follows:

$$F_i = F_{\text{sidewall } i} + F_{\text{cushion } i} + F_{\text{seals } i} + F_{\text{aerodynamic } i}$$
$$+ F_{\text{appendages } i} + F_{\text{propulsion } i} + F_{\text{control } i} + F_{\text{waves } i}$$

where $i = 1$ to 6, represents a particular mode or direction of motion. The calculation of each of the component forces is discussed in the following sections.

3.0 FORCES AND MOMENTS - CRAFT DYNAMICS

3.1 Sidehull Forces

The calculation of the forces acting on the sidehulls assumes that each component of these forces falls into one of the two major catagories, namely viscous and non-viscous. The non-viscous portions are those directly related to the dynamic fluid pressure resulting from the sidehull motion. These forces are intimately associated with the energy exchanges between the fluid and the moving sidehull and can be deduced from the fundamental principles of classical mechanics. Consequently, all non-viscous terms, both linear and non-linear, can be analytically identified as functions of the body added inertia, provided that the non-viscous dissipative damping is negligible. The viscous portions are drags created through various origins. The term drag customarily refers to the total resistance of the craft in its axial direction, which consists of several components attributive to several different items, and will be considered in detail in a later section. In the present section, only contributions due to sidehulls are considered. These contributions are normally treated as dependent on the square of the velocity through proportional empirical constants. Some details for the calculation of both the viscous and non-viscous forces on the sidehull are given in the following:

(a) Hydrodynamic pressure on sidehull

Because of the narrow hull geometry, the calculation of the hydrodynamic forces on the sidehull can be performed according to the fundamental concept of slender body theory. For a slender body of constant speed U in an inviscid, incompressible fluid the linearized free surface condition is given by:

$$U^2\Phi_{xx} + g\,\Phi_z = o \tag{3}$$

Where Φ is the velocity potential and g the gravitational constant. Since the sidehull immersion is normally small in comparison with the craft length, the above condition is more conveniently analyzed through its non-dimensional form as follows:

$$F^2 \frac{d}{L}\,\Phi_{x'x'} + \Phi_{z'} = o \tag{4}$$

Here F is the Froude number based on the craft speed and sidehull length; x' is a non-dimensional axial coordinate referenced to the craft length L, and z' is a non-dimensional vertical coordinate referenced to the craft immersion d. This normalization brings $\phi_{x'x'}$ and $\phi_{z'}$ to the same order of magnitude. The Froude number F is typically of the order of 1 or 2 for an SES. Since the immersion ratio d/L is small (of the order of 10^{-2} for a normal sidehull), the second term in the above equation is normally dominant. Consequently, the free surface condition can be approximated by

$$\phi_z = o \tag{5}$$

which is equivalent to the condition for a positive reflection in the free surface.

The expression of the boundary condition suggests that the problem can be treated as a body moving in an infinite medium, in which the dissipative damping is negligible and as shown by Lamb [4], the hydrodynamic effect is entirely determinable as a function of the added mass along the principal axes of the body. Following the procedure of classical mechanics, the effects of the hydrodynamic pressure on the craft can be easily obtained.

In the derivation of the force relations, the three dimensional sidehull is considered as a number of segments along the longitudinal axis. Each segment is considered individually as a two dimensional problem; interferences between segments are ignored. Consequently, the relative fluid velocities at the center of a segment x are given by

$$
\begin{aligned}
u_r\ (x,t) &= u \\
v_r\ (x,t) &= v + xr - fp \\
w_r\ (x,t) &= w - xq + hp
\end{aligned}
\tag{6}
$$

here

$$u^2 + v^2 + w^2 = U^2$$

and U the resultant velocity of the craft. The variables h and f are the lateral and vertical moment arms about the craft center of gravity, respectively. The above relations are applicable to both the starborad and port sidehulls; a negative value of h should be used for the port sidehull.

We shall first consider the segment to be axially symmetric and having component added masses m_{yy} and m_{zz} along the craft lateral and vertical axes, respectively. For asymmetrical segments with respect to the axial axis, additional treatment will be considered later. The added mass component along the axial direction is ignored in the analysis according to the slender body approach; however, estimates of surge effect by a gross approximation of this component are included in the numerical model, as will be shown in Appendix A. Specifically, m_{yy} and m_{zz} are written as follows:

$$
\begin{aligned}
m_{yy}\ (x) &= k_{yy} \cdot \frac{\pi}{2}\, d^2\ (x) \\
m_{zz}\ (x) &= k_{zz} \cdot \frac{\pi}{8}\, b^2\ (x)
\end{aligned}
\tag{7}
$$

where k_{yy} and k_{zz} are the added mass coefficients which are generally a function of geometry and frequency; b(x) is the local beam of the segment at water line and d(x) is the local draft.

The kinetic energy of a unit slice of fluid can be written as

$$T(x,t) = \tfrac{1}{2}(m_{yy}\, v_r^{\,2} + m_{zz}\, w_r^{\,2}) \tag{8}$$

The hydrodynamic forces and moments acting on a unit axial length are then given by:

$$\begin{aligned}
\frac{dY}{dx} &= - \frac{d}{dt}\frac{\partial T}{\partial v} + p\,\frac{\partial T}{\partial w} \\
\frac{dZ}{dx} &= - \frac{d}{dt}\frac{\partial T}{\partial w} - p\,\frac{\partial T}{\partial v} \\
\frac{dK}{dx} &= h\,\frac{dZ}{dx} - f\,\frac{dY}{dx} \\
\frac{dM}{dx} &= - \frac{d}{dt}\frac{\partial T}{\partial q} + u\,\frac{\partial T}{\partial w} + p\,\frac{\partial T}{\partial r} - r\,\frac{\partial T}{\partial p} \\
\frac{dN}{dx} &= - \frac{d}{dt}\frac{\partial T}{\partial r} - u\,\frac{\partial T}{\partial v} + q\,\frac{\partial T}{\partial p} - p\,\frac{\partial T}{\partial q}
\end{aligned} \tag{9}$$

The kinetic energy T at a fixed cross flow plane is a function of x and t. The total derivative $\frac{d}{dt}$ therefore must reflect the changing coordinate of the cross flow plane with time, thus

$$\frac{d}{dt} = \frac{\partial}{\partial t} - u\,\frac{\partial}{\partial x}$$

Substituting (8) into (9), carrying out the differentiation, and then integrating over the sidewall length, gives the total hydrodynamic forces and moments acting on the craft. These forces and moments include both the linear and non-linear hydrodynamic contributions. A detailed breakdown of these contributions is given in Appendix A.

It has been mentioned earlier that m_{yy} and m_{zz} are for axially symmetric sections. More often the sidewall sections are asymmetrical. This asymmetricity gives rise to cross coupling effects which are estimated as follows:

$$m_{yz}(x) = k_y \cdot m_{zz}(x)$$
$$m_{zy}(x) = k_z \cdot m_{yy}(x) \tag{10}$$

where $m_{yz}(x)$ represents the sectional added mass at station x, relating the fluid momentum in the lateral direction y to the local normal motion in the direction z. Similarly, $m_{zy}(x)$ can be interpreted as the added mass relating vertical fluid momentum to the local lateral motion. The coefficients k_y and k_z are estimated using:

$$K_y = \frac{1}{K_z} = \frac{N_y(x)}{N_z(x)} \tag{11}$$

where $N_y(x)$ and $N_z(x)$ are average values of the horizontal and vertical unit normal components of the hull cross-section at station x. The average is taken with respect to the wetted length of the hull cross sectional area.

(b) Hydrostatic Forces and Moments

The hydrostatic force acting on the body is obtained by integrating the hydrostatic pressure over the entire wetted body surface and is numerically equal to $\rho g \Delta$, where ρ is the density of the fluid, g is the acceleration of gravity and Δ is the volume of the displaced fluid. Let the sectional area at station x be s(x), which is a function of draft d defined as

$$d(x) = D(x) + \zeta - x\sin\theta + B\sin\phi \tag{12}$$

where D(x) is the initial draft at station x and B is the half-spacing of the sidehulls; ζ, θ and ϕ have been defined before as the instantaneous motion displacements of heave, pitch and roll, respectively. The total buoyancy force is then given by:

$$F_{Buoy} = \rho g \int s(x)\ dx \tag{13}$$

where the integration is carried over the sidehull length from stern to bow. The force component along the body normal axis z is then given by:

$$Z_{Buoy} = -\rho g \cos\theta \int s(x)\ dx \tag{14}$$

and the component along the longitudinal axis is

$$X_{Buoy} = \rho g \sin\theta \int s(x)\ dx \tag{15}$$

The hydrostatic restoring moments are

$$M_{Buoy} = \rho g \int s(x)\ x\ dx \quad \text{(pitch)} \tag{16}$$

$$K_{Buoy} = -\rho g \int s(x) \cdot h(x)\ dx \quad \text{(roll)} \tag{17}$$

where h(x) is the buoyancy arm from the craft centerline. This quantity normally does not vary significantly over the sidehull length and approximately equals to the half-spacing B. Consequently, the righting moment can be approximated by

$$K_s = B \cdot Z_{Buoy} = -\rho g B \int s(x)\ dx \tag{18}$$

(c) Sidehull Drag

The axial drag on the sidehulls arise from two basic sources. Firstly, the frictional drag caused by the viscous effects of the fluid over the body, and secondly the base pressure drag which arises due to the wave separation aft the transom. In addition to these two basic sources, there exists expecially at high speed a significant spray drag. In this subsection, we shall limit our discussion only to these three components which relates with the sidehull geometry. Drag contributions related with other sources, including cushion pressure (wave), craft aerodynamics and cushion seals will be discussed separately later.

The sidehull viscous drag is primarily a function of the Reynolds number and surface finish of the body and is determined by:

$$D_{Fric} = \tfrac{1}{2} \rho u^2 S_w C_F \qquad (19)$$

where S_w is the sidehull wetted surface. Assuming the surface finish smooth, the standard ITTC relationship is used to approximate the skin drag coefficient:

$$C_F = \frac{0.075}{(\mathrm{Log}_{10} Rn - 2)^2} \qquad (20)$$

where

$$Rn = \frac{UL}{\nu} \text{ , the Reynolds number,}$$

in which

L = sidehull length

ν = kinematic viscosity of fluid.

The pressure drag component is estimated by another drag coefficient given by the following expression [5]:

$$C_B = \frac{0.10}{\sqrt{C_{fB}}} \qquad (21)$$

and the base pressure drag is then calculated based upon the sidehull base area S_B as follows:

$$D_{Base} = \tfrac{1}{2}\,\rho u^2 S_B C_B \qquad (22)$$

The coefficient C_{fB} in Equation (21) is a base-area based skin drag coefficient defined as follows:

$$C_{fB} = C_f\,\frac{S_w}{S_B} \qquad (23)$$

At high speeds and/or at shallow immersions the likelehood of ventilation is almost certain. Under this condition, a base drag coefficient defined by the following is applied:

$$C_B = \frac{2}{F_d^{\,2}} \qquad (24)$$

Here, F_d = Froude number based on transom immersion d. The transition from a wetted wake regime to a fully vented regime is a function of F_d. Empirically established relation shows that the base is fully vented when $F_d \geq 3.2$.

The spray drag is one of the most important parameters to affect the sidehull performance. Unfortunately very little information exists regarding this drag component. In an effort to provide some insight into this area, some experimental works [3] were done to ascertain the degree of spray generation by utilizing photographs to determine the added wetting caused by spray. On the assumption that the major contribution of spray to drag is due to frictional effects, this information is used to generate a spray drag coefficient. This latter assumption is supported by investigations performed on surface piercing struts in [6]. In keeping with the findings of [6], the spray drag component is cast in the form:

$$D_{spray} = f(q,c,t) \tag{25}$$

where q is the dynamic pressure, c is the characteristic length from the point of generation of the spray to the maximum thickness point and t is the maximum thickness of the body.

Based on the results of [3] the following formula is used for estimating the spray drag caused by a typical SES sidehull configuration:

$$D_{spray} = 0.75\ C_f\ qct \tag{26}$$

In this formula the value of t is taken to be the maximum thickness in the waterline plane and the friction coefficient C_f is evaluated at the appropriate Reynolds number. This result has shown excellent agreement with the test results [3].

(d) Viscous Cross-Flow Effect

In contrast to the hydrodynamic pressure forces presented in (a), this component arises from the real fluid effects on the sidehull. The contribution of this term to the overall force on the sidehull is small for small hull excursions but becomes dominant as the craft motions become large. In the present study, this force is calculated according to the following formula:

$$\text{Cross-flow forces} = \tfrac{1}{2}\,\rho\, C_D S\, |V_r|\, V_r \tag{27}$$

where

C_D = cross flow drag coefficient

S = projected area of the sidehull

V_r = relative flow velocity

The coefficient C_D is a function of the hull geometrical shape and the Reynolds number. It is usually obtained from experimental data by judicial interpretation of the results from tests done on idealized geometric shapes.

3.2 Cushion Pressure Forces

In addition to the forces imparted to the craft through the sidehulls, the cushion pressure supporting the craft has a significant effect on the craft dynamics. For the present investigation, since a general type of craft is being considered, the supporting air cushion is considered as basically a rectangular box bounded by the sidehulls and the forward and aft seals. The plenum is fed by a fan, or system of fans, with a specified fan characteristic. The basic equation governing the air flow into and out from the cushion is the conservation of mass which states that

$$\dot{m} = \rho (Q_{in} - Q_{out}) \tag{28}$$

where $\dot{m}$ = rate of change of mass in the plenum

Q_{in} = total flow into the plenum

Q_{out} = leakage flow out under the seals and sidehulls

The flow into the air plenum is governed by the lift fan characteristic Q_f which is a function of the cushion pressure p_c as follows:

$$Q_{in} = Q_f = \alpha_o + \alpha_1 p_c + \alpha_2 p_c^2 \tag{29}$$

where $\alpha_0, \alpha_1, \alpha_2$ are proportional constants. The leakage flow is considered to be governed by an orifice type flow equation given by:

$$Q_{out} = C_O A_L \sqrt{\frac{p_c - p_a}{\rho}} \tag{30}$$

where C_o = discharge coefficient

ρ = density

p_a = atmospheric pressure

p_c = cushion pressure

A_L = leakage area

The leakage area in this equation is comprised of several components. These can be represented as

$$A_L = A_o + A_{sw} + A_s \tag{31}$$

where A_o = equilibrium leakage flow area

A_{sw} = leakage area under the sidehull

A_s = leakage area under the seals

The equilibrium leakage area is that leakage required to maintain the craft at a given equilibrium condition when not disturbed by any waves. Under actual conditions this leakage area can be adjusted by changing the setting of the seals and determines the equilibrium immersion of the craft. The equilibrium state is obviously given by:

$$(p_c - p_a)\, A_c = W - F_{Buoy} \tag{32}$$

where W = craft weight

F_{Buoy} = buoyancy force

A_c = plenum area

The areas A_{sw} and A_s are obtained at each instant in time by integrating the clearance of the sidehull and seals with respect to the local water elevation. The total leakage area A_L obviously changes as a function of time depending on the craft motions and the free surface elevation.

The pressure in the plenum is assumed to vary according to an adiabatic compression law, namely

$$p_c \, V^{\gamma} = \text{constant} \tag{33}$$

where V is the plenum volume and $\gamma=1.4$, the adiabatic constant. By substituting $m=\rho V$, the mass conservation equation becomes:

$$\dot{V} = Q_{in} - Q_{out} \tag{34}$$

These equations together determine the cushion pressure and air flows into the plenum and consequently the resulting forces and moments on the craft can be calculated as follows:

$$\begin{aligned}
X_{pres} &= (p_c - p_a)\, A_c \tan\theta \\
Y_{pres} &= -\,(p_c - p_a)\, A_c \tan\phi \\
Z_{pres} &= -\,(p_c - p_a)\, A_c \\
K_{pres} &= -\,Y_{pres}\,(VCG - \frac{B_p}{2}\tan\phi) \\
M_{pres} &= X_{pres}\,(VCG - \frac{L_p}{2}\tan\theta)
\end{aligned} \tag{35}$$

where VCG = Vertical height of CG above mean water level

B_p = Width of the plenum

L_p = Length of the plenum

ϕ = Roll angle

θ = Pitch angle

In addition to the pressure forces, the cushion pressure acting on the free surface generates waves and causes a significant drag effect. The calculation of the wave resistance for a pressure patch is straight-forward. Following the method of Yim [7], the total wave resistance for a combination of a pressure planform and two sidehulls in a channel of width W can be written as follows:

$$X_{wave} = \sum_{m=0}^{\infty} \varepsilon_m \frac{1 + \sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}{\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}} (P^2 + Q^2) \tag{36}$$

where

$$P + iQ = \frac{k_o^2}{4\rho g W} \iint_S p_c(x,y) \exp[ik_o \lambda_m x + i2\pi y \frac{m}{W}]\, dxdy$$

$$+ \frac{16\pi^2 \rho k_o}{W} \iint_D \sigma(x,z) \exp[k_o \lambda_m (\lambda_m z + ix) + i2\pi B \frac{m}{W}] dxdz$$

$$\varepsilon_m = \begin{cases} 1 \text{ for } m = 0 \\ 2 \text{ for } m \geq 1 \end{cases}$$

$p_c(x,y)$ = pressure distribution on planform S

k_o = g/U^2

g = gravitational acceleration

U = ship speed

ρ = density of water

$\sigma(x,y)$ = singularity distribution for representation of sidehull D

B = Half-spacing of sidehull

$$\lambda_m = \sqrt{\tfrac{1}{2} + \tfrac{1}{2}\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}$$

Assuming that the pressure planform is rectangular and the sidehulls are of parabolic shape, the above integrals can be evaluated easily and the result is given by:

$$X_{wave} = \tfrac{1}{2} \rho U^2 L_p^{\,2} \sum_{m=0}^{\infty} \varepsilon_m \frac{1 + \sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}{\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}$$

$$\cdot \left\{ \frac{8b}{L} \frac{1}{k_1 \sqrt{k_o W}} \cos\left(2\pi \frac{B_p}{L_p} \frac{m}{W_1}\right) \cdot \frac{1-e^{-\lambda_m^2 k_o H}}{\lambda_m^{\,2}}\right.$$

$$\cdot \left[\frac{1}{b_m} \cos(k_1 \lambda_m) - \frac{\sin(k_1 \lambda_m)}{k_1 \lambda_m^{\,2}} \right] - 2 \frac{L_p}{B_p} \sqrt{\frac{k_1}{W_1}}$$

$$\left. \cdot \left(\frac{\overline{W}}{\rho g L_p^{\,3}} \right) \sin(k_1 \lambda_m) \sin(2\pi \frac{B_p}{L_p} \frac{m}{W_1}) \Big/ \frac{\pi m}{W_1} \right\}^2 \qquad (37)$$

where

$k_1 = k_o L_p/2$

$W_1 = W/L_p/2$

$\overline{W}$ = total weight of the craft = $p_c B_p L_p$

B_p = plenum width

L_p = plenum length

b = sidehull width

H = sidehull draft.

The above equation is derived for the case of a finite channel width W. Numerical results show that when $w > 10\ L_p$ the above relation asymptotically applies to the case of unrestricted waters.

3.3 Seal Forces

In the present study a very simplified seal configuration has been adopted. The purpose of this simplification is to avoid too many details which would reflect a given design rather than a general craft.

These seals are assumed to be of the flexible fabric type, such as a bag and finger design, which when immersed in the water simply deflect and lie on the water surface. Hence, they do not contribute any forces or moments to the craft except for their axial drag and the forces and moments arising due to the shift of the center of air pressure in the plenum caused by the changing imprint length on the water. Referring to Figure 3, which shows the deflection of a simple bow seal, the following equations are derived:

$$Z_{seal} = -(p_c - p_a)\, l_w\, B_p$$
$$M_{seal} = Z_{seal}\, l_s \tag{38}$$

where

$$l_w = l_s \frac{\tan\theta}{\sin\theta_B}$$

l_s = distance of seal tip to C.G.

θ_B = sheer angle of seal

θ = trim of craft

the axial drag due to the bow seal is:

$$X_{seal} = C_f \frac{\rho}{2} u^2\, l_w B_p \tag{39}$$

here C_f is the friction coefficient, derived from the Reynolds number as follows:

$$C_f = \frac{0.044}{R_n^{1/6}} \tag{40}$$

and R_n is the Reynolds number based on the seal wetted length l_w. Similarily, the force and moment due to the deflection of the stern seal can be calculated.

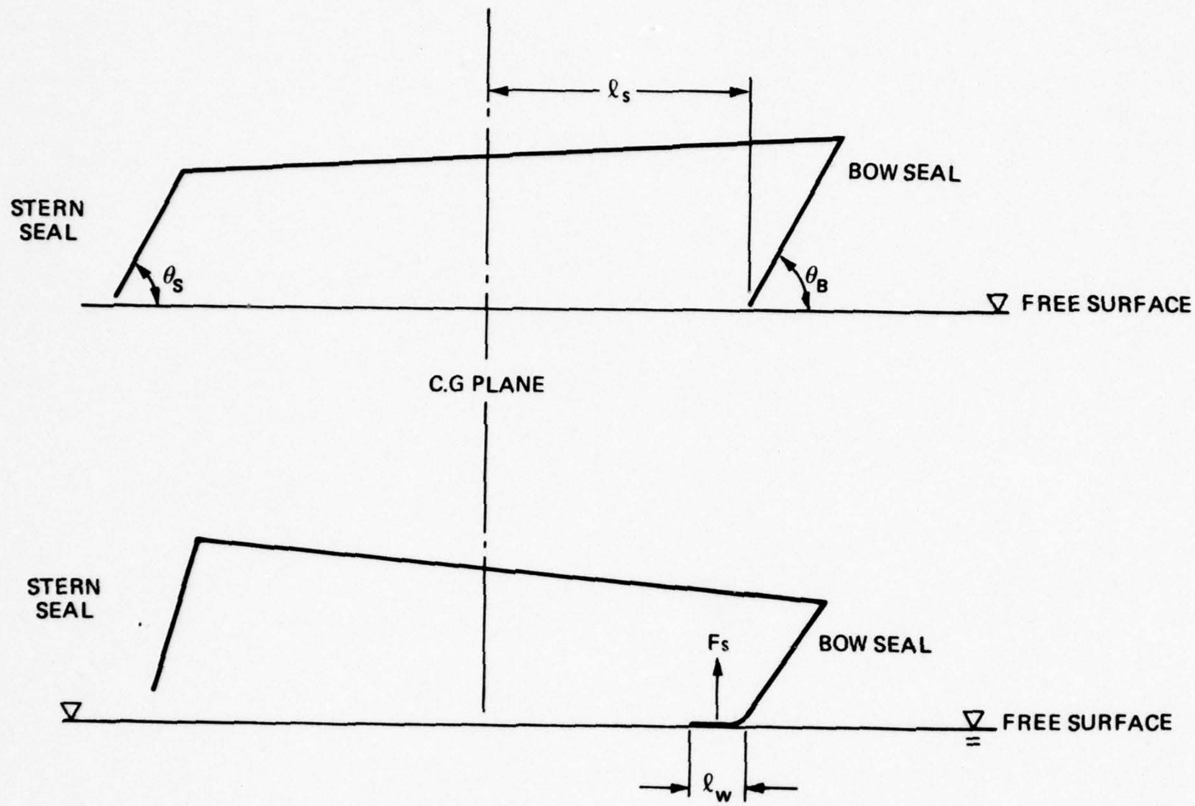

Figure 3: Schematic of Seal Force

3.4 Aerodynamic Forces

The aerodynamic forces and moments acting on the craft have been simplified and are represented by an overall drag coefficient based on the frontal area of the craft. This drag coefficient has been selected to correspond to test results on typical SES configurations. The force is simply:

$$X_{aero} = C_D \tfrac{1}{2} \rho U^2 A_f \tag{41}$$

where A_f is the frontal area of the craft.

No aerodynamic lift or moments have been used in the present study and no wind conditions are considered. Consequently, only an axial aerodynamic force is included in the present study.

3.5 Propulsion and Thrust Control

Various methods of propelling and control for SES exist. Current emphasis for SES propulsion is a waterjet. This device allows for thrust vectoring or differential thrust for maneuver and turning. Although only straight line operation is considered in the present study, a typical propulsion and control scheme is included in the numerical code. Some details for the calculation of these forces are given in the following.

(a) Propulsion

The present scheme assumes that four waterjet nozzles are used for propulsion and control. These four nozzles are distributed athwart the transom so as to deliver thrust for propulsion as well as to provide turning moment for maneuvering. In the present study the engine thrust of the following form is used for the numerical modeling

$$T_g = A_1U^2 + A_2U + A_3 \tag{42}$$

Here T_g represent the gross thrust and U is the craft speed; A_1, A_2 and A_3 are the proportional constants. Similarly, the total momentum drag of the waterjet system is approximated by a linear function of U and given by

$$D_m = B_1U + B_2 \tag{43}$$

where B_1 and B_2 are constants.

(b) Thrust Control

The basic control scheme considered here is thrust vectoring by which the side thrust and turning moment are generated through deflecting the nozzles as well as varying the power level on different nozzles. A special case of this scheme is known as differential thrust, in which the turning moment is generated by increasing the power on one jet and decreasing it on the other without deflecting the nozzle direction.

Let δ be the horizontal deflection angle of the jet nozzle, positive toward portside and α be the vertical tilt angle, positive upward, then the force and moment contributions for a craft with a trim angle θ are given by:

$$X_\delta = \sum_{i=1}^{4} [T_{gi}\cos\delta_i\cos(\alpha_i-\theta)-D_{mi}]$$

$$Y_\delta = \sum_{i=1}^{4} T_{gi}\sin\delta_i\cos(\alpha_i-\theta)$$

$$K_\delta = \sum_{i=1}^{4} T_{gi}[\sin(\alpha_i-\theta)y_i-\sin\delta_i\cos(\alpha_i-\theta)z_i] \tag{44}$$

$$N_\delta = \sum_{i=1}^{4} [T_{gi}\cos(\alpha_i - \theta)(y_i\cos\delta_i - x_i\sin\delta_i) - D_{mi}y_i]$$

in which x_i, y_i and z_i are the coordinates of the centerline location of the ith nozzle, T_{gi} is the gross thrust at the same nozzle and D_{mi} the corresponding momentum drag of the waterjet inlet. The turning forces and moments are assumed to be confined in a horizontal plane, so that no heave and pitch effects are developed from the maneuver.

3.6 Appendages

Usually, especially in the case of an SES, directional stabilizers or fins are fitted in order to ensure directional stability. In the present study a nominal configuration of fins has been assumed. Standard representations of these appendages are included in the analysis to account for drag and lift forces.

These fins are considered as base vented parabolic sections designed to produce the required lateral stiffness to the craft to ensure stability. Two items attributing to the total drag of these fins, namely pressure drag and frictional drag, are considered. Since the quality of these surfaces has to be kept smooth and constantly clean to ensure cavitation free operation, it is assumed that for all intents and purposes the surface is close to be hydrodynamically smooth and consequently the frictional drag is computed on this basis. The total drag of the stabilizer surface can be written as:

$$X_{fin} = \tfrac{1}{2}\,\rho U^2 A[C_d + 2\,C_f] \tag{45}$$

where

A = fin surface area
C_d = pressure drag coefficient
C_f = frictional drag coefficient

For a base venting parabolic section we have

$$C_d = \frac{\pi}{8}\left(\frac{t}{c}\right)^2 \tag{46}$$

where $\frac{t}{c}$ is the thickness-chord ratio, and, for a smooth surface the frictional coefficient can again be approximated by the formula:

$$C_f = 0.044/R_n^{1/6} \tag{47}$$

here R_n is the Reynolds number based on the mean chord.

The lift force from the fin is calculated using the following classical lift equation.

$$Y_{fin} = \tfrac{1}{2}\,\rho U^2 A C_L \tag{48}$$

where

$$C_L = 2\pi\,\frac{AR}{AR+3}$$

AR = aspect ratio of the fin.

3.7 Motion Alleviation and Control

It is essential for the proper operation of SES to maintain the cushion bubble through a series of blowers or fans. A proper control of the fan rpm to vary the plenum pressure may not only alleviate the craft motion but also maintain the craft's forward speed. In this present study, a simplified but representative control scheme is included in the analysis so that a gross effect of the control device to the craft response can be identified.

Heave acceleration is coupled directly to the fluctuations of cushion pressure. When an SES running over a wave crest, the resultant displacement of the water surface compresses the cushion air and creates an upward force or acceleration. Conversely when the SES passes over a wave trough, the expansion of the air volume bring the craft downward until it is again supported by the proper pressure. The basic concept of the present scheme is to regulate the pressure of the cushion plenum so as to compensate the force excited by the environment and keep the craft in a nominal elevation. A fundamental method to control the air pressure is by means of regulating the cushion venting or the equilibrium leakage. For instance, when the plenum air is compressed the vent can be opened more, and conversely when the plenum pressure is dropping, the area of the opening should be reduced or entirely closed. Let A_{ha} be the area of the vent. In general the regulation of this area can be expressed by:

$$A_{ha} = f(p_c, \dot{p}_c, \zeta, \dot{\zeta}, \ddot{\zeta}) \tag{49}$$

The above equation simply indicates that the area of the vent is to be controlled not only by the cushion pressure and its rate of changes but also the craft heave motion and its derivatives. A proper design of the control constants for each of this variable is required in order to maintain the craft elevation and the riding comfort. Since the design optimization of these control constants is out of the scope of the present study, a simplified but representative scheme as follows, depending upon only $\dot{p}_c$ and $\ddot{\zeta}$, is considered in the analysis.

$$A_{ha} = c_1 \ddot{\zeta} + c_2 \dot{p}_c \tag{50}$$

where c_1 and c_2 are the control constants. In addition to the two control constants, an upper and lower limits of the total opening area of the vent are possibly assigned in the computer model.

4.0 WAVE ENVIRONMENT AND WAVE FORCES

4.1 Wave Representation

The computation of explosion generated waves can be divided into three parts; they are the modeling of the source condition, the calculation of propagation and transformation of waves over a given bottom topography, and the determination of breaking inception and wave run-up according to some acceptable criteria. The last two parts would involve tedious bookkeeping of propagation history from point to point, should the bottom topography be irregular. Since the study emphasizes specifically the mathematical modeling of the craft, the details of the bottom irregularities are not considered. In the analysis, the continental shelf is assumed to be two-dimensional and have a constant mild slope, consequently, the wave environment can simply be classified into two characteristically different groups; deep water and shallow water waves.

4.2 Deep Water Wave Generation

The deep water waves theoretically can be represented by sinusoids of various frequencies. While the craft responses in sinusoidal waves are to provide a general indication of the craft characteristics as a function of wave period, they provide little information as to how the craft responds when it is sufficiently close to the source region, as the wave amplitudes are normally very large such that the linear superposition technique is not valid and applicable. The present model is capable of simulating either a sinusoidal wave system or an idealized explosion-generated wave system at a given stand-off distance from the source at any time after detonation. Since the sinusoidal wave form is simpler and well-known, only modeling of the explosion-generated waves is discussed in the following.

The problem concerning waves generated by an arbitrary but localized disturbance on a free surface has been investigated by Kajiura [8]. In analyzing the explosion-generated waves, the initial disturbance is assumed as a parabolic crater-like shape with radial symmetry such that:

$$\begin{aligned} \bar{\eta}_o(r) &= \eta_o[2(r/R_o)^2-1] && \text{for } r < R_o \\ &= o && \text{for } r > R_o \end{aligned} \tag{51}$$

where η_o = crater height

R_o = crater radius

r = radial distance

The waves resulting from this disturbance at a distance r from the center have been given by Le Mehaute [9] as

$$\bar{\eta}(r,t) = \frac{\sigma_o R_o}{r} \left[- \frac{V/k}{dV/dk}\right] J_3(kR_o) \cos(kr-\omega t) \tag{52}$$

where k = wave number, determinable from the relationship between the group velocity V and the arrival time t, such that

$$V(k) = \tfrac{1}{2} \frac{\omega}{k} \left(1 + \frac{2kd}{\sinh 2kd}\right) = \frac{r}{t}$$

$$\omega = \sqrt{gk \tanh kd}$$

d = water depth

J_3 = Bessel function of the 1st kind of order 3.

The above equation shows that the traveling wave train possesses a series of amplitude peaks primarily governed by the modulating Bessel function J_3. The problem that remains is to relate the crater dimension η_o and R_o to the yield of a given explosion so that prediction of waves at a given location r and time t can be made.

It is noted that both η_o and R_o are not easily measurable. What one can measure are the wave height and period at a large distance from the source disturbance. It is in fact more convenient to measure the peak amplitude η_{max} in the first wave envelope at a given range r, and the corresponding wave number k_{max} can be evaluated by knowing the arrival time t from the above equations. Analytically, one can show that, for a particular source disturbance $\bar{\eta}_o(r)$, the amplitude of the maximum wave η_{max} is inversely proportional to r, and the corresponding wave number k_{max} depends only on the crater radius R_o. For an explosion in sufficiently deep water, the relationship between k_{max} and R_o can be determined from the first stationary value of J_3 as:

$$k_{max} R_o = 4.2 \tag{53}$$

Once the measurement of k_{max} is obtained, the crater radius can be readily estimated. From equation (52), one also finds:

$$\eta_o R_o = 1.63 \eta_{max} r \tag{54}$$

when $k = k_{max}$. Consequently, the crater height can also be estimated from the measurement of wave height at a distance r.

Empirical correlations of measurements of η_{max} with the explosion yield W and the detonation depth Z show that there is a certain trend between the parameter $\eta_{max} r/W^{0.54}$ and the parameter $Z/W^{0.3}$ (W in lbs of TNT equivalent); this is best presented graphically by plotting the experimental data points as shown in Figure 4. It is noted that there are two peaks appearing in the former parameter over a range of the latter. One of these peaks occurs

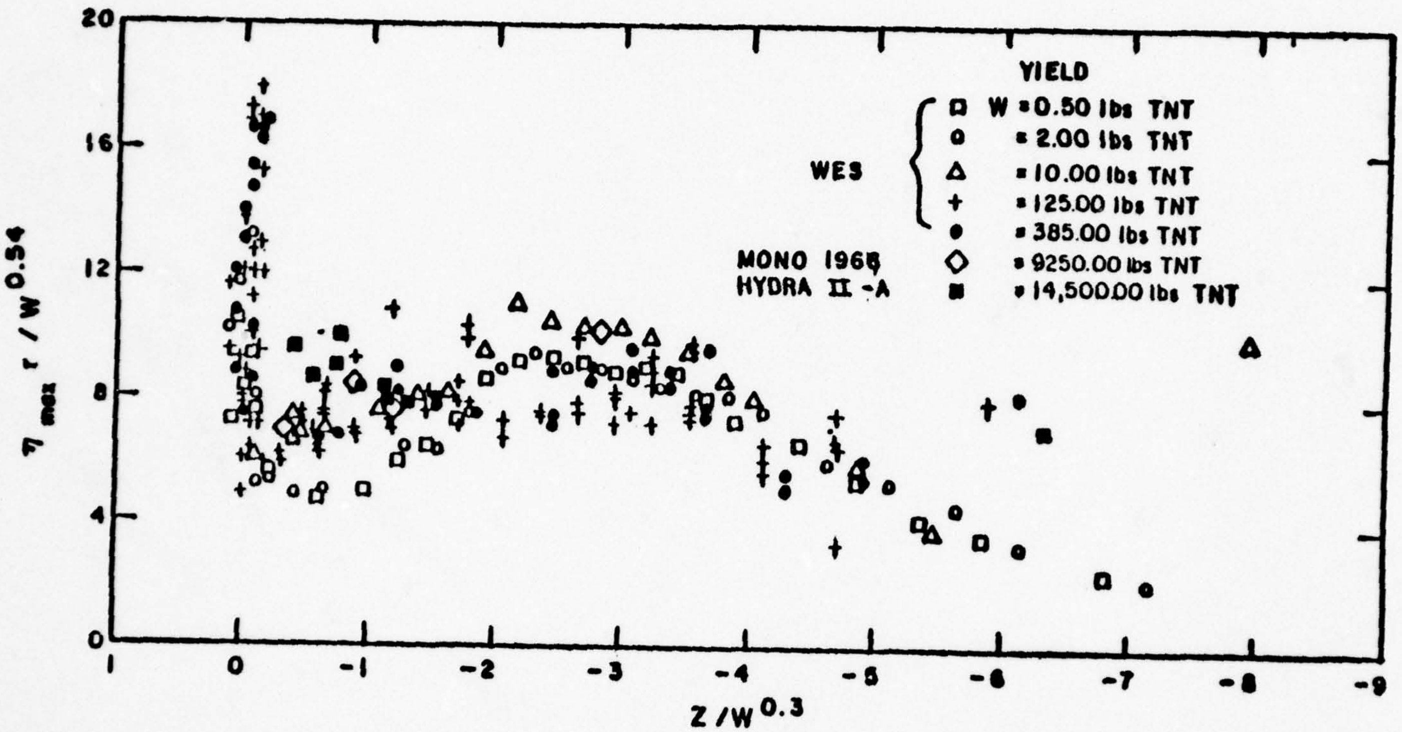

Figure 4 An Empirical Scaling Fit Relating Values of η_{max}, Charge Depth and Explosion Yield (data provided by Waterways Experiment Station).

at $Z/W^{0.3} = -0.05$ and is commonly termed as the upper critical depth. Detonation at this depth is seen to produce the highest responses. The other peak occurs at $Z/W^{0.3} = -2.7$ and is usually called as the lower critical depth.

As discussed before, the parameter k_{max} can be determined by measuring the arrival time of the first wave at a given distance. By analyzing the wave profiles obtained from the measurements, empirical relationships between the parameter k_{max} and the yield wight W have also been established through experiments of small chemical charges in deep water [9]:

$$\begin{aligned} k_{max} &= 0.44\ W^{-0.3} \quad \text{for } 0 > Z/W^{0.3} > -0.25 \\ &= 0.39\ W^{-0.3} \qquad -0.25 > Z/W^{0.3} > -7.5 \end{aligned} \tag{55}$$

Using these empirical relations together with the measured results as shown in Figure 4, the source parameters η_o and R_o can be determined for any yield at any water depth and detonation depth. Consequently, the wave history at any point r and time t can be calculated according to Eq. (52).

4.3 Shallow Water Waves

Two types of waves should be considered with regard to shallow water wave generation: (1) waves produced in deep water as a result of an offshore explosion which transform their height, shape and internal characteristics through the process of shoaling, refraction and reflection when they propagate shoreward into shallower water; (2) waves directly generated by explosions in shallow water on the continental shelf. As far as the wave characteristics are concerned, these waves can be considered identical and treated in a similar manner. Before entering into the discussion of how to model these waves mathematically, however, correlations of yield with wave generation in shallow water are briefly outlined below.

The method of correlation between wave heights and yields discussed in the previous section is limited to deep water wave generation such that $d > 6W^{0.3}$. For explosions in water of depth such that $1 < d/W^{0.3} < 6$, Le Mehaute [9] proposed a simple interpolation rule to fit the experimental data as follows:

$$\bar{\eta} = \bar{\eta}_{deep}\left[\frac{1}{2} + \frac{1}{10}(d/W^{0.3}-1)\right] \quad (56)$$

This shows that the generation efficiency is reduced by half when the parameter $d/W^{0.3}$ approaches unity. In the case of very shallow water where $d/W^{0.3} << 1$, the linear model is no longer valid and different correlations must be used. Unfortunately, there are very few data collected from shallow water explosions. Among the available data as listed in Table 2, only the WES test data [10] provide a systematic information of charge weight and water depth.

By means of small-scale charges (0.5 - 2048 lbs.) the WES program was designed to estimate wave effects from a 20 KT explosion in water of 30 to 200 feet deep. The charge position varied from beneath the bottom to above the free surface. The results showed that variations of Z/d from -1.0 to 0 had little effect on wave height. In contrast to deep water explosions, the most significant parameter for wave generation in shallow water is water depth, instead of charge position.

The other significant feature is that the dispersion law is different for waves propagating in deep and shallow water. In deep water, wave height varies inversely with radial distance r as a combined result of frequency and radial dispersions. In extremely shallow water, however, the large leading wave is expected to behave like a solitary wave and its height should vary inversely as $r^{2/3}$ instead of r. In moderately shallow water, the relation below should hold

TABLE 2

EXPERIMENTAL DATA

	BAKER[11]	MONO LAKE I[12]	MONO LAKE II[12]	WES[10]
EXPLOSIVES	NUCLEAR	TNT	TNT	TNT
CHARGE WEIGHT W (lbs)	4.6×10^7	9.2×10^3	9.2×10^3	0.5 - 2048
WATER DEPTH d (ft)	180	14	10	0.07 - 7.43
DETONATION DEPTH Z (ft)	90	10	10	
$\frac{d}{W^{1/3}}$	0.5	0.67	0.47	0.088 - 0.585

[10] WES (1955)
[11] Glasstone, S. (1962)
[12] Garcia, W.J. (1970)

$$\bar{\eta}\, r^{\beta} = \text{constant} \qquad 2/3 \leq \beta(d) \leq 1 \tag{57}$$

By correlating the WES test data, the following empirical formula have been derived

$$\frac{\eta_{max} r^{\beta}}{W^{\beta/3+0.25}} = 1.44\,(d/W^{1/3})^{0.93} \tag{58}$$

and

$$\beta = 0.83\,(d/W^{1/3})^{0.07} \tag{59}$$

It is noted that the power β varies as a function of the depth parameter $d/W^{1/3}$; for the very shallow case, β approaches 2/3 as a limit. While the derivation of the above relationship has assumed that reasonable extrapolation of the WES data is valid, it must be noted that the correlation is based upon the experimental data covering $d/W^{1/3}$ only up to 0.585. There is no indication that it will approach the empirical relation (56) as d increases.

Equation (58) provides an empirical relationship for predicting the maximum wave height at any distance r from a shallow water explosion. After the wave height is determined for a given explosion, the important procedure required for numerical simulation is a mathematical representation of the wave history as a function of time. As mentioned earlier, disregarding whether the waves are generated in shallow water or are propagated into shallow water from offshore, their internal characteristics can be regarded the same if both of their height and period are identical.

The most important parameter which affects these waves in this case is the local water depth. As is well known, when waves propagate into shallower water, their crests become more peaked through shoaling. When the local depth d becomes so shallow that the wave height $h \simeq 0.67\ d$ to $0.78\ d$, waves start to break. Analytical and experimental studies of wave propagation and transformation have been discussed in detail by Le Mehaute et al. [13]. Their analyses show that, among many existing wave theories, the cnoidal wave theory is good for describing the transition from deep water waves to shallow water waves but the solitary wave theory best describes the long, shallow water waves including the spilling type breakers. In the present study, the solitary wave form is used for numerical modeling of the long period waves on the continental shelf. After the wave height and period is determined according to the yield weight, the mathematical representation of waves in water of depth d is given by

$$\bar{\eta}(r,t) = h \operatorname{sech}^2 \alpha(r-ct) \tag{60}$$

where

h = wave height

$\alpha = \sqrt{3h/4d^3}$

$c = \sqrt{gd}\,(1 + h/2d)$, the wave celerity

4.4 Wave Forces

Equations (52) and (60) give the mathematical forms of the deep water explosion generated waves and the corresponding shallow water representation as a function of location r and time t. In terms of ship coordinates, the wave elevation at (x,y,z) is given by

(a) explosion generated waves

$$\bar{\eta}(x,y,z,t) = \frac{\eta_o R_o}{x_o}\left[-\frac{V/k}{dV/dk}\right] J_3(kR_o)\cos k(x_o + x') - \eta_1 \tag{61}$$

(b) solitary wave

$$\bar{\eta}(x,y,z,t) = h \operatorname{sech}^2 \alpha x' - \eta_1 \tag{62}$$

where

x_o = distance of craft center from the burst

x' = $(x \cos\theta + z \sin\theta) \cos\psi + y \sin\psi + (U-c)t$

η_1 = $x \sin\theta - \zeta - y \tan\phi$

U = ship speed

c = wave celerity

ζ, ϕ, θ and ψ have been defined in Table 1

From these equations, the wave elevation at any location of the craft can be determined. The calculation of the wave forces and moments follows the same technique of slender body theory applied previously to obtain the sidehull forces and moments. In this manner, the wave forces acting on each sidehull segment are first determined. In the derivation of these wave forces, the validity of the Froude-Kriloff hypothesis is assumed. Under this assumption the pressure in the wave system is not affected by the presence of the body. This assumption is justified in the present analysis, as the wave systems which we are presently dealing with are very long period waves, in which the static behavior or the pressure effect is dominant over all the dynamic influences. After the wave force on each sidehull segment is determined, the total forces and moments are obtained by integration over the entire craft length.

5.0 *NUMERICAL PROCEDURES*

5.1 Method of Solution

Summarizing the forces and moments derived in the previous sections into the equations of motion (Eq. 1) provides the complete information of this dynamic system. The six equations describe the force and moment balances along the body coordinates and form a set of first order differential equations with six independent variables u, v, w, p, q and r. In order to find the trajectory and orientation of the craft with respect to the inertial frame, six more first order differential equations are needed to perform the kinematic transformation; they are

$$\begin{bmatrix} \dot{x}_o \\ \dot{y}_o \\ \dot{z}_o \end{bmatrix} = \begin{bmatrix} \cos\theta \cos\psi & \sin\theta \sin\phi \cos\psi - \cos\phi \sin\psi & \sin\theta \cos\phi \cos\psi + \sin\phi \sin\psi \\ \cos\theta \sin\psi & \sin\theta \sin\phi \sin\psi + \cos\phi \cos\psi & \sin\theta \cos\phi \sin\psi - \sin\phi \cos\psi \\ -\sin\theta & \cos\theta \sin\phi & \cos\theta \cos\phi \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$$\begin{aligned} p &= \dot{\phi} - \dot{\psi} \sin\theta \\ q &= \dot{\theta} \cos\phi + \dot{\psi} \cos\theta \sin\phi \\ r &= \dot{\psi} \cos\theta \cos\phi - \dot{\theta} \sin\phi \end{aligned} \tag{63}$$

where x_o, y_o and z_o represent the craft c.g. location with respect to the inertial frame; all other variables have been defined in Table 1. In summary, there are 12 variables and 12 equations. In addition, the cushion volume is controlled by the equation of state and the fan flow which are independent from all the motion variables. Including the cushion volume Equation 34, there are altogether 13 equations and 13 unknown variables. These 13 first order equations have been programmed in a numerical code solving simultaneously through time-wise integration. The solution of this model provides time history of the craft trajectory and orientations for any given wave environment.

5.2 Computer Program

The computer program developed to integrate the equations of motions under the influence of the forces and moments inputed to the craft by the wave environments described previously is now briefly discussed.

Initiation of the computation is made by entering into the program the initial conditions of the craft such as altitude, speed and craft weight. Overall craft dimensions and the geometry of the sidehulls and seals are also required. With the above information the submerged geometry of the sidehulls and seals are calculated and the forces and moments from all sources described in Sections 3 and 4 are calculated. The initial values of all the variables are then used as starting values at time t=0, to initiate integration of the equations of motion.

An overview flow chart illustrating the general operations performed in the computer is shown in Figure 5. The input/out format is given as Appendix B and the complete program listing is included as Appendix C.

A fourth order Runge-Kutta scheme is used for the integration. Through numerical exercises, this method has shown to be extremely efficient. The time step used in calculation varies depending upon the input exciting wave form and frequency. Normally for a sinusoidal wave run, the time step is selected equal to 1/16 the encounter period. For long period solitary waves or explosion waves, 1/64-1/128 of the encounter period has been shown to be appropriate. In general, the time steps used for most of the calculations are between 0.1 - 0.2 second or on the order of 0.05 in terms of non-dimensional time. Typically, for a 100-second real time simulation, a CP time of 19 second is required using a CDC 7600 computer.

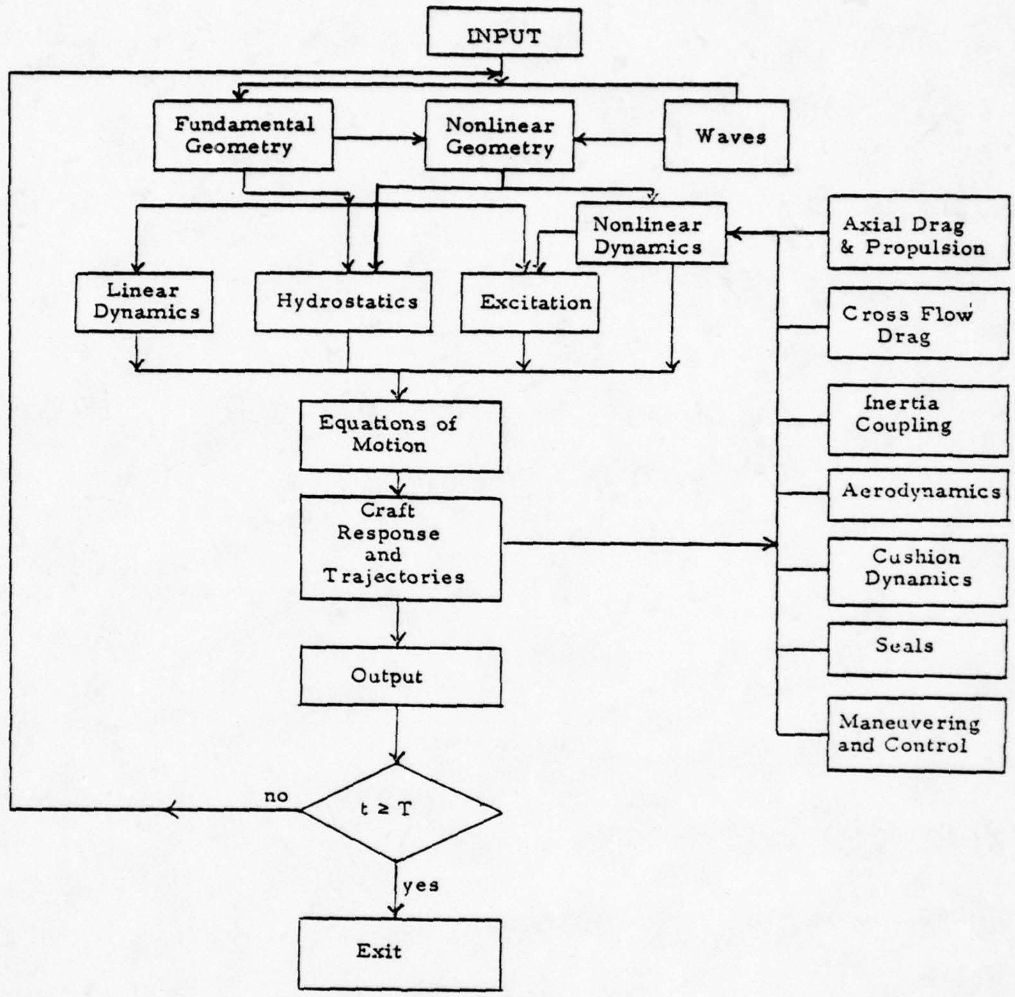

Figure 5 Flow Chart of Computer Code.

6.0 SES RESPONSE IN WAVES

6.1 Craft Characteristics

The computer program has been exercised under various wave conditions and craft headings to investigate the response of a typical SES. Several assumptions are made regarding the craft size and dimensions. In order to make the results relevant to current interests, an SES having characteristics similar to the 2000 ton class was chosen. Some of the salient features of this craft are listed below:

Craft Weight	=	2000 tons
Cushion Length	=	240 feet
Cushion Width	=	88 feet
Center of Gravity location	=	130 feet forward of transom 24 feet above keel

Engine Thrust Characteristics:

Gross thrust in lbs:

$$T_g = 16.1\ U^2 - 190\ U + 528{,}000 - (1-\alpha) \times 4 \times 10^5$$

Momentum drag in lbs:

$$D_m = 3900\ U - 1400\ (1-\alpha)\ U$$

Here α = power percentage level and U = craft speed in knots

Lift Fan Characteristics:

$$Q_f = 75{,}497 - 121\ (p_c - p_a)\ \text{cfs}$$

Bow Seal Angle	=	30 degrees
Stern Seal Angle	=	60 degrees
Initial Air Leakage Area	=	49 ft^2

The definitions of inputs to the computer program and a sample input case are shown in Appendix B. This input provides further information, including details of the sidehull shapes chosen. This shape is representative of typical sidehull designs for SES.

6.2 Sinusoidal Wave Response

In order to exercise the program and obtain a reference base of craft response, a series of runs is conducted using a sinusoidal wave excitation. This wave is chosen to correspond to the significant wave height and period of a Sea State 3,

Wave Height = 5 feet
Period = 6 seconds

Figures 6 through 9 illustrate the results of these runs for the craft at a maximum speed of 80 knots and heading angles of 0°, 45°, 135° and 180°, respectively. The heading is defined as the angle of the course of the craft relative to the direction of wave propagation. A 0° heading indicates that waves move in the same direction as the craft and normally it is termed as following seas. A 90° beam-sea indicates that waves propagate from port to starboard and 180° heading refers to head seas. In these figures the cushion pressure and wave profile are shown in the upper figure; the pitch and yaw in the middle and the heave and roll responses in the lower diagram. The curves are shown as a function of a non-dimensional time, T. The required conversion factor to real time is given in each caption. The craft immersion at the center of gravity is 2.0 feet at an initial trim of 1.0 degree.

The initial conditions for all these runs are set correspondingly to those for operating in calm water. In order to obtain a smooth transition from calm water to the desired wave height, the excitational wave train is modulated by an exponential function as follows:

$$f = 1 - e^{-\alpha t}$$

where t is time and α is a positive constant. This constant is selected such that the resulting wave would reach its steady sinusoidal behavior in about three cycles.

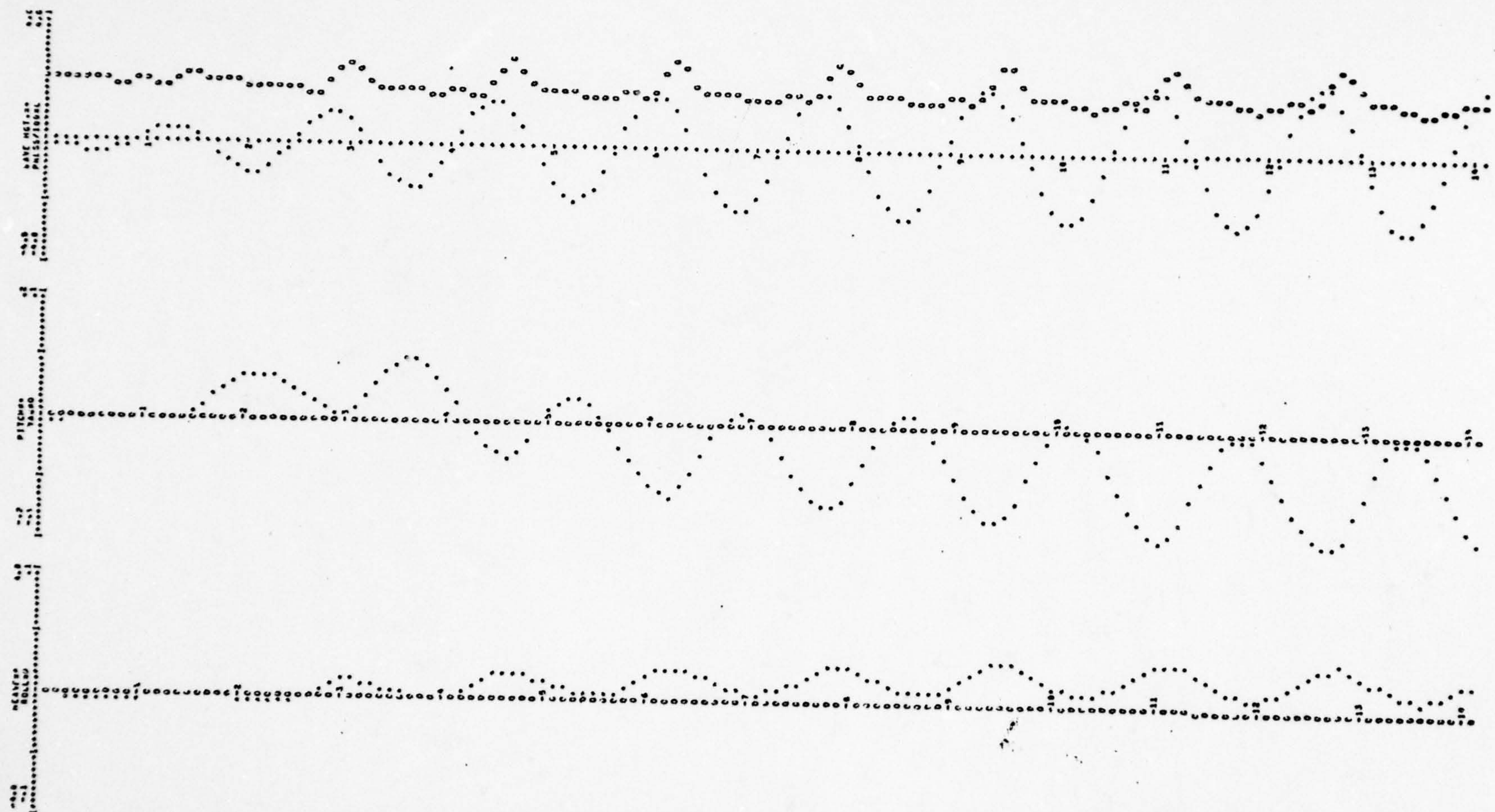

Figure 6 Craft Response in Sinusoidal Waves - wave height = 5 ft, wave period = 6 sec, craft speed = 80 knots, craft heading = 0 deg, t/T = 1.10 sec

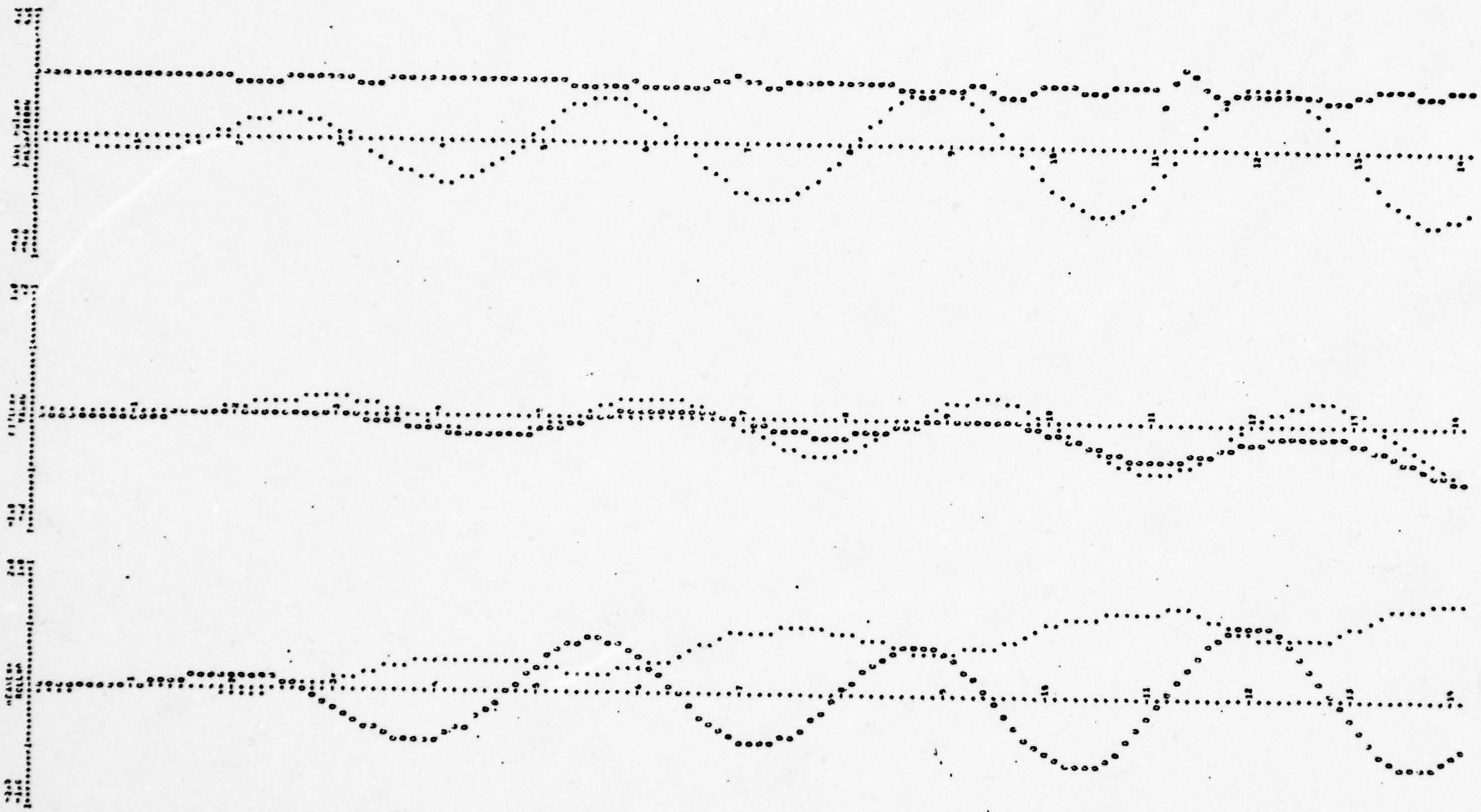

Figure 7 Craft Response in Sinusoidal Waves - wave height = 5 ft, wave period = 6 sec, craft speed = 80 knots, craft heading = 45 deg, t/T = 0.89 sec

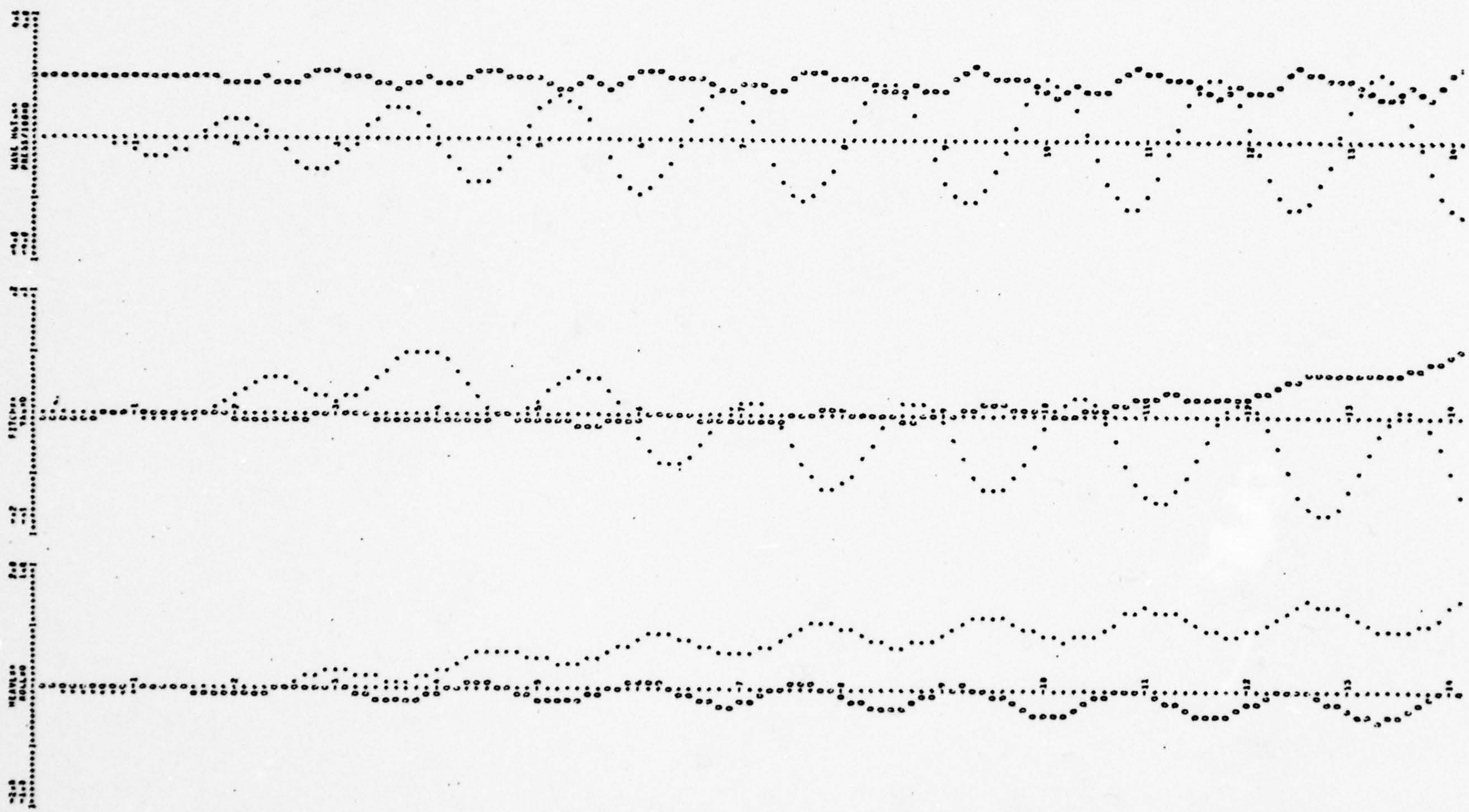

Figure 8 Craft Response in Sinusoidal Waves - wave height = 5 ft, wave period = 6 sec, craft speed = 80 knots, craft heading = 135 deg, t/T = 0.91 sec

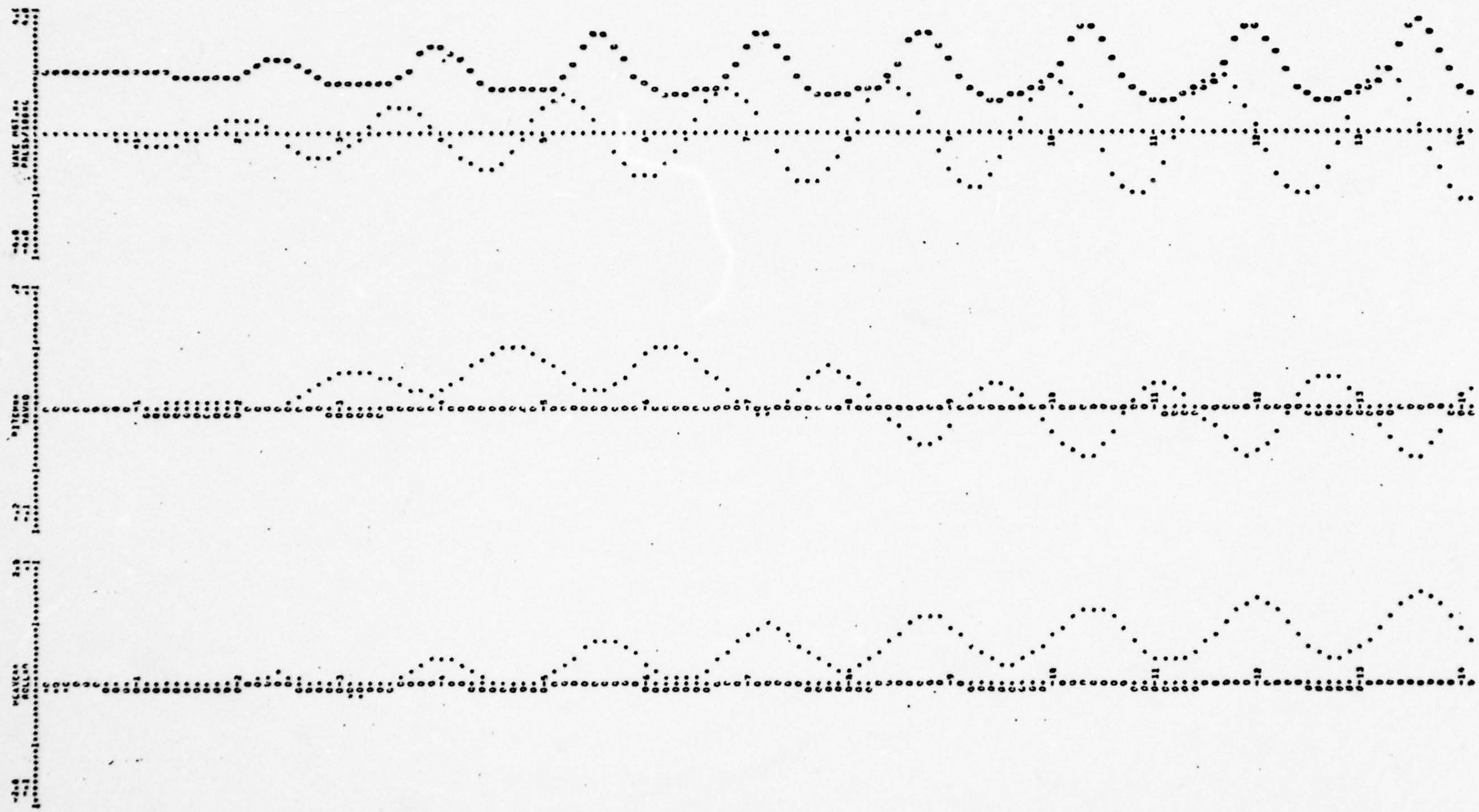

Figure 9   Craft Response in Sinusoidal Waves - wave height = 5 ft, wave period = 6 sec, craft speed = 80 knots, craft heading = 180 deg, t/T = 0.70 sec

A summary of these results are given in Table 3. Two values are given for the motion response; they are the maximum excursion and the peak to peak value. A positive maximum excursion of heave indicates an increased immersion in waves, and similarly a negative maximum excursion of pitch indicates that the bow trims downward in these waves.

As seen from these results, the craft is generally well behaved in this sea state. A relatively larger response in heave and pitch occurs in head and following seas as expected. Particularly of interest is that fairly large oscillations in cushion pressure occur in head seas. Comparison of Figure 6 and 9 specifically illustrates that the cushion pressure is certainly more responsive to head seas than to following seas. The cases with quartering seas, Figures 7 and 8, show roll and yaw responses. The maximum roll amplitude is less than 1 degree in this sea state. The small yaw angles in these two cases simply indicate that the craft would be slightly off the course due to the uneven pressure on the craft caused by oblique waves.

It should be noted that no heave alleviation is considered in all these runs presented above. In order to illustrate the effect of heave alleviation control, a duplicate run for the head sea case was conducted. In this run control constants $C_1 = - 1.34$ ft sec^2 and $C_2 = 0$ are included in the control logic as given in Eq. (50). The results of this run are shown in Figure 10. In comparing with Figure 9, it shows that both the cushion pressure oscillation and the heave excursion are substantially reduced. The improvement of craft behavior through a heave alleviation control seems clearly demonstrated in this example. Again it should be mentioned that the control parameters included in this example are for illustration purpose only, as no optimization analysis of these constants has been conducted.

Table 3

SES Response to Sinusoidal Waves

wave height = 5 feet
wave period = 6 seconds
craft speed = 80 knots

Heading	Heave (ft)	Pitch (deg)	Roll (deg)	Control Constants c_1	c_2	Reference Figure No.
0°	1.67/1.08	-0.19/0.19	0	0	0	6
45°	1.82/0.69	-0.46/0.18	0.77/1.38	0	0	7
135°	1.17/0.51	-0.17/0.15	0.20/0.24	0	0	8
180°	1.50/1.00	-0.08/0.14	0	0	0	9
180°	1.16/0.55	-0.09/0.09	0	-1.34	0	10

Responses are given as maximum excursion/peak-to-peak excursion

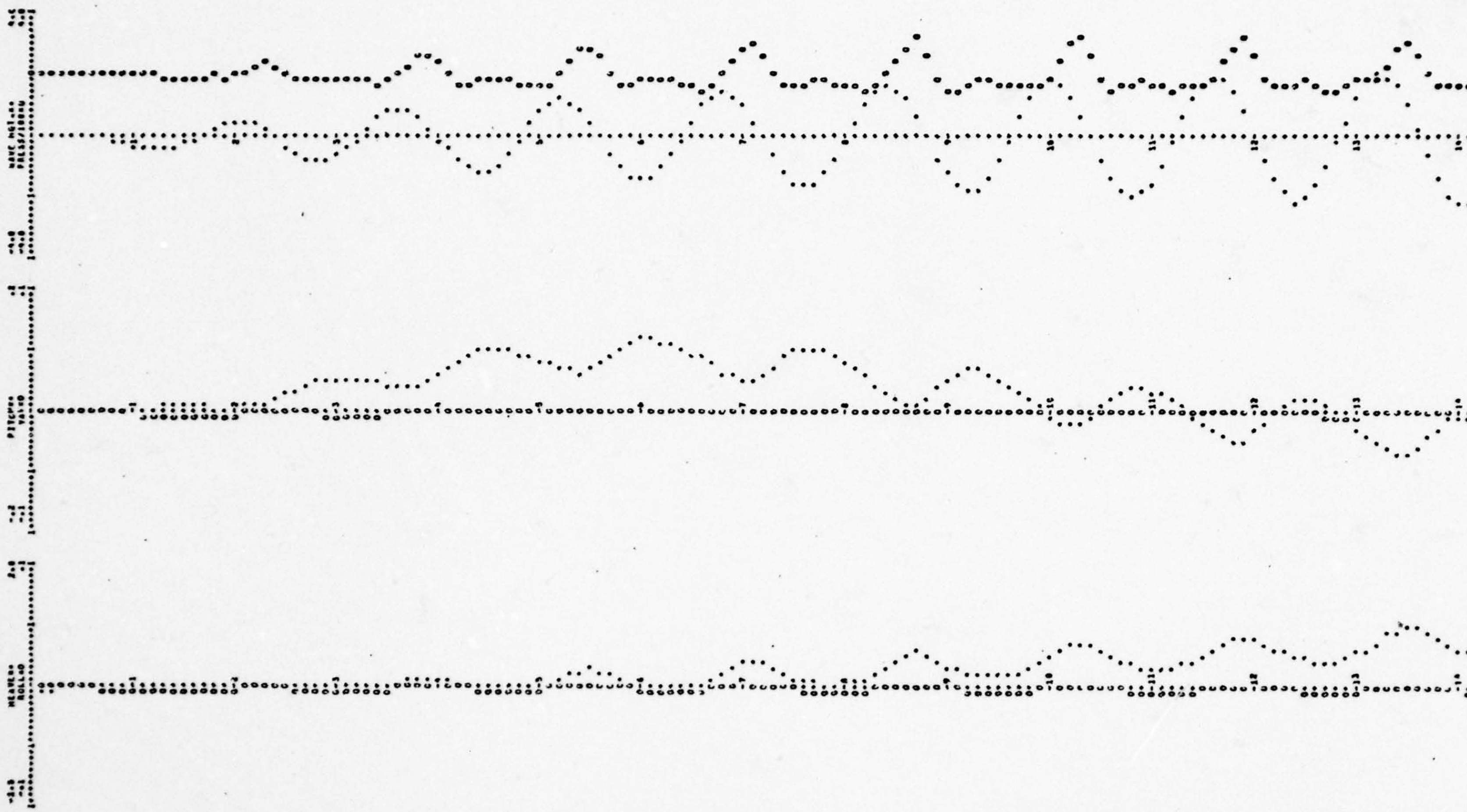

Figure 10 Craft Response with Heave Alleviation Control in Sinusoidal Waves - wave height = 5 ft, wave period = 6 sec, craft speed = 80 knots, craft heading = 180 deg, heave control constant $c_1 = -1.34$ ft sec^2, $t/T = 0.70$ sec

6.3 Solitary Wave Response

As discussed in section 5, the waves caused by deep water explosion when propagated into shallow water can be represented by solitary waves. In this regard, a series of runs to investigate the craft response to a solitary wave at various headings has been conducted. Furthermore, the effect of varying water depth and wave height is examined. For these runs the initial trim and center of gravity immersion are the same as before taken to be 1 degree and 2 feet, respectively. Figures 11 through 17 show the results of these runs for a craft speed of 50 knots, except one run in a near hovering mode (acutal speed is 5 knots). The maximum craft excursions are summarized and shown in Table 4.

The hovering condition is shown in Figure 11. In this run, the water depth is taken as 60 feet with a wave period of 15 seconds and wave height of 6 feet. With these conditions the ratio of wave length to cushion length is 2.88. Behavior of the craft is quite acceptable with the maximum pitch and heave excursions shown in Table 4.

The effects of varying heading angle for the conditions described in the above case are shown in Figures 12, 13 and 14. As seen from these figures, the pitch excursions increase as the heading varies from a beam sea condition to a head sea. Attendant with this change in heading, the roll and yaw decreases. In the case of 90^{o} heading or beam seas the roll motion is excited at a natural period of about 4.7 seconds. It is apparent from these curves that the craft will survive this wave environment without undue difficulty.

Figures 15, 16 and 17 illustrate the behavior of the craft under different combinations of wave height, water depth and wave period for a head sea, i.e., heading of 180^{o}. In the first two cases,

Table 4

SES Response to Solitary Waves

Water Depth (ft)	Wave		Heading (deg)	Speed (kn)	Maximum Excursions				Wave length/ Cushion Length	Reference Figure No.
	Period (sec)	Height (ft)			Heave (ft)	Pitch (deg)	Roll (deg)	Yaw (deg)		
60	15	6	0	0	-4.70	-3.61	0	0	2.88	11
			90	50	-5.00	-0.31	5.10	-2.70	-	12
			135	50	-4.48	-1.97	4.19	-0.89	-	13
			180	50	-4.72	-3.69	0	0	2.88	14
60	30	10	180	50	-8.08	-5.37	0	0	5.95	15
30	30	5	180	50	4.46	-3.55	0	0	4.21	16
30	15	6.5	180	50	7.90	-5.78	0	0	2.15	17

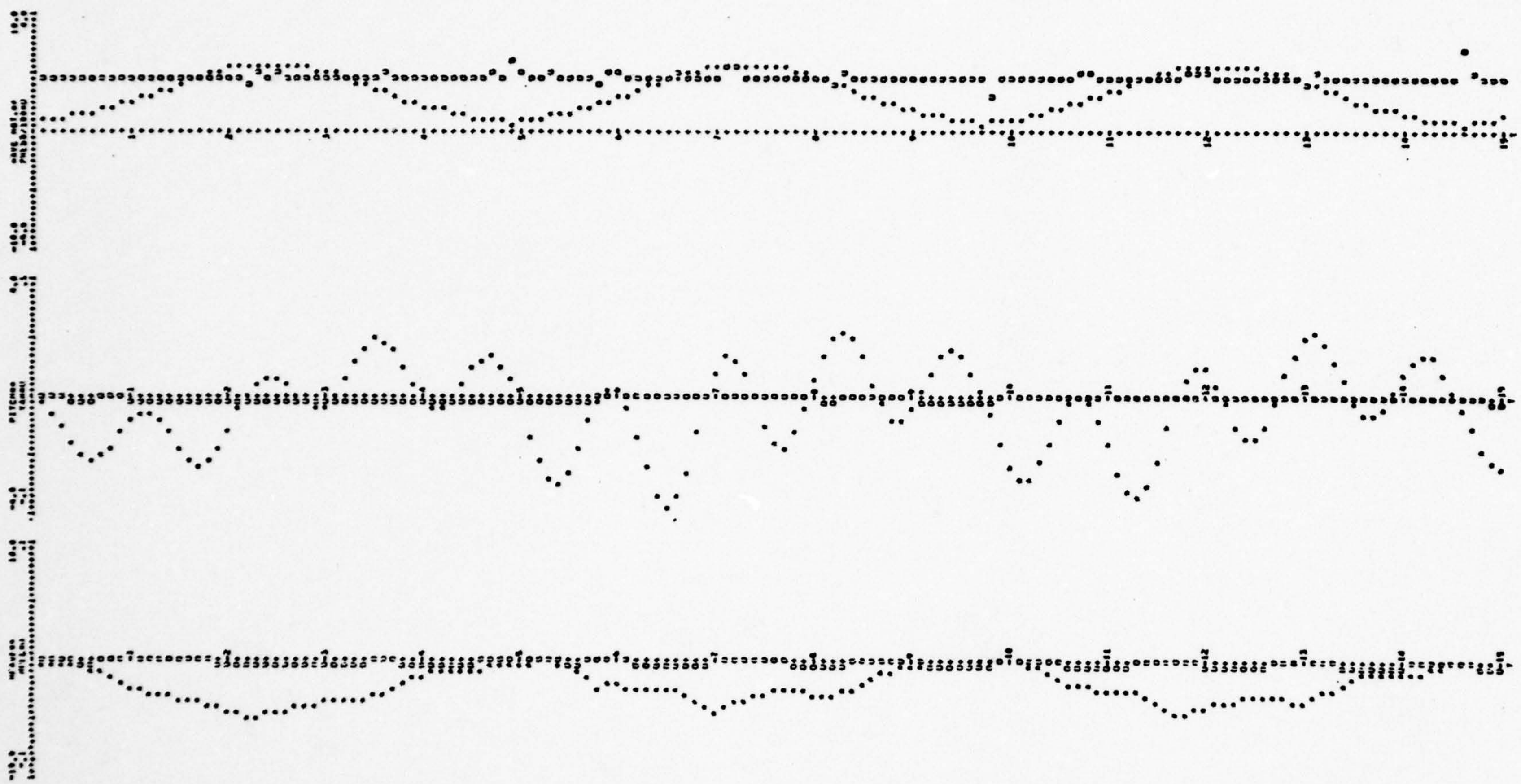

Figure 11 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 0 (hovering), craft heading = 0 deg, $\frac{t}{T} = 3.82$ sec

Figure 12 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 90 deg, t/T = 3.12 sec

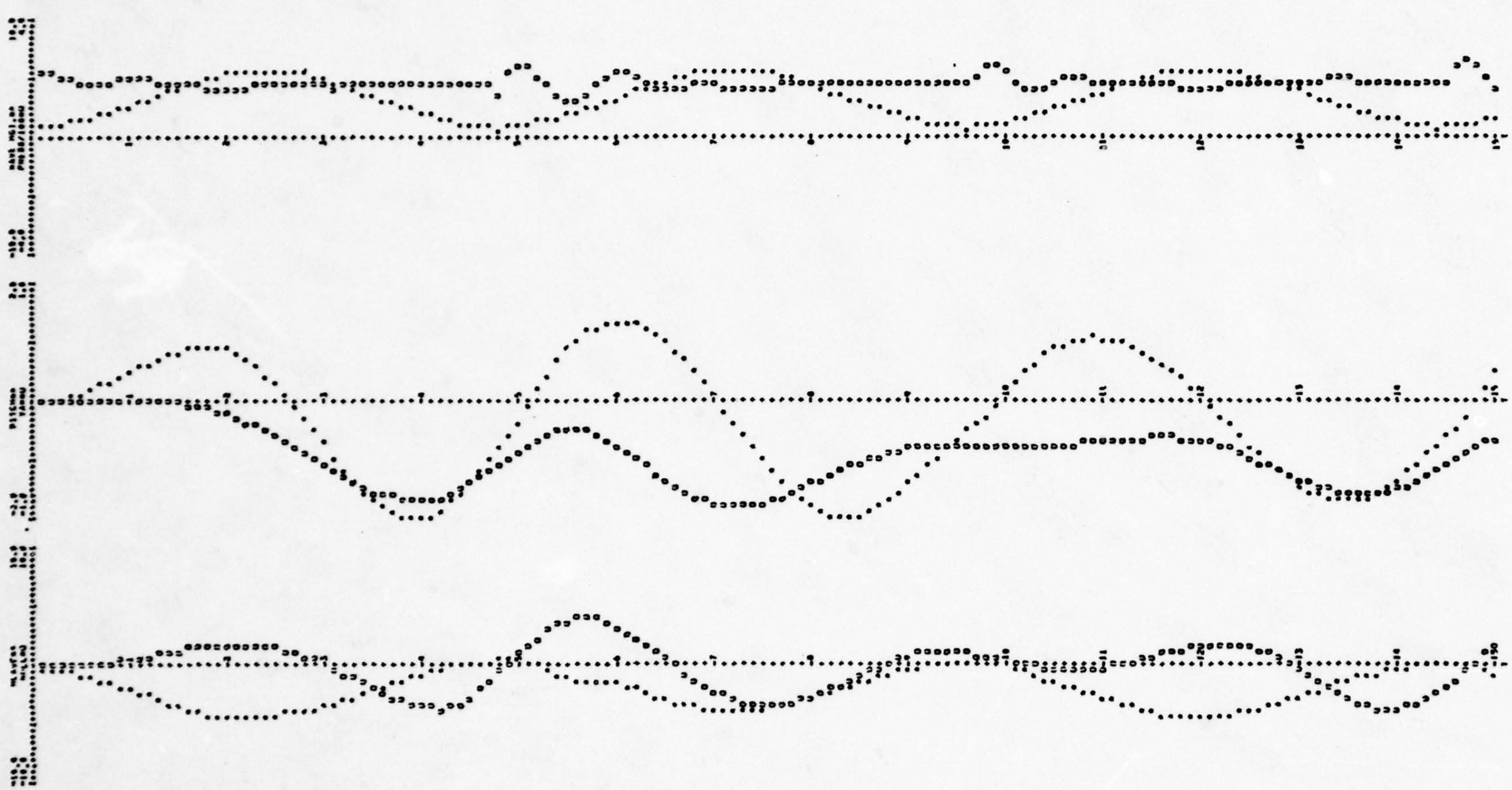

Figure 13 Craft Response in Shallow Water, water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 135 deg, $\frac{t}{T}$ = 1.36 sec

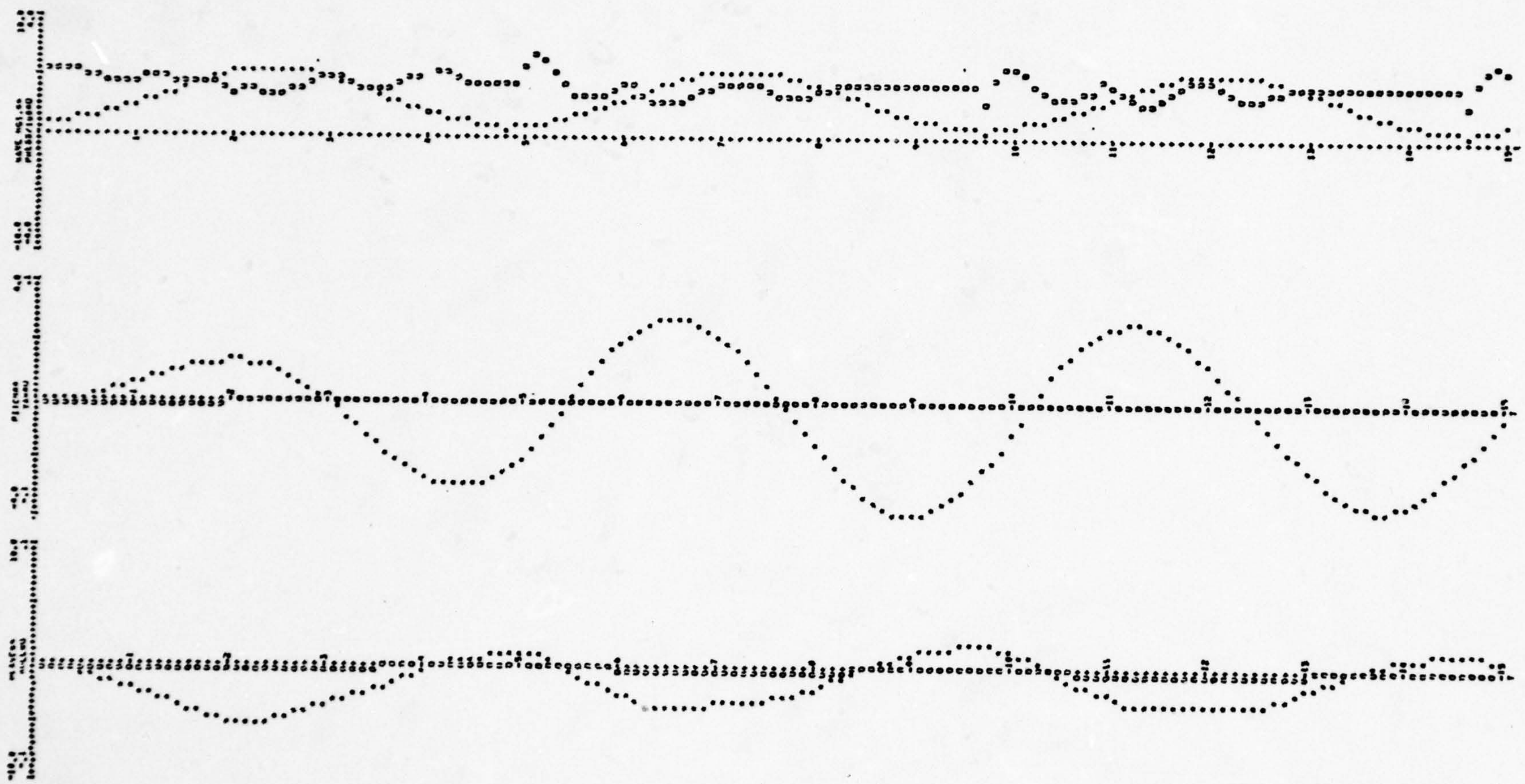

Figure 14 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 180 deg, $\frac{t}{T}$ = 1.10 sec

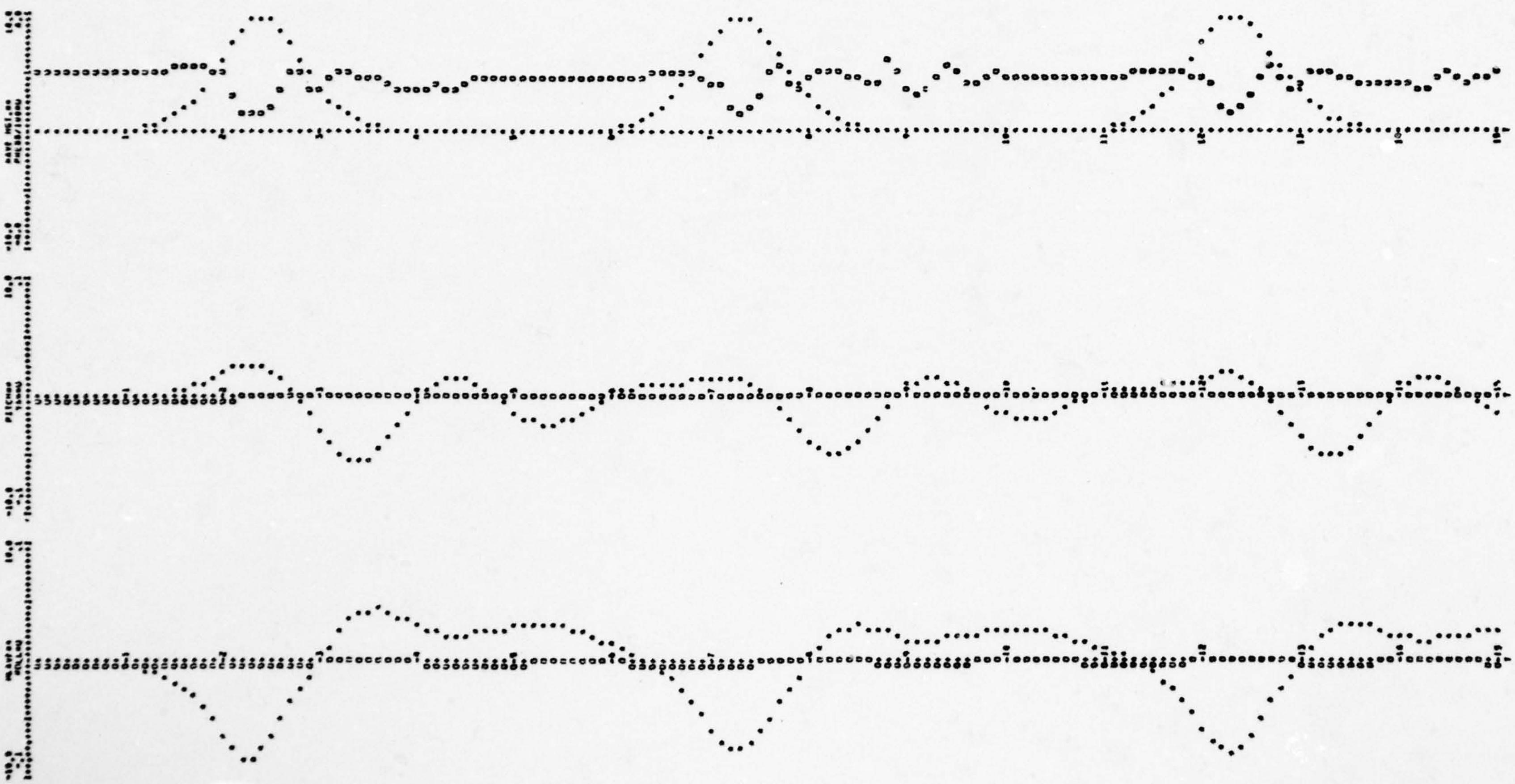

Figure 15 Craft Response in Shallow Water - water depth = 60 ft, wave period = 30 sec, wave height = 10 ft, craft speed = 50 knots, craft heading = 180 deg, $\frac{t}{T}$ = 2.25 sec

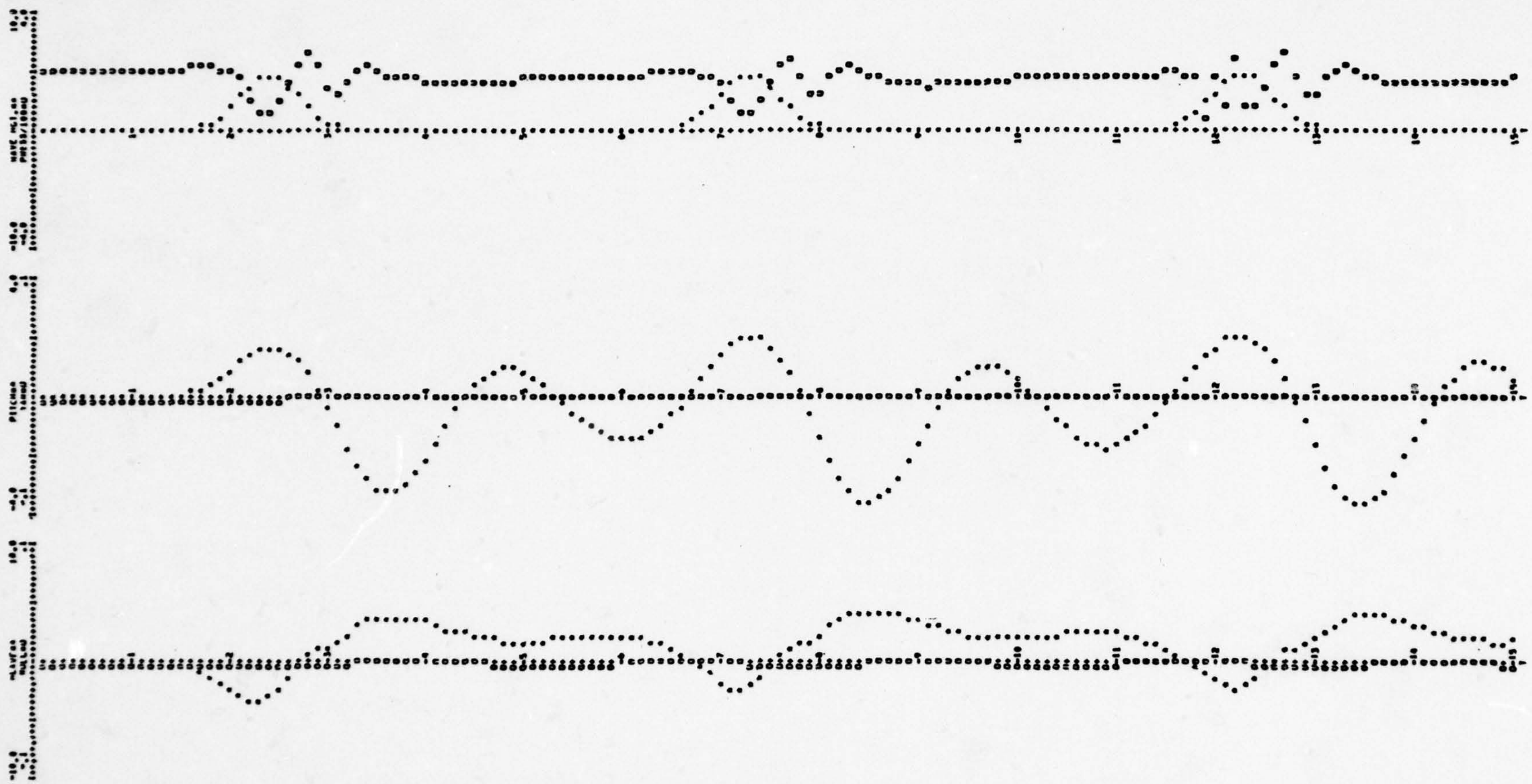

Figure 16 Craft Response in Shallow Water - water depth = 30 ft, wave period = 30 sec, wave height = 5 ft, craft speed = 50 knots, craft heading = 180 deg $\frac{t}{T}$ = 1.78 sec

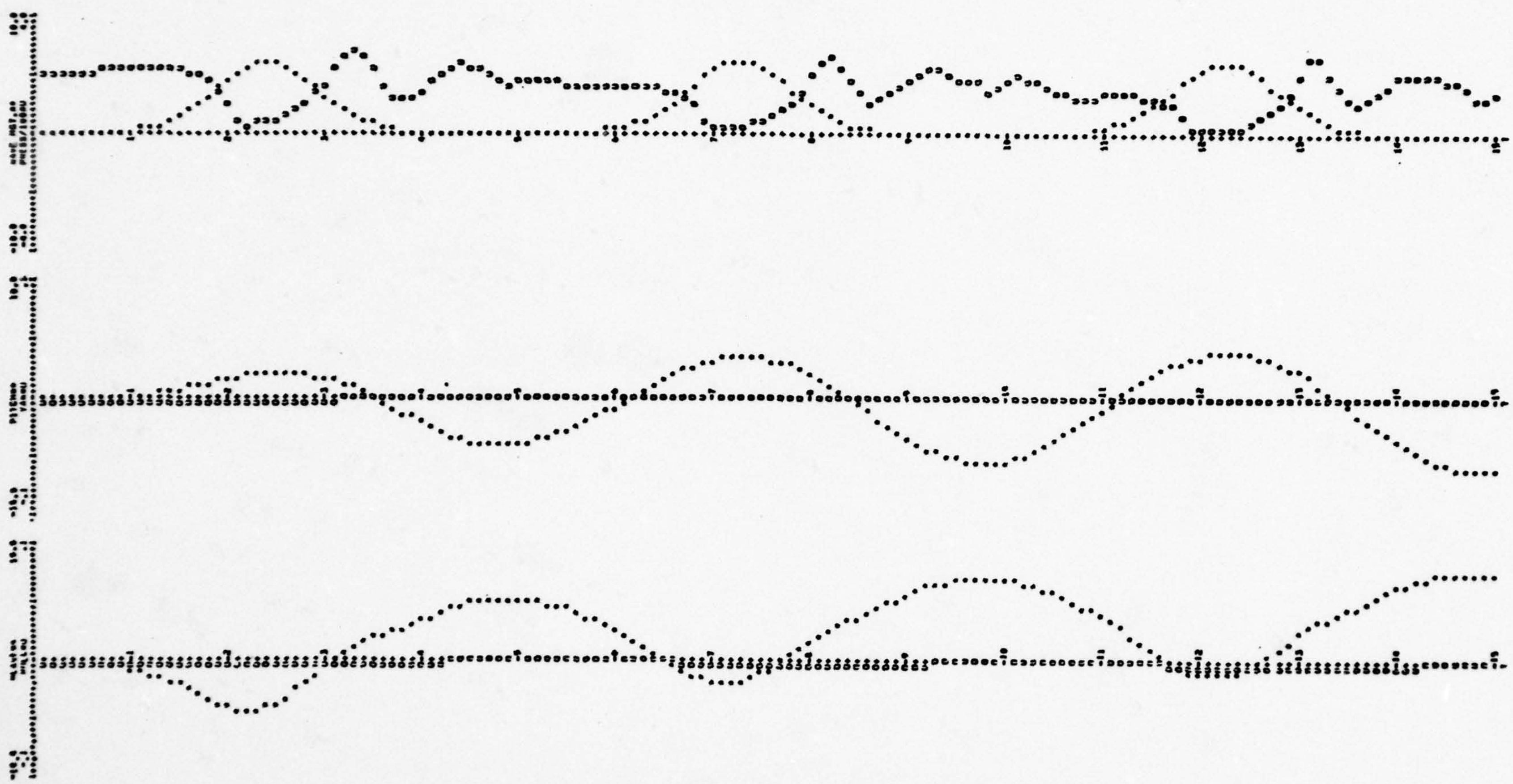

Figure 17 Craft Response in Shallow Water - water depth = 30 ft, wave period = 15 sec, wave height = 6.5 ft, craft speed = 50 knots, Craft heading = 180 deg, $\frac{t}{T}$ = 0.91 sec

as shown in Figures 15 and 16, craft response is reasonable although some relatively large heave and pitch excursions occur in the 10 foot wave condition.

The normal reaction of the craft on encountering the wave front is to increase its trim with a simultaneous increase in immersion. This behavior is to be anticipated since the craft is impacting the wave. In accordance with the larger trim angle, the cushion pressure decreases due to increase leakage. After the wave crest has passed, trim decreases and leakage closes and cushion pressure returns to normal. The craft continues its pitch oscillations at its own natural period (~4.3 second) and consequently the immersion remains deeper than the nominal. In Figure 17 it is apparent that large excursions in pitch and heave are occurring and furthermore these motions are diverging. This particular run condition is taken at a ratio of wave length to cushion length of 2.15, which is very close to the wave pumping condition of 2. Therefore it is expected that severe conditions will arise. As seen in Table 4, the maximum heave and pitch are larger in relation to the wave amplitude than in all other cases. It is apparent that under this condition the craft is not likely to survive without evasive action.

6.4 Deep Water Explosion Wave Response

Samples of calculated results presented in this section are for a deep water explosion wave environment generated by an explosion yield of 1 kiloton. A device having this yield and exploding at the upper critical depth would cause a disturbance having a crater radius of 835 ft. and crater height of 49 ft. It is assumed that the stand-off distance of the craft from the center of the blast is 7500 ft. The initial significant wave disturbances would take about 80 seconds to reach to the craft at this stand-off position. Allowing the craft to have 80 seconds reaction time to initiate its action, some calculated results are shown in Figures 18 through 21.

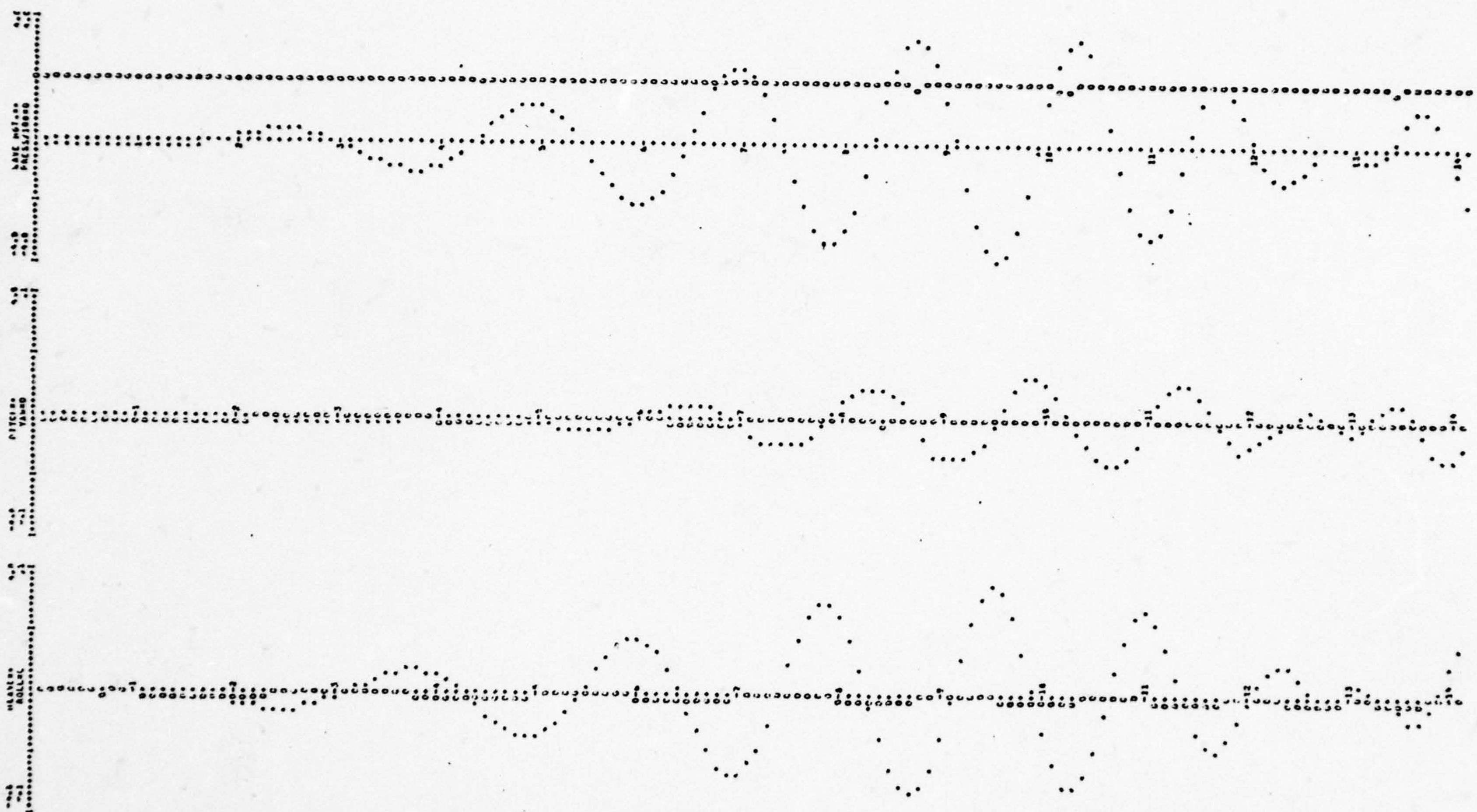

Figure 18 Craft Response to Explosion Waves in Deep Water - yield = 1 KT, stand-off distance = 7,500 ft, craft speed = 0 (hovering), craft heading = 180 deg, t/T = 8.93 sec, T_o = 80 sec

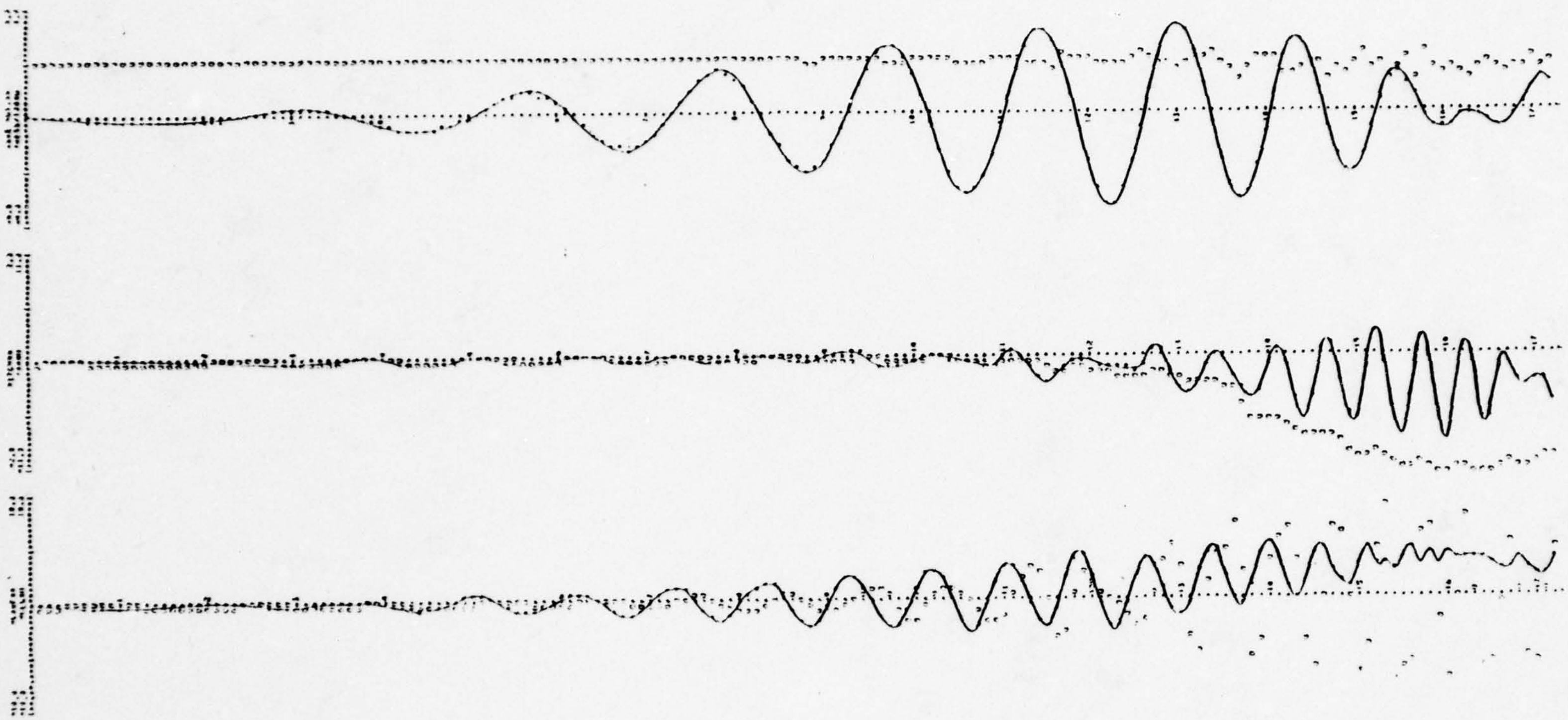

Figure 19 Craft Response to Explosion Waves in Deep Water - yield = 1 KT, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 90°, $\frac{t}{T}$ = 9.36 sec, T_o = 80 sec

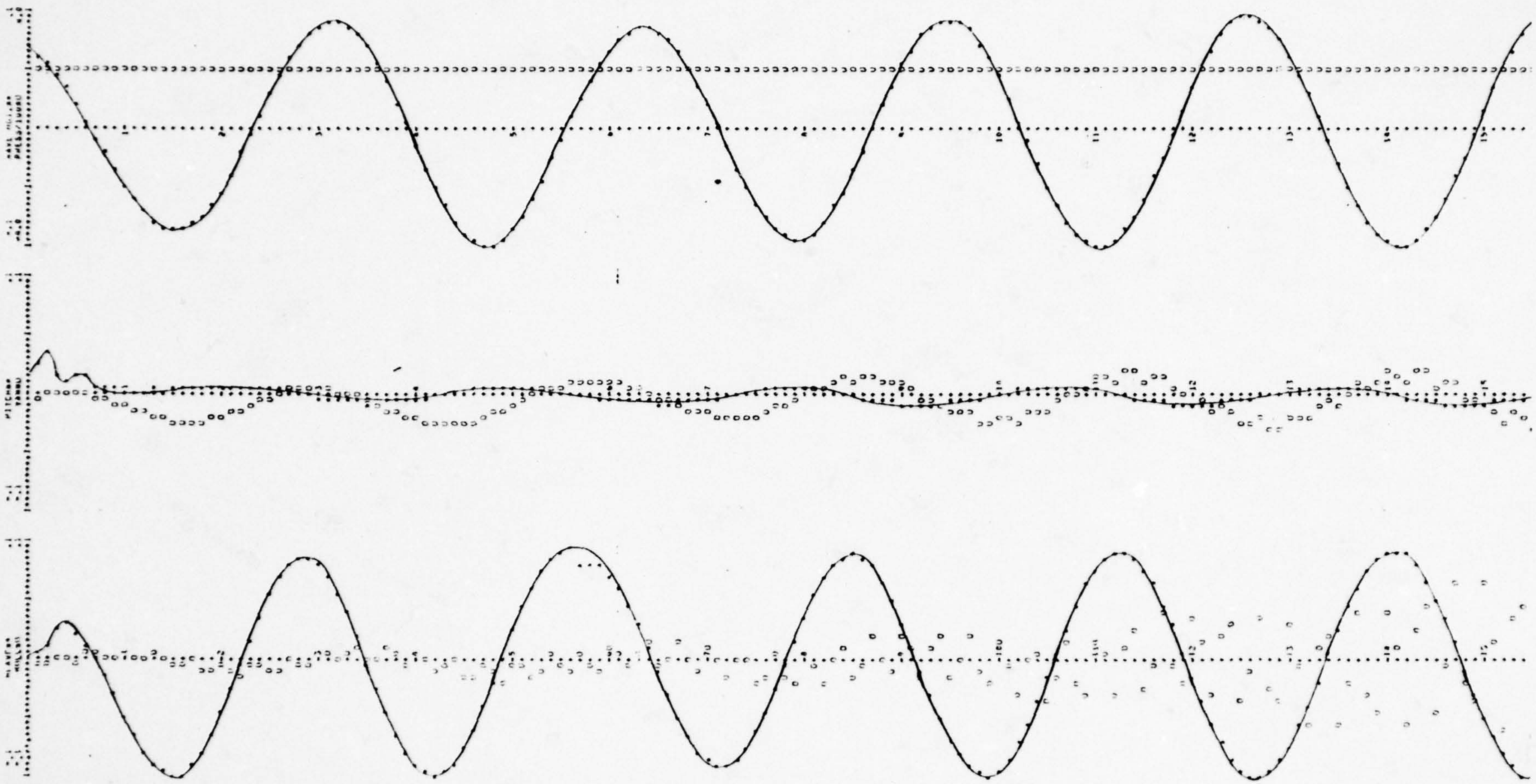

Figure 20 Craft Response to Explosion Waves in Deep Water - yield = 1 KT, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 45°, $\frac{t}{T}$ = 15.3 sec, T_o = 80 sec

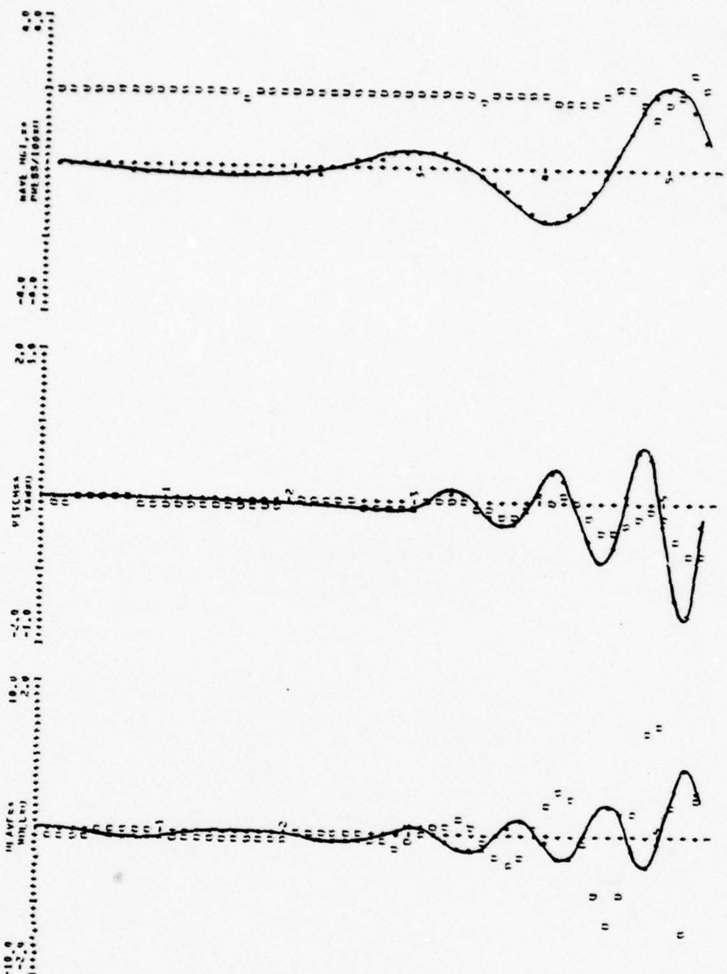

Figure 21 Craft Response to Explosion Waves in Deep Water - yield = 1 KT, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 135°, $\frac{t}{T}$ = 6.76 sec, T_o = 80 sec

From Figure 18 it is seen that at this distance from the blast, the maximum wave height encountered is approximately 7 feet. The graph shows the arrival of the first wave group and the subsequent response of the craft. The results are for the craft in hovering mode, head into the waves. As seen all the variables are within normal excursions with a maximum pitch of -1.55° and heave of 2.85 ft. The wave envelope shown in this figure is typical of the explosion generated wave envelopes.

Should a blast occur off the beam of the craft when operating at 50 knots the results indicate that the craft will probably not survive the waves. As seen in Figure 19 large excursions in roll and heave are experienced. The maximum excursion in these variables are 8.98° and 4.85 ft, respectively. The maximum pitch angle experienced is -1.52° which is nominal. The larger negative yaw excursion indicates that the craft tends to alter its course and turn its bow into the wave front. It is apparent from this response that the craft is quite vulnerable to beam explosions.

Should the craft be operating at 50 knots and an explosion occur the question arises as to what evasive action it should take. As a preliminary maneuver it has been assumed that a reaction time of 80 seconds is required for the craft to either alter its course to another heading or head up into the blast and kill its engines. We have seen that in this latter mode it can survive the present explosion. The question arises as to whether an alternative course heading is preferable. To investigate this possibility, two headings of 45° and 135° are investigated.

Figure 20 shows the response of the craft to the waves environment on a heading of 45° assuming such a heading is achieved 80 seconds after the blast. As is seen little if any motion occurs to the craft since the craft is heading away from the wave front and is apparently in small, long period waves ahead of the main group of waves. Provided sufficient clear sea is available the craft could outrun the wave until the waves had decayed sufficiently to allow a change in heading. The same conclusion can be applied for a 0° heading or the following wave case.

Should the craft head into the blast on a 135° course, an unlikely situation unless it was already on this course when the blast occurred, the response is shown in Figure 21. Here it will be seen that the motions are diverging and indeed, based on the present analysis, the craft will not survive. As will be seen the run was actually terminated before the motions become excessive.

It is apparent from this sample survey that dependent on the location of the blast relative to the craft and the available response time, several possible scenarios exist for evasive action subsequent to a blast. It is also clear that relatively moderate yields can cause an SES considerable difficulty if cognizance of the seriousness of the situation is not realized.

7.0 VULNERABILITY ANALYSIS

7.1 Scope of the Study

In the present study, we limit our analysis to a 2000-ton class SES, the characteristics of which have been defined in Section 6.1. Although the most current trend of the U. S. Navy interest is a 3000 -ton craft, there should be little significant difference in performance between these two ships, as their forms and sizes are not drastically different. The design speed of a 2000-ton craft is taken to be 80 knots. Because of the speed-drag characteristics of this kind of vehicle, the cruising speed is around 50 knots. This speed occurs at an optimum on-cushion drag condition and yield the least lift-drag ratio for the craft. In this analysis, therefore we conduct all the exercises at the one craft speed of 50 knots. since the SES has another unique mode of operation - the hovering mode, several runs at this condition are conducted for comparison purposes.

The major parameters to be varied in this analysis are the yield, stand-off distance and heading. The effects of these parameters in both deep and shallow water environments are considered. In summary, the ranges for each variable investigated are given in Table 5.

Table 5. Range of Investigation

Craft Size	2000 ton
Speed	Cruising (50 knots) and hovering (0 knots)
Yield Range	0.5 - 2.0 K-tons
Heading	0° - 180°
Stand-off	7,500 - 20,000 ft
Water Depth	Deep ocean and shallow shelf with 0.01 slope.

7.2 Deep Water Hazard

In order to investigate the craft behavior in wave environments of various yield explosions, the wave history as function of position and time corresponding to each yield device must first be determined. As discussed in Section 4.2, the wave history for an explosion is controlled by two parameters, the crater radius and the crater height, which are in turn controlled by the charge depth. It is known that better generation efficiency occurs when the charge is placed at the upper critical depth. As shown in Figure 4, at this depth the maximum wave parameter $\eta_{max} r/w^{0.54}$ may reach as high as 18. Nevertheless, the measurements are very much scattered, especially at this charge depth. In the present analysis, taking a conservation estimate, we assume $\eta_{max} r/w^{0.54}$ to be 10, which corresponds to an average value for a charge at the upper critical depth. This, together with the empirical relation $k_{max} = 0.29\ w^{-0.3}$ (Eq. 55) determines the crater radius and height. The results for four different yield explosions are calculated and given in Table 6. With the crater radius and height known, the wave history as a function of position and time can be readily claculated according to Eq. 52.

Table 6. Crater Dimensions

Yield Weight W	Crater Radius R_o	Crater Height η_o
KT	ft	ft
0.5	680	41
1.0	835	49
1.5	945	54
2.0	1025	58

Four stand-off distances are considered, they are 7,500', 10,000', 15,000' and 20,000'. The heights of the maximum wave in the leading wave envelope at these distances are calculated and given in Table 7. The period and the phase velocity of this maximum wave for each yield weight are also determined and included in this table.

The craft responses at the four stand-off positions have been calculated for each explosion considered. The craft headings are varied from 0° to 180°, which are representative for all possible encounter directions for a craft having a transverse symmetry. These exercises have been performed for the purpose to identify that stand-off position for a particular craft heading at which the craft would marginally survive the explosion. A sufficient number of computer runs have been performed to complete the exercise. From the results of these computer runs, operational envelopes to define the region for safe maneuvers are obtained and shown in Figure 22. The craft is defined unsafe in a given operating condition if its motions, especially pitch and roll, diverge to cause large cushion leakage. These envelopes are plotted with the craft headings as a parameter. For a given heading, an envelope defines the limit of safe stand-off distances as a function of the explosive yield. The operating area under each curve provides a means of identifying the degree of safety for the particular heading. Alternatively, these curves can be used to determine a safe heading to take for a known yield explosion w at a known stand-off distance x. For instance, a craft would operate safely at any heading if the environmental coordinates (x,w) fall under the $\pm 180^{\circ}$ envelope. On the other hand, if the explosive yield is so large or the stand-off distance is so close to the blast that the coordinates (x,w) are just under the $\pm 90^{\circ}$ curve, the craft may only operate safely with its absolute heading angle less than 90°, beyond which the craft becomes vulnerable.

Table 7. Wave Characteristics at Various Stand-off Distances

Yield Weight	Stand-off Distance	Height of Max. wave	Period of Max. wave	Celerity of Max. wave
K-ton	ft	ft	sec	ft/sec
0.5	7,500	4.64	14.11	72.29
	10,000	3.47		
	15,000	2.32		
	20,000	1.74		
1.0	7,500	6.73	15.61	80.02
	10,000	5.05		
	15,000	3.37		
	20,000	2.53		
1.5	7,500	8.38	16.60	85.06
	10,000	6.30		
	15,000	4.19		
	20,000	3.15		
2.0	7,500	9.80	17.29	88.63
	10,000	7.34		
	15,000	4.90		
	20,000	3.67		

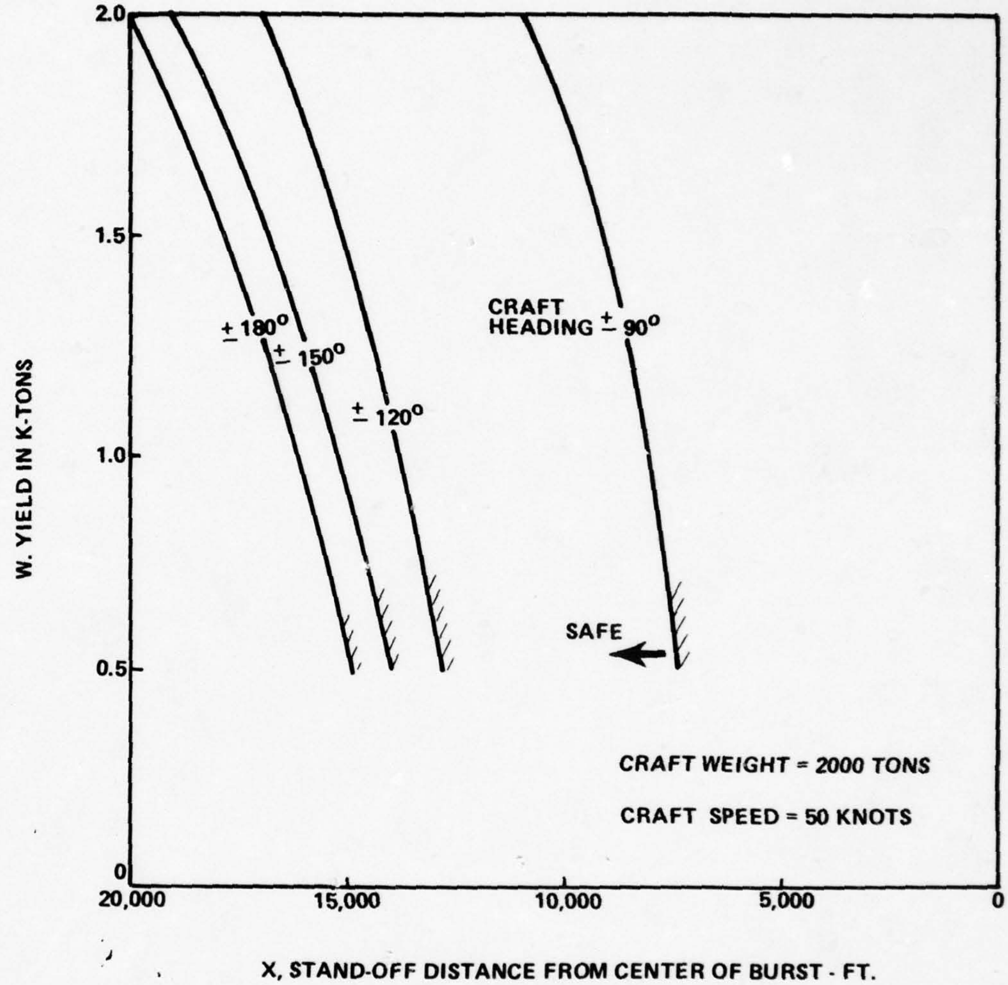

FIGURE 22 - OPERATION ENVELOPE AS A FUNCTION OF CRAFT HEADINGS

The results show also that the craft is not too sensitive to the size of explosion within the range of yields considered in the present analysis, but is very much affected by the craft heading and the stand-off distance. For instance, the figure shows that at a stand-off distance of 20,000 ft the craft may head in any direction without difficulties at a cruising speed of 50 knots, regardless of whether the explosion is due to a 0.5 kilo-ton or a 2.0 kilo-ton device. Similarly, when the stand-off distance is 7,500 ft, the craft can only head away from the explosion or run out from the waves in order to survive. In other words, the craft should avoid any heading greater than 90° (port or starboard), no matter whether it is a 0.5 kilo-ton or a 2.0 kilo-ton explosion. As defined previously, a craft heading between 0 and $\pm 90^{\circ}$ corresponds to following and stern waves and a heading between $\pm 90^{\circ}$ and $\pm 180^{\circ}$ corresponds to bow and head waves. It is unlikely in any event that a craft would deliberately head into the direction of an explosion (between $\pm 90^{\circ}$ and $\pm 180^{\circ}$), unless it had been already on that course and could not alter it before the wave arrives. Should there be sufficient time available, however, Figure 22 definitely provides a useful guidance for a proper response under any given set of prevailing circumstances defined.

7.3 Shallow Water Hazard

As discussed in section 4.3, shallow water waves can be generated by explosions in two ways, (1) produced by explosions in deep water and transmitted into the shallow water shelf, and (2) produced by explosions over the shallow water region of the continental shelf. Since the yield size in this study is limited to 2.0 k-ton,the waves generated by a device of this size in deep water region would not produce significant effects on the shallow water region close to the shore as a result of spreading and dispersion across the long distance over the continental shelf. Therefore, only the second case is considered here.

For the purpose of calculating the shallow water hazard, an idealized ocean bottom topography is assumed here. The width of a typical continental shelf is in the order of 100 nautical miles with a slope of 0.01, and the water depth at the edge of the continental slope is therefore about 6,000 ft. It is known that shallow water explosions are not as efficient as a deep water explosion. Hence, the present analysis is centered only on the largest yield, i.e. a 2.0 k-ton device. Explosions at two water depths, 100 ft and 50 ft, are considered. With the idealized continental shelf assumed above, the charge location for a 100 ft deep water explosion is approximately 10,000 ft from the shoreline and that for a 50 ft deep water 5,000 ft. Assuming that the effects of dispersion and refraction are negligible and considering simply that these waves are two-dimensional and parallel with the shoreline, the procedures presented in Section 4.3 can be used to calculate the characteristics of waves generated in shallow water of constant depth. When these waves propagate toward the shoreline to even shallower water, however, a correction to the wave height due to shoaling must be taken into account. If H_o is the height of the waves in deep water, through shoaling the height in shallow water of a depth h would be

$$H = H_o \left[\tanh kh \left(1 + \frac{2\ kh}{\sinh 2\ kh}\right)\right]^{-\frac{1}{2}} \qquad (64)$$

where k is the wave number which has been defined in Section 4.2. The ratio of H/H_o is called the shoaling factor. Given in Table 8 are the wave heights calculated at various stand-off distances from the explosion detonated at two charge positions on the continental shelf. As mentioned in the foregoing, the wave generation efficiency in shallow water is not as good as in deep water; however, because of the bottom slope, the wave heights at comparable stand-off distances are considerable higher due to the shallow water shoaling effect as shown in Table 8.

Table 8. Shallow Water Waves at Various Stand-off Locations.

Water Depth at Charge Location	Craft Location			Wave Height	Wave Height/ Water Depth
	From Burst	From Shore	Local Water Depth		
ft	ft	ft	ft	ft	
100	2,500	7,500	75	10.50	0.14
	5,000	5,000	50	7.27	0.15
	7,500	2,500	25	7.39	0.30
50	2,500	2,500	25	7.9	0.32

As discussed in Section 5, when waves are high in relatively shallow water, they can be depicted as solitary waves. The primary parameter controlling the solitary wave form is the wave height/water depth ratio. Waves become very peaked when this ratio is large and when this ratio reaches a value of about 0.7, the waves start to break and form a series of breakers, as is commonly seen at a beach. Consequently, the important parameter with regard to the craft dynamics in this case is also the wave height/water depth ratio rather than the wave height itself. A series of computer runs to analyze the craft motions was performed for each case listed in Table 8. Again, a craft cruising speed of 50 knots is assumed. Craft headings are varied from 0° to 180° in the computer runs in order to identify the sensitivity of this parameter to the craft survivability. As expected, for the cases of lower wave height/water depth ratio (0.14 and 0.15 in Table 8), the calculated results show the craft is safe to run in any direction with no catastrophic results. When the wave height/water depth ratio reaches 0.3, however, the operation headings are limited only to stern and following waves, or 0 to $\pm 90^{\circ}$. The strategy here is essentially to outrun the waves by heading away from the blast. An additional feasible operation for survival in these cases is to head into the waves (180° heading) in a hovering mode. This mode of operation is especially useful when the craft is very close to the shore with little room for maneuvering or alternatively when no time is available for any other action.

The above discussion has assumed that the craft is caught between the explosion and the shore. On the other hand, if the craft happens to be seaward of the explosion, the threat becomes much less. First of all, the wave would be much smaller in deeper water for the same stand-off distance, and secondly, the craft has ample room to run from the waves toward the ocean. Interesting to note is that as contrast to the deep water explosion case, the stand-off distance is not the primary controlling factor for the craft safety in the shallow water case. As shown in Table 8, the waves present no threat when the craft is 2,500 ft away in water of 75 ft deep, but the craft becomes vulnerable at 7,500 ft stand-off only because the water there is shallower (25 ft) and the wave height/ water depth ratio becomes large.

7.4 Effect of Heave Attenuation

In the previous sections, the safe operational envelope for an SES craft in both deep and shallow water explosion environment has been discussed. It is noted that all the computations presented in the previous sections do not include any control for heave attenuation. Whereas it is not the intention of the present effort to design an optimum control system for the craft, some calculations including a simple control logic have been exercised so as to demonstrate that the operational envelope defined previously can be improved through heave alleviation control.

Figure 22 has indicated that, without heave alleviation control, the craft could not survive a 1 k-ton explosion on the beam at a stand-off distance of 7,500 ft. Computations have been performed for the same case to include a simple control logic described by Eq. 50 with the control constants assigned as $C_1 = -1.34$ ft sec^2 and $C_2 = 0$. The results are plotted and shown in Figure 23. As seen, the calculation shows that the craft would now remain safe in this wave environment. This exercise demonstrates the importance of heave control devices in SES dynamics. Since no optimization of the control constants has been performed for the craft, no attempt to improve the operational envelope through heave alleviation controls has been conducted. The control system design is considered beyond the scope of the present study. Suffice it to say that such a system improves performance and greatly enhances craft maneuverability.

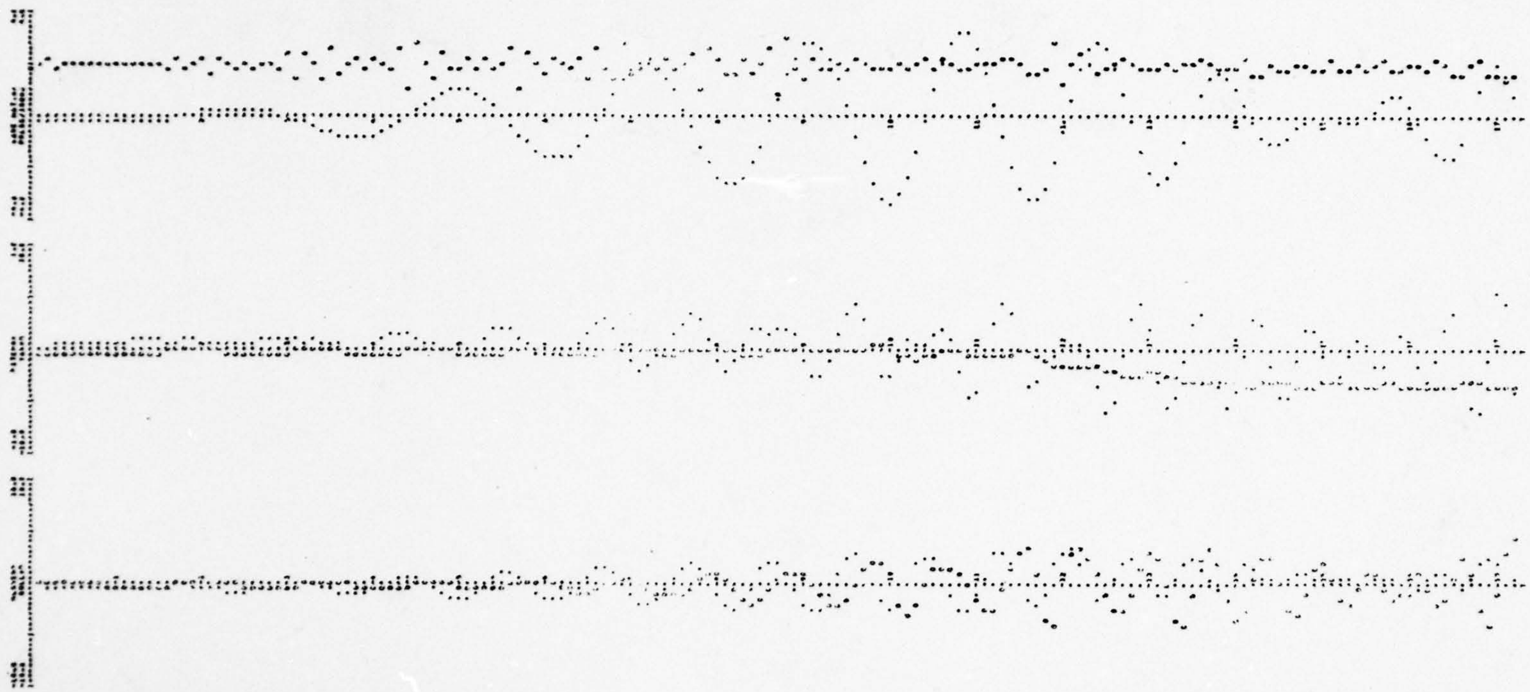

Figure 23 Craft Response to Explosion Waves with Heave Alleviation Control - yield = 1 KT, stand-off distance = 7,500 ft, craft speed = 50 knots, craft heading = 90 deg, t/T = 9.36 sec, T_o = 80 sec

7.5 Hovering Mode

The operational envelope defined in the previous sections can be used as a guide for the execution of proper maneuvers in cases where the craft is caught in an explosion generated wave environment. As will be discussed later, one of the prime parameters of concern is the reaction time between blast occurrence and initiation of a maneuver. In the case where there is no sufficient time available for a ship commander to change his course into a safe heading, he must immediately take an alternate measure to minimize the threat so as to keep his craft afloat. The methodology of minimizing the potential threat is to set the craft into a passive mode at a condition of maximum stability. This can be achieved by slowing down the craft speed into a hovering mode while altering its heading either into or away from the waves (180° or 0°) so as to minimize its lateral motions, because most seagoing vessels including the SES have a better stability longitudinally. In the event that the craft can change its course away from the waves in time, it should always try to outrun the waves at all available speed. The conditions considered here, however, refer to the case where the craft may possibly alter its heading to 0° or 180° whichever is more easily achievable, but have no sufficient time to react otherwise.

As shown in the operational envelope presented in Figure 22, the present craft would not survive at a 7,500 ft stand-off distance to any explosion, should it happen to run into the direction of waves. As has been presented in Section 6.3, Figure 18, however, the craft is well behaved in a hovering mode at this stand-off distance under a 1 k-ton explosion. Similarly, the responses of the craft in a hovering mode to 1.5 and 2.0 kilo-ton explosions are shown in Figures 24 and 25. These figures show that the craft again behaves very well although the yields are considerably larger. These examples would therefore indicate that in many cases a reasonable tactics for an SES under certain conditions is to head into

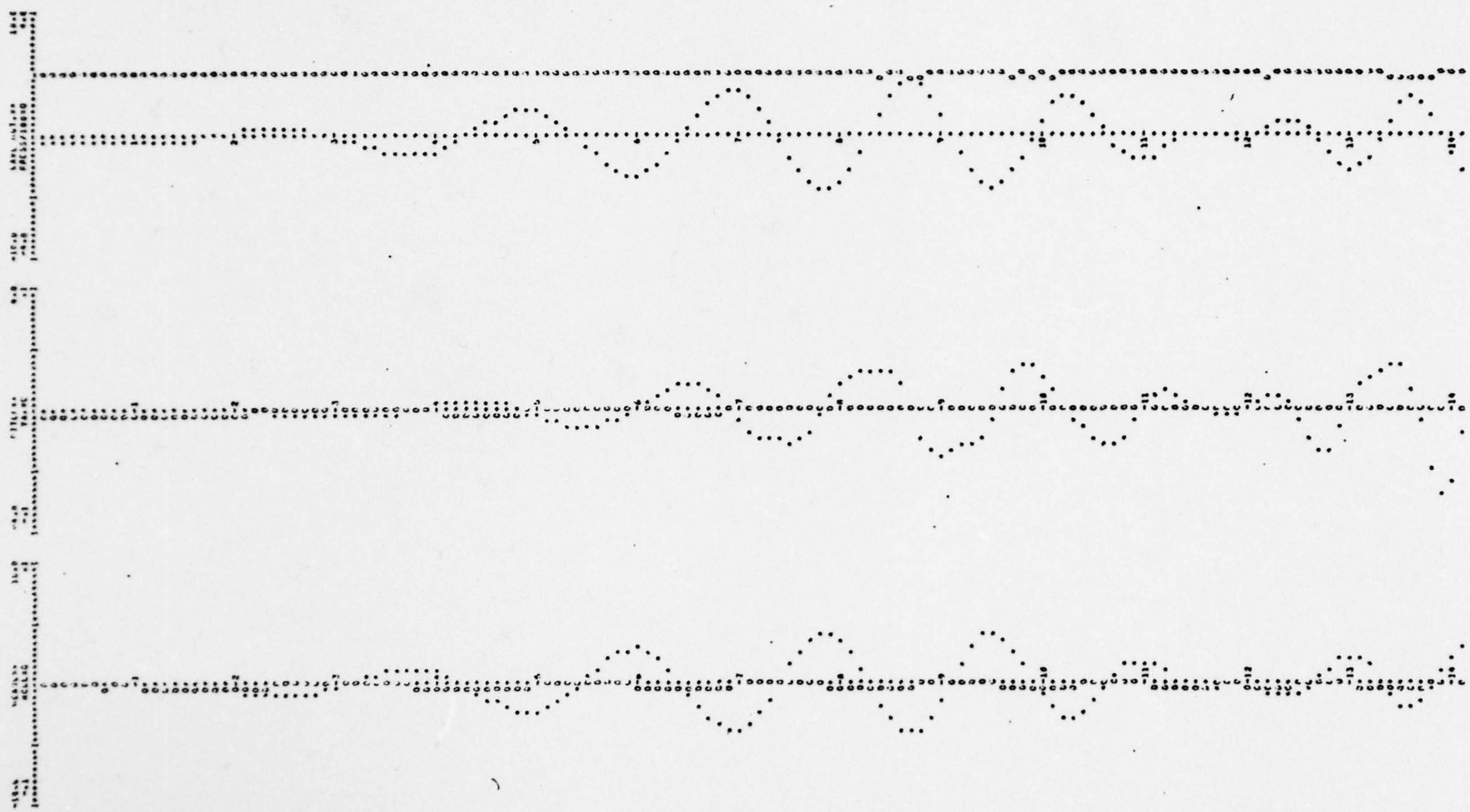

Figure 24 Craft Response Under Hovering Mode, yield = 1.5 KT, stand-off distance = 7,500 ft, craft speed = 0 , craft heading = 180 deg, t/T = 8.93 sec, T_o = 80 sec

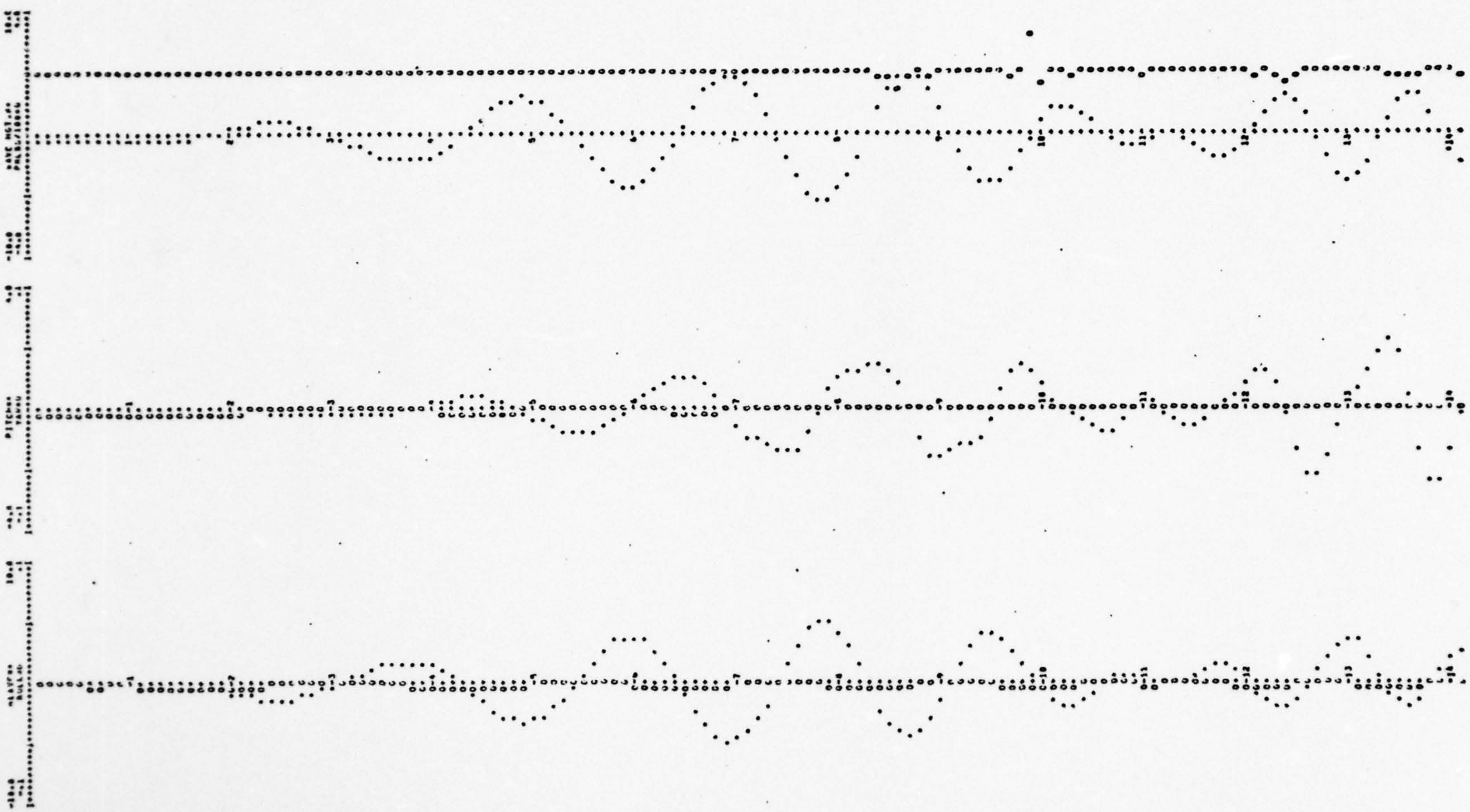

Figure 25 Craft Response Under Hovering Mode, yield = 2.0 KT, stand-off distance = 7,500 ft, craft speed = 0, craft heading = 180 deg, t/T = 8.93 sec, T_o = 80 sec

or away from the blast in a hovering mode. This tactic obviously presumes that such a hovering mode is feasible from a normal operational standpoint.

7.6 Reaction Time and Optimum Maneuver

The celerity of the maximum wave in the leading wave group of an explosion generated wave train can be estimated based upon the empirical formula given in Section 4.2, and the calculated results of the wave celerity for 0.5 to 2.0 kilo-ton yield explosions have been given in Table 7. Based upon these estimates, the arrival time of the maximum wave in the leading wave group at any distance away from the center of blast can be straightforwardly determined. In general, however, several initial disturbances, although of smaller amplitude, arrive much earlier than the maximum wave. A rough estimate indicates that the approximate arrival times of the leading disturbances are 80, 120, 180, and 240 seconds, respectively for stand-off distances of 7,500, 10,000, 15,000 and 20,000 ft, within the yield weight range considered in the present analysis.

These arrival times provide a good guidance as to how quickly a craft should react in order to avoid undesirable consequences. From the discussion in the previous section it is also clear that the craft should avoid head or bow waves at a stand-off distance of less than 7,500 ft. If we define this as a critical stand-off distance, then the critical reaction time is about 80 seconds. In other words, the craft must react within a period of 80 seconds to adjust to a favorable course in the event it is within the critical stand-off distance of 7,500 ft.

The cruising speed considered here is 50 knots, or 84.45 ft/sec, which is slightly higher than the celerity of the maximum wave from a 0.5 k-ton or 1.0 k-ton yield explosion but slightly lower than that from 1.5 k-ton and 2.0 k-ton yield explosions. Within the range of the yields considered, the best course for action for the craft is to take a 0° heading, as it can almost always outrun the waves resulted from explosions of these magnitudes. In addition, even if the craft is caught by the waves at a later time, the stand-off distance has increased and consequently the waves have necessarily reduced. If the craft is in an undesirable course at the time of attack, the commander must take the proper action within the allowable reaction time, which, of course, will vary depending upon the stand-off distance. The proper action implied here is to change its course into a heading within the operation envelope as defined in Figure 22. Should there be no sufficient time for reaction, the best choice then would be to bring the craft into a hovering mode and head into or away from the waves (180° or 0°).

8.0 CONCLUSIONS

Analytical findings derived from modeling the response of a typical SES to an explosion-generated wave environment have been presented. Based upon these results, analyses to illustrate the potential vulnerability of such a vehicle to explosion-generated waves have been obtained and operation envelopes with respect to this wave environment has been developed. The operational envelopes developed provide information to identify the required stand-off distances and necessary craft headings under which survivability in explosions of a charge weight ranging from 0.5 to 2.0 kilo-ton can be assured. The results indicate that the waves generated by these explosions present no threat to the craft when its stand-off distance is larger than 20,000 ft. However, if the stand-off distance is no more than 7,500 ft the craft can only survive at headings between 0^{o} and $\pm 90^{o}$ (following or stern waves).

The operational envelopes are developed based upon a craft cruising speed of 50 knots. It has been shown that all the evasive actions suggested by the resulting diagram depend very much upon the available reaction time. A critical reaction time has been established for the yield range considered. For a typical 2,000 ton class SES, this critical reaction time is 80 seconds. In otherwords, the craft must be able to adjust to a favorable operating condition within 80 seconds after blast in order to escape the hazard at a critical stand-off distance, defined as 7,500 ft.

Assuming there is sufficient time for the craft to maneuver before the leading waves reach it, the most favorable course should always be a 0^{o} heading or away from the blast, provided that there is no obstruction in that direction. The primary reason for this maneuver is that in this direction the craft may easily outrun the waves with its 50 knots crusing speed; secondly, even if the craft should be caught by waves at a later time, the waves will be much less severe at this greater stand-off distance due to the dispersion and spreading effects. Should the craft have insufficient time to adjust to a favorable evasive heading, the best strategy for survival is to head the craft into the waves and maintain a hovering mode.

When explosions occur in shallow water over the continental shelf, the waves generated are different from that generated by deep water explosions in form as well as in characteristics. In this analysis, these waves are represented by solitary waves, the characteristics of which vary with the height of the waves as well as the depth of the water. Using this wave representation, the craft behavior in shallow water explosion has been calculated and analyzed. In contrast to the craft behavior in deep water explosions, the results show that the craft safety does not heavily depend upon the stand-off distance. Within the yield range considered, the wave height/water depth ratio instead has been found to be the major parameter affecting the craft behavior in shallow water explosion waves.

A limited number of computer runs to investigate the effect of heave alleviation control on the craft dynamics has been conducted. With a simple control logic the model has shown that the craft may reduce motions and in many cases may even assure survival under a hazardous situation which may otherwise prove fatal.

The above summarizes the results obtained in the present study. It should be noted that in the present analysis, the craft dimensions and characteristics have been treated only in general terms in order to represent a typical SES and accordingly the results presented herein must be regarded in this light. It is nevertheless worth mentioning that the model developed here includes complete details to ensure that the information on evasive procedures for other craft can be generated should the specifics for that vehicle be defined. In particular, the model has capability to simulate non-linear motions of SES in six degrees of freedom in various wave environments, including deep water regular waves (sinusoidal waves) shallow water waves (solitary waves) and irregular wave trains (e.g. explosion generated waves). Specific features include heave alleviation control, thrust control, and various schemes for turning and maneuvers. Most importantly, the model is efficient for time domain solution and the program has been shown to be exceedingly fast on high speed computers. Typically a 100 second real time simulation can be obtained in 19 seconds of computer time on a CDC 7600 computer.

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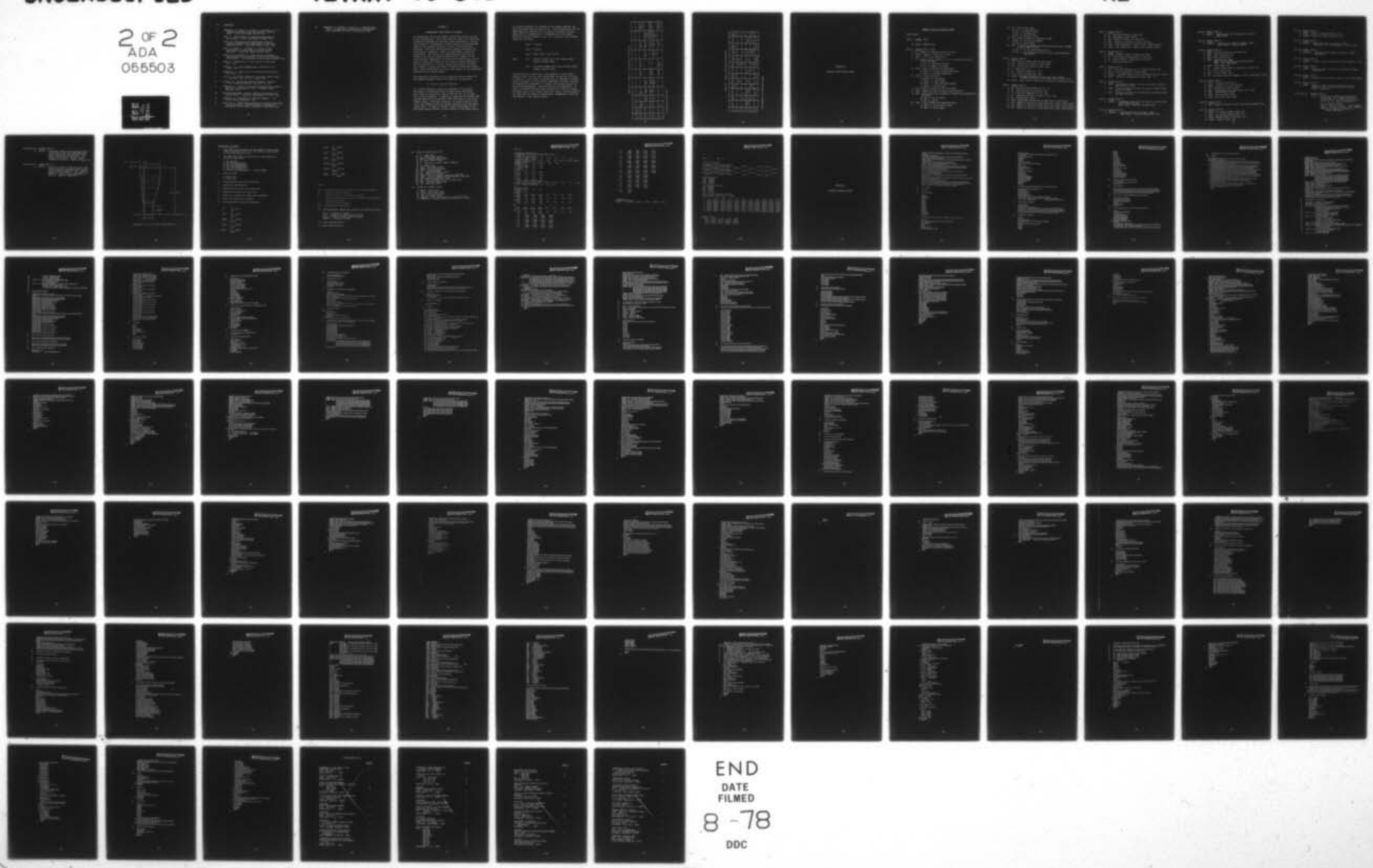

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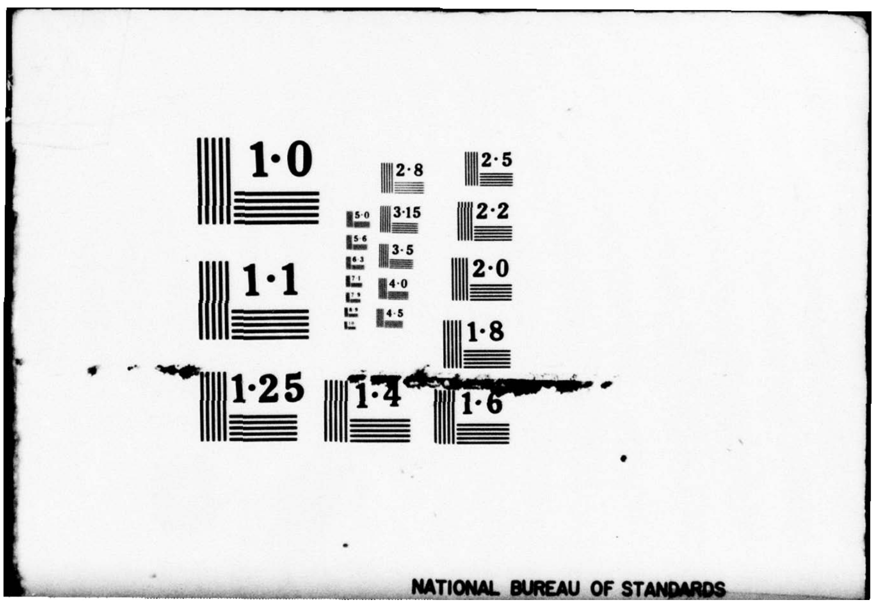
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APPENDIX A

HYDRODYNAMIC COEFFICIENTS OF SIDEHULL

The hydrodynamic forces and moments include both linear and non-linear contributions. The linear terms are those in the equations of motion identifiable by the first order coefficients. The non-linear terms in a hydrodynamic inviscid flow are the second order terms in the equations of motion, arising from fluid inertia couplings. The linear coefficients are usually classified into three general categories: static (or resistance), rotary and acceleration. The static force coefficients are the rates of change of any force or moment coefficient with respect to the linear velocity components; the rotary force coefficients are the rates of change with respect to the angular velocity components; and the acceleration or virtual inertia coefficients are those with respect to either the linear or angular acceleration components. These coefficients are linear with respect to the appropriate variables within limited ranges.

The fundamental dependence of any particular force or moment on the complete dynamical history of a body can be written as

$$F = f[u, v, w, p, q, r, \dot{u}, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}]$$

In a general expansion, there are altogether 72 first order derivatives or coefficients and 18 second order derivatives. Among these 90 derivatives, some of them are zero if the body has a plane of symmetry. In addition, based upon the slender body approach applied in the analysis, there should be no first order dynamic forces in the axial direction, nor should there be first order terms depending upon the dynamic variables along the longitudinal axis. In order to provide a simple approximate of the body surge effect, however, a gross estimate of the added inertia in the axial direction is included in the present analysis; let this total added mass for surge be $\bar{m}_1$. The two-dimensional section added masses are defined by m_2, m_3 and m_4 for motions of sway, heave and roll, respectively. In comparing with the symbols defined for single sidehull in Eq. (7) in the text, the following identities are noted

$$m_2(x) = 2\, m_{yy}(x)$$

$$m_3(x) = 2\, m_{zz}(x)$$

$$m_4(x) = m_2(x)\, f^2(x) + m_3(x)\, h^2(x)$$

where $f(x)$ = vertical moment arm of the lateral hydrodynamic inertia force

$h(x)$ = horizontal moment arm of the vertical hydrodynamic inertia force.

Not including the effects due to the asymmetry of the sidehull geometry itself, the non-zero hydrodynamic derivatives are listed in Table A-1. This table is arranged with the dependent variables (force and moment) in rows and the independent variables (velocity and acceleration components) in columns, and the derivatives can be read correspondingly. These derivatives are dimensional. In order to non-dimensionalize these derivatives a reference length and speed equal to the sidehull waterline length L and ship speed U are taken and the system of normalization recommended by ITTC has been adopted in the numerical model.

Table A-1a   Summary of Hydrodynamic Derivatives

	$\dot{u}$	$\dot{v}$	$\dot{w}$	$\dot{p}$	$\dot{q}$	$\dot{r}$	v	w	p	q	r
X	$-\bar{m}_1$										
Y		$-\int m_2 dx$		$\int m_2 f dx$ *		$-\int m_2 x dx$	$u \int m_2' dx$		$-u \int (m_2 f)' dx$ *		$u \int m_2' x dx$ $+ u(X_{\dot{u}} - Y_{\dot{v}})$
Z			$-\int m_3 dx$	$-\int m_3 h dx$ *	$\int m_3 x dx$			$u \int m_3' dx$	$u \int (m_3 h)' dx$ *	$-u \int m_3' x dx$ $-u(X_{\dot{u}} - Z_{\dot{w}})$	
K		$Y_{\dot{p}}$ *	$Z_{\dot{p}}$ *	$-\int m_4 dx$	$\int m_3 x h dx$ *	$\int m_2 x f dx$ *	Y_p *	Z_p *	$u \int m_4' dx$	$-u \int (m_3 x h)' dx$ *	$-u \int (m_2 x f)' dx$ *
M			$Z_{\dot{q}}$	$K_{\dot{q}}$ *	$-\int m_3 x^2 dx$			$-u \int m_3' x dx$ $+uX_{\dot{u}}$	$K_q - uZ_{\dot{p}}$ *	$u \int m_3' x^2 dx$ $+uZ_{\dot{q}}$	
N		$Y_{\dot{r}}$		$K_{\dot{r}}$ *		$-\int m_2 x^2 dx$	$u \int m_2' x dx$ $-uX_{\dot{u}}$		$K_r + uY_{\dot{p}}$ *		$u \int m_2' x^2 dx$ $-uY_{\dot{r}}$

*Term Disappears for Single Hull Vessels.

Table A-1b Summary of Hydrodynamic Derivatives

	vw	vp	vq	vr	wp	wq	wr	pp	pq	pr	qq	qr	rr
X				$-Y_{\dot{v}}$		$Z_{\dot{w}}$			$Z_{\dot{p}}$ *	$-Y_{\dot{p}}$ *	$Z_{\dot{q}}$		$-Y_{\dot{r}}$
Y					$-Z_{\dot{w}}$			$-Z_{\dot{p}}$ *	$-Z_{\dot{q}}$				
Z		$Y_{\dot{v}}$						$Y_{\dot{p}}$ *		$Y_{\dot{r}}$			
K	$-Y_{\dot{v}}+Z_{\dot{w}}$	$Z_{\dot{p}}$ *	$Y_{\dot{r}}+Z_{\dot{p}}$		$-Y_{\dot{p}}$ *		$-K_{vq}$		$K_{\dot{r}}$ *	$-K_{\dot{q}}$ *		$N_{\dot{r}}-M_{\dot{q}}$	
M		$-Y_{\dot{r}}$		$Y_{\dot{p}}$ *			$Z_{\dot{p}}$ *	$-K_{\dot{r}}$ *		$K_{\dot{p}}-N_{\dot{r}}$		$M_{\dot{p}}$ *	$K_{\dot{r}}$ *
N			$-Y_{\dot{p}}$ *		$Z_{\dot{q}}$	$-Z_{\dot{p}}$ *		$K_{\dot{q}}$ *	$M_{\dot{q}}-K_{\dot{p}}$		$-K_{\dot{q}}$ *	$-K_{\dot{r}}$ *	

*Term Disappears for Single Hull Vessels.

APPENDIX B

COMPUTER INPUT/OUTPUT FORMAT

Computer Input and Output Format

Input Format:

Card 1: Format (20A4)

1) TITLE - Heading card.

Card 2: Format (F10.0, 14I5)

1) DT - Number of intervals per wave period.
2) NSTEP - Number of integration steps.
3) NPRNT - Plot every NPRNT point.
4) IP - Debug flag for component forces and moments, printed in main program.
   If IP = 0, debug not printed.
   If IP ≠ 0, debug is printed.
5) IFIN - Flag on inclusion of stabilizer.
   If IFIN = 0, do not include stabilizer.
   If IFIN ≠ 0, include stabilizer.
6) IPLOT - Flag on plotting.
   If IPLOT = 0, call PLOTT.
   If IPLOT = 1, call PLOTXY.
   If IPLOT = 2, call PLOTT AND PLOTXY.
   If IPLOT > 2, do not plot.
7) IPT - Number of points to plot for PLOTT.
8) NJET - Number of jets for thrust vector control.
9) INT - Flag for printing cumulative integrals and geometrical variables.
   If INT = 0, do not print.
   If INT ≠ 0, print.
10) IBUG - Flag on debug for subroutine BUOY.
   If IBUG = 0, do not print debug.
   If IBUG ≠ 0, print debug.

11) IW - Flag on wave type.

If IW = 1, sinusoidal wave.

If IW = 2, solitary wave

If IW = 3, explosion wave

12) IPR - Flag on debug for subroutine VLDOT.

If IPR = 0, do not print debug.

If IPR = 0, print debug.

13) ICO - Flag for generating new derivatives when draft changes by more than ICO feet.

If ICO = 0, do not change derivatives.

If ICO > 0, ICO equals the change in draft required update derivatives.

Card 3: Format (8F10.0)

1) THT - Initial pitch angle of craft (deg).

2) PHI - Initial roll angle of craft (deg).

3) PSI - Initial yaw angle of craft (deg).

4) Z - Heave (set = 0)

5) C1 - Control constant Eq. (50).

6) C2 - Control constant Eq. (50).

7) CVENT - Minimum percentage of vent area to be closed; (1-CVENT) representing the upper limit of vent area.

8) DVENT - Lower limit of vent area in percent of total vent area.

Card 4: Format (8F10.0)

1) AA - Distance from transom to C.G. (ft).

2) BB - Half spacing of side walls (ft).

3) CC - Side wall immersion at C.G. (ft).

4) DD - Distance from keel of craft to C.G. (ft).

5) AM - Craft weight (tons).

6) DXDU - Added mass coefficient of side wall in axial flow.

7) AIX - Moment of inertia of craft about the x-axis (ton-ft-sec^2).

8) AIZ - Moment of inertia of craft about the z-axis (ton-ft-sec^2).

9) AIY - Moment of inertia of craft about the y-axis (ton-ft-sec^2).

Card 5: Format (8F10.0)

1) WL - Reference length of craft (ft).

2) SP - Approaching speed (knots).

3) RHO - Density of water (lb. sec^2/ft^4).

4) ANU - Kinematic viscosity of water (ft^2/sec).

5) CDLL - Drag coefficient, lateral force, lateral motion.

6) CDNN - Drag coefficient, normal force, normal motion.

Card 6: Format (8F10.0)

1) OMEGA - Dihedral angle of stabilizer (deg).

2) CR - Chord length of stabilizer at root (ft).

3) CT - Chord length of stabilizer at tip (ft).

4) S - Stabilizer span (ft).

Card 7: Format (8F10.0

1) CCO - Side wall immersion at C.G. before turning (ft).

2) THTO - Pitch angle before turning (deg).

3) SPTURN - Assigned speed at turn if different from SP (knots).

4) DFTH - Control for differential thrust (set = 0).

Card 8: Format (8F10.0)

1) XARM - Longitudinal distance of water jet nozzle location from craft C.G. (ft).

2) ZARM - Vertical distance of water jet nozzle location below craft C.G. (ft).

3) BACE - Vertical location of the stabilizer attachment below the keel line (ft).

Card 9: Format (8F10.0)

1) YARM(I) - Transverse location of Ith water jet nozzle from craft centerline (ft) NJET values. Positive starboard side.

Card 10: Format (8F10.0)

1) DELJET(I) - Deflection angle of nozzle I (deg). NJET values. Positive toward port side.

Card 11: Format (8F10.0)

1) RMCP(I) - Engine power level delivered to nozzle I. NJET values.

Card 12: Format (8F10.0)

1) ALPHA(I) - Vertical tilt angle of nozzle I (deg). NJET values. Positive upward.

Card 13: Format (8F10.0)

1) DWET - Height from keel to wet deck (ft).

2) WAMP - Wave amplitude (ft).

3) WPER - Wave period (sec).

4) BETA - Heading angle (deg)
BETA = 0^{o}, following or overtaking waves.
BETA = 180^{o}, head waves.

5) WDEP - Water depth (ft).

6) XO - Distance from center of explosion to craft (ft).

7) RO - Crater radius (ft).

8) ETAO - Crater height (ft).

9) TO - Reference time with respect to time of detonation (sec).

Card 14: Format (8F10.0)

1) CDIS - Discharge coefficient.

2) RHOWA - Density of air (lb sec^2/ft).

3) ATM - Atmospheric pressure (psf).

4) PHIO Coefficients for least square fit of fan
5) PHI1 characteristic curve.

6) THTB - Bow seal angle (deg).

7) THTS - Stern seal angle (deg).

Card 15: Format (16I5)

1) NST - Number of sections along craft from transom to bow.

Card 16: Format (8F10.0)

1) BUBL - Air cushion bubble length (ft).

2) BUBB - Air cushion bubble width (ft).

3) WALB - Maximum width of side wall (ft).

4) DEPTH - Depth of craft (ft).

Card 17: Format (8F10.0)

1) SLBOW - Length of planing bow seal (ft).

2) SLSTRN - Length of planing stern seal (ft).

Card 18: Format (8F10.0)

1) DRISE(I) - Dead rise angle at station I (deg). NST values. I = 1 at transom, I = NST at bow.

Card 19: Format (8F10.0)

1) ENTRCE(I) - Average entrance angle at station I (deg). NST values.

Card 20: Format (8F10.0)

1) CHINE(I) - Height of chine above keel line at station I (ft).

Card 21: Format (8F10.0)

1) NSW(I) - Number of water lines used for defining offsets at station I.

Card 22: Format (8F10.0)

1) XSW(I) - Distance from transom to station I (ft). NST values.

Card 23: Format (8F10.0)

1) HSW(I) - Height of bottom profile above keel line at station I (ft). If profile below keel line HSW(I) is negative.

Card Group 24: Format (8F10.0)

1) D1(I,J) - Height of Jth waterline above keel at Ith station (ft). NSW(I) values of D1 for each I. All values are positive. D1(I,1) = 0.0. Refer to Figure A.1.

D1 is input as follows:
Card 1 - D1(1,I), D1(1,2),...D1(1, NSW(1)).
Card 2 - D1(2,1), D1(2,2),...D1(2, NSW(2)).
Card NST - D1(NST,1), D1(NST,2),...
D1(NST, NSW (NST)).

Card Group 25: Format (8F10.0)

1) W1(I,J) - Horizontal offset of the starboard wall, right side of vertical reference plane, at Ith station an Jth waterline (ft). NSW(I) values for W1 for each I. All values are positive. W1(I,J) input similarly to D1(I,J). Refer to Figure B.1.

Card Group 26: Format (8F10.0)

1) W2(I,J) - Horizontal offset of the port wall, left side of vertical reference plane, at Ith station and Jth waterline (ft). NSW(I) values of W2 for each I. All values are positive. W2(I,J) input similarly to D1(I,J). Refer to Figure B.1.

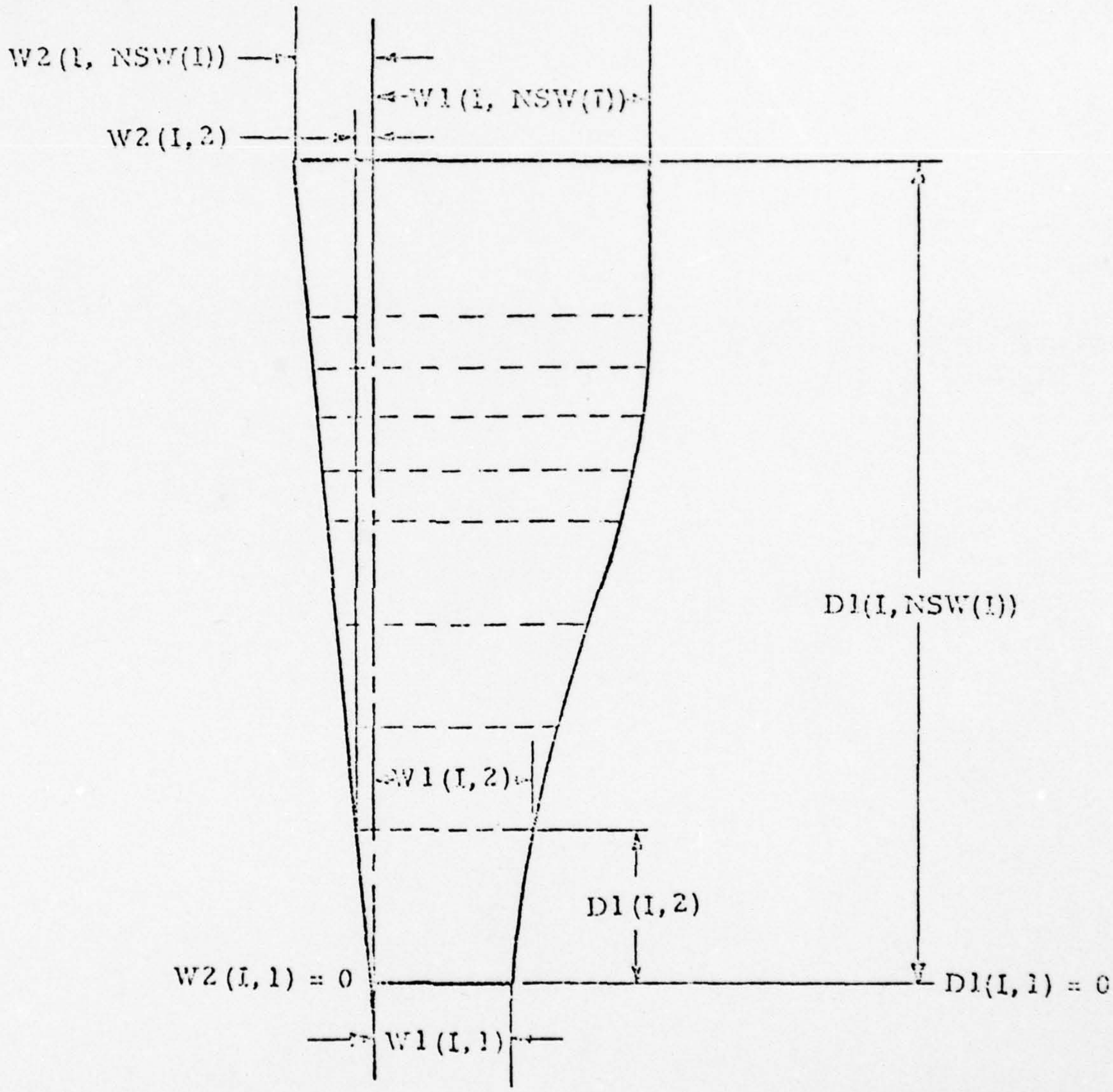

Figure B-1: D1, W1, W2 for Cross Section I.

Definition of Output

1. Input data are reproduced as they appear on data cards, with the exception of D1, W1, W2 which are not printed in the order they are read.

2. Any input data that are converted in the program are printed in new units.

   1) SP (ft/sec).
   2) AM (non-dimensional).
   3) AIX (non-dimensional).
   4) AIY (non-dimensional).
   5) AIZ (non-dimensional)
   6) FROUDE (non-dimensional) - Froude number

3. Craft attitude

   1) Draft (ft).
   2) Trim (deg).

4. Non-dimensional derivatives printed.

5. Stabilizer coefficients.

6. Coefficients for ship plus stabilizer.

7. Stability criterion for ship only.

8. Stability criterion for ship plus stabilizer.

9. Center of pressure of sidewall.

10. Non-dimensional cumulative integrals.

DI $- \int_{p\&s} D \, dF$

DFI $- \int_{p\&s} DF \, dF$

DF2I $- \int_{p\&s} DF^2 dF$

DF3I $- \int_{p\&s} DF^3 dF$

DCI $- \int_{p\&s} DC \, dF$

$$DC2I - \int_{p\&s} DC^2 dF$$

$$DC3I - \int_{p\&s} DC^3 dF$$

$$DCFI - \int_{p\&s} DCF\, dF$$

$$DCF2I - \int_{p\&s} DCF^2 dF$$

$$DC2FI - \int_{p\&s} DC^2 F\, dF$$

$$B3BI - BB^3 \int_{p\&s} B\, dF$$

where

p&s - Integration limits over both port and starboard sidewalls.

D - Draft at successive stations.

F - Distance from C.G. to successive stations.

C - Vertical moment arm, at successive stations, for submerged portions of craft (ft).

B - Beam at successive stations.

BB - Half spacing of side walls.

11. Non-dimensional Geometrical Variables as Function of Roll.

GI(I) - Integral of girder.
SI(I) - Integral of cross sectional area.
S1(I) - Cross sectional area at transom.
TDRAF(I) - Draft at transom.

12. Craft characteristics.

13. Wave characteristics.

14. Table of output plus units:

1) T - Time (sec).
2) U - Craft speed (knots).
3) BETA - Sideslip angle (deg).
4) W - Heave rate (ft/sec).
5) X
6) Y Location of craft (craft lengths).
7) Z - Heave (ft).
8) PHI - Roll angle (deg).
9) THETA - Pitch angle (deg).
10) PSI - Yaw angle (deg).
11) PC - Cushion pressure, (psf).
12) QF - Fan flow (ft^3/sec).
13) DPDT - Rate of pressure variation (psf/sec).
14) DVDT - Rate of cushion volume variation (ft^3/sec).
15) WD - Heave acceleration (G's).
16) WH - Wave elevation at C.G. of craft (ft).
17) VOL - Cushion volume (ft^3).
18) A1 - Vent area (ft^2).

15. Legend for computer plots:

1) HEAVE - Heave (ft).
2) ROLL - Roll angle (deg).
3) Pitch -Pitch angle (deg).
4) YAW - Yaw angle (deg).
5) WAV HGT - Wave elevation at C.G. of craft (ft).
6) PRESS/100 - Cushion pressure divided by 100 (psf).

```
INPUT DATA

TEST SIDEWALL - EXPLOSION WAVE
DT,NSTEP,NPRNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR,ICC
   128.00    25    4    0    1    0   25    4    0    0    3    0    1
THT,PHI,PSI,Z,C1,C2,CVENT,DVENT
     0.00      0.00      0.00      0.00     -1.34      0.00      0.00      0.00
AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
   130.000    44.000     2.000    24.000    2000.0     0.000   65000.0  300000.0  250000.0
WL,SF,RHO,ANU,CULL,CONN
   237.500    50.000     1.986  .000012817     1.300     1.000
OMEGA,CR,CT,S
    30.00     10.00      5.00     10.00
CCC,THTC,SPTURN,DFTH
     2.00      1.00     50.00      0.00
XARM,ZARM,BACE
   130.00      4.00      0.00
YARM(I)
    50.00    -50.00     38.00    -38.00
DELJET(I)
     0.00      0.00      0.00      0.00
RMCP(I)
     1.00      1.00      1.00      1.00
ALPHA(I)
     0.00      0.00      0.00      0.00
D.ET,WAMP,WPER,BETA,WDEF,XO,RO,ETAU,TC
    18.00     10.00     30.00     90.00   6000.00   7500.00    835.00     49.00     86.00
CDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS
     .70   .002378 2117.0075497.09 -121.25     30.00     60.00
NST
   12
BUBL,BUBB,WALB,DEPTH
   240.00     86.00      8.00     30.00
SLBOW,SLSTRN
    20.00     20.00
DRISE(I)
    85.00     85.00     85.00     79.00     60.00     49.00     44.00     43.00
    45.00     56.00     78.00     78.00
ENTRCE(I)
     0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
     1.50      6.50     10.50      0.00
CHINE(I)
     5.00      5.00      5.00      5.00      5.00      5.00      5.00      5.00
     5.00      6.00      9.00      0.00
NSW
    4    4    4    4    4    4    4    4    3    3    3    1
XSW
     0.00     25.00     50.00     75.00    100.00    125.00    150.00    175.00
   200.00    225.00    237.50    250.00
HSW
     0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
     0.00      0.00      0.00     20.00

    1  D1        0.000       5.000      10.000      20.000
       W1        7.000       7.500       8.000       8.000
       W2        0.000       0.000       0.000       0.000

    2  D1        0.000       5.000      10.000      20.000
       W1        7.000       7.500       8.000       8.000
       W2        0.000       0.000       0.000       0.000

    3  D1        0.000       5.000      10.000      20.000
       W1        7.000       7.500       8.000       8.000
       W2        0.000       0.000       0.000       0.000
```

4	D1	0.000	5.000	10.000	20.000
	W1	6.500	7.500	8.000	8.000
	W2	0.000	0.000	0.000	0.000
5	D1	0.000	5.000	10.000	20.000
	W1	4.000	7.000	8.000	8.000
	W2	0.000	0.000	0.000	0.000
6	D1	0.000	5.000	10.000	20.000
	W1	2.000	6.500	8.000	8.000
	W2	0.000	0.000	0.000	0.000
7	D1	0.000	5.000	10.500	20.000
	W1	.700	6.000	8.000	8.000
	W2	0.000	0.000	0.000	0.000
8	D1	0.000	5.000	13.500	20.000
	W1	0.000	5.500	8.000	8.000
	W2	0.000	0.000	0.000	0.000
9	D1	0.000	5.000	20.000	
	W1	0.000	5.000	8.000	
	W2	0.000	0.000	0.000	
10	D1	0.000	6.000	20.000	
	W1	0.000	4.000	6.500	
	W2	0.000	0.000	0.000	
11	D1	0.000	9.000	20.000	
	W1	0.000	2.000	5.000	
	W2	0.000	0.000	0.000	
12	D1	0.000			
	W1	0.000			
	W2	0.000			

CONVERTED INPUT
SP,AM,AIX,AIY,AIZ,FROUDE
64.45 .1045E-01 .1939E-03 .7457E-03 .8949E-03 .9657

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DRAFT= 2.00 TRIM= 1.00

NON DIMENSIONAL DERIVATIVES

DYP	DYQ	DYR	DYV	DYW	DYDP	DYDQ	DYDR	DYDV	DYDW
-.9364E-03	0.	.1517E-02	-.2772E-02	0.	-.2365E-03	0.	.2843E-03	-.9062E-03	0.

DZP	DZQ	DZR	DZV	DZW	DZDP	DZDQ	DZDR	DZDV	DZDW
0.	-.1655E-02	0.	0.	-.2484E-02	0.	-.4103E-03	0.	0.	-.1310E-02

DKP	DKQ	DKR	DKV	DKW	DKDP	DKDQ	DKDR	DKDV	DKDW
.4082E-05	0.	.1296E-03	-.2404E-03	0.	.2178E-05	0.	.2410E-04	-.7779E-04	0.

DMP	DMQ	DMR	DMV	DMW	DMDP	DMDQ	DMDR	DMDV	DMDW
0.	-.4337E-03	0.	0.	-.3235E-03	0.	-.1611E-03	0.	0.	-.4103E-03

DNP	DNQ	DNR	DNV	DNW	DNDP	DNDQ	DNDR	DNDV	DNDW
.5519E-04	0.	-.3462E-03	.6111E-03	0.	.7378E-04	0.	-.1211E-03	.2843E-03	0.

STABILIZER COEFFICIENTS
FINYV= -.4682E-02
FINYR= .2489E-02
FINKV= .8015E-04
FINKR= -.4579E-04
FINNV= .2489E-02
FINNR= -.1323E-02

SHIP PLUS STABILIZER COEFFICIENTS
SFYV= -.7454E-02
SFYR= .4006E-02
SFKV= -.1543E-03
SFKR= .8377E-04
SFNV= .3100E-02
SFNR= -.1869E-02

STABILITY CRITERION FOR SHIP ONLY= .6973E-05
STABILITY CRITERION FOR SHIP PLUS FIN= .3391E-04
CENTER OF PRESSURE AT CENTER OF GRAVITY= 22.85

SEC	DI	DFI	DF2I	DF3I	DCI	DC2I	DC3I	DCFI	DCF2I	DC2FI	BSBI
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	.180E-02	-.893E-03	.449E-03	-.229E-03	.166E-03	.153E-04	.142E-05	-.825E-04	.415E-04	-.762E-05	.209E-04
3	.340E-02	-.152E-02	.701E-03	-.331E-03	.315E-03	.293E-04	.272E-05	-.141E-03	.649E-04	-.131E-04	.416E-04
4	.481E-02	-.193E-02	.821E-03	-.368E-03	.448E-03	.418E-04	.390E-05	-.179E-03	.763E-04	-.167E-04	.620E-04
5	.602E-02	-.215E-02	.866E-03	-.377E-03	.564E-03	.528E-04	.494E-05	-.201E-03	.805E-04	-.187E-04	.797E-04
6	.704E-02	-.223E-02	.875E-03	-.378E-03	.662E-03	.622E-04	.584E-05	-.208E-03	.813E-04	-.194E-04	.950E-04
7	.787E-02	-.221E-02	.877E-03	-.378E-03	.742E-03	.699E-04	.659E-05	-.206E-03	.816E-04	-.192E-04	.102E-03
8	.851E-02	-.213E-02	.890E-03	-.376E-03	.803E-03	.759E-04	.717E-05	-.198E-03	.828E-04	-.185E-04	.107E-03
9	.895E-02	-.203E-02	.914E-03	-.370E-03	.847E-03	.801E-04	.759E-05	-.188E-03	.852E-04	-.175E-04	.110E-03
10	.920E-02	-.194E-02	.941E-03	-.360E-03	.871E-03	.826E-04	.783E-05	-.180E-03	.874E-04	-.167E-04	.112E-03
11	.925E-02	-.192E-02	.950E-03	-.357E-03	.876E-03	.831E-04	.788E-05	-.178E-03	.888E-04	-.165E-04	.112E-03
12	.926E-02	-.192E-02	.953E-03	-.355E-03	.878E-03	.832E-04	.790E-05	-.177E-03	.891E-04	-.164E-04	.112E-03

GEOMETRICAL VARIABLES

ROLL(DEG)	GI	SI	SI	1DRAF
2.000	.4822E-01	.3302E-03	.7502E-03	.2444E-01
1.000	.4045E-01	.2600E-03	.6476E-03	.2121E-01
0.000	.3344E-01	.2043E-03	.5459E-03	.1797E-01
-1.000	.2420E-01	.1279E-03	.4009E-03	.1339E-01
-2.000	.1956E-01	.8104E-04	.3018E-03	.1007E-01

APPENDIX C

COMPUTER PROGRAM LISTING

```
      PROGRAM SESWAVE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1
     *,TAPE2)
      DIMENSION Y(13),YP(13)
      DIMENSION PHID(700),XP(700);YYP(700),THTD(700),ZP(700)
     *,PSID(700),WAV(700),PCP(700)
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH,SPRAYL
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /DERV/ XUDELU,DRAGY,DRAGN,DFTH,IFIN,CCX
      COMMON /FLOW/ PC,QF,QO,VDOTP,AOP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALGD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY,CCC,THTC
      COMMON /PRNT/ DT,NSTEP,NPRNT,IP
      COMMON /TEMP/SX,SY,SK,SN,WAVEDG,AERODG,SPRYDG,SEALDG,
     *SKINDG,FINDG,SHIPDG,TOTLDG
      COMMON /THRST/ THIGH,TLOW
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DFLJET(4),RMCP(4),NJET
     *,ALPHA(4)
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEF,OFFSET
     *,WLG,ICO,XO,RO,ETAO,TO
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON/X/ ISECT(25),DI(25),DF1(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2F1(25),B3BI(25),XSW(25)
      COMMON /PRES/ CDIS,PHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM,IPR
      COMMON /AYEYE/ AI,C1,C2,A1,A2,DPDT,CVENT,DVENT
C
C     CALL INPUT
C
      CALL INPT
C
C     INITIALIZATION
C
      T=0.0
      SHIPDG=0.
      TOTLDG=0.
      NE=13
      Y(1)=U
      Y(2)=V
      Y(3)=W
      Y(4)=P
      Y(5)=Q
      Y(6)=R
      Y(7)=X
      Y(8)=YY
      Y(9)=Z
      Y(10)=PHI
      Y(11)=THT
      Y(12)=PSI
C
C     CALCULATE WEIGHT OF CRAFT AT INITIAL TRIM WITH NO WAVE
C
      INWGT=0
      CALL SEAWAV (WX,WY,WZ,WK,WM,WN,VOL,AC,Y,T)
      Y(13)=VOL/WL**3
      BUOYAN=-WZ
      WMO=WM
      WXO=WX
      FB=BUOYAN*DEM
      PC=(WEIGHT-FB)/AC +ATM
```

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```
      PCGAGE=PC-ATM
      AG=(PHIC+PHI1*PCGAGE)/(CDIS*SQRT(2.*(PCGAGE)/RHOWA))
      A1=DVENT*AQ
      A2=2.*AG*(1.-CVENT)
      VOLDOT=0.
      INWGT=1
      INDX=0
      AI=AG*(1.-CVENT)
      CALL RUNGS(T,DT,NE,Y,YP,INDX)
      KNT=1
      TP=T*WL/SP
      UP=U*SP/1.689
      VP=-ATAN(V/U)/DTR
      WP=W*SP
      WD=YP(3)*SP**2/WL/G
      XP(KNT)=X
      YYP(KNT)=YY
      ZP(KNT)=Z*WL
      PHID(KNT)=PHI/DTR
      THTD(KNT)=THT/DTR
      PSID(KNT)=PSI/DTR
      PCP(KNT)=PC-ATM
      WAV(KNT)=0.
      VDOTP=0.
      DPDT=0.
C
C     CALCULATE AND PRINT CRAFT AND WAVE CHARACTERISTICS
C
      PAM=AM*G/2240.*(0.5*RHO*WL**3)
      PBB=2.*BB
      PTHTO=THTO/DTR
      PSP=SP/1.689
      PBETA=BETA/DTR
      CRAFTL=XSW(NST)*WL
      WRITE(6,300) PAM,  CRAFTL,PBB,PTHTO,CC,PSP
      IF(IW.LT.3) WRITE(6,301) PBETA,WAMP,WPER,WLG,CEL,CAY
      IF(IW.EQ.3) WRITE(6,302)            PBETA,WDEP,RO,ETAO,XO,TO
C
C     PRINT OUTPUT HEADINGS
C
      WRITE(6,220)
      WRITE(6,222)
      IF(IP.NE.0) WRITE(6,221)
      WRITE(6,200) TP,UP,VP,WP,XP(KNT),YYP(KNT),ZP(KNT),PHID(KNT),
     *THID(KNT),PSID(KNT),PCP(KNT),OF,DPDT,VDOTP,WD,WAV(KNT),ACP,AI
      IF(IP.NE.0) WRITE(6,208) SX,SY,SK,SN,XUDELU,DRAGY,DRAGN,THIGH
     *,TLOW,TOTLDG,WAVEDG,AERODG,SPRYDG,SEALDG,SKINDG,FINDG
C
C     INTEGRATION BY RUNGS
C
      INTRY=0
      CCX=CC
      DO 2 I=1,NSTEP
      IF(INTRY.EQ.1.AND. ICC.NE.0) CALL SECDER
      INTRY=0
      CALL RUNGS(T,DT,NE,Y,YP,INDX)
      U=Y(1)
      V=Y(2)
      W=Y(3)
      P=Y(4)
```

```
      G=Y(5)
      R=Y(6)
      X=Y(7)
      YY=Y(8)
      Z=Y(9)
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
      KNT=KNT+1
      TP=T*.L/SP
      UP=U*SP/1.689
      VP=-ATAN(V/U)/DTR
      WP=W*SP
      WD=YP(3)*SP**2/WL/G
      XP(KNT)=X
      YYP(KNT)=YY
      ZP(KNT)=Z*WL
      PHID(KNT)=PHI/DTR
      THTD(KNT)=THT/DTR
      PSID(KNT)=PSI/DTR
      PCP(KNT)=PC-ATM
C
C     GENERATE WAVE FORM FOR PLOTTING
      XCO=YCO=ZCO=0.
      CALL SWAVE(XCO,YCO,ZCO,Y,T,ETA)
      WAV(KNT)=ETA
C
C     PRINT RESULTS
C
      WRITE(6,200) TP,UP,VP,WP,XP(KNT),YYP(KNT),ZP(KNT),PHID(KNT),
     *THTD(KNT),PSID(KNT),PCP(KNT),GF,DPDT,VDOTF,WD,WAV(KNT),ACP,AI
      IF(IP.NE.0) WRITE(6,208) SX,SY,SK,SN,XUDELU,DRAGY,DRAGN,THIGH
     *,TLOW,TCTLDG,WAVEDG,AERODG,SPRYDG,SEALDG,SKINDG,FINDG
C
C     TEST TO SEE IF DERIVATIVES NEED TO BE CHANGED
C
      IF(ICO.EQ.0) GO TO 2
      ZTEST=ZP(KNT)+WAV(KNT)
      ZTST=ABS(ZTEST+CC-CCX)
      IF(ZTST.LT.ICO) GO TO 2
      INTRY=1
      CCX=CC +ZTEST
    2 CONTINUE
C
C     SELECT EVERY NPRNT POINT FOR PLOTTING AND PLOT
C
      INP=0
      DO 843 IJK=1,KNT,NPRNT
      INP=INP+1
      ZP(INP)=ZP(IJK)
      PHID(INP)=PHID(IJK)
      THTD(INP)=THTD(IJK)
      PSID(INP)=PSID(IJK)
      WAV(INP)=WAV(IJK)
  843 PCP(INP)= PCP(IJK)/100.
      IPT=INP
      IF(IPLOT.GT.2) CALL EXIT
      IF(IPLOT.EQ.0) CALL PLOTT(ZP,THTD,WAV,PHID,PSID,PCP,IPT,NC,NG)
      IF(IPLOT.EQ.1) CALL PLOTXY(XP,YYP,KNT)
      IF(IPLOT.EQ.2) CALL PLOTT(ZP,THTD,WAV,PHID,PSID,PCP,IPT,NC,NG)
```

```
      IF(IPLOT.EQ.2) CALL PLOTXY(XP,YYP,KNT)
C
C     FORMATS
C
  200 FORMAT(6F7.2,4F7.2,F6.0,3F8.0,2F7.2,F9.0,F6.0)
  206 FORMAT(8X, 9E11.3)
  220 FORMAT(1H1,5X,1HT,6X,1HU,3X,4HBETA,6X,1HW,6X,1HX,6X,1HY,6X,1HZ
     *,4X,3HPHI,2X,5HTHETA,4X,3HPSI,4X,2HPC,6X,2HGF,4X,4HDPDT,4X,4HDVDT,
     *5X,2HWD,5X,2HWH,6X,3HVOL,4X,2HAI)
  221 FORMAT(17X,2HSX,9X,2HSY,9X,2HSK,9X,2HSN,5X,6HXUDELU,6X,5HDRAGY,
     *6X,5HDRAGN,6X,5HTHIGH,7X,4HTLOW/5X,6HTOTLDG,13X,6HWAVEDG,5X,
     *6HAERODG,5X,6HSPRYDG,5X,6HSEALDG,5X,6HSKINDG,6X,5HFINDG)
  222 FORMAT(3X,4HSECS,2X,5HKNOTS,4X,3HDEG,1X,6HFT/SEC,4X,3H/LC,4X,3H/LC
     *,5X,2HFT,4X,3HDEG,4X,3HDEG,4X,3HDEG,3X,3HPSF,1X,7HFT3/SEC,1X,
     *7HPSF/SEC,1X,7HFT3/SEC,4X,3H G ,5X,2HFT,6X,3HFT3,3X,3HFT2/)
  300 FORMAT(1H1,21HCRAFT CHARACTERISTICS/5X,7HWEIGHT=,F6.0,5H TONS/
     *5X,13HCRAFT LENGTH=  ,F6.1,4H FT./5X,14HCUSHION WIDTH=,F6.1,4H FT.
     */5X,13HINITIAL TRIM=,F6.2,5H DEG./5X,14HINITIAL DRAFT=,F7.3,4H FT.
     */5X,14HINITIAL SPEED=,F5.0,6H KNOTS)
  301 FORMAT(//21H WAVE CHARACTERISTICS/5X,8HHEADING=,F5.0,5H DEG./
     *5X,7HHEIGHT=,F5.1,4H FT./5X,7HPERIOD=,F5.1,5H SEC.
     */5X,7HLENGTH=,F6.1,4H FT./5X,9HCELERITY=,F6.1,7H FT/SEC
     */5X,6HWAV NO.=,F7.4)
  302 FORMAT(//21H WAVE CHARACTERISTICS/5X,8HHEADING=,F5.0,5H DEG.
     */5X,5HUDEP=,F6.1,4H FT./5X,3HPC=,F7.1,4H FT.
     */5X,5HETAC=,F6.1,4H FT./5X,3HXC=,F8.1,4H FT.
     */5X,3HTC=,F6.1,5H SEC.)
      STOP
      END
```

```
      SUBROUTINE INPT
      DIMENSION TITLE(20)
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH,SPRAYL
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /CDE/ DRISE(23),ENTRCE(23),CHINE(23),HSPRAY(23)
      COMMON /DERV/ XUDELU,DRAGY,DRAGN,DFTH,IFIN,CCX
      COMMON /FCOEF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FOYL/ C,ALFA,GAMA,XF
      COMMON /GEOMM/NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY,CCO,THTO
      COMMON /INDER/ CR,CT,S,OMEGA
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM,IPR
      COMMON /PRNT/ DT,NSTEP,NPRNT,IP
      COMMON /PSEAL/ THTB,THTS
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /TEMP/ SX,SY,SK,SN
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
     *,ALPHA(4)
      COMMON /U/ GI(25),SI(25),S1(25),PHO(25),TDRAF(25)
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEP,OFFSET
     *,WLG,ICC,XO,RO,ETAO,TO
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /AYEYE/ AI,C1,C2,A1,A2,DPDT,CVENT,DVENT
C
C     DEFINITION OF INPUT FLAGS
C
C     DT=NUMBER OF INTERVALS PER WAVE PERIOD
C     NSTEP=NO. OF TIME STEPS TO EXECUTE
C     NPRNT=PLOT EVERY NPRNT POINT
C     IP-----------DEBUG FLAG FOR COMPONENT FORCES AND MOMENTS
C                  SX,SY,SN,XUDELU,DRAGY,DRAGN,THIGH,TLOW,WAVEDG,
C                  AERODG,SPRYDG,SEALDG,SKINDG,FINDG
C                  IF IP=0, DONT PRINT
C                  IF IP.NE.0, PRINT
C     IFIN---------FLAG ON INCLUSION OF STABILIZER
C                  IFIN=0,DONT INCLUDE STABILIZER
C                  IFIN.NE.0, INCLUDE STABILIZER
C     IPLOT--------FLAG ON PLOTTING
C                  IF IPLOT =0,PLOT PLOTT
C                  IF IPLOT =1 PLOT PLOTXY
C                  IF IPLOT =2 PLOT PLOTT AND PLOTXY
C                  IF IPLOT GT 2 DONT PLOT
C     IPT----------NUMBER OF STEPS TO PLOT PLOTT
C     NJET---------NUMBER OF JETS FOR THRUST VECTOR CONTROL
C     INT----------PRINT FLAG FOR CUMULATIVE INTEGRALS AND GEOMETRICAL VARIABLES
C                  IF INT=0, DONT PRINT
C                  IF INT.NE.0, PRINT
C     IBUG---------FLAG ON DEBUG FOR SUBROUTINE BUOY
C                  IF IBUG=0, DO NOT PRINT
C                  IF IBUG.NE.0,PRINT
C     IW-----------FLAG FOR WAVE TYPE
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C                    IF IW=1, SINUSOIDAL WAVE
C                    IF IW=2, SOLITARY WAVE
C                    IF IW=3, EXPLOSION WAVE
C      IPR----------FLAG ON DEBUG FOR SUBROUTINE PRESS
C                    IF IPR=0,DO NOT PRINT
C                    IF IPR.NE.0,PRINT
C      ICO----------FLAG FOR GENERATING NEW CERIVATIVES WHEN DRAFT
C                    CHANGES MORE THAN ICO FEET
C                    IF ICO=0, DONT CHANGE DERIVATIVES
C                    IF ICO.NE.0, CHANGE IN DRAFT REQUIRED TO CHANGE CERIVATIVES
C
C
C      READ AND WRITE INPUT
C
       READ(5,103) (TITLE(I),I=1,20)
       READ(5,101) DT,NSTEP,NPPNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR
      *,ICO
       READ(5,100) THT,PHI,PSI,Z,C1,C2,CVENT,DVENT
       READ(5,100) AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
       READ(5,100) WL,SP,RHO,ANU,CDLL,CDNN
       READ(5,100) OMEGA,CR,CT,S
       READ(5,100) CCO,THTO,SPTURN,DFTH
       READ(5,100) XARM,ZARM,BACE
       READ(5,100)(YARM(I),I=1,NJET)
       READ(5,100) (DELJET(I),I=1,NJET)
       READ(5,100) (RMCP(I),I=1,NJET)
       READ(5,100) (ALPHA(I),I=1,NJET)
       WRITE(6,200)
       WRITE(6,201) (TITLE(I),I=1,20)
       WRITE(6,202)DT,NSTEP,NPPNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR
      *,ICO
       WRITE(6,203) THT,PHI,PSI,Z,C1,C2,CVENT,DVENT
       WRITE(6,204)AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
       WRITE(6,205)WL,SP,RHO,ANU,CDLL,CDNN
       WRITE(6,207) OMEGA,CR,CT,S
       WRITE(6,208)CCO,THTO,SPTURN,DFTH
       WRITE(6,210) XARM,ZARM,BACE
       WRITE(6,211)
       WRITE(6,100) (YARM(I),I=1,NJET)
       WRITE(6,212)
       WRITE(6,100) (DELJET(I),I=1,NJET)
       WRITE(6,213)
       WRITE(6,100) (RMCP(I),I=1,NJET)
       WRITE(6,214)
       WRITE(6,100) (ALPHA(I),I=1,NJET)
C
C      READ AND WRITE INPUT FOR WAVE
C
       READ(5,100) DWET,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO
       WRITE(6,241) DWET,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO
C
C      READ AND WRITE INPUT FOR PRESSURE
C
       READ(5,100) CDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS
       WRITE(6,242)CDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS
C
C      READ AND WRITE INPUT FOR SPRAY
C
       READ(5,102) NST
       READ(5,100)       BUBL,BUBB,WALB,DEPTH
```

```
      READ(5,100) SLBOW,SLSTRN
      READ(5,100) (DRISE(I),I=1,NST)
      READ(5,100) (ENTRCE(I),I=1,NST)
      READ(5,100) (CHINE(I),I=1,NST)
      READ(5,102)      (NSW(I),I=1,NST)
      READ(5,100) (XSW(I),I=1,NST)
      READ(5,100) (HSW(I),I=1,NST)
      DO51 I=1,NST
      NVS=NSW(I)
   51 READ(5,100) (D1(I,J),J=1,NVS)                                    C
      DO52 I=1,NST
      NVS=NSW(I)
   52 READ(5,100) (W1(I,J),J=1,NVS)                                    C
      DO53 I=1,NST
      NVS=NSW(I)
   53 READ(5,100) (W2(I,J),J=1,NVS)                                    C
      WRITE(6,215) NST
      WRITE(6,216)      BUBL,BUBB,WALB,DEPTH
      WRITE(6,217)SLBOW,SLSTRN
      WRITE(6,218)
      WRITE(6,100)(DRISE(I),I=1,NST)
      WRITE(6,219)
      WRITE(6,100)(ENTRCE(I),I=1,NST)
      WRITE(6,220)
      WRITE(6,100)(CHINE(I),I=1,NST)
      WRITE(6,221)
      WRITE(6,102)  (NSW(I),I=1,NST)
      WRITE(6,222)
      WRITE(6,100)  (XSW(I),I=1,NST)
      WRITE(6,223)
      WRITE(6,100)  (HSW(I),I=1,NST)
      DO54 I=1,NST
      NVS=NSW(I)
      WRITE(6,224)(I,(D1(I,J),J=1,NVS))
      WRITE(6,225)  (W1(I,J),J=1,NVS)
      WRITE(6,226)  (W2(I,J),J=1,NVS)
   54 CONTINUE
C
C     CONSTANTS
C
      NC=20
      NG=6
      G=32.2
      PI=3.1415927
      DTR=PI/180.
      P=Q=R=V=W=X=YY=0.
      U0=1.
      U=U0
C
C     CONVERT TO RADIANS
C
      THT=THT*DTR
      PHI=PHI*DTR
      PSI=PSI*DTR
      OMEGA=OMEGA*DTR
      THTO=THTO*DTR
      BETA=BETA*DTR
      THTB=THTB*DTR
      THTS=THTS*DTR
C
```

```
C     CONVERT AND NON DIMENSIONALIZE INPUT
C
      SP=SP*1.689
      SPTURN=SPTURN*1.689
      FROUDE=SP/SQRT(G*WL)
      WEIGHT=AM*2240.
      DENOM=0.5*RHO*WL**5
      AIX=AIX*2240./DENOM
      AIY=AIY*2240./DENOM
      AIZ=AIZ*2240./DENOM
      AM=(WEIGHT/G)/(0.5*RHO*WL**3)
      Z=Z/WL
      XLG=AA/WL
      XFG=1.-XLG
      XARM=XARM/WL
      ZARM=ZARM/WL
      DO 20 I=1,NJET
   20 YARM(I)=YARM(I)/WL
      DO 21 I=1,NST
      F(I)=XSW(I)-AA
   21 XSW(I)=XSW(I)/WL
      WRITE(6,227) SP,AM,AIX,AIY,AIZ,FROUDE
C
C     CALCULATE CAY,CEL,F,OFFSET FOR SUBROUTINE SWAVE
C
      CON1=4.*PI**2/G
      CON2=0.5*G/PI
      GO TO (41,42,43),IW
   41 CAY=CON1/WPER**2
      CEL=CON2*WPER
      WLG=CEL*WPER
      GO TO 44
   42 CAY=0.866*SQRT(WAMP/WDEP)/WDEP
      CEL=0.5*SQRT(G*WDEP)*(2.+WAMP/WDEP)
      WLG=CEL*WPER
      OFFSET=0.5*WLG
      GO TO 44
   43 CAY=CON1/900.
      CEL=CON2*30.
      WLG=CEL*30.
   44 CONTINUE
C
C     CALCULATE TIME INCREMENT
C
      DT=(WLG/ABS(CEL-SP*COS(BETA)))/DT
      DT=DT*SP/WL
C
C     CALCULATE N1,N2,DEL1,DEL2
C
      NSTI=NST-1
      DO 5  I=2,NSTI
      ISAVE=I
      DEL1=XSW(I)-XSW(I-1)
      DEL1=DEL1*WL
      DEL2=XSW(I+1)-XSW(I)
      DEL2=DEL2*WL
      IF(ABS(1.-DEL2/DEL1).GT.0.1) GO TO 6
    5 CONTINUE
    6 N1=ISAVE
      N2=NST-ISAVE+1
```

```
C
C     CALCULATE AC,DEM FOR PRESSURE
C
      AC=2.*BB*XSW(N1)*WL
      DEM=0.5*RHO*WL**2*SP**2
C
C     CALCULATE FO AT CG
C
      DO 3 I=2,NST
      FO1=ABS(AA-XSW(I-1)*WL)
      FO2=ABS(AA-XSW(I)*WL)
      IF(FO2.LT .FO1) KFO=I
    3 CONTINUE
C
C     CALCULATE NON DIMENSIONAL DERIVATIVES
C
      IPDER=0
      THTOPR=THTO/DTR
      WRITE(6,209) CCO,THTOPR
      CALL DER(AA,BB,CCO,DD,THTO,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,XSW,
     *D1,W1,W2,RHO,WL)
      CALL GEO(AA,BB,CCO,DD,WL,NST,THTO,KFO,FO)
      GO TO 1002
      ENTRY SECDER
      IF(INT.EQ.0) IPDER=1
      CALL DER(AA,BB,CCX,DD,THTO,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,XSW,
     *D1,W1,W2,RHO,WL)
      CALL GEO(AA,BB,CCX,DD,WL,NST,THTO,KFO,FO)
C
C     CALCULATE SPRAYL
C
 1002 N11=N1+1
      DO 14 I=1,NST
      ISAV=I-1
      IF(ENTRCE(I).NE.0.0) GO TO 15
   14 CONTINUE
   15 SPRAYL=(XSW(N11)-XSW(ISAV))*WL
C
C     CALCULATE AND PRINT FIN COEFFICIENTS,SHIP PLUS FIN COEFFICIENTS,
C     AND PRINT NON DIMENSIONAL DERIVATIVES
C
      SX=SY=SK=SN=0.
      CALL FIN(SX,SY ,SK,SN,CR,CT,S,OMEGA)
      SFYV=DYV+FINYV
      SFYR=DYR+FINYR
      SFKV=DKV+FINKV
      SFKR=DKR+FINKR
      SFNV=DNV+FINNV
      SFNR=DNR+FINNR
      SC=DYV*DNR-(DYR-AM)*DNV
      SCF=SFYV*SFNR-(SFYR-AM)*SFNV
      IF(IPDER.NE.0) RETURN
      IF(IPDER.NE.0) WRITE(6,209) CCX,THTOPR
      WRITE(6,225)
      WRITE(6,229) DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *               DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *               DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *               DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *               DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      WRITE(6,233)
```

```
      WRITE(6,234) FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      WRITE(6,235)
      WRITE(6,236) SFYV,SFYR,SFKV,SFKR,SFNV,SFNR
      WRITE(6,237) SC
      WRITE(6,238) SCF
C
C     WRITE CUMULATIVE INTEGRALS
C
      WRITE(6,231) FO
      WRITE(6,232)
      WRITE(6,233) (I,DI(I),DFI(I),DF2I(I),DF3I(I),DCI(I),DC2I(I),
     *DC3I(I),DCFI(I),DCF2I(I),DC2FI(I),B36I(I),I=1,NST)
C
C     CONVERT TO DEGREES AND PRINT GEOMETRICAL VARIABLES
C
      DO33 I=1,5
   33 PHO(I)=PHO(I)/DTR
      WRITE (6,239)
      WRITE(6,240)  (PHO(I),GI(I),SI(I),S1(I),TDRAF(I),I=1,5)
C
C     CONVERT  TO RADIANS
C
      DO63 I=1,5
   63 PHO(I)=PHO(I)*DTR
C
C     FORMATS
C
  100 FORMAT(8F10.2)
  101 FORMAT(F10.0,14I5)
  102 FORMAT(16I5)
  103 FORMAT(20A4)
  200 FORMAT(1H1,10HINPUT DATA //)
  201 FORMAT(1X,20A4)
  202 FORMAT(  1X,57HDT,NSTEP,NPRNT,IP,IFIN,IFLOT,IFT,NJET,INT,IEUG,IW,I
     *PR,ICO /F10.2,12I5)
  203 FORMAT(1X,32HTHT,PHI,PSI,Z,C1,C2,CVENT,DVENT /8F10.2)
  204 FORMAT(  1X,31HAA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY/
     *4F10.3,F10.1,F10.3,3F10.1)
  205 FORMAT(  1X,23HWL,SP,RHO,ANU,CDLL,CDNN/3F10.3,F12.9,2F10.3)
  207 FORMAT(1X,13HOMEGA,CR,CT,S    /8F10.2)
  208 FORMAT(  1X,20HCCO,THTO,SPTURN,DEPTH  /8F10.2)
  209 FORMAT(1H1,6HDRAFT=,F6.2,10X,5HTRIM=,F6.2)
  210 FORMAT(  1X,14HXARM,ZARM,BACE  /8F10.2)
  211 FORMAT(  1X,8HYARM(I) )
  212 FORMAT(  1X,9HDELJET(I) )
  213 FORMAT(   1X,7HRMCP(I) )
  214 FORMAT(  1X,10HALPHA(I)     )
  215 FORMAT(1X,3HNST /I5)
  216 FORMAT(1X,     20HPUBL,PUBB,WALP,DEPTH /8F10.2)
  217 FORMAT(1X,18HSLBOW,SLSTRN        /8F10.2)
  218 FORMAT(1X,8HDRISE(I)  )
  219 FORMAT(1X,9HENTRCE(I) )
  220 FORMAT(1X,8HCHINE(I) )
  221 FORMAT(1X,3HNSW)
  222 FORMAT(1X,3HXSW)
  223 FORMAT(1X,3HHSW)
  224 FORMAT(/I5,2X,2HD1,2X,8F11.3/(11X,8F11.3))
  225 FORMAT(7X,2HW1,2X,8F11.3/(11X,8F11.3))
  226 FORMAT(7X,2HW2,2X,8F11.3/(11X,8F11.3))
  227 FORMAT(/////1X,16HCONVERTED INPUT /1X,24HSP,AM,AIX,AIY,AIZ,FROUDE
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```
     */6G12.4)
 228 FORMAT(///1X,27HNON DIMENSIONAL DERIVATIVES   /)
 229 FORMAT(1X,44HDYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW/10E12.4/
     *        1X,44HDZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW/10E12.4/
     *        1X,44HDKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW/10E12.4/
     *        1X,44HDMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW/10E12.4/
     *        1X,44HDNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW/10E12.4)
 231 FORMAT( 1X,40HCENTER OF PRESSURE AT CENTER OF GRAVITY=  ,F10.2)
 232 FORMAT(    /1X,3HSEC, 9X,2HDI,8X,3HDFI,7X,4HDF2I,7X,4HDF3I,
     *8X,3HDCI,7X,4HDC2I,7X,4HDC3I,7X,4HDCFI,6X,5HDCF2I,6X,5HDC2FI,
     *7X,4HB3BI)
 233 FORMAT(I5,11E11.3)
 234 FORMAT(/1X,23HSTABILIZER COEFFICIENTS
     *          /7H FINYV=,E13.4/7H FINYR=,E13.4/7H FINKV=,E13.4/
     *7H FINKR=,E13.4/7H FINNV=,E13.4/7H FINNR=,E13.4)
 235 FORMAT(  /,1X,33HSHIP PLUS STABILIZER COEFFICIENTS     )
 236 FORMAT(   6H SFYV=,E13.4/6H SFYR=,E13.4/ 6H SFKV=,E13.4/
     *6H SFKR=,E13.4/ 6H SFNV=,E13.4/6H SFNR=,E13.4)
 237 FORMAT( /1X, 34HSTABILITY CRITERION FOR SHIP ONLY= ,E12.4)
 238 FORMAT(  1X,38HSTABILITY CRITERION FOR SHIP PLUS FIN=  ,E12.4)
 239 FORMAT(/////1X,21HGEOMETRICAL VARIABLES  /,1X,9HROLL(DEG)   ,
     *10X,2HGI,10X,2HSI,10X,2HS1,7X,5HTDRAF)
 240 FORMAT(1X,F10.3,4G12.4)
 241 FORMAT(1X,38HDWET,WAMP,WPER,BETA,WDEP,XC,RO,ETAO,TO/9F10.2)
 242 FORMAT(1X,34HCDIS,RHOWA,ATM,PHIC,PHI1,THTB,THTS/F8.2,F10.6,6F8.2)
     RETURN
     END
vv
```

```
      SUBROUTINE DERIVE(T,N,Y,YP)
      REAL KC,MC,NC
      DIMENSION A(6,5),B(5),A1(4,3),B1(3),Y(13),YP(13)
      COMMON /ABC/ DRAFT(25),WEIGHT,DUMMIE(5),THETA
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /DERV/ XUDELU,DRAGY,DRAGN,DFTH,IFIN,CCX
      COMMON /FLOW/ PC,GF,GO,VDOTP,AOP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NG,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /INDER/ CR,CT,S,OMEGA
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATK,PMAX,AC,DEM
      COMMON /PSEAL/ THTB,THTS
      COMMON /TEMP/SX,SY,SK,SN,WAVEDG,AERODG,SPRYDG,SEALDG,
     *SKINDG,FINDG,SHIPDG,TOTLDG
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA
      COMMON /AYEYE/ AI,C1,C2,AI1,AI2,DPDT,CVENT,DVENT
C
C     THE COMPONENT FORCES AND MOMENTS GENERATED BY EACH
C     SUBROUTINE ARE INDICATED BELOW
C
C     DRAG - CROSS FLOW DRAG
C     AUXILY - HYDROSTATIC EFFECTS DUE TO ROLL AND THEIR INFLUENCE ON DRAG
C     FIN - STABILIZERS
C     THRUST - THRUST
C     LINVEL - LINEAR VELOCITY
C     INERTIA - INERTIA
C     SEAWAV - WAVES
C     DRAGV - VERTICAL DRAG
C     PRESS - CUSHION PRESSURE
C     SEALFM - BOW AND STERN SEALS
C
      SZ=SM=TZ=TM=0.
      DXPHIF=DYPHIF=DZPHIF=DMPHIF=DRAGZ=DRAGM=0.
      U=Y(1)
      V=Y(2)
      W=Y(3)
      P=Y(4)
      Q=Y(5)
      R=Y(6)
      X=Y(7)
      YY=Y(8)
      Z=Y(9)
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
C
C     GENERATE FORCES AND MOMENTS
C
      ARWALL=2.*CC/WL
      ECOEF=0.9
      CDI=2.*(0.5*DYV*V*U)**2/(PI*ARWALL*ECOEF)*WL/CC
      CALL DRAG(DRAGY,DRAGK,DRAGN,P,R,V)
      IF(T.EQ.0.) CALL AUXILY(PHI,U,XUDELU,DNPHIF,DKPHIF)
      IF(IFIN.NE.0) CALL FIN(SX,SY,SK,SN,CR,CT,S,OMEGA)
```

```
      CALL THRUST(U,THT,DFTH,TX,TY,TK,TN,SHIPDG,TOTLDG)
C     SET THRUST EQUAL TO SHIP DRAG AT T=0.
      IF(T.EQ.0) TXO=SHIPDG-SX
      TX=TXO
      DRAGX=XUDELU-SHIPDG
      CALL SEAWAV(WX,WY,WZ,WK,WM,WN,VOL,AO,Y,T)
      CALL DRAGV(DZ2,DM2,DK2,F,W,Q,2)
      CALL DRAGV(DZ3,DM3,DK3,F,W,Q,3)
      DZ=DZ2+DZ3
      DM=DM2+DM3
      DK=DK2+DK3
      CALL PRESS(T,Y,VOL,XC,YC,ZC,KC,MC,NC)
      CALL VLDOT(T,AO,VOLDOT)
      CALL LINVEL(FXLV,FYLV,FZLV,FKLV,FMLV,FNLV)
      CALL INERTIA(FXIC,FYIC,FZIC,FKIC,FMIC,FNIC)
      CALL SEALFM(SLZ,SLK,SLM,Y,T)
      WZ=WZ+SLZ
      WK=WK+SLK
      WM=WM+SLM
      COSTH=COS(THT)
      SINTH=SIN(THT)
      XWGT=WEIGHT*SINTH/DEM
      ZWGT=WEIGHT*COSTH/DEM
C
C     CALCULATE UDOT,VDOT,WDOT,PDOT,QDOT,RDOT
C     YP(1)=UDOT,YP(2)=VDOT,YP(3)=WDOT,YP(4)=PDOT,YP(5)=QDOT,YP(6)=RDOT
C
      A(1,1)=AM-DYDV
      A(1,2)=-DYDW
      A(1,3)=-DYDP
      A(1,4)=-DYDQ
      A(1,5)=-DYDR
      A(2,1)=-DZDV
      A(2,2)=AM-DZDW
      A(2,3)=-DZDP
      A(2,4)=-DZDQ
      A(2,5)=-DZDR
      A(3,1)=-DKDV
      A(3,2)=-DKDW
      A(3,3)=AIX-DKDP
      A(3,4)=-DKDQ
      A(3,5)=-DKDR
      A(4,1)=-DMDV
      A(4,2)=-DMDW
      A(4,3)=-DMDP
      A(4,4)=AIY-DMDQ
      A(4,5)=-DMDR
      A(5,1)=-DNDV
      A(5,2)=-DNDW
      A(5,3)=-DNDP
      A(5,4)=-DNDQ
      A(5,5)=AIZ-DNDR
C
C     B(1)=FY,B(2)=FZ,B(3)=FK,B(4)=FM,B(5)=FN
C
      FX=-AM*(Q*W-R*V)+FXLV+SX+FXIC+TX+DRAGX+DXPHIF-CDI+WX-XWGT+XC
      B(1)=-AM*(R*U-P*W)+FYLV+SY+FYIC+TY+DRAGY+DYPHIF+WY+YC
      B(2)=-AM*(P*V-Q*U)+FZLV+SZ+FZIC+TZ+DRAGZ+DZPHIF+WZ+ZWGT+ZC+DZ
      B(3)=-(AIZ-AIY)*Q*R+FKLV+SK+FKIC+TK+DRAGK+DKPHIF+WK+KC+DK
      B(4)=-(AIX-AIZ)*R*P+FMLV+SM+FMIC+TM+DRAGM+DMPHIF+WM+MC+DM
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```
      B(5)=-(AIY-AIX)*P*Q+FNLV*SN+FNIC*TN*DRAGN*DNPHIF*WN*NC
      NEQ=5
      CALL COMB(A,NEQ,6,B,1,NER,DET)
      YP(1)=FX/(AM-DXDU)
      YP(2)=B(1)
      YP(3)=B(2)
      YP(4)=B(3)
      YP(5)=B(4)
      YP(6)=B(5)
C
C     CALCULATE XDOT,YDOT,ZDOT
C     YP(7)=XDOT,YP(8)=YDOT,YP(9)=ZDOT
C
      COSPHI=COS(PHI)
      SINPHI=SIN(PHI)
      COSPSI=COS(PSI)
      SINPSI=SIN(PSI)
      YP(7)=U*COSTH*COSPSI+V*(SINTH*SINPHI*COSPSI-COSPHI*SINPSI)+
     *W*(SINTH*COSPHI*COSPSI+SINPHI*SINPSI)
      YP(8)=U*COSTH*SINPSI+V*(SINTH*SINPHI*SINPSI+COSPHI*COSPSI)+
     *W*(SINTH*COSPHI*SINPSI-SINPHI*COSPSI)
      YP(9)=-U*SINTH+V*COSTH*SINPHI+W*COSTH*COSPHI
C
C     CALCULATE PHIDOT,THTDOT,PSIDOT
C     YP(10)=PHIDOT,YP(11)=THTDOT,YP(12)=PSIDOT
C
      A1(1,1)=1.
      A1(1,2)=0.
      A1(1,3)=-SINTH
      A1(2,1)=0.
      A1(2,2)=COSPHI
      A1(2,3)=COSTH*SINPHI
      A1(3,1)=0.
      A1(3,2)=-SINPHI
      A1(3,3)=COSTH*COSPHI
      B1(1)=P
      B1(2)=Q
      B1(3)=R
      NEQ=3
      CALL COMB(A1,NEQ,4,B1,1,NER,DET)
      YP(10)=B1(1)
      YP(11)=B1(2)
      YP(12)=B1(3)
      YP(13)=VOLDOT/(WL**2*SP)
      GAM=1.4
      DPDT=-GAM*PC/VOL *VOLDOT
      AI=AI+C1*YP(3)*SP**2/WL+C2*DPDT
      IF(AI.GT.AI2) AI=AI2
      IF(AI.LE.AI1) AI=AI1
      RETURN
      END
VV
```

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```
      SUBROUTINE SEAWAV(WX,WY,WZ,WK,WM,WN,VOL,AO,Y,T)
      REAL MWK,MWM,MWN
      DIMENSION Y(13)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /WFOR/ FWX(25),FWY(25),FWZ(25),MWK(25),MWM(25),MWN(25),
     *AREA(25),FLEAK(25)
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON /BSLEAK/ BLEAK,SLEAK
      DO 1 I=1,NST
    1 CALL BUOY(I,Y,T)
C     INTEGRATE FOR WAVE FORCES AND MOMENTS
      CALL SIMPSN(NST,N1,DEL1,DEL2,FWX,WX)
      CALL SIMPSN(NST,N1,DEL1,DEL2,FWY,WY)
      CALL SIMPSN(NST,N1,DEL1,DEL2,FWZ,WZ)
      CALL SIMPSN(NST,N1,DEL1,DEL2,MWK,WK)
      CALL SIMPSN(NST,N1,DEL1,DEL2,MWM,WM)
      CALL SIMPSN(NST,N1,DEL1,DEL2,MWN,WN)
      DEMF =0.5*RHO*WL**2*SP**2
      DEMM=DEMF*WL
      WX=WX/DEMF
      WY=WY/DEMF
      WZ=WZ/DEMF
      WK=WK/DEMF/WL
      WM=WM/DEMF/WL
      WN=WN/DEMF/WL
      CALL SIMPSN(N1,N1,DEL1,DEL1,AREA,VOL)
      CALL SIMPSN(N1,N1,DEL1,DEL1,FLEAK,AO)
      BLEAK=FLEAK(N1)*0.5
      SLEAK=FLEAK(1)*0.5
      IF(INWGT.EQ.0) GO TO 2
      WX=WX-WXO
      WM=WM-WMO
    2 CONTINUE
      RETURN
      END
vv
```

```
      SUBROUTINE SWAVE(XC,YC,ZC,Y,T,ETA,AYETA,AZETA)
      DIMENSION Y(13)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEP,OFFSET
     *,WLG,ICO,XO,RO,ETAO,TO
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      SINH(U)=(EXP(U)-EXP(-U))/2.
      SECH(ARG)=2./(EXP(ARG)+EXP(-ARG))
      DATA C00,C01,C02,C03,C04/11.53924656,-52.76716255,107.1876292,
     *-100.9056818,35.23071874/
      HEAVE=Y(9)*WL
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
C
C     SET HEAVE,PHI,THT,PSI=0 TO CALCULATE WAVE FORM FOR PLOTTING
      TEST=XC+YC+ZC
      IF(TEST.EQ.0.) HEAVE=PHI=THT=PSI=0.
      PSO=BETA-PSI
      COST=COS(THT)
      TW=T*WL/SP
      UT=(Y(7)*COS(BETA)+Y(8)*SIN(BETA))*WL
      ARG1=XC*TAN(THT)-HEAVE/COST-YC*TAN(PHI)/COST
      ARG2=(XC*COST+ZC*SIN(THT))*COS(PSO)+YC*SIN(PSO)
      AYETA=AZETA=0.
      GO TO (1,2,3),IW
C
C     SINUSOIDAL WAVE
C
    1 CT=CEL*TW
      COF=1.-EXP(-T/3.)
      AMPW=WAMP*COF
      ETA=-AMPW*SIN(CAY*(ARG2+UT-CT))/COST-ARG1
      AYETA=-AMPW*G*CAY*SIN(PSO)*COS(CAY*(ARG2+UT-CT))
      AZETA= AMPW*G*CAY*SIN(CAY*(ARG2+UT-CT))
      RETURN
C
C     SOLITARY WAVE
C
    2 A1=CAY*(XC-OFFSET)
      ETA=WAMP*SECH(A1)**2
      IF(INWGT.EQ.0) RETURN
      CT=CEL*TW
      I=ABS(UT-CT)/WLG
      A1=CAY*(ARG2+UT-CT+OFFSET+I*WLG)
      ETA=WAMP*SECH(A1)**2/COST-ARG1
      RETURN
C
C     EXPLOSION WAVE
C
    3 ETA=0.
      IF(INWGT.EQ.0) RETURN
      H=WDEP
      TW=TW+TO
      R=UT+XO
      RF=R/TW/SQRT(G*H)
      IF(RF.GE..3) GO TO 4
      X=1./(4.*RF**2)
```

```
      GO TO 5
    4 RF2=RF*RF
      RF3=RF2*RF
      RF4=RF3*RF
      X =C04*RF4+C03*RF3+C02*RF2+C01*RF+C00
    5 CAY=X/H
      OMEGA=CAY*SQRT(G*TANH(X)/CAY)
      CEL=OMEGA/CAY
      CT=CEL*T
      HK2=2.*X
      SHK2=SINH(HK2)
      ARG=HK2/SHK2
      ARG3=1.+ARG
      ARG4=-ARG3/(ARG*(1.-HK2/TANH(HK2))+0.5*ARG3**2-ARG3)
      ROK=CAY*RO
      CALL BESSEL(3,ROK,BJ3)
      ARG5=(CAY*(X0+ARG2+UT-CT))/COST
C
C     SET ARG5 TO CALCULATE WAVE FORM FOR PLOTTING
C
      IF(TEST.EQ.0.) ARG5=CAY*(X0-CT+UT)
      ETA=(ETA0*RO/R)*SQRT(ARG4)*BJ3*COS(ARG5)-ARG1
      RETURN
      END
```

```
      SUBROUTINE BUOY(I,Y,T)
C     DEFINITION OF PARAMETERS
      REAL MWK,MWM,MWN
      DIMENSION JTRAN(4),SGN(4),DINT(4),Y(13)
      DIMENSION DFT(25,4),BEAM(25,4),AWY(4),AWZ(4)
      COMMON /BEEM2/ BEM2(25),BEM3(25),ARMS,ARMP
      COMMON /GEOMM/ NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY,CCO,THTO
      COMMON /SES/ HSW(25)
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25)
      COMMON /WFOR/ FWX(25),FWY(25),FWZ(25),MWK(25),MWM(25),MWN(25),
     *AREA(25),FLEAK(25)
      DATA SGN/-1.,1.,-1.,1./
      IF(1.EQ.1.AND.IBUG.NE.0) WRITE(6,202) AA,BB,CC,DD,Y(1),Y(7),Y(9)
     *,Y(10),Y(11),Y(12)
  202 FORMAT(     * AA,BB,CC,DD,U,SURGE,HEAVE,PHI,THT,PSI*/10G12.4)
      FWX(I)=FWY(I)=FWZ(I)=MWK(I)=MWM(I)=MWN(I)=0.
      AREA(I)=          BEM2(I)=BEM3(I)=0.
      JJ=NSW(I)
      IF(JJ.EQ.1) RETURN
      RHOG=RHO*G
      DO 1 K=2,3
      JTRAN(K)=0
      DFT(I,K)=BEAM(I,K)=0.
      DO 2 J=2,JJ
      D1TOP=D1(I,J)
      D1BOT=D1(I,J-1)
      W1TOP=W1(I,J)
      WT=BB
      IF(K.GT.2) WT=-WT
      Z=DD-HSW(I)-D1TOP
      HGT=CC-D1TOP-HSW(I)-F(I)*TAN(THTO)
      CALL SWAVE(F(I),WT,Z,Y,T,ETA,AYETA,AZETA)
      AWY(K)=AYETA
      AWZ(K)=AZETA
      HCHK=HGT+ETA
      IF(HCHK.GE.0.) GO TO 2
      DFT(I,K)=D1TOP+HCHK
      BEAM(I,K)=W1TOP
      JTRAN(K)=J
      DINT(K)=DFT(I,K)-D1BOT
      IF(DINT(K).GT.0.)GO TO 1
      JTRAN(K)=1
      GO TO 1
    2 CONTINUE
      JTRAN(K)=JJ
      DFT(I,K)=D1TOP
      BEAM(I,K)=W1TOP
      DINT(K)=D1TOP-D1BOT
    1 CONTINUE
      BEM2(I)=BEAM(I,2)
      BEM3(I)=BEAM(I,3)
      IF(DFT(I,2).LT.0.) DFT(I ,2)=0.
      IF(DFT(I,3).LT.0.) DFT(I ,3)=0.
      AREAS=0.5*DFT(I,2)*(BEAM(I,2)+W1(I,1))
      AREAP=0.5*DFT(I,3)*(BEAM(I,3)+W1(I,1))
      ARMS=BB+0.25*(BEAM(I,2)+W1(I,1))
      ARMP=-(BB+0.25*(BEAM(I,3)+W1(I,1)))
```

```
      AZS=DD-HSW(I)-DFT(I,2)/2.
      AZP=DD-HSW(I)-DFT(I,3)/2.
      DINT(1)=DINT(2)
      DINT(4)=DINT(3)
      CALL VOLUME(I ,BB,JTRAN,DINT,DWET,FLK,AR)
      AREA(I)=AR
      FLEAK(I)=FLK
      RN=Y(1)*SP*WL/ANU
      ARG=(ALOG10(RN)-2.)**2
      CF=0.075/ARG+.0004
      DPO=CC-F(I)*TAN(THTO)
      AWYS=AWY(2)*EXP(-CAY*DFT(I,2)/2.)
      AWZS=AWZ(2)*EXP(-CAY*DFT(I,2)/2.)
      AWYP=AWY(3)*EXP(-CAY*DFT(I,3)/2.)
      AWZP=AWZ(3)*EXP(-CAY*DFT(I,3)/2.)
      AKZS=AKZP=1.
      IF(AREAS.NE.0.) AKZS=AREAS/BEM2(I)/DFT(I,2)
      IF(AREAP.NE.0.) AKZP=AREAP/BEM3(I)/DFT(I,3)
      AKYS=2.4*AKZS+0.4
      AKYP=2.4*AKZP+0.4
      AMYS=AKYS*DFT(I,2)**2
      AMZS=AKZS*BEM2(I)**2
      AMYP=AKYP*DFT(I,3)**2
      AMZP=AKZP*BEM3(I)**2
      FYS=RHO*(AREAS+AMYS)*AWYS
      FYP=RHO*(AREAP+AMYP)*AWYP
      FZS=-RHOG*AREAS+RHO*(AREAS+AMZS)*AWZS
      FZP=-RHOG*AREAP+RHO*(AREAP+AMZP)*AWZP
      FXS=-CF*(DFT(I,2)-DPO)*RHO*(SP*Y(1))**2
      FXP=-CF*(DFT(I,3)-DPO)*RHO*(SP*Y(1))**2
      FWX(I)=FXS+FXP
      FWY(I)=FYS+FYP
      FWZ(I)=FZS+FZP
      MWK(I)=-FYS*AZS-FYP*AZP+FZS*ARMS+FZP*ARMP
      IF(ABS(MWK(I)).LT.1.E-6) MWK(I)=0.
      MWM(I)=-(FZS+FZP)*F(I)
      MWN(I)=(FYS+FYP)*F(I)-(FXS*ARMS+FXP*ARMP)
      MWN(I)=0.
      RETURN
      END
VV
```

```
      SUBROUTINE VOLUME(I,BB,JTRAN,DINT,DWET,FLEAK,AREA)
C     SUBROUTINE TO CALCULATE AREA BETWEEN CALM WATER SURFACE
C     AND WET DECK AND LEAKAGE FOR CROSS SETION I
      DIMENSION JTRAN(4),DINT(4)
      COMMON /GEOMM/ NSW(25),W1(25,25),W2(25,25),D1(25,25)
      FLEAK=0.
C     STARBOARD SIDEWALL
      DS=DINT(2)
      JS=JTRAN(2)
      IF(JS.EQ.1) GO TO 1
      JS1=JS-1
      HGTS=DWET-D1(I,JS1)-DS
      GO TO 2
    1 HGTS=DWET-DS                                                   C
      FLEAK=-DS
C     PORT SIDEWALL
    2 DP=DINT(3)
      JP=JTRAN(3)
      IF(JP.EQ.1) GO TO 3
      JP1=JP-1
      HGTP=DWET-D1(I,JP1)-DP
      GO TO 4
    3 HGTP=DWET-DP                                                   C
      FLEAK=FLEAK-DP
    4 AREA=BB*(HGTP+HGTS)
      RETURN
      END
vv
```

```
      SUBROUTINE PRESS(T,Y,VOL,XC,YC,ZC,KC,MC,NC)
      REAL KC ,MC,NC
      DIMENSION Y(13)
      COMMON/ABC/ DRAFT(25),WEIGHT
      COMMON /BSLEAK/ BLEAK,SLEAK
      COMMON /FLOW/ PC,QF,QO,VDOTP,AOP
      COMMON /IN/  AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FC,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM,IFR
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      GAM=1.4
      HEV=Y(9)
      PHI=Y(10)
      THT=Y(11)
      VOLC=Y(13)*WL**3
      AOP=VOL
    1 PC=PC   *VOLC**GAM/VOL**GAM
      Y(13)=VOL/WL**3
      IF(PC.LT.ATM) PC=ATM
   10 PDIF=PC-ATM
      ZARM=DD-CC-HEV*WL
      AN =AC*THT                                                        C
      BTAN=WL*TAN(THT)                                                  C
      BTBL=BTAN-BLEAK
      IF(THT.LT.0.) BTBL=BTAN+SLEAK
      IF(BTBL.GE.18.) BTBL=18.
      IF(BTBL.LT.-18.) BTBL=-18.
      IF(BLEAK.GT.0.) ZARM=DD-0.5*BTBL
      IF(SLEAK.GT.0.) ZARM=DD+0.5*BTBL
      IF((BLEAK+SLEAK).NE.0.) AN=2.*BB*BTBL
      XC=     AN*PDIF/DEM                                               C
      YC=-PHI*AC*PDIF/DEM
      ZC=-AC*PDIF/DEM
      KC=-YC*ZARM/WL
      MC=XC*ZARM/WL                                                     C
      NC=0.
      RETURN
      END
  vv
```

```
      SUBROUTINE VLDOT(T,AO,VOLDOT)
      COMMON /AYEYE/ AI,C1,C2
      COMMON /BSLEAK/ BLEAK,SLEAK
      COMMON /FLOW/ PC,QF,QO,VDOTP,AOP
      COMMON /IN/ AA,A1X,A1Z,AM,BB
      COMMON /PRES/ CDIS,RHOWA,PHI0,PHI1,ATM,PMAX,AC,DEM,IPR
      COMMON /PVO/ PVOL
      PMAX=ATM-PHI0/PHI1
    1 ASB=2.*BB*(BLEAK+SLEAK)
      AT=AI+AO+ASB
      PDIF=PC-ATM
      IF(PDIF.GT.0.) GO TO 20
      QF=PHI0
      QL=AT*CDIS*SQRT(2.*ABS(PDIF)/RHOWA)
      QO=AO*CDIS*SQRT(2.*ABS(PDIF)/RHOWA)
      IF(IPR.NE.0) WRITE(6,202) T,PC
  202 FORMAT(1X,*PC LESS THAN ATMOSPHERIC PRESSURE*,
     *5X,*T=*,F10.2,5X,*PC=*,F10.2)
      GO TO 2
   20 IF(PC.LT.PMAX) GO TO 3
      AF=49.
      QF=-CDIS*AF*SQRT(ABS(PC-PMAX)/RHOWA)
      QL=-AT*CDIS*SQRT(2.*PDIF/RHOWA)
      QO=-AO*CDIS*SQRT(2.*PDIF/RHOWA)
      IF(IPR.NE.0) WRITE(6,203) T,PC
  203 FORMAT(1X,*PC GREATER THAN PMAX*,5X,*T=*,F10.2,5X,*PC=*,F10.2)
      GO TO 2
    3 QF  =PHI0+PHI1*(PC-ATM)
      QL  =-AT*CDIS*SQRT(2.*(PC  -ATM)/RHOWA)
      QO  =-AO*CDIS*SQRT(2.*(PC  -ATM)/RHOWA)
    2 VOLDOT=QF+QL
      VDOTP=VOLDOT
      RETURN
      END
```

```
      SUBROUTINE INERTIA(FXIC,FYIC,FZIC,FMIC,FNIC,FKIC)
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,FSI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      FXIC= -DYDV*R*V-DYDP*R*P-DYDR*R*R+DYDW*W*Q+DZDQ*Q*Q+DZDP*P*Q
      FYIC= -DZDW*W*P-DZDQ*P*Q-DZDP*P*P
      FZIC= DYDV*V*P+DYDR*P*R+DYDP*P*P
      FMIC= -DYDR*P*V+DYDP*R*V+(DKDP-DNDR)*P*R+DNDP*(R*R-P*P)
     * +DZDP*W*R+DMDP*Q*R
      FNIC=-DZDP*W*Q+DZDQ*W*P+(DMDQ-DKDP)*P*Q+DKDQ*(P*P-Q*Q)
     * -DYDP*V*Q-DNDP*Q*R
      FKIC=(DZDW-DYDV)*V*W-(DYDR+DMDW)*R*W+(DZDQ+DNDV)*V*Q
     *+(DNDR-DMDQ)*R*Q-DYDP*P*W+DZDP*V*P-DMDP*R*P+DNDP*Q*P
      RETURN
      END
```

```
      SUBROUTINE LINVEL(FXLV,FYLV,FZLV,FKLV,FMLV,FNLV)
      COMMON /B/ P,Q,R,X,Y,Z,U,V,W,PHI,THT,PSI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      FXLV=0.
      FYLV=(DYV*V+DYW*W+DYP*P+DYQ*Q+DYR*R)*U
      FZLV=(DZV*V+DZW*W+DZP*P+DZQ*Q+DZR*R)*U
      FKLV=(DKV*V+DKW*[illegible]+DKP*P+DKQ*Q+DKR*R)*U
      FMLV=(DMV*V+DMW*W+DMP*P+DMQ*Q+DMR*R)*U
      FNLV=(DNV*V+DNW*W+DNP*P+DNQ*Q+DNR*R)*U
      RETURN
      END
```

```
      SUBROUTINE SEALFM(SLZ,SLK,SLM,Y,T)
C     SUBROUTINE TO CALCULATE FORCE AND MOMENT ON BOW AND STERN SEALS
      DIMENSION Y(13)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NO,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /PSEAL/ THTB,THTS
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM
      COMMON /FLOW/ PC,GF,QO,VDOTP,AOP
      PCGAGE=PC-ATM
      NI=11
      TESTB=AMIN1(BETA/DTR+.0001,180.)
      IF(BETA.EQ.0..OR.TESTB.EQ.180.) NI=1
      DELSL=2.*BB/NI
      CON= DELSL*PCGAGE
      ZSL=DD-CC
C     BOW SEAL
      BSLM=BSLK=0.
      XSL=XFG*WL
      YSL=-(BB+0.5*DELSL)
      DO 1 I=1,NI
      YSL=YSL+DELSL
      CALL SWAVE(XSL,YSL,ZSL,Y,T,ETASL,DUMX,DUMY)
      DEP=ETASL
      IF(DEP.LE.0.) GO TO 1
      WID=DEP/TAN(THTB)
      DELZ=-CON*WID
      XSLA=XSL+WID/2.
      BSLM=BSLM-DELZ*XSLA
      BSLK=BSLK+DELZ*YSL
    1 CONTINUE
C     STERN SEAL
      SSLM=SSLK=0.
      XSL=-XLG*WL
      YSL=-(BB+0.5*DELSL)
      DO 2 I=1,NI
      YSL=YSL+DELSL
      CALL SWAVE(XSL,YSL,ZSL,Y,T,ETASL,DUMX,DUMY)
      DEP=ETASL
      IF(DEP.LE.0.) GO TO 2
      WID=DEP/TAN(THTS)
      DELZ=CON*WID
      XSLA=XSL+WID/2.
      SSLM=SSLM-DELZ*XSLA
      SSLK=SSLK+DELZ*YSL
    2 CONTINUE
      SLZ=0.
      SLM=BSLM+SSLM
      SLK=BSLK+SSLK
      SLZ=SLZ/DEM
      SLM=SLM/DEM/WL
      SLK=SLK/DEM/WL
      RETURN
      END
VV
```

```
      SUBROUTINE FIN(SX,SY,SK,SN,CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT
      COMMON /FCOEF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,DUMMY,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY,CCO,THTO
      COMMON /LIFT/ ETA(30),CLIFT,GAMMA,XLAM
      COMMON /TVCC/ XARM,ZARM,BACE
      U2=U**2
      IF(SX.NE.0.0) GO TO 5
      NE=11
      CLIFT=0.2*PI
      SINO=SIN(OMEGA)
      COSO=COS(OMEGA)
      TCBAR=0.1
      CBAR=(CR+CT)/2
      A=CBAR*S
      AR=S**2/A
      XLAM=CT/CR
      GAMMA=ATAN(0.75*CR*(1.-XLAM)/S)
      BBP=BB-S*SINO/2.
      DDP=DD+S*COSO/2.+BACE
      XFN=-(XLG-CBAR/(2.*WL))
      DEL=S/(NE-1)
      DELI=1./(NE-1)
      ETA(1)=0.0
      DO 4 I=2,NE
    4 ETA(I)=ETA(I-1)+DEL
      VORX=VORY=VORK=VORN=0.
      CALL FINCOF(CR,CT,S,OMEGA)
    5 IF(THTO.GE.0.0) GO TO 10
      BETA=-(V+XFG*R)/U
      CALL VORTEX(VORX,VORY,VORK,VORN,BETA ,CR,CT,S,OMEGA)
   10 FBETA=-(V+XFN*R)*COSO/U
      RN=U*CBAR/ANU*SP
      CF=0.044/(RN**0.1666)
      CD=0.125*PI*TCBAR**2
      DRAG=(CD+2.*CF+(FYNCL*FBETA)**2/(PI*AR))*A/WL**2*U2
      FINX=-2.*DRAG
      SX=FINX+VORX
      SY=(FINYV*V+FINYR*R)*U+VORY
      SK=(FINKV*V+FINKR*R)*U+VORK
      SN=(FINNV*V+FINNR*R)*U+VORN
      RETURN
      END
```

```
      SUBROUTINE FINCOF(CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO
      COMMON /FCOEF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL
      IVOR=0
      CALL LIFTC(0.,CL,CL,CR,CT,S,OMEGA,IVOR)
      FYNCL=CL
      FBC=COSO/UO
      FINLV=CL*A/WL**2*UO**2*FBC
      FINLR=FINLV*XFN
      SFV=FINLV*COSO
      SFR=FINLR*COSO
      VFV=FINLV*SINO
      VFR=FINLR*SINO
      FINYV=-2.*SFV
      FINYR=-2.*SFR
      FINKV=-2.*VFV*BBP/WL+2.*SFV*DDP/WL
      FINKR=-2.*VFR*BBP/WL+2.*SFR*DDP/WL
      FINNV=FINYV*XFN
      FINNR=FINYR*XFN
      RETURN
      END
```

```
      SUBROUTINE LIFTC(BETA,CL,CLR,CR,CT,S,OMEGA,IVOR)
      DIMENSION CLC(30),CLCR(30)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /B/ P,Q,R,X,YY,Z,U,V,DUM,PHI,THT,PSI
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /LIFT/ ETA(30),CLIFT,GAMMA,XLAM
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC
      W=WP=0.
      ALPHA=ALPHAR=1.
      CON=(1.-XLAM)/S
      CON1=2.*PI*AR/(2.+AR)
      CON2=4.*(1.-COS(GAMMA))
      PI4=4./PI
      S2=S*S
      DO 40 L=1,NE
      IF(IVOR.EQ.0) GO TO 20
      IF(BETA.EQ.0.0) GO TO 19
C
C     CALCULATE SIDEWALL PARAMETERS
C
      SINT=SIN(THT)
      DT=CC+AA*SINT
      DF=CC-(WL-AA)*SINT                                                C
      D=DF
      IF(DT.GE.0.0) GO TO 10
      D=-WL*SINT                                                        C
      DT=0.0
   10 D2=D**2
C
C     CALCULATE LIFT ON SIDEWALL
C
      XLIFT=CLIFT*U2*D2*BETA                                            C
C
C     CALCULATE VORTEX STRENGTH AND POSITION
C
      SINB=SIN(ATAN(BETA))                                              C
      H=0.25*PI*D
      GRK=XLIFT/(U*H)
      Y1=SINB*WL                                                        C
      Y2=ETA(L)*SINO
      Y=Y1+Y2
      YP=Y1-Y2
      C1=ETA(L)*COSO
      C2=H-C1-DT
      C3=H+C1+DT
      R1=SQRT(C2**2+Y**2)
      R1P=SQRT(C2**2+YP**2)
      Q1=GRK/(2.*PI*R1)
      Q1P=GRK/(2.*PI*R1P)
      IF(Y.EQ.0.0) XMU1=PI*0.5
      IF(Y.EQ.0.0) GO TO 22
      XMU1=ATAN(ABS(C2/Y))
   22 W1=Q1*SIN(XMU1-OMEGA)
      IF(YP.EQ.0.0) XMU1=PI*0.5
      IF(YP.EQ.0.0) GO TO 23
      XMU1=ATAN(ABS(C2/YP))
   23 W1P=Q1P*SIN(XMU1-OMEGA)
C
C     SIDEWASH CALCULATION FOR IMAGE VORTEX
```

```
C
      R2=SQRT(C3**2+Y**2)
      R2P=SQRT(C3**2+YP**2)
      Q2= GRK/(2.*PI*R2)
      Q2P=GRK/(2.*PI*R2P)
      IF(Y.EQ.0.0) XMU2=PI*0.5
      IF(Y.EQ.0.0) GO TO 11
      XMU2=ATAN(ABS(C3/Y))
   11 W2=Q2*SIN(XMU2+OMEGA)
      IF(YP.EQ.0.0) XMU2=PI*0.5
      IF(YP.EQ.0.0) GO TO 12
      XMU2=ATAN(ABS(C3/YP))
   12 W2P=Q2P*SIN(XMU2+OMEGA)
      W=W1+W2
      WP=W1P+W2P
   19 ALPHA=-WP/U
      ALPHAR=-W/U
C
C     CALCULATE FORCE ON FINS
C
   20 CETA=CR-CR*ETA(L)*CON
      CLOR=CON1*ALPHAR
      CLO=CON1*ALPHA
      CON3=0.5*(CETA/CBAR+PI4*SQRT(1.-ETA(L)**2/S2)-(1.-ETA(L)/S)*CON2)
      CLCR(L)=CON3*CLOR
      CLC(L)=CON3*CLO
   40 CONTINUE
      CALL SIMPSN(NE,NE,DELI,DELI,CLC,CL)
      CALL SIMPSN(NE,NE,DELI,DELI,CLCR,CLR)
      RETURN
      END
VV
```

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```
      SUBROUTINE AUXILY(PHI,U,XUDELU,DNPHIF,DKPHIF)
      COMMON /IN/ AA,AIX,AIZ,AM,B5,CB,DUMMY,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU
      COMMON /U/ GI(25),S1(25),SI(25),PHO(25),TDRAF(25)
      COMMON /WALL/ VOLO,DRAGO,DELDRG
      YO(X0,X1,X2,Y1,Y2)=Y1+(X0-X1)*(Y2-Y1)/(X2-X1)
      CQ(DTRA)=2./(SP/SQRT(G*DTRA))**2
      NVAL=5
      IF(U.NE.1) GO TO 10
      KO=NVAL/2+1
      UO=1.
      CON=SP*WL/ANU
      RN=UO*CON
      ARG=(ALOG10(RN)-2.)**2
      CFO=0.075/ARG+0.0004
      RN=U*CON
      ARG=(ALOG10(RN)-2.)**2
      CF=0.075/ARG+.0004
      SWAO=GI(KO)
      SBAO=S1(KO)
      VOLO=SI(KO)
      TDRAFO=TDRAF(KO)*WL
      CBO=0.0
      IF(SBAO.LE.0.0) GO TO 9
      CFB=CFO*SWAO/SBAO
      CBO=0.029/SQRT(CFB)
      CFR=CQ(TDRAFO)
      IF(CFR.LT.CBO) CBO=CFR
    9 DRAGO=(CFO*SWAO+CBO*SBAO)*UO**2
   10 DO 1 I=2,NVAL
      K=I
      IF(PHI.GE.PHO(I).AND.PHI.LT.PHO(I-1)) GO TO 2
    1 CONTINUE
    2 SWAR=YO(PHI,PHO(K),PHO(K-1),GI(K),GI(K-1))
      SBAR=YO(PHI,PHO(K),PHO(K-1),S1(K),S1(K-1))
      VOLR=YO(PHI,PHO(K),PHO(K-1),SI(K),SI(K-1))
      TDRAFR=YO(PHI,PHO(K),PHO(K-1),TDRAF(K),TDRAF(K-1))*WL
      CBR=0.0
      IF(SBAR.LE.0.0) GO TO 11
      CFB=CF *SWAR/SBAR
      CBR=0.029/SQRT(CFB)
      CFR=CQ(TDRAFR)
      IF(CFR.LT.CBR) CBR=CFR
      PHIM=-PHI
   11 DO 3 I=2,NVAL
      K=I
      IF(PHIM.GE.PHO(I).AND.PHIM.LT.PHO(I-1)) GO TO 4
    3 CONTINUE
    4 SWAL=YO(PHIM,PHO(K),PHO(K-1),GI(K) ,GI(K-1))
      SBAL=YO(PHIM,PHO(K),PHO(K-1),S1(K),S1(K-1))
      VOLL=YO(PHIM,PHO(K),PHO(K-1),SI(K),SI(K-1))
      TDRAFL=YO(PHIM,PHO(K),PHO(K-1),TDRAF(K),TDRAF(K-1))*WL
      CBL=0.0
      IF(SBAL.LE.0.0) GO TO 12
      CFB=CF *SWAL/SBAL
      CBL=0.029/SQRT(CFB)
      CFR=CQ(TDRAFL)
      IF(CFR.LT.CBL) CBL=CFR
   12 CONTINUE
      U2=U*U
```

```
      SUBROUTINE THRUST(U,THT,DFTH,TX,TY,TK,TN,SHIPDG,TOTLDG)
      DIMENSION DELJ(4),DP(4),TJET(4)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY,CCO,THTO
      COMMON /THRST/ THIGH,TLOW
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
     *,ALPHA(4)
      DELT(XX)=XX
      DELH(YY)=0.01334*YY**2+0.2667*ABS(YY)
      FMIP(SS)=16.6*(SS/1.689)**2-190.*(SS/1.689)+528000.
      DGMOM(WW)=WW/1.689*(3900.-350.*(4.-TCON4))
      RMIP(SS)= 2.4*(SS/1.689)**2-10.*(SS/1.689)+82000.
      TCON3=0.
      TCON4=RMCP(1)+RMCP(2)+RMCP(3)+RMCP(4)
      IF(U.NE.1.) GO TO 1
      CALL RESOLD(SP,CCO,THTO,SHIPDG,TOTLDG)
      THMEAN=TOTLDG
      IF(CC.NE.CCO) CALL RESOLD(SP,CC,THT,DUMMY,DUMMY)
      V=SP
      THMIP=FMIP(V)
      COFF=.5*RHO*WL**2*SP**2
      CONST1=100000./COFF
      CONST2=60000./COFF
      THMIPO=THMIP/COFF
      THMARG=TCON3/COFF
      THCONT=THMIPO-THMARG
      THMCP=THCONT
      THREVS=RMIP(V)/COFF
      THTURN=THMEAN
      IF(SPTURN.EQ.SP) GO TO 3
      CALL RESOLD(SPTURN,CC,THT,DUMMY,THTURN)
      THMIPO=FMIP(SPTURN)/COFF
      THCONT=THMIPO-THMARG
    3 IF(THTURN.GT.THCONT) THTURN=THCONT
      DIFF=THCONT-THTURN
      THRGD=THMCP -DIFF
      DO 4 I=1,NJET
      DELJ(I)=DELT(DELJET(I))*DTR
      DP(I)=DELH(DELJET(I))
      IF(ABS(DELJET(I)).EQ.90.) DP(I)=0.
      IF(DELJET(I).EQ.180.) DP(I)=0.
    4 CONTINUE
      GO TO 5
    1 CONTINUE
      V=U*SP
      CALL RESOLD(V,CC,THT,SHIPDG,TOTLDG)
      THMIP=FMIP(V)
      THMIPO=THMIP/COFF
      THCONT=THMIPO-THMARG
      THRGD=THCONT-DIFF
      THREVS=RMIP(V)/COFF
    5 CONTINUE
      IF(DFTH.NE.0) GO TO 26
      DO 25 I=1,NJET
      ANJET=NJET
      TJET(I)=THCONT/ANJET
      TJET(I)=TJET(I)-(1.-RMCP(I))*CONST1
      IF(DELJET(I).EQ.180.) TJET(I)=THREVS-(1.-RMCP(I))*CONST2
      IF(ABS(DELJET(I)).EQ.90.) TJET(I)=THREVS-(1.-RMCP(I))*CONST2
```

```
      TJET(I)=TJET(I)*(1.-DP(I)/100.)
   25 CONTINUE
      GO TO 10
   26 CONTINUE
      PAIR=NJET/2.
      THIGH=(THMIPO-DGMOM(V)/COFF)/NJET
      RQD=THRQD/PAIR
      IF(THIGH.GE.RQD) THIGH=RQD
      TLOW=RQD-THIGH
      NJT=NJET-1
      DO 40 I=1,NJT,2
      TJET(I)=THIGH
   40 TJET(I+1)=TLOW
      IF(DFTH.GT.0) GO TO 10
      DO 50 I=1,NJT,2
      TJET(I)=TLOW
   50 TJET(I+1)=THIGH
   10 TX=0.
      TY=0.
      TK=0.0
      TN=0.
      DO 30 I=1,NJET
      T1=TJET(I)
      DEL1=DELJ(I)
      ALF1=ALPHA(I)*DTR
      TX=TX+T1*COS(ALF1)*COS(DEL1)
      TY=TY+T1*COS(ALF1)*SIN(DEL1)
      TK=TK+T1*SIN(ALF1)*YARM(I)
      TN=TN-T1*COS(ALF1)*COS(DEL1)*YARM(I)
   30 CONTINUE
      IF(DFTH.EQ.0.) TX=TX-DGMOM(V)/COFF
      TK=TK-TY*ZARM
      TN=TN-TY*XARM
      RETURN
      END
vv
```

```
      SUBROUTINE RESCLD(V,DRFT,TRIM,SHIPDG,TOTLDG)
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH,SPRAYL
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,CTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL
      COMMON /RSEAL/ THTB,THTS
      COMMON /TEMP/SX,SY,SK,SN,WAVEDG,AERODG,SPRYDG,SEALDG,
     *SKINDG,FINDG
      COMMON /WALL/ VOLO,DRAGC,DELDRG
      RO=RHO
      IF(V.NE.SP) GO TO 10
      BOL=BUBB/BUBL
      HOL=DRFT/BUBL
   10 C= VOLO*RO*G/WEIGHT*2.*WL**3
      F=V/SQRT(G*BUBL)
      CVT=WEIGHT/(RO*G)/BUBL**3
      CALL WAVE(BOL,HOL,C,F,WAVET)
      WAVEDG=0.5*RO*G*BUBL**3*CVT**2*WAVET
      CALL AERO(WL,DEPTH,BUBB,WALB,DRFT,V,AERODG)
      CALL SPRAY(V,SPRAYL,SPRYDG)
      CALL SEAL(BUBB,V,SLBOW,SLSTRN,THTB,THTS,SEALDG)
      FREC=0.5* RO*WL**2*SP**2
      SKINDG=2.*DRAGC*FREC
      FINDG=-SX*FREC
      SHIPDG=(WAVEDG+AERODG          +SPRYDG+SEALDG+SKINDG)/FREC
      TOTLDG=SHIPDG+DELDRG+FINDG/FREC
      RETURN
      END
```

```
      SUBROUTINE VORTEX(SX,SY,SK,SN,BETA,CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,CXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL
      IVOR=1
      CALL LIFTC(BETA,CL,CLR,CR,CT,S,OMEGA,IVOR)
      CON1=A/WL**2*U2
      CON2=PI*AR*CON1
      FINLR=CLR*CON1
      FINL=CL*CON1
      DRAGR=CLR**2/CON2
      DRAG=CL**2/CON2
      SFR=FINLR*COSO
      SF=FINL*COSO
      SX=-(DRAG+DRAGR)
      VFR=FINLR*SINO
      VF=-FINL*SINO
      SY=SF+SFR
      SN=SY*XFN+(DRAGR-DRAG)*BBP/WL
      SK=(VFR-VF)*BBP/WL-SY*DDP/WL
      RETURN
      END
```

```
SUBROUTINE AERO(SLFT,DEPTH,B,B1,DRFT,V,AERODG)
ANU=1.56E-04
RO=0.00238
RENOLD=V*SLFT/ANU
CF=0.455/ALOG10(RENOLD)**2.58
CON=DEPTH-DRFT
AREA=SLFT*(B+B1+2.*CON)
FRONT=CON*(B+B1*2.)
PRE=0.5*RO*V**2
FRNTDG=PRE*0.6*FRONT
SKINDG=PRE*CF*AREA
AERODG=FRNTDG+SKINDG
RETURN
END
```

```
      SUBROUTINE WAVE(BOL,HOL,C,F,TOTAL)
      PI=3.14159
      W=10.
      W1=2.*W
      TOTAL=WAVEDG=0.
      DIFF=EPSL=1.
      GAMA=1.-C
      B1OL=C/(4./3.*HOL)
      AK1=0.5/F**2
      F2=F*F
      BOL2=2.*BOL
      W1PI=W1/PI
      CON1=4.*PI*F2/W
      CON2=2.*PI*BOL/W1
      CON5=2.*AK1*HOL
      CON6=8.*B1OL/(AK1*SQRT(W/F2))
      CON7=2./BOL*SQRT(AK1/W1)*GAMA
      DO 10 M=1,20
      AM=M-1
      ALFA=CON1*AM
      BETA=CON2*AM
      CON3=SQRT(1.+ALFA**2)
      FAC=(1.+CON3)/CON3
      SB=SQRT(0.5+0.5*CON3)
      SB2=SB*SB
      CON4=AK1*SB
      SIGMA=COS(CON4)/SB-SIN(CON4)/(CON4*SB)
      DELTA=CON5*SB2
      A=CON6*COS(BETA)*(1.-EXP(-DELTA))*SIGMA/SB2
      IF(AM) 5,6,5
    5 PSI=W1PI*SIN(BETA)/AM
      GO TO 7
    6 PSI=BOL2
    7 B=CON7*SIN(CON4)*PSI
      WAVEDG=(A-B)**2*FAC*F2*EPSL+WAVEDG
      EPSL=2.
      IF(TOTAL.EQ.0.) GO TO 8
      DIFF=ABS((WAVEDG-TOTAL)/TOTAL)
    8 TOTAL=WAVEDG
      IF(DIFF.LE.0.001) GO TO 99
   10 CONTINUE
   99 RETURN
      END
```

```
      SUBROUTINE SPRAY(V,SPRAYL,SPRYDG)
      COMMON /ABC/ DRAFT(25)
      COMMON /CDE/ DRISE(23),ENTRCE(23),CHINE(23),HSPRAY(23)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      FAC=3.14159/180.
      CON=0.5*V*V/G
      DO 10 I=1,NST
   10 HSPRAY(I)=0.
      DO 30 I=1,NST
      ANG=SIN(DRISE(I)*FAC)*SIN(ENTRCE(I)*FAC)
      HSPRAY(I)=CON*ANG*ANG
      CHK=CHINE(I)-DRAFT(I)
      IF(CHK.LT.0.0) CHK=0.0
      IF(HSPRAY(I).GT.CHK) HSPRAY(I)=CHK
   30 CONTINUE
      CALL SIMPSN(NST,N1,DEL1,DEL2,HSPRAY,AREA)
      M=N1+1
      U=V*COS(ENTRCE(M)*FAC/2.)
      RENOLD=V*SPRAYL/ANU
      CF=0.075/(ALOG10(RENOLD)-2.)**2 +0.0004
      PRE=0.5*RHO*U*U
      SPRYDG=PRE*AREA*2.*CF
      RETURN
      END
```

```
      SUBROUTINE SEAL(B,V,SLBOW,SLSTRN,THTB,THTS,SEALDG)
      COMMON /ABC/ DRAFT(25)
      COMMON /IN/ AA,AIX,AIZ,AM,BP,CB,ZZ,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SF,UO,WL,XLG,XFG,CDLL,CONN,FROUDE,CC,DD,ANU
      COMMON /SES/ HS.(25),DEL1,DEL2,N1
      N3=N1+1
      RBOW=0.
      PRE=0.5*RHO*V*V
      PREB=PRE*B
      VANU=V/ANU
      SL1=DRAFT(N3)/SIN(THTB)
      IF(SL1.GE.SLBOW) SL1=SLBOW
      BOWSL=SL1*COS(THTB)
      IF(BOWSL.LE.0.) GO TO 10
      RENOLD=BOWSL*VANU
      CF=0.044/(RENOLD**(1./6.))
      RBOW=PREB*BOWSL*CF
   10 CONTINUE
      RSTRN=0.
      SL2=DRAFT(1 )/SIN(THTS)
      IF(SL2.GE.SLSTRN) SL2=SLSTRN
      STRNSL=SL2*COS(THTS)
      IF(STRNSL.LE.0.) GO TO 20
      RENOLD=STRNSL*VANU
      CF=0.044/(RENOLD**(1./6.))
      RSTRN=PREB*STRNSL*CF
   20 SEALDG=RBOW+RSTRN
      RETURN
      END
```

```
      SUBROUTINE DRAG(DY,DK,DN,P,R,V)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSF(25)
      COMMON /Z/ AR,ARL,ARL2,ARL3,ARF,ARF2,ARF3,ARFL,ARFL2,ARF2L,B3B
      P2=P*P
      R2=R*R
      V2=V*V
      RP2=R*P*2.
      VP2=V*P*2.
      VR2=V*R*2.
      VO=V-FO*P/WL
      ONE=SIGN(1.0,VO)
      IF(R.EQ.0.)GO TO 7
      X0=-VO/R
    7 CONTINUE
      AREA=DI(NST)
      AREAL=DFI(NST)
      AREAL2=DF2I(NST)
      AREAL3=DF3I(NST)
      AREAF=DCI(NST)
      AREAF2=DC2I(NST)
      AREAF3=DC3I(NST)
      AREAFL=DCFI(NST)
      AFL2=DCF2I(NST)
      AF2L=DC2FI(NST)
      DY=-CDLL*(V2*AREA+R2*AREAL2+P2*AREAF2+VR2*AREAL-RP2*AREAFL-
     *VP2*AREAF)
      DN=-CDLL*(V2*AREAL+R2*AREAL3+P2*AF2L+VR2*AREAL2-RP2*AFL2-
     *VP2*AREAFL)
      DK=CDLL*(V2*AREAF+R2*AFL2+P2*AREAF3+VR2*AREAFL-RP2*AF2L-
     *VP2*AREAF2)
      DKV=-CDNN*B3BI(NST)*P*ABS(P)
      IF(R.EQ.0.)GO TO 2
      IF(X0+XLG) 2,2,1
    1 IF(X0-XFG) 3,2,2
    3 CALL GEOM(X0)
      AY=-CDLL*(V2*AR+R2*ARL2+P2*ARF2+VR2*ARL-RP2*ARFL-VP2*ARF)
      AN=-CDLL*(V2*ARL+R2*ARL3+P2*ARF2L+VR2*ARL2-RP2*ARFL2-VP2*ARFL)
      AK=CDLL*(V2*ARF+R2*ARFL2+P2*ARF3+VR2*ARFL-RP2*ARF2L-VP2*ARF2)
      ONEP=SIGN(1.0,-X0)
      DY=(DY-AY*2.)*ONEP
      DK=(DK-AK*2.)*ONEP
      DN=(DN-AN*2.)*ONEP
    2 DY=DY*ONE*2.
      DK=2.*DK*ONE +DKV
      DN=DN*ONE*2.
      RETURN
      END
```

```
      SUBROUTINE GEOM(X0)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /Z/ AR,ARL,ARL2,ARL3,ARF,ARF2,ARF3,ARFL,ARFL2,ARF2L,B3B
      YO(X0,X1,X2,Y1,Y2)=Y1+(X0-X1)*(Y2-Y1)/(X2-X1)
      X0=X0+AA/WL
      DO 1 I=2,NST
      K=I
      IF(X0.GE.XSW(I-1).AND.X0.LT.XSW(I)) GO TO 2
    1 CONTINUE
    2 K1=K-1
      X1=XSW(K1)
      X2=XSW(K)
      AR=YO(X0 ,X1,X2,DI(K1) ,DI(K))
      ARL=YO(X0,X1,X2,DFI(K1),DFI(K))
      ARL2=YO(X0,X1,X2,DF2I(K1),DF2I(K))
      ARL3=YO(X0,X1,X2,DF3I(K1),DF3I(K))
      ARF=YO(X0,X1,X2,DCI(K1),DCI(K))
      ARF2=YO(X0,X1,X2,DC2I(K1),DC2I(K))
      ARF3=YO(X0,X1,X2,DC3I(K1),DC3I(K))
      ARFL=YO(X0,X1,X2,DCFI(K1),DCFI(K))
      ARFL2=YO(X0,X1,X2,DCF2I(K1),DCF2I(K))
      ARF2L=YO(X0,X1,X2,DC2FI(K1),DC2FI(K))
      B3B=YO(X0,X1,X2,B3BI(K1),B3BI(K))
      RETURN
      END
```

```
      SUBROUTINE DRAGV(DZ,DM,DK,F,W,Q,K)
      COMMON /BEEM/ BEAM(25),BEAMI(25),BEAMFI(25),BEAMF2I(25)
     *,BEAMF3I(25)
      COMMON /BEEM2/ BEM2(25),BEM3(25),ARMS,ARMP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN
      COMMON /X/ DUMMY(300),XSW(25)
      COMMON /Z1/ BR,BRL,BRL2,BRL3
      DIMENSION F(25)
      TRAP(H,Y1,Y2)=0.5*H*(Y1+Y2)
      DO 3 I=1,NST
      BEAM(I)=BEM2(I)
      IF(K.EQ.3) BEAM(I)=BEM3(I)
    3 CONTINUE
      W2=W*W
      Q2=Q*Q
      WQ2=W*Q*2.
      ONE=SIGN(1.0,W)
      IF(Q.EQ.0.) GO TO 17
      X0=W/Q
   17 CONTINUE
      BEAMI(1)=BEAMFI(1)=BEAMF2I(1)=BEAMF3I(1)=0.
      DO 14 I=2,NST
      H=XSW(I)-XSW(I-1)
      H=H*WL
      BFI=BEAM(I)*F(I)
      BFI1=BEAM(I-1)*F(I-1)
      BF2I=BFI*F(I)
      BF2I1=BFI1*F(I-1)
      BF3I=BF2I*F(I)
      BF3I1=BF2I1*F(I-1)
      B1=TRAP(H,BEAM(I),BEAM(I-1))
      B2=TRAP(H,BFI,BFI1)
      B3=TRAP(H,BF2I,BF2I1)
      B4=TRAP(H,BF3I,BF3I1)
      BEAMI(I)=BEAMI(I-1)+B1/WL**2
      BEAMFI(I)=BEAMFI(I-1)+B2/WL**3
      BEAMF2I(I)=BEAMF2I(I-1)+B3/WL**4
      BEAMF3I(I)=BEAMF3I(I-1)+B4/WL**5
   14 CONTINUE
      AREA=BEAMI(NST)
      AREAL=BEAMFI(NST)
      AREAL2=BEAMF2I(NST)
      AREAL3=BEAMF3I(NST)
      DZ=-CDNN*(W2*AREA+Q2*AREAL2-WQ2*AREAL)
      DM= CDNN*(W2*AREAL+Q2*AREAL3-WQ2*AREAL2)
      IF(Q.EQ.0.) GO TO 12
      IF(X0+XLG) 12,12,11
   11 IF(X0-XFG) 13,12,12
   13 CALL GEOMV(X0)
      BZ=-CDNN*(W2*BR+Q2*BRL2-WQ2*BRL)
      BM=-CDNN*(W2*BRL+Q2*BRL3-WQ2*BRL2)
      ONEP=SIGN(1.,-X0)
      DZ=(DZ-BZ*2.)*ONEP
      DM=(DM-BM*2)*ONEP
   12 DZ=DZ*ONE
      DM=DM*ONE
      ARM=ARMS
      IF(K.EQ.3) ARM=ARMP
      DK= DZ*ARM
```

```
      RETURN
      END
```

```
      SUBROUTINE GEOMV(XOB)
C
C     VERTICAL DRAG
C
      COMMON /BEEM/ BEAM(25),BEAMI(25),BEAMFI(25),BEAMF2I(25)
     *,BEAMF3I(25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN
      COMMON /X/ DUMMY(300),XSW(25)
      COMMON /Z1/ BR,BRL,BRL2,BRL3
      YO(XO,X1,X2,Y1,Y2)=Y1+(XO-X1)*(Y2-Y1)/(X2-X1)
      XOB=XOB+AA/WL
      DO 1 I=2,NST
      K=I
      IF(XOB.GE.XSW(I-1).AND.XOB.LT.XSW(I)) GO TO  2
    1 CONTINUE
    2 K1=K-1
      X1=XSW(K1)
      X2=XSW(K)
      BR=YO(XOB,X1,X2,BEAMI(K1),BEAMI(K))
      BRL=YO(XOB,X1,X2,BEAMFI(K1),BEAMFI(K))
      BRL2=YO(XOB,X1,X2,BEAMF2I(K1),BEAMF2I(K))
      BRL3=YO(XOB,X1,X2,BEAMF3I(K1),BEAMF3I(K))
      RETURN
      END
vv
```

```
      SUBROUTINE DER(AA,BB,CC,DD,THT,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,
     *XSW,D1,W1,W2,RHO,WL)
      DIMENSION HSW(1),NSW(1),XSW(1)
      DIMENSION D(25),F(25)
      DIMENSION B(25),S(25),CSZ(25),SWAYC(25),HEAVC(25)
      DIMENSION D1(25,25),W1(25,25),W2(25,25)
      DO 1 M=1,NST
      F(M)=XSW(M)*WL-AA
      D(M)=CC-HSW(M)   -THT*F(M)
      IF(D(M).LT.0.) D(M)=0.
    1 CALL SECT(M,D,D1,NSW,W1,W2,B,S,CSZ,DD)
C     COMPUTE DERIVATIVES WITH RESPECT TO F
C     FORM INTEGRALS
C     INTEGRATE AXIALLY
      CALL INTEG(B,D,F,S,CSZ,N1,N2,DEL1,DEL2,NST,SWAYC,HEAVC)
      CALL NONDIM(BB,     RHO,WL,B,D,F,CSZ,SWAYC,HEAVC)
      RETURN
      END
```

```
      SUBROUTINE SECT(I,D,D1,NSW,W1,W2,B,S,CSZ,DD)
      DIMENSION B(25),S(25),CSZ(25),D1(25,25),W1(25,25),W2(25,25)
      DIMENSION D(1),NSW(1)
      FLINER(X,X2,X1,Y2,Y1)=Y1+(X-X1)*(Y2-Y1)/(X2-X1)
      B(I)=S(I)=CSZ(I)=TEMP1=0.
      DRAFT=D(I)
      JJ=NSW(I)
      KL1=0
      DO 1 J=2,JJ
      RD2=D1(I,J)
      RD1=D1(I,J-1)
      RW12=W1(I,J)
      RW11=W1(I,J-1)
      RW22=W2(I,J)
      RW21=W2(I,J-1)
      IF(DRAFT.LE.0.0) GO TO 4
      IF(DRAFT.GE.D1(I,J)) GO TO 2
      RW12=FLINER(DRAFT,RD2,RD1,RW12,RW11)
      RW22=FLINER(DRAFT,RD2,RD1,RW22,RW21)
      KL1=1
      RD2=DRAFT
C
C     CALCULATE AREA,GIRDER,AND BEAM
C
    2 DELD=RD2-RD1
      W1D=RW12-RW11
      W2D=RW22-RW21
      DELS=0.5*DELD*(RW12+RW11+RW22+RW21)
      B(I)=RW12+RW22
      S(I)=S(I)+DELS
      BJM1=RW11+RW21
C
C     CALCULATE CENTROID FOR AREA ABOUT Y-AXIS
C
      TD2=D(I)-RD2
      SMOM=(TD2+0.5*DELD)*BJM1*DELD+
     *(TD2+DELD/3.)*0.5*DELD*(W1D+W2D)
      TEMP1=TEMP1+SMOM
      IF(KL1.EQ.1) GO T O 3
    1 CONTINUE
    3 CSZ(I)=TEMP1/S(I)+DD-D(I)
    4 RETURN
      END
VV
```

```
      SUBROUTINE INTEG(B,D,F,S,CSZ,N1,N2,DEL1,DEL2,NST,SWAYC,HEAVC)
      DIMENSION SWAYC(25),HEAVC(25),B2(25),B2F(25),B2F2(25),B2CSZ(25),
     *B2FCSZ(25),B2DDF(25),B2FDDF(25),D2(25),D2F(25),D2F2(25),
     *D2CSZ(25),D2CSZ2(25),D2DDF(25),D2FCSZ(25),DCSZDF(25),D2FDDF(25)
     *,D2CZDF(25)
      COMMON /INTEGL/ B2I,B2FI,B2F2I,B2CSZI,BFCSZI,B2DDFI,BFDDFI,
     *D2I,D2FI,D2CSZI,DCSZ2I,D2DDFI,DFCSZI,DFDDFI,D2F2I,DCZDFI
      DIMENSION B(1),D(1),F(1),S(1),CSZ(1)
C
C     COMPUTE DERIVATIVES OF D AND CSZ WITH RESPECT TO F
C
      N11=N1-1
      DCSZDF(1)=(CSZ(2)-CSZ(1))/DEL1
      DCSZDF(N1)=(CSZ(N1)-CSZ(N11))/DEL1
      DO 1 I=2,N11
    1 DCSZDF(I)=0.5*(CSZ(I+1)-CSZ(I-1))/DEL1
      N21=N1+1
      N22=NST-1
      DCSZDF(NST)=(CSZ(NST)-CSZ(N22))/DEL2
      DO 2 I=N21,N22
    2 DCSZDF(I)=0.5*(CSZ(I+1)-CSZ(I-1))/DEL2
C
C     COMPUTE AND STORE VARIABLES FOR AXIAL INTEGRATION.
C
      DO 3 I=1,NST
      IF(B(I).EQ.0.0.OR.D(I).EQ.0.0) HEAVC(I)=1.0
      IF(B(I).EQ.0.0.OR.D(I).EQ.0.0) GO TO 4
      HEAVC(I)=S(I)/B(I)/D(I)
    4 SWAYC(I)=2.4*HEAVC(I)+0.4
      B2(I)=B(I)*B(I)*HEAVC(I)
      B2F(I)=B2(I)*F(I)
      B2F2(I)=B2F(I)*F(I)
      B2CSZ(I)=B2(I)*CSZ(I)
      B2FCSZ(I)=B2F(I)*CSZ(I)
      B2DDF(I)=B2(I)*DCSZDF(I)
      B2FDDF(I)=B2DDF(I)*F(I)
      D2(I)=D(I)*D(I)*SWAYC(I)
      D2F(I)=D2(I)*F(I)
      D2F2(I)=D2F(I)*F(I)
      D2CSZ(I)=D2(I)*CSZ(I)
      D2CSZ2(I)=D2CSZ(I)*CSZ(I)
      D2DDF(I)=D2(I)*DCSZDF(I)
      D2FCSZ(I)=D2F(I)*CSZ(I)
      D2FDDF(I)=D2DDF(I)*F(I)
    3 D2CZDF(I)=D2(I)*CSZ(I)*DCSZDF(I)
C
C     PERFORM AXIAL INTEGRATION
C
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2,B2I)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2F,B2FI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2F2,B2F2I)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2CSZ,B2CSZI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2FCSZ,BFCSZI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2DDF,B2DDFI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,B2FDDF,BFDDFI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2,D2I)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2F,D2FI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2CSZ,D2CSZI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2CSZ2,DCSZ2I)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2DDF,D2DDFI)
```

```
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2FCSZ,DFCSZI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2FDDF,DFDDFI)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2F2,D2F2I)
      CALL SIMPSN(NST,N1,DEL1,DEL2,D2CZDF,DCZDFI)
      RETURN
      END
```

```
      SUBROUTINE GEO(AA,BB,CC,DD,WL,NST,THT,KFO,FO)
      DIMENSION B(25),CSZ(25),F(25),G(25),S(25),DF(25),DF2(25),DF3(25),
     *DCSZ(25),DCSZ2(25),DCSZ3(25),DCSZF(25),DCSZF2(25),DCSZ2F(25)
     *,D(25)
      COMMON /ABC/ DRAFT(25)
      COMMON /GEOMM/NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /U/ GI(25),SI(25),S1(25),PHO(25),TDRAF(25)
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
C
C     STATEMENT FUNCTION FOR TRAPEZOIDAL INTEGRATION
C
      TRAP(H,Y1,Y2)=0.5*H*(Y1+Y2)
C
C
C     STATEMENT FUNCTION FOR LINEAR INTERPOLATION
C
      STATE(X,X2,X1,Y2,Y1)=Y1+(X-X1)*(Y2-Y1)/(X2-X1)
C     CONSTANTS
C
      WL2=WL*WL
      WL3=WL2*WL
      WL4=WL3*WL
      WL5=WL4*WL
      DTR=3.1415927/180.
      PHIZ=2.*DTR
      DO 999 K=1,5
      PHI=PHIZ-(K-1)*DTR
      PHO(K)=PHI
C     CALCULATE DRAFT AND CC
C
      DO 9 M=1,NST
      F(M)=XSW(M)*WL-AA
      D(M)=CC-HSW(M)   -THT*F(M)+BB*PHI
      IF(D(M).LE.0.0) D(M)=0.0
      IF(K.EQ.3) DRAFT(M)=D(M)
      IF(K.EQ.3) CCO=CC
C
C     CALCULATE GIRDER AND CROSS SECTIONAL AREA
C
      I=M
      DRFT=D(M)
      G(I)=W1(I,1)+W2(I,1)
      B(I)=CSZ(I)=DF(I)=DF2(I)=DF3(I)=DCSZ(I)=DCSZ2(I)=DCSZ3(I)=
     *DCSZF(I)=DCSZF2(I)=DCSZ2F(I)=S(I)=TEMP1=0.
      JJ=NSW(I)
      KL1=0
      DO 8  J=2,JJ
      RD2=D1(I,J)
      RD1=D1(I,J-1)
      RW12=W1(I,J)
      RW11=W1(I,J-1)
      RW22=W2(I,J)
      RW21=W2(I,J-1)
      IF(DRFT .LE.0.0) GO TO 9
      IF(DRFT .GE.D1(I,J)) GO TO 7
      RW12=STATE(DRFT ,RD2,RD1,RW12,RW11)
      RW22=STATE(DRFT ,RD2,RD1,RW22,RW21)
      KL1=1
```

```
      RD2=DRFT
    7 DELD=RD2-RD1
      DELD2=DELD*DELD
      W1D=RW12-RW11
      W2D=RW22-RW21
      DELS=0.5*DELD*(RW12+RW11+RW22+RW21)
      DELG1=SQRT(W1D*W1D+DELD2)
      DELG2=SQRT(W2D*W2D+DELD2)
      DELG=DELG1+DELG2
      B(I)=RW12+RW22
      BJM1=RW11+RW21
      TD2=D(I)-RD2
      SMOM=(TD2+0.5*DELD)*BJM1*DELD+(TD2+DELD/3.)*0.5*DELD*(W1D+W2D)
      TEMP1=TEMP1+SMOM
      S(I)=S(I)+DELS
      G(I)=G(I)+DELG
      CSZ(I)=TEMP1/S(I) +DD-D(I)
      IF(KL1.EQ.1) GO TO 12
    8 CONTINUE
   12 IF(K.NE.3) GO TO 9
      DF(I)=D(I)*F(I)
      DF2(I)=DF(I)*F(I)
      DF3(I)=DF2(I)*F(I)
      PARM=CSZ(I)
      DCSZ(I)=D(I)*PARM
      DCSZ2(I)=DCSZ(I)*PARM
      DCSZ3(I)=DCSZ2(I)*PARM
      DCSZF(I)=D(I)*F(I)*PARM
      DCSZF2(I)=DCSZF(I)*F(I)
      DCSZ2F(I)=DCSZF(I)*PARM
    9 CONTINUE
C
C     INTEGRATES FOR WETTED SURFACE AREA AND DISPLACEMENT
C
      CALL SIMPSN(NST,N1,DEL1,DEL2,S,SI(K))
      CALL SIMPSN(NST,N1,DEL1,DEL2,G,GI(K))
      SI(K)=SI(K)/WL3
      GI(K)=GI(K)/WL2
      S1(K)=S(1)/WL2
      TDRAF(K)=D(1)/WL
      IF(K.NE.3) GO TO 999
      DI(1)=DFI(1)=DF2I(1)=DF3I(1)=DCI(1)=DC2I(1)=DC3I(1)=DCFI(1)=
     *DCF2I(1)=DC2FI(1)=B3BI(1)=0.
      FO=CSZ(KFO)
      DO 1 I=2,NST
      H=(XSW(I)-XSW(I-1))*WL
      A1=TRAP(H,D(I),D(I-1))
      A2=TRAP(H,DF(I),DF(I-1))
      A3=TRAP(H,DF2(I),DF2(I-1))
      A4=TRAP(H,DF3(I),DF3(I-1))
      A5=TRAP(H,B(I),B(I-1))
      A6=TRAP(H,DCSZ2(I),DCSZ2(I-1))
      A7=TRAP(H,DCSZ(I),DCSZ(I-1))
      A8=TRAP(H,DCSZF(I),DCSZF(I-1))
      A9=TRAP(H,DCSZF2(I),DCSZF2(I-1))
      A10=TRAP(H,DCSZ3(I),DCSZ3(I-1))
      A11=TRAP(H,DCSZ2F(I),DCSZ2F(I-1))
      DI(I)=DI(I-1)+A1/WL2
      DFI(I)=DFI(I-1)+A2/WL3
      DF2I(I)=DF2I(I-1)+A3/WL4
```

```
      DF3I(I)=DF3I(I-1)+A4/WL5
      DCI(I)=DCI(I-1)+A7/WL3
      DC2I(I)=DC2I(I-1)+A6/WL4
      DC3I(I)=DC3I(I-1)+A10/WL5
      DCFI(I)=DCFI(I-1)+A8/WL4
      DCF2I(I)=DCF2I(I-1)+A9/WL5
      DC2FI(I)=DC2FI(I-1)+A11/WL5
      B3BI(I)=B3BI(I-1)+BB**3*A5/WL5
    1 CONTINUE
  999 CONTINUE
      RETURN
      END
vv
```

```
      SUBROUTINE NONDIM(BB,      RHO,WL,B,D,F,CSZ,TEMPA,TEMPR)
      REAL          K1P ,K1Q ,K1W ,K1DP,K1DQ,K1DW,M1P ,M1Q ,M1W ,M1DP,
     *              M1DQ,M1DW,
     *              K2P ,K2Q ,K2W ,K2DP,K2DQ,K2DW,N2P ,N2Q ,N2W ,N2DP,
     *              N2DQ,N2DW,
     *              K3P ,K3R ,K3V ,K3DP,K3DP,K3DV,N3P ,N3R ,N3V ,N3DP,
     *              N3DR,N3DV,
     *              K4P ,K4R ,K4V ,K4DP,K4DR,K4DV,M4P ,M4R ,M4V ,M4DP,
     *              M4DR,M4DV,
     *              L2  ,L3  ,L4  ,L5
      DIMENSION B(1),D(1),F(1),CSZ(1),TEMPA(1),TEMPR(1)
      COMMON /INTEGL/ B2I,B2FI,B2F2I,B2CSZI,BFCSZI,B2DDFI,BFDDFI,
     *D2I,D2FI,D2CSZI,DCSZ2I,D2DDFI,DFCSZI,DFDDFI,D2F2I,DCZDFI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *              DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *              DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *              DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *              DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      PI=3.1415927
      AKY=0.
      AKZ=0.
      H= 0.25*PI*RHO
      C1= H
      C2= C1*AKY
      C3= H
      C4= C3*AKZ
      L2= 0.5*RHO*WL**2
      L3= L2*WL
      L4= L3*WL
      L5= L4*WL
      Z1DW= -B2I*C1
      Z1DP=BB*Z1DW
      Z1Q =(B(1)**2*F(1))*C1*TEMPR(1)
      Z1DQ= B2FI*C1
      Z1W= -B(1)**2*C1*TEMPR(1)
      Z1P = BB*Z1W
      M1DW= B2FI*C1
      M1DP= BB*M1DW
      M1Q =(-B(1)**2*F(1)**2*TEMPR(1)-B2FI)*C1
      M1DQ= -B2F2I*C1
      M1W = (B(1)**2*F(1)*TEMPR(1)+B2I)*C1
      M1P = BB*M1W
      K1DW= BB*Z1DW
      K1DP= BB*Z1DP
      K1Q = BB*Z1Q
      K1DQ= BB*Z1DQ
      K1W = BB*Z1W
      K1P = BB*Z1P
      Y2DW= -B2I*C2
      Y2DP= BB*Y2DW
      Y2Q = (B(1)**2*F(1))*C2*TEMPR(1)
      Y2DQ= B2FI*C2
      Y2W = -B(1)**2*C2*TEMPR(1)
      Y2P = BB*Y2W
      N2DW= -B2FI*C2
      N2DP= BB*N2DW
      N2Q = (B(1)**2*F(1)**2*TEMPR(1)+B2FI)*C2
      N2DQ= B2F2I*C2
      N2W = (-B(1)**2*F(1)*TEMPR(1)-B2I)*C2
      N2P = BB*N2W
```

```
K2DW= B2CSZI*C2
K2DP= BB*K2DW
K2Q = (-B(1)**2*F(1)*CSZ(1)*TEMPR(1)-BFDDFI)*C2
K2DQ= -BFCSZI*C2
K2W = (B(1)**2*CSZ(1)*TEMPR(1)+B2DDFI)*C2
K2P = BB*K2W
Y3DV= -D2I*C3
Y3R = (-D(1)**2*F(1))*C3*TEMPA(1)
Y3DR= -D2FI*C3
Y3DP= D2CSZI*C3
Y3V = -D(1)**2*C3*TEMPA(1)
Y3P = (D(1)**2*CSZ(1)*TEMPA(1)         )*C3
N3DV= -D2FI*C3
N3R = (-D(1)**2*F(1)**2*TEMPA(1)-D2FI)*C3
N3DR= -D2F2I*C3
N3DP= DFCSZI*C3
N3V = (-D(1)**2*F(1)*TEMPA(1)-D2I)*C3
N3P = (D(1)**2*F(1)*CSZ(1)*TEMPA(1)+D2CSZI         )*C3
K3DV= D2CSZI*C3
K3R = (D(1)**2*F(1)*CSZ(1)*TEMPA(1)+DFDDFI)*C3
K3DR= DFCSZI*C3
K3DP= -DCSZ2I*C3
K3V = (D(1)**2*CSZ(1)*TEMPA(1)+D2DDFI)*C3
K3P = (-D(1)**2*CSZ(1)**2*TEMPA(1)-    DCZDFI)*C3
Z4DV= -D2I*C4
Z4R = (-D(1)**2*F(1))*C4*TEMPA(1)
Z4DR= -D2FI*C4
Z4DP= D2CSZI*C4
Z4V = -D(1)**2*C4*TEMPA(1)
Z4P = (D(1)**2*CSZ(1)*TEMPA(1)+D2DDFI)*C4
M4DV= D2FI*C4
M4R = (D(1)**2*F(1)**2*TEMPA(1)+D2FI)*C4
M4DR= D2F2I*C4
M4DP= -DFCSZI*C4
M4V = (D(1)**2* F(1)*TEMPA(1)+D2I)*C4
M4P = (-D(1)**2*CSZ(1)*F(1)*TEMPA(1)-D2CSZI-DFDDFI)*C4
K4DV= BB*Z4DV
K4R = BB*Z4R
K4DR= BB*Z4DR
K4DP= BB*Z4DP
K4V = BB*Z4V
K4P = BB*Z4P
DYP    = (Y2P+Y3P)/L3
DYQ    = Y2Q/L3
DYR    = Y3R/L3
DYV    = Y3V/L2
DYW    = Y2W/L2
DYDP    = (Y2DP+Y3DP)/L4
DYDQ    = Y2DQ/L4
DYDR    = Y3DR/L4
DYDV    = Y3DV/L3
DYDW    = Y2DW/L3
DZP    = (Z1P+Z4P)/L3
DZQ    = Z1Q/L3
DZR    = Z4R/L3
DZV    = Z4V/L2
DZW    = Z1W/L2
DZDP    = (Z1DP+Z4DP)/L4
DZDQ    = Z1DQ/L4
DZDR    = Z4DR/L4
```

```
      DZDV   = Z4DV/L3
      DZDW   = Z1DW/L3
      DKP   = (K1P+K2P+K3P+K4P)/L4
      DKQ   = (K1Q+K2Q)/L4
      DKR   = (K3R+K4R)/L4
      DKV   = (K3V+K4V)/L3
      DKW   = (K1W+K2W)/L3
      DKDP   =(K1DP+K2DP+K3DP+K4DP)/L5
      DKDQ   =(K1DQ+K2DQ)/L5
      DKDR   = (K3DR+K4DR)/L5
      DKDV   = (K3DV+K4DV)/L4
      DKDW   = (K1DW+K2DW)/L4
      DMP   = (M1P+M4P)/L4
      DMQ   = M1Q/L4
      DMR   = M4R/L4
      DMV   = M4V/L3
      DMW   = M1W/L3
      DMDP   = (M1DP+M4DP)/L5
      DMDQ   = M1DQ/L5
      DMDR   = M4DR/L5
      DMDV   = M4DV/L4
      DMDW   = M1DW/L4
      DNP   = (N2P+N3P)/L4
      DNQ   = N2Q/L4
      DNR   = N3R/L4
      DNV   = N3V/L3
      DNW   = N2W/L3
      DNDP   = (N2DP+N3DP)/L5
      DNDQ   = N2DQ/L5
      DNDR   = N3DR/L5
      DNDV   = N3DV/L4
      DNDW   = N2DW/L4
C     COEFFICIENTS FOR TWO HULLS
      DYW=DYQ=DKW=DKQ=DNW=DNQ=DYDW=DYDQ=DKDW=DKDQ=DNDW=DNDQ=0.
      DYV=2.*DYV
      DYP=2.*Y3P/L3
      DYR=2.*DYR
      DZW=2.*DZW
      DZP=Z4P/L3
      DZQ=2.*DZQ
      DKV=2.*K3V/L3
      DKP=2.*(K1P+K3P)/L4
      DKR=2.*K3R/L4
      DMW=2.*DMW
      DMP=M4P/L4
      DMQ=2.*DMQ
      DNV=2.*DNV
      DNP=2.*N3P/L4
      DNR=2.*DNR
      DYDV=2.*DYDV
      DYDP=2.*Y3DP/L4
      DYDR=2.*DYDR
      DZDW=2.*DZDW
      DZDP=Z4DP/L4
      DZDQ=2.*DZDQ
      DKDV=2.*K3DV/L4
      DKDP=2.*(K1DP+K3DP)/L5
      DKDR=2.*K3DR/L5
```

```
      DMDW=2.*DMDV
      DMDP=M4DP/L5
      DMDQ=2.*DMDQ
      DNDV=2.*DNDV
      DNDP=2.*N3DP/L5
      DNDR=2.*DNDR
C     DZP,DZR,DZV,DZDP,DZDR,DZDV,DMP,DWR,DMV,DMDP,DMDR,DMDV  APE ODD FUNCTIONS
      RETURN
      END
vv
```

```
      SUBROUTINE  RUNGS (X,H,N,Y,YPRIME,INDEX)
      DIMENSION Y(13),YPRIME(13),Z(13),W1(13),W2(13),W3(13),W4(13)
CRUNGS - RUNGE-KUTTA SOLUTION OF SET OF FIRST ORDER O.D.E.  FORTRAN 99
C     DIMENSIONS MUST BE SET FOR EACH PROGRAM
C     X   INDEPENDENT VARIABLE
C     H   INCREMENT DELTA X, MAY BE CHANGED IN VALUE
C     N   NUMBER OF EQUATIONS
C     Y   DEPENDENT VARIABLE BLOCK     ONE DIMENSIONAL ARRAY
C     YPRIME  DERIVATIVE BLOCK  ONE DIMENSIONAL ARRAY
C     THE PROGRAMMER MUST SUPPLY INITIAL VALUES OF  Y(1) TO Y(N)
C     INDEX  IS A VARIABLE WHICH SHOULD BE SET TO ZERO BEFORE EACH
C     INITIAL ENTRY TO THE SUBROUTINE, I.E., TO SOLVE A DIFFERENT
C     SET OF EQUATIONS OR TO START WITH NEW INITIAL CONDITIONS.
C     THE PROGRAMMER MUST WRITE A SUBROUTINE CALLED DERIVE WHICH COM-
C     PUTES THE DERIVATIVES AND STORES THEM
C     THE ARGUMENT LIST IS    SUBROUTINE DERIVE(X,N,Y,YPRIME)
      IF (INDEX) 5,5,1
    1 DO 2 I=1,N
      W1(I)=H*YPRIME(I)
    2 Z(I)=Y(I)+(W1(I)*.5)
      A=X+H/2.
      CALL DERIVE(A,N,Z,YPRIME)
      DO 3 I=1,N
      W2(I)=H*YPRIME(I)
    3 Z(I)=Y(I)+.5*W2(I)
      A=X+H/2.
      CALL DERIVE(A,N,Z,YPRIME)
      DO 4 I=1,N
      W3(I)=H*YPRIME(I)
    4 Z(I)=Y(I)+W3(I)
      A=X+H
      CALL DERIVE (A,N,Z,YPRIME)
      DO 7 I=1,N
      W4(I)=H*YPRIME(I)
    7 Y(I)=Y(I)+(((2.*(W2(I)+W3(I)))+W1(I)+W4(I))/6.)
      X=X+H
      CALL DERIVE (X,N,Y,YPRIME)
      GO TO 6
    5 CALL DERIVE (X,N,Y,YPRIME)
      INDEX=1
    6 RETURN
      END
vv
```

```
      SUBROUTINE BESSEL(IO,X,V)
      DIMENSION T(1000)
      TW=1./12.
      TH=1./3.
      OR=IO
      M=3.+3.*X**TW+9.*X**TH+AMAX1(OR,X)
      IF(MOD(M,2).NE.0) M=M+1
      M1=M-1
      M2=M-2
      T(M)=0
      T(M1)=1.
      Z=2./X
      J=M2+1
      MX=M2/2
      SNORM=0.
      DO 1 I=1,MX
      J=J-1
      T(J)=J*Z*T(J+1)-T(J+2)
      J=J-1
      T(J)=J*Z*T(J+1)-T(J+2)
    1 SNORM=SNORM+T(J)
      SNORM=2.*SNORM-T(1)
      V=T(IO+1)/SNORM
      RETURN
      END
```

```
      SUBROUTINE COMB(A,N,ND,B,M,NERR,D)
C     SOLUTION OF SIMULT.EQ. FORMING KUTTA COND.
      DIMENSION  A(1), B(1)
      EQUIVALENCE  (I,FI), (K,FK)
      D=NERR=1
   10 DO 90  I=1,N
      AIJMAX = A(I)
      IJMAX = I
      IF(N.EQ.1)GO TO 30
      DO 25  J=2,N
      IJ = I + (J-1)*ND
      IF(ABS(A(IJ))-ABS(AIJMAX))25,25,20
   20 AIJMAX = A(IJ)
      IJMAX = IJ
   25 CONTINUE
      IF  (AIJMAX)  30,999,30
   30 DO 35  J=1,N
      IJ = I + (J-1)*ND
   35 A(IJ) = A(IJ)/AIJMAX
      D = D * AIJMAX
      DO 40  J=1,M
      IJ = I + (J-1)*ND
   40 B(IJ) = B(IJ)/AIJMAX
      DO 70  K=1,N
      IF  (K-I)  50,70,50
   50 KJMAX = IJMAX + (K-I)
      ARAT  =   -A(KJMAX)
      KJ = K
      IJ = I
      DO 60   J=1,N
      IF  (A(IJ))  55,58,55
   55 A(KJ) = ARAT*A(IJ) + A(KJ)
   58 KJ = KJ + ND
   60 IJ = IJ + ND
      A(KJMAX) = 0.0
      KJ = K
      IJ = I
      DO 69 J=1,M
      IF (B(IJ))  65,68,65
   65 B(KJ) = ARAT*B(IJ) + B(KJ)
   68 KJ = KJ + ND
   69 IJ = IJ + ND
   70 CONTINUE
      KJ = IJMAX - I+1
   90 A(KJ) = FI
      DO 100  I=1,N
      K = I
   93 I1 = K*ND - ND + 1
      FK = A(I1)
      IF (K-I)  93,100,95
   95 IJ = I
      IK = K
      DO 99  J=1,M
      A(2) = B(IJ)
      B(IJ) = B(IK)
      B(IK) = A(2)
      IJ = IJ + ND
   99 IK = IK + ND
  100 CONTINUE
      NERR  =   0
```

```
999 RETURN
    END
```

```
      SUBROUTINE SIMPSN(NP,NB,D1,D2,Y,A)
C
C     SUBROUTINE TO INTEGRATE BY SIMPSON RULE FOR EVEN NUMBEP OF INCREMENTS
C     OR BY TRAPEZOIDAL RULE IF THE NUMBER OF INCREMENTS IS ODD
C
C     THIS ROUTINE WILL INTEGRATE FOR ONE OR TWO STEP SIZES
C     IF ONLY ONE STEP SIZE,SET NP=NB AND D1=D2.
C
C     NP - TOTAL NUMBER OF POINTS TO BE INTEGRATED
C     NB - INDEX DIVIDING TWO STEP SIZES
C     D1 - STEP SIZE FROM INDEX 1 TO NB
C     D2 - STEP SIZE FROM INDEX NB TO NP
C     Y - FUNCTION TO BE INTEGRATED
C     A - INTEGRAL OF Y
C
      DIMENSION Y(1) ,D(2)
      A=0.
      D(1)=D1
      D(2)=D2
      IF=1
      IL=NN=NB
      DO 5 J=1,2
      IF(NN.EQ.1) GO TO 6
      IF1=IF+1
      IL1=IL-1
      IF(MOD(NN,2).NE.1) GO TO 2
C     SIMPSON INTEGRATION
      IL2=IL1-2
      A2=0.
      A4=Y(IL1)
C     IF THE ARRAY HAS ONLY 3 POINTS, A=H*(Y(1)+4*Y(2)+Y(3))/3
      IF(NN.EQ.3) GO TO 7
      DO 1 I=IF1,IL2,2
      A4=A4+Y(I)
    1 A2=A2+Y(I+1)
    7 A1=D(J)*(Y(IF)+Y(IL)+2.*A2+4.*A4)/3.
      GO TO 4
C     TRAPEZOIDAL INTEGRATION
    2 A1=0.5*(Y(IF)+Y(IL))
C     IF THE ARRAY HAS ONLY 2 POINTS, A=H*(Y(1)+Y(2))/2.
      IF(NN.EQ.2) GO TO 8
      DO 3 I=IF1,IL1
    3 A1=A1+Y(I)
    8 A1=D(J)*A1
    4 IF=NB
      IL=NP
      NN=NP-NB+1
    5 A=A+A1
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SCALE(NRNG,A,NP,A1,RNG,RNGM)
      DIMENSION A(1),A1(1)
C     FIND MAXIMUM VALUE OF ARRAY A1
      YMAX=A1(1)
C     DETERMINE AXIS SCALE
      DO 1 I=2,NP
    1 YMAX=AMAX1(YMAX,ABS(A1(I)))
      DO 2 I=1,NRNG
      ISAVE=I
      IF(YMAX.LE.A(I)) GO TO 3
    2 CONTINUE
      IUP=YMAX
      RNG=IUP
      RNGM=-RNG
      RETURN
    3 RNG=A(ISAVE)
      RNGM=-RNG
      RETURN
      END
```

```
      SUBROUTINE PLOTT(A1,A2,A3,A4,A5,A6,NP,NC,NG)
      REAL NUM(10)
      DIMENSION A1(1),A2(1),A3(1),A4(1),A5(1),A6(1)
      DIMENSION IZERO(6),RANGE(6),A(132),STAR(6),PRNG(8),RANGM(6)
      DATA IZERO/21,66,111,21,66,111/
      DATA RRNG/.1,.2,1.,2.,4.,10.,20.,40./
      DATA STAR/1H*,1H*,1H*,1H0,1H0,1H0/
      DATA BLANK/1H /
      DATA DASH /1H-/
      DATA EYE /1HI/
      DATA PLUS /1H+/
      DATA TEE/1HT/
      DATA NUM/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      SF(Q)=IZ+Q*SCL
C
C     INITIALIZE
C
      NG=6
      NRNG=8
      NCT=131
      NX=10
      KX=10
C
C     SCALING FOR AXIS
C
      CALL SCALE(NRNG,RRNG,NP,A1,RANGE(1),RANGM(1))
      CALL SCALE(NRNG,RRNG,NP,A2,RANGE(2),RANGM(2))
      CALL SCALE(NRNG,RRNG,NP,A3,RANGE(3),RANGM(3))
      CALL SCALE(NRNG,RRNG,NP,A4,RANGE(4),RANGM(4))
      CALL SCALE(NRNG,RRNG,NP,A5,RANGE(5),RANGM(5))
      CALL SCALE(NRNG,RRNG,NP,A6,RANGE(6),RANGM(6))
C
C     PRINT Y-AXIS
C
      WRITE(6,200) RANGM(1),RANGE(1),RANGM(2),RANGE(2),RANGM(3),RANGE(3)
  200 FORMAT(1H1,F5.1,12X,7HHEAVE=*,13X,F4.1,4X,F5.1,11X,7HPITCH=*,
     *14X,F4.1,4X,F5.1,10X,11HWAVE HGT.=*,11X,F4.1)
      WRITE(6,201) RANGM(4),RANGE(4),PANGM(5),RANGE(5),RANGM(6),RANGE(6)
  201 FORMAT(1X,F5.1,13X,6HROLL=0,13X,,F4.1,4X,F5.1,13X,5HYAW=0,14X,
     *F4.1,4X,F5.1,10X,11HPRESS/100=0,11X,F4.1)
C
C     PREPARE PLOTTING ARRAY
C
      DO 1 I=1,NP
      DO 2 K=1,NCT
    2 A(K)=BLANK
      DO 3 J=1,NG
      IZ=IZERO(J)
      RNG=RANGE(J)
      SCL=NC/RNG
      IF(I.NE.1) GO TO 5
      IHI=IZ+NC
      ILO=IZ-NC
      KNT=10
      DO 6 K=ILO,IHI
      A(K)=PLUS
      IF(KNT.NE.NX) GO TO 6
      A(K)=EYE
      KNT=0
    6 KNT=KNT+1
```

```
    5 GO TO (7,8,9,10,11,14),J
    7 A(IZ)=PLUS
      IC=SF(A1(I))
      GO TO 12
    8 A(IZ)=PLUS
      IC=SF(A2(I))
      GO TO 12
    9 A(IZ)=PLUS
      IC=SF(A3(I))
      GO TO 12
   10 IC=SF(A4(I))
      GO TO 12
   11 IC=SF(A5(I))
      GO TO 12
   14 IC=SF(A6(I))
   12 A(IC)=STAR(J)
    3 CONTINUE
      IF(KX.NE.NX) GO TO 13
      IZ1=IZERO(1)
      IZ2=IZERO(2)
      IZ3=IZERO(3)
      A(IZ1)=A(IZ2)=A(IZ3)=DASH
      IF(I.EQ.1) GO TO 16
      K1=(I-1)/10+.1
      K2=K1+1
      IF(K1.GE.10) GO TO 17
      A(IZ1+1)=A(IZ2+1)=A(IZ3-1)=NUM(K2)
      GO TO 16
   17 I2=MOD(K1,10)
      I1=(K1-I2)/10+1
      I2=I2+1
      A(IZ1+1)=A(IZ2+1)=A(IZ3-2)=NUM(I1)
      A(IZ1+2)=A(IZ2+2)=A(IZ3-1)=NUM(I2)
   16 KX=0
   13 KX=KX+1
      WRITE(6,202) (A(K),K=1,NCT)
  202 FORMAT(1X,131A1)
    1 CONTINUE
      DO 15 I=1,NCT
   15 A(I)=BLANK
      IZ1=IZERO(1)
      IZ2=IZERO(2)
      IZ3=IZERO(3)
      A(IZ1)=A(IZ2)=A(IZ3)=TEE
      WRITE(6,202) (A(K),K=1,NCT)
      RETURN
      END
```

```
      SUBROUTINE PLOTXY(XP,YYP,NP)                                        C
      DIMENSION A(91),RANGE(4),AX(10),XP(1),YYP(1),IP(500)
      DATA BLANK /1H /
      DATA EYE/1HI/
      DATA DASH  /1H-/
      DATA PLUS /1H+/
      DATA STAR/1H*/
      DATA RANGE   /4.,5.,10./
      DATA AX/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
C
C     SCALE
C
      KXAXIS=0
      YMAX=ABS(YYP(1))
      DO 11 I=2,NP
      NPSAV=I
      IF(XP(I).LT.0.0.OR.ABS(YYP(I)).GT.80.) GO TO 18
   11 YMAX=AMAX1(YMAX,ABS(YYP(I)))
   18 NP=NPSAV
      YHI=80.
C
C     ORDER X
C
      DO 1 I=1,NP
      KNT=1
      DO 2 J=1,NP
      IF(I.EQ.J) GO TO 2
      IF(XP(I).GT.XP(J)) KNT=KNT+1
    2 CONTINUE
      IP(I)=KNT
    1 CONTINUE
C
C     INITIALIZE
C
      IZ=81
      IF(YYP(NP).LT.0.0) IZ=11
      KSAVE=0
      LINE=1
      NC=80
      NL=91
      SCL=NC/YHI
      LY=10
      KY=LY
      LX=10
      KX=LX
      IF(YYP(NP).GE.0.0) WRITE(6,201)
  201 FORMAT(1H1,56X,7HY VS. X/
     *20X,3H+80,17X,3H+60,17X,3H+40,17X,3H+20,19X,1H0/)
      IF(YYP(NP).LT.0.0) WRITE(6,202)
  202 FORMAT(1H1,56X,7HY VS. X/
     *30X,1H0,18X,3H-20,17X,3H-40,17X,3H-60,17X,3H-80/)
C
C     PREPARE PLOTTING ARRAY
C
      DO 3 K=1,NL
      A(K)=PLUS
      IF(KY.NE.LY) GO TO 14
      A(K)=EYE
      KY=0
   14 KY=KY+1
```

```
    3 CONTINUE
      DO 9 I=1,NP
      A(IZ)=PLUS
      DO 4 J=1,NP
    4 IF(IP(J).EQ.I) IO=J
      IY=IZ-SCL*YYP(IO)
      IX=1+(XP(IO)*SCL+5./10.)*2.
      IF(KSAVE.EQ.0) GO TO 5
      IF(IX.NE.KSAVE) GO TO 7
    5 IF(IX.GT.LINE) GO TO 7
      A(IY)=STAR
      KSAVE=LINE
      IF(I.EQ.NP) GO TO 7
      GO TO 9
    7 IF(KX.NE.LX) GO TO 10
      KXAXIS=KXAXIS+1
      IF(KXAXIS.EQ.1) GO TO 17
      IF(YYP(NP).LT.0.0) GO TO 15
      IZONE=IZ+1
      IZTWO=IZ+2
      GO TO 16
   15 IZONE=IZ-2
      IZTWO=IZ-1
   16 A(IZONE)=AX(KXAXIS)
      A(IZTWO)=AX(1)
   17 A(IZ)=DASH
      KX=0
   10 KX=KX+1
      IF(A(IZ).NE.DASH.AND.A(IZ).NE.STAR) A(IZ)=PLUS
      WRITE(6,200) (A(IJ),IJ=1,NL)
  200 FORMAT(20X,91A1)
      IF(I.EQ.NP.AND.LINE.EQ.IX) CALL EXIT
      DO 8 K=1,NL
    8 A(K)=BLANK
      LINE=LINE+1
      GO TO 5
    9 CONTINUE
      RETURN
      END
```

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