UNIVERSITY OF HOUSTON

CULLEN COLLEGE OF ENGINEERING

A HYBRID COMPUTER STUDY OF A DYNAMIC SHIP POSITIONING SYSTEM

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ACKNOWLEDGMENT

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ABSTRACT

Dynamic positioning is a method of anchoring a vessel
in deep areas of the ocean. The essential components of a
dynamic positioning system are a vessel with positioning
forces; a position measuring system; a comparator; and a
controller. These components position a vessel by inter-
acting with each other and with the environment.

Mathematical models define each component of the
positioning system. The hybrid computer simulates the posi-
tioning system, and the aerodynamic and hydrodynamic forces
present on the ocean's surface.

This report investigates the excitation/response
characteristics of the model for a variety of environmental
conditions. Optimum headings with respect to positioning
thrust result for each environmental case. A vessel search
algorithm is developed to locate an optimum heading.

INTRODUCTION

The hybrid computer simulates physical conditions for
the efficient real-time analysis of physical systems. This
simulation permits the study of the effects of parameter
changes on the excitation-response characteristics of a
system. To study a physical system in this manner, it is
necessary to formulate a detailed model and then to tailor
the model to that system. The model is a series of mathe-
matical and logical equations. One important objective of
such a study is the optimization of the system with respect
to one or more criteria or performance functions.

The ocean is man's next frontier. Water covers more
than seventy per cent of the earth. There are three main
topographical divisions of the surface beneath the water:
continental shelf, continental slope, and abyssal plain.
The continental shelf is a shallow bank or gently sloping region
which usually extends to a depth of no more than six hundred
feet. The continental slope is a very steep area much like
the side of a cliff and extends from the edge of the conti-
nental shelf to the ocean floor, or abyssal plain. Exploration
and exploitation of this vast area of the earth's surface
present major problems to the engineer and the scientist.
The subject of this thesis is a hybrid study of a method to

solve some of these problems.

Scientists and engineers have developed mooring techniques to stabilize vessels in the ten per cent of the ocean area that is the continental shelf. Static, or normal, mooring techniques are impractical, however, for all the ocean areas beyond the continental shelf. Most of the oceans are one thousand to twenty thousand feet deep. The difficulties of mooring a vessel at this depth hamper work in the deep oceans.

Currently, vessels of the conventional ship-hull class are employed as stable working platforms for such deep water work as drilling into the sea floor, gathering oceanographic data, tracking satellites, and launching missiles. These operations require that the vessel be mobile for travel. Once the vessel reaches its location, it must also be capable of quick and easy anchorage for extended periods of time. Dynamic positioning is a method for anchoring which is comparable to the hovering action of a helicopter. This method uses the self-contained energy of the vessel to produce forces which counteract the adverse physical changes at the ocean surface. This process is the only known practical method of maintaining a given geographical position in water depths beyond the continental shelf.

The four essential subsystems required for dynamic positioning are:
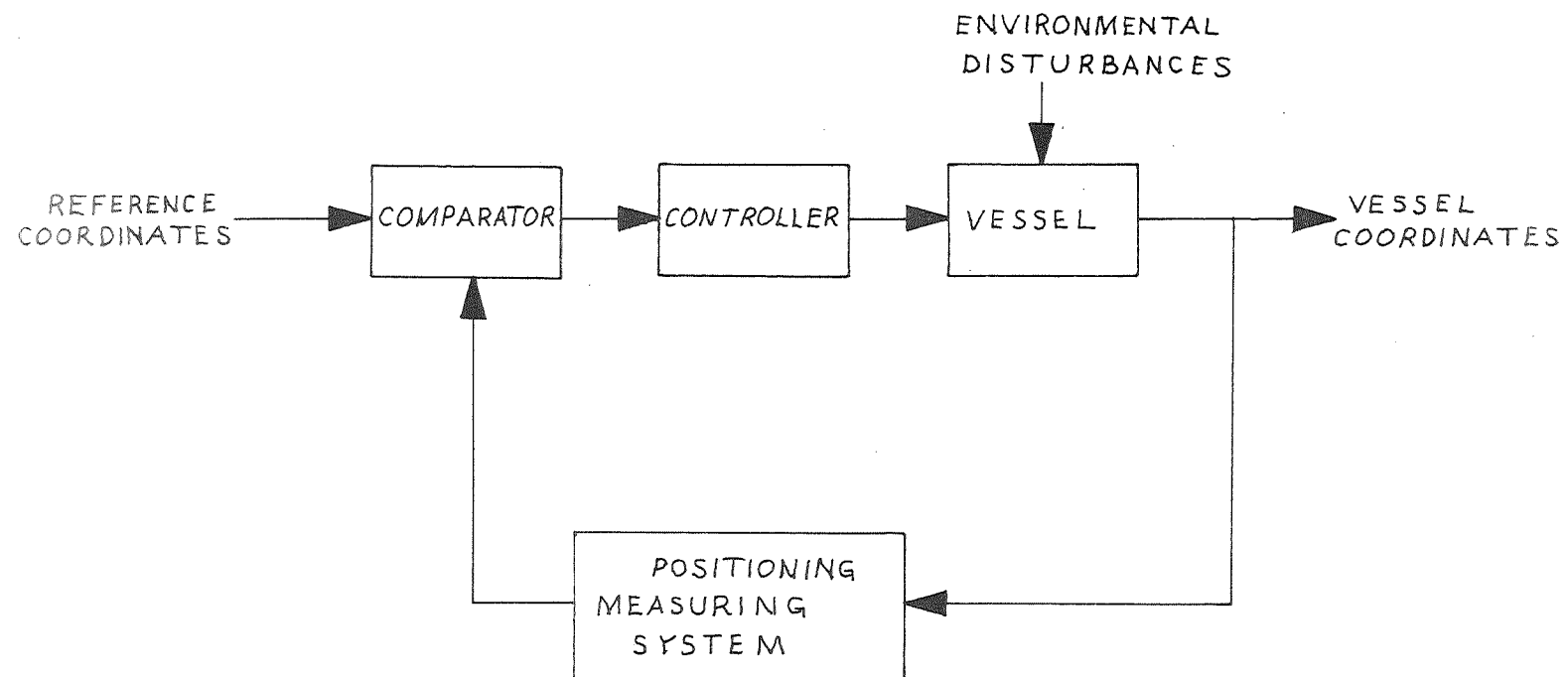
1. a vessel with positioning forces;

2. a position measuring system to define the actual
    vessel coordinates with respect to reference
    coordinates;

3. a comparator to indicate the vessel's deviation
    from the desired position; and

4. a controller to regulate the vessel's propulsion
    system in order to offset the deviation.

Figure 1.1 is a block diagram of the dynamic positioning
system; Figure 1.2 is an illustration of that system.

Dynamic positioning is a closed-loop feedback control
system. The comparator compares the input reference coor-
dinates with the actual position of the ship. If there is
deviation, the comparator generates an error signal. The
controller processes the error signal and adjusts the thrust
level of the vessel's propulsion system. This correction
reduces the deviation so that when the deviation is zero,
the measured position coincides with the reference position.
If at any time the vessel moves as a result of physical changes
such as winds, waves, or currents, the dynamic positioning
process begins again.

This type of dynamic positioning is presently in
operation, but no one has attempted to optimize the system
using any criteria. This thesis explores optimization with
respect to required thrust. By this criterion, the ship
holds position with a minimum amount of thrust.

REFERENCE
COORDINATES → COMPARATOR → CONTROLLER → VESSEL → VESSEL COORDINATES

ENVIRONMENTAL DISTURBANCES

POSITIONING MEASURING SYSTEM

DYNAMIC POSITIONING FEEDBACK SYSTEM

FIGURE 1.1

COMPARATOR AND CONTROLLER
ELECTRONICS

MAIN SCREWS

STERN THRUSTERS

HYDROPHONE
RECEIVERS

BOW THRUSTERS

SEA FLOOR
BEACON
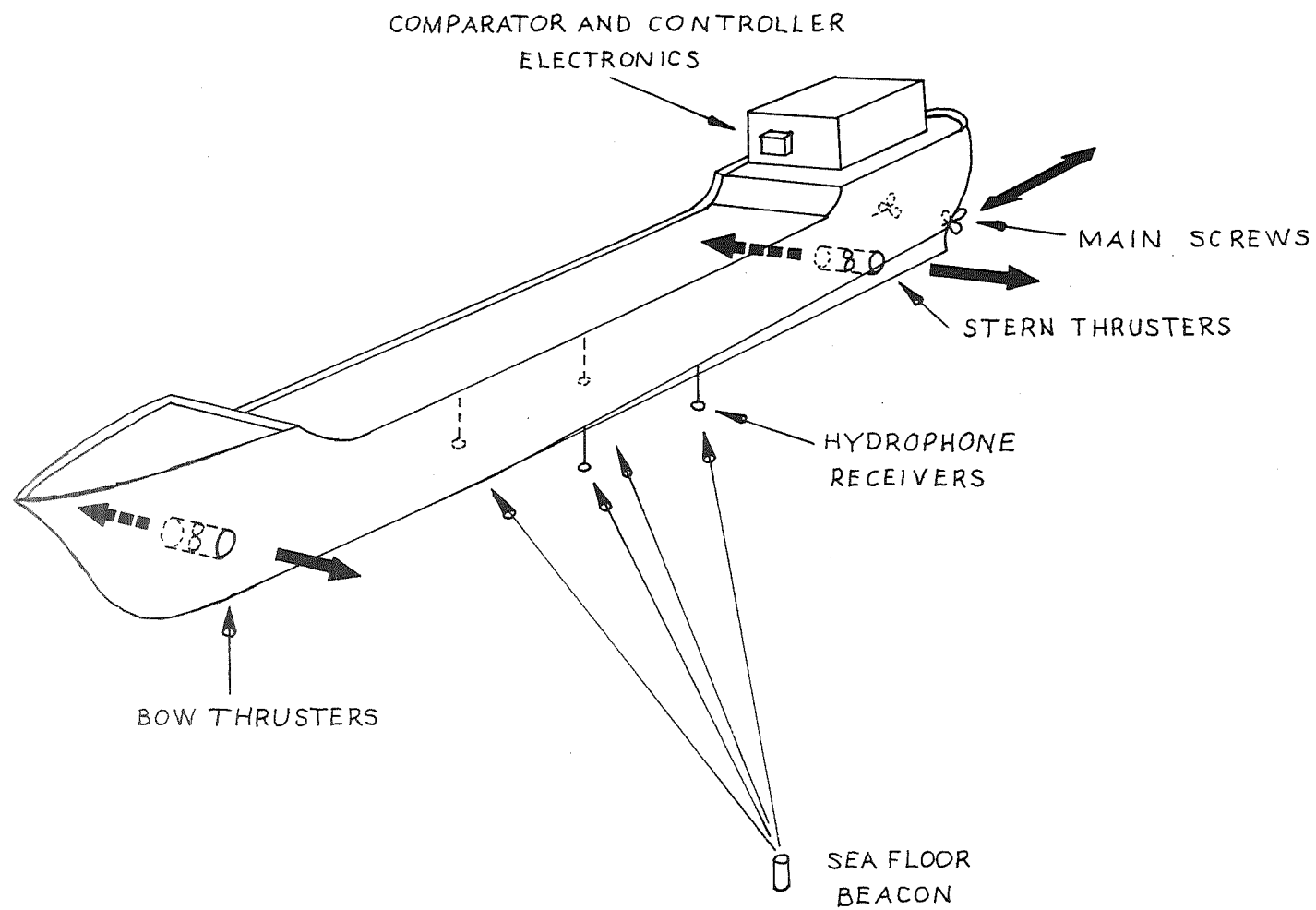
POSITIONING SYSTEM ILLUSTRATION

FIGURE 1.2

A hybrid study can provide general information on the overall station-keeping abilities of ship-hull vessels. The three specific questions of this study are:

1. Does an optimum vessel heading exist for specific environmental conditions?

2. If there is an optimum heading, is it a well-defined optimum that will provide a practical payout with respect to the necessary effort required to obtain it?

3. Can a practical vessel-search routine be formulated to find this optimum heading?

CHAPTER II

MATHEMATICAL MODEL

A mathematical model is a collection of equations
which defines and delimits a physical system. This model
is the link between the computer and the researcher in a
hybrid study.

Figure 2.1 illustrates the coordinate system used
for the simulation. X and Y form the inertial coordinate
frame; x and y are the vessel coordinates; ψ is the heading
angle. The model restricts the motion of the vessel to the
X, Y plane with ψ the single angular degree of freedom.

Newton's laws of motion govern the mathematical model
of the vessel. The equations of acceleration in the vessel-
coordinates are:

$$\frac{d}{dt}(V_x) = \frac{F_x}{m_x} + \omega V_y \qquad (2.1)$$

$$\frac{d}{dt}(V_y) = \frac{F_y}{m_y} - \omega V_x \qquad (2.2)$$

$$\frac{d}{dt}(\omega) = \frac{M_\psi}{I_\psi} \qquad (2.3)$$

The integration of equations (2.1), (2.2), and (2.3)
yields the x, y, and ψ velocities of the vessel. The velocity
equations in the vessel coordinates are:

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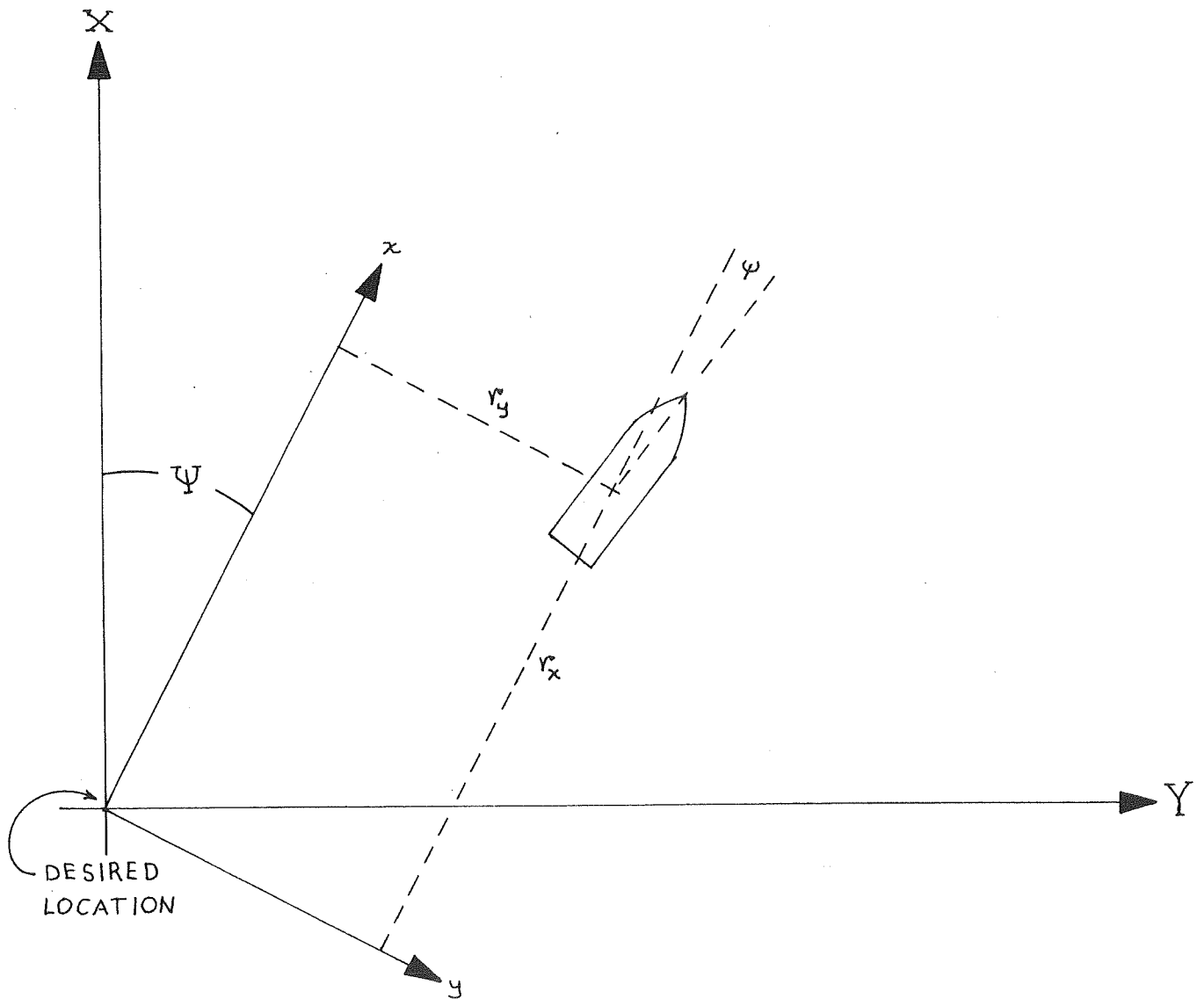
COORDINATE SYSTEM

FIGURE 2.1

$$\frac{d}{dt}(r_x) = V_x + \omega\, r_y \tag{2.4}$$

$$\frac{d}{dt}(r_y) = V_y - \omega\, r_x \tag{2.5}$$

$$\frac{d}{dt}(\psi) = \omega \tag{2.6}$$

The integration of equations (2.4), (2.5), and (2.6) yields the vessel position and heading.

Error functions representing the comparator output result from adding the conjugate value of the vessel position and heading to the reference position and heading. The error functions in the vessel coordinates are:

$$x_\epsilon = X - r_x \tag{2.7}$$

$$y_\epsilon = Y - r_y \tag{2.8}$$

$$\psi_\epsilon = \Psi - \psi \tag{2.9}$$

The thrust demand is a function of the following variables:

1. the position and heading errors;

2. the velocity of the vessel; and

3. the steady-state environmental forces acting on

the vessel.

The control system, which is a function of these three variables; the physical system delays; and the noise filters regulate the vessel's propulsion system.

Laplace transforms are useful in understanding the mathematical model of the control system. Figure 2.2 illustrates a model of the control system. The model includes a second order filter for noise reduction; the control gains; and a first order time delay. Equations (2.1), (2.2), and (2.3) contain three functions, F_x, F_y, and M_φ . These functions are a summation of the thruster, the hydrodynamic, and the aerodynamic forces and moments.

$$F_x = F_{xT} + F_{xH} + F_{xA} \tag{2.10}$$

$$F_Y = F_{YT} + F_{YH} + F_{YA} \tag{2.11}$$

$$M_\varphi = M_{\varphi T} + M_{\varphi H} + M_{\varphi A} \tag{2.12}$$

The output of the controller subsystem indicated in Figure 2.2 is a thruster force or moment.

The hydrodynamic and aerodynamic force components of equations (2.10) through (2.12) are drag forces. Equations (2.13) through (2.18) are empirical representations of the drag forces resulting from the flow of a fluid about an

CONTROL GAINS

NOISE
FILTER

THRUSTER
DYNAMICS

ERROR
SIGNAL

$$\frac{1}{s^2 + as + b}$$

$$\frac{K_I}{s}$$

$$K_P$$

$$K_D s$$

$$\frac{1}{cs + 1}$$

THRUSTER
FORCE
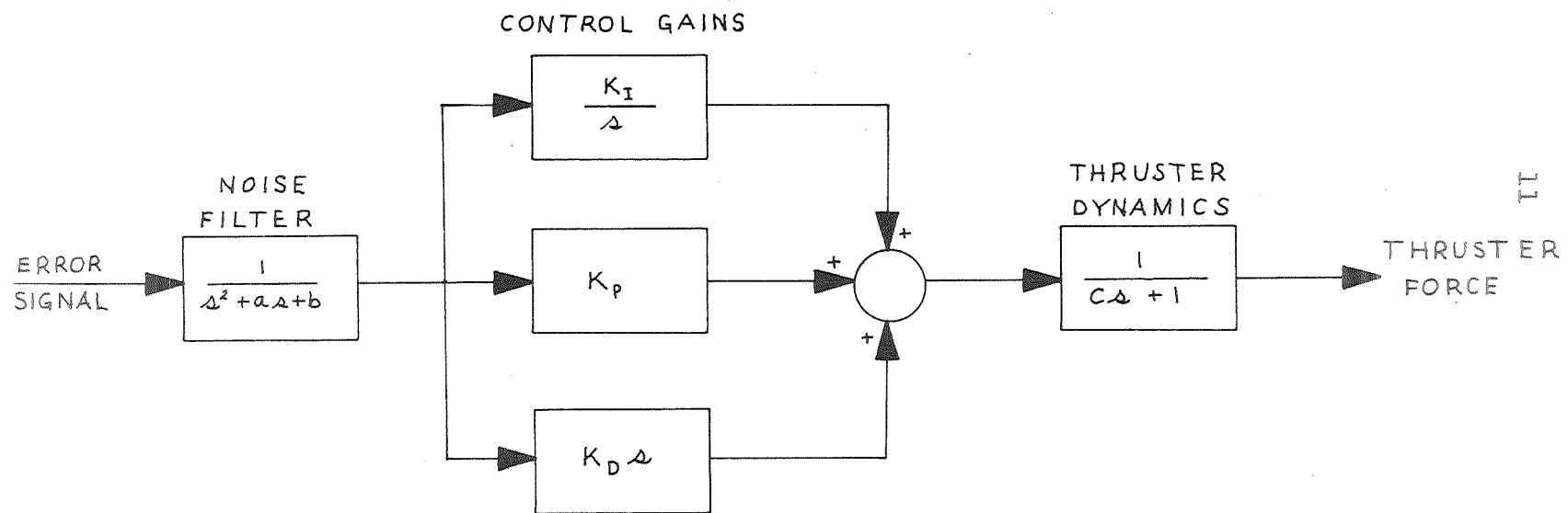
CONTROLLER SUBSYSTEM

FIGURE 2.2

object.[1]

Equations (2.13), (2.14), and (2.15) formulate the hydrodynamic components of equations (2.10), (2.11), and (2.12).

$$F_{XH} = K_{XH} \, V_R \, |V_R|$$ (2.13)

$$F_{YH} = K_{YH} \, V_R \, |V_R|$$ (2.14)

$$M_{\psi H} = K_{\psi H} \, V_R \, |V_R|$$ (2.15)

An analysis of hydrodynamic drag force data taken in wave tank model studies for ship-hull vessels yields the values of K_{XH}, K_{YH}, and $K_{\psi H}$. The relative velocity V_R in the ship's coordinates is the velocity of the ship with respect to the water. V_R is a function of the ship's velocity; the steady-state current velocity; and the instantaneous horizontal particle velocity of the ocean waves.

Simplifying equations of the small amplitude wave theory yields the instantaneous horizontal particle velocity. These wave equations are an approximation of the complete theoretical description of wave behavior. The errors resulting from practical assumptions and simplifications of the theory

[1]R. G. Dean and D. R. F. Harleman, "Interaction of Structures and Waves," A. T. Ippen (ed.), Estuary and Coastline Hydrodynamics (New York: McGraw-Hill, 1966), 341-403.

are negligible in this hybrid computer study. Appendix A contains a complete derivation of the hydrodynamic wave equations used for this model. Appendix B contains graphs of typical hydrodynamic and aerodynamic drag force functions for ship-hull vessels.

Equations (2.16), (2.17), and (2.18) formulate the aerodynamic components of equations (2.10), (2.11), and (2.12).

$$F_{XA} = K_{XA} V_A |V_A| \tag{2.16}$$

$$F_{YA} = K_{YA} V_A |V_A| \tag{2.17}$$

$$M_{\psi A} = K_{\psi A} V_A |V_A| \tag{2.18}$$

An analysis of aerodynamic drag force data taken in wind tunnel tests on ship-hull vessels produces the values of K_{XA}, K_{YA}, and $K_{\psi A}$. V_A is a function of the steady-state wind velocity and the instantaneous wind gust velocity.

The equations presented in this chapter are the mathematical model of a typical dynamic ship positioning system.

CHAPTER III

COMPUTER MODE ASSIGNMENTS

The hybrid system used for this study is an IBM
System/360 Model 44 general purpose digital computer with
32,000 words of core memory; an HSI SS-100 Analog/Hybrid
computer with one hundred analog amplifiers; and an HSI Model
1044 Hybrid Linkage unit with multichannel communication
paths. For this study one or both computers simulate the
functions of each component of the dynamic positioning system.
Figure 3.1 illustrates the computer mode assignments.

This study assigns the vessel simulation to the analog
computer. The basic ship dynamics--acceleration, velocity,
and position--are the central elements of the analog model.
The process of integration is a primary task of analog com-
puters. The integration of the vessel's acceleration gives
the velocity; the integration of the velocity gives the position.

An analog summer-amplifier simulates the vessel's
comparator subsystem. Either manual or servo-set potentiometers
simulate the reference coordinates.

The controller subsystem filters noise from the com-
parator's error signal; modifies the signal by applying control
gains; and sets the thrust demand level. Analog computing
elements simulate the control system and filtering techniques
of this model because the integral operator in the analog
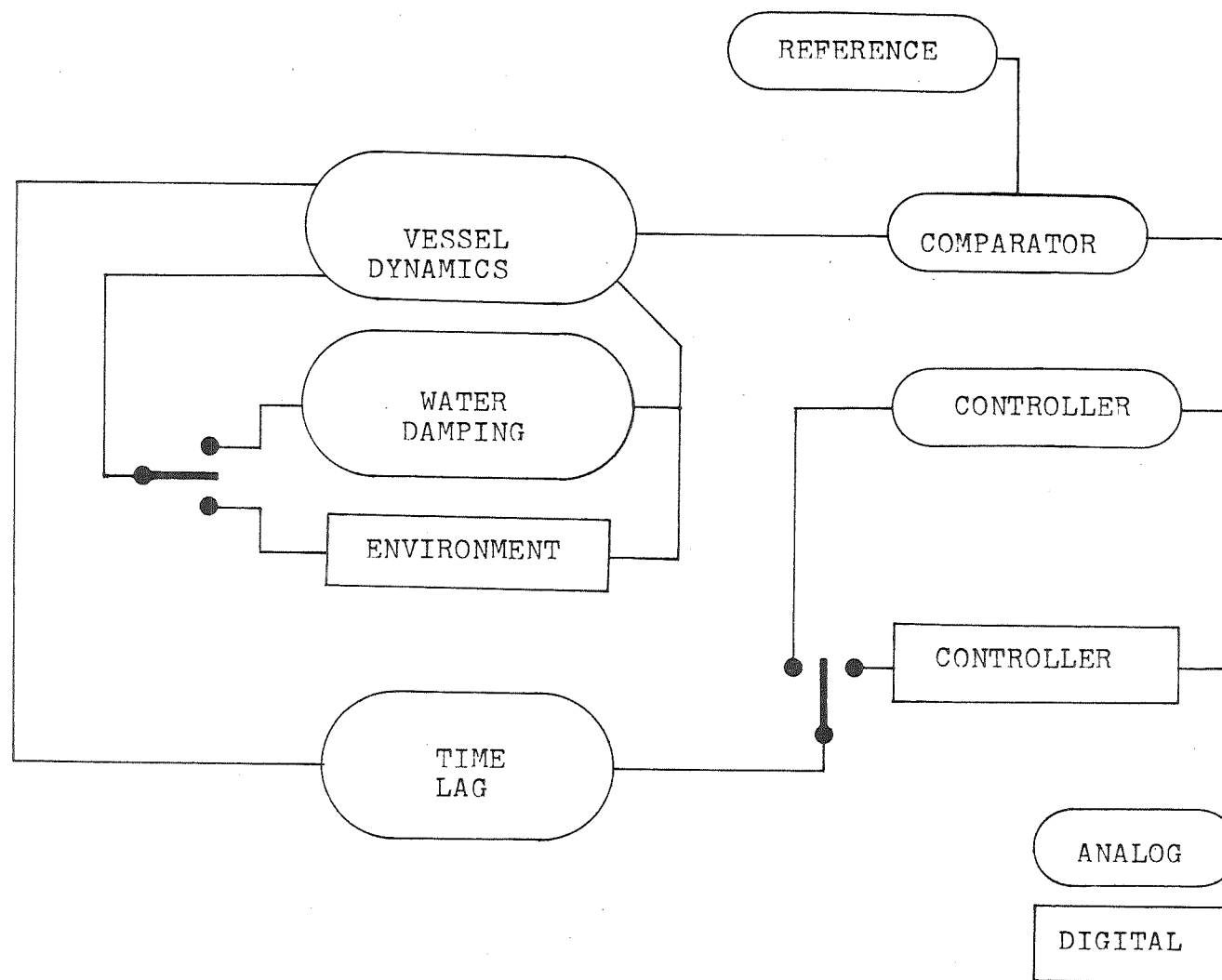
COMPUTER MODE ASSIGNMENTS

FIGURE 3.1

computer can linearly replace the Laplace operator, "1/s".

Simulation of the controller on the analog computer
is efficient for research purposes, but in actual practice,
the controller subsystem of a dynamically positioned vessel
would probably be a digital computer. For this reason, both
computers simulate the control system. Digitally controlled
signal switching places either control system into the feed-
back loops.

Generally, there is a time lag associated with the
response of electromechanical systems. In this system, the
time lag occurs between the demand for thrust and the response
of the thrusters. The time lag is simulated by the analog
computer by a first order lag function.

On the other hand, the digital computer primarily
simulates the complex environmental forces at the ocean's
surface. However, an option in the digital program allows
an analog computer simulation of the steady state environ-
mental forces and the hydrodynamic damping.

This discussion describes the design of the model.
Chapter IV and Chapter V describe the fabrication of the
hybrid model.

CHAPTER IV

ANALOG MODEL

The analog model of the vessel and control system
results from constructing three separate closed loops:
X-position loop, Y-position loop, and ψ-heading loop. These
loops simulate vessel dynamics in the three degrees of freedom
which this study allows. The analog representation of equations
(2.1) through (2.6) forms the model of the vessel.

Dynamic range is one of the limitations of an analog
computer. The analog computer for this study has a maximum
dynamic range of plus and minus one hundred volts. Since the
variables and constants of most models are not within this
range, magnitude scaling is necessary. The steps in magnitude
scaling are:

1. obtain the unscaled equations for each amplifier;

2. substitute an equivalent scaled program variable
    for each problem variable. For example, if the
    problem contains a variable, x, whose maximum value
    can be as high as 500, this variable is replaced in
    the equation with the computer variable, 500[x/500],
    without unbalancing the equation;

3. solve the equations for the scaled outputs in terms
    of the scaled inputs;

4. adjust the amplifier gains so that all potentiometer settings are less than unity.

In order to perform magnitude scaling of equations (2.1) through (2.6), it is necessary to define the maximum value of each variable and constant. Table I lists the parameters and their maximum values used in this study.

Substitution of the maximum parameter values from Table I into equations (2.1) through (2.6) yields the scaled model of the vessel. The scaled variables are bracketed and the potentiometer settings are shown in parentheses.

$$\frac{d}{dt} 20\left[\frac{V_x}{20}\right] = \frac{5.0 \times 10^4}{7.5 \times 10^5}\left[\frac{F_x}{5.0 \times 10^4}\right] \bigg/ \left[\frac{M_x}{7.5 \times 10^5}\right] + 0.1\left[\frac{\omega}{0.1}\right] 2.0\left[\frac{V_y}{2.0}\right]$$

$$\frac{d}{dt}\left[\frac{V_x}{20}\right] = (0.0033)\left[\frac{F_x}{5.0 \times 10^4}\right] \bigg/ \left[\frac{M_x}{7.5 \times 10^5}\right] + (0.0100)\left[\frac{\omega}{0.1}\right]\left[\frac{V_y}{2.0}\right] \tag{4.1}$$

$$\frac{d}{dt} 500\left[\frac{r_x}{500}\right] = 20\left[\frac{V_x}{20}\right] + 0.1\left[\frac{\omega}{0.1}\right] 500\left[\frac{r_y}{500}\right]$$

$$\frac{d}{dt}\left[\frac{r_x}{500}\right] = (0.0400)\left[\frac{V_x}{20}\right] + (0.1000)\left[\frac{\omega}{0.1}\right]\left[\frac{r_y}{500}\right] \tag{4.2}$$

$$\frac{d}{dt} 2.0\left[\frac{V_y}{2.0}\right] = \frac{5.0 \times 10^4}{1.1 \times 10^6}\left[\frac{F_y}{5.0 \times 10^4}\right] \bigg/ \left[\frac{M_y}{1.1 \times 10^6}\right] - 0.1\left[\frac{\omega}{0.1}\right] 20\left[\frac{V_x}{20}\right]$$

$$\frac{d}{dt}\left[\frac{V_y}{2.0}\right] = (0.0227)\left[\frac{F_y}{5.0 \times 10^4}\right] \bigg/ \left[\frac{M_y}{1.1 \times 10^6}\right] - (0.9999)\left[\frac{\omega}{0.1}\right]\left[\frac{V_x}{20}\right] \tag{4.3}$$

$$\frac{d}{dt} 500\left[\frac{r_y}{500}\right] = 2.0\left[\frac{V_y}{2.0}\right] - 0.1\left[\frac{\omega}{0.1}\right] 500\left[\frac{r_x}{500}\right]$$

$$\frac{d}{dt}\left[\frac{r_y}{500}\right] = (0.0040)\left[\frac{V_y}{2.0}\right] - (0.1000)\left[\frac{\omega}{0.1}\right]\left[\frac{r_x}{500}\right] \tag{4.4}$$

$$\frac{d}{dt} 0.1\left[\frac{\omega}{0.1}\right] = \frac{1.0 \times 10^7}{1.375 \times 10^{10}}\left[\frac{M_\psi}{1.0 \times 10^7}\right] \bigg/ \left[\frac{I_z}{1.375 \times 10^{10}}\right]$$

$$\frac{d}{dt}\left[\frac{\omega}{0.1}\right] = (0.0072)\left[\frac{M_\psi}{1.0 \times 10^7}\right] \bigg/ \left[\frac{I_z}{1.375 \times 10^{10}}\right] \tag{4.5}$$

$$\frac{d}{dt} 3.14\left[\frac{\psi}{3.14}\right] = 0.1\left[\frac{\omega}{0.1}\right]$$

$$\frac{d}{dt}\left[\frac{\psi}{3.14}\right] = (0.0318)\left[\frac{\omega}{0.1}\right] \tag{4.6}$$

Three summer amplifiers, one in each loop, represent the vessel's position and heading comparator subsystem. The sum of the vessel position (heading) and the conjugate of the reference coordinate is the vessel position (heading) error signal.

The control system operates on the error signal from the comparator which in turn receives its information from the position measuring system located remotely from the vessel. Because of the high ambient noise level, filtering at the input to the control system is necessary. This filtering is simulated by modeling a second order polynomial for the X-position loop and the heading loop, and a fourth order polynomial for the Y-position loop. Figures 4.1, 4.2, and 4.3 are block diagrams of these position and heading control loops.

The outputs of these control loops are the thrust demand signals. Since there is a time lag associated with the response of the vessel to the thrust demands, simulation of a time delay is necessary. The models of these delays are first order analog lags and the outputs of the lags are the vessel thruster forces. The sum of the environmental forces and the thruster forces is the input to the vessel's dynamic model which closes the loop.
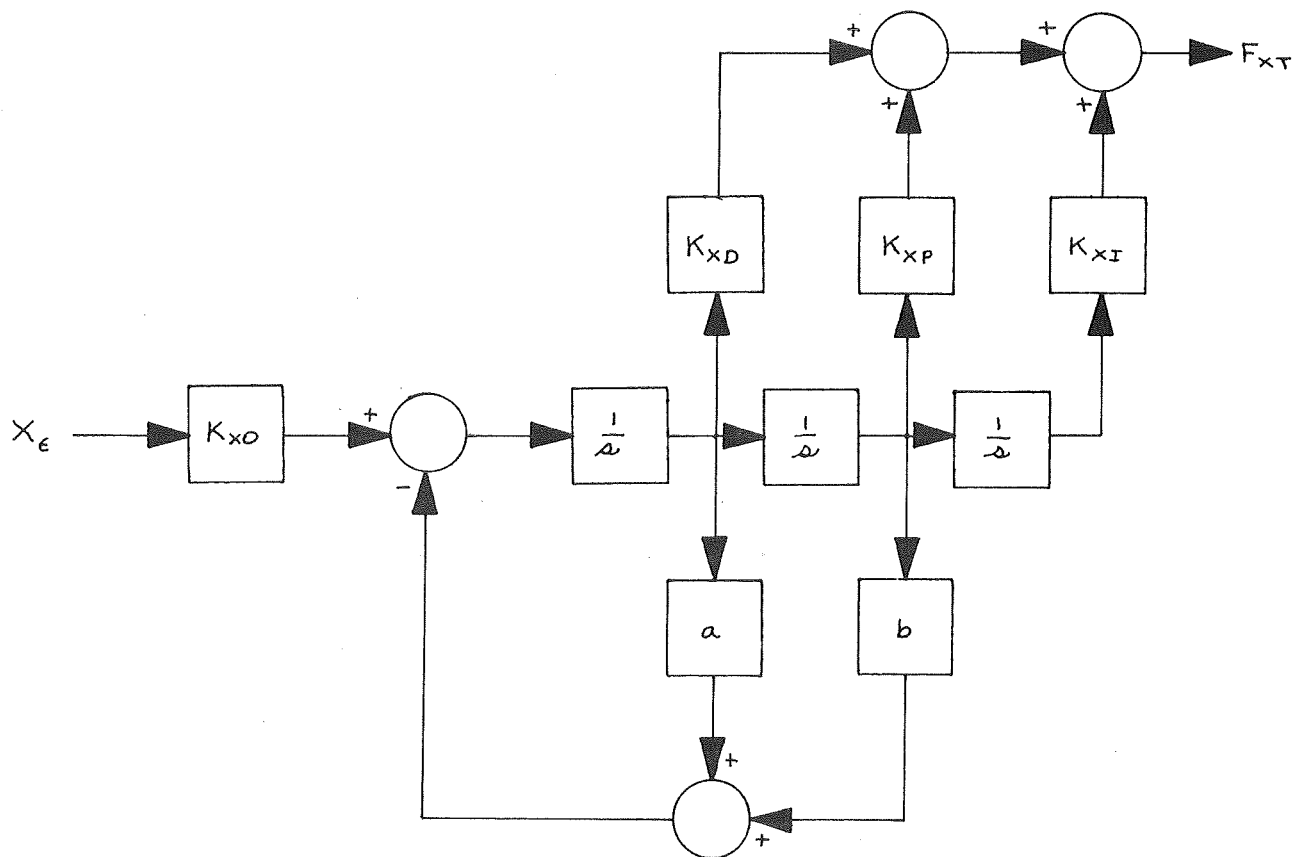
BLOCK DIAGRAM OF
X-LOOP CONTROL SYSTEM

FIGURE 4.1

23
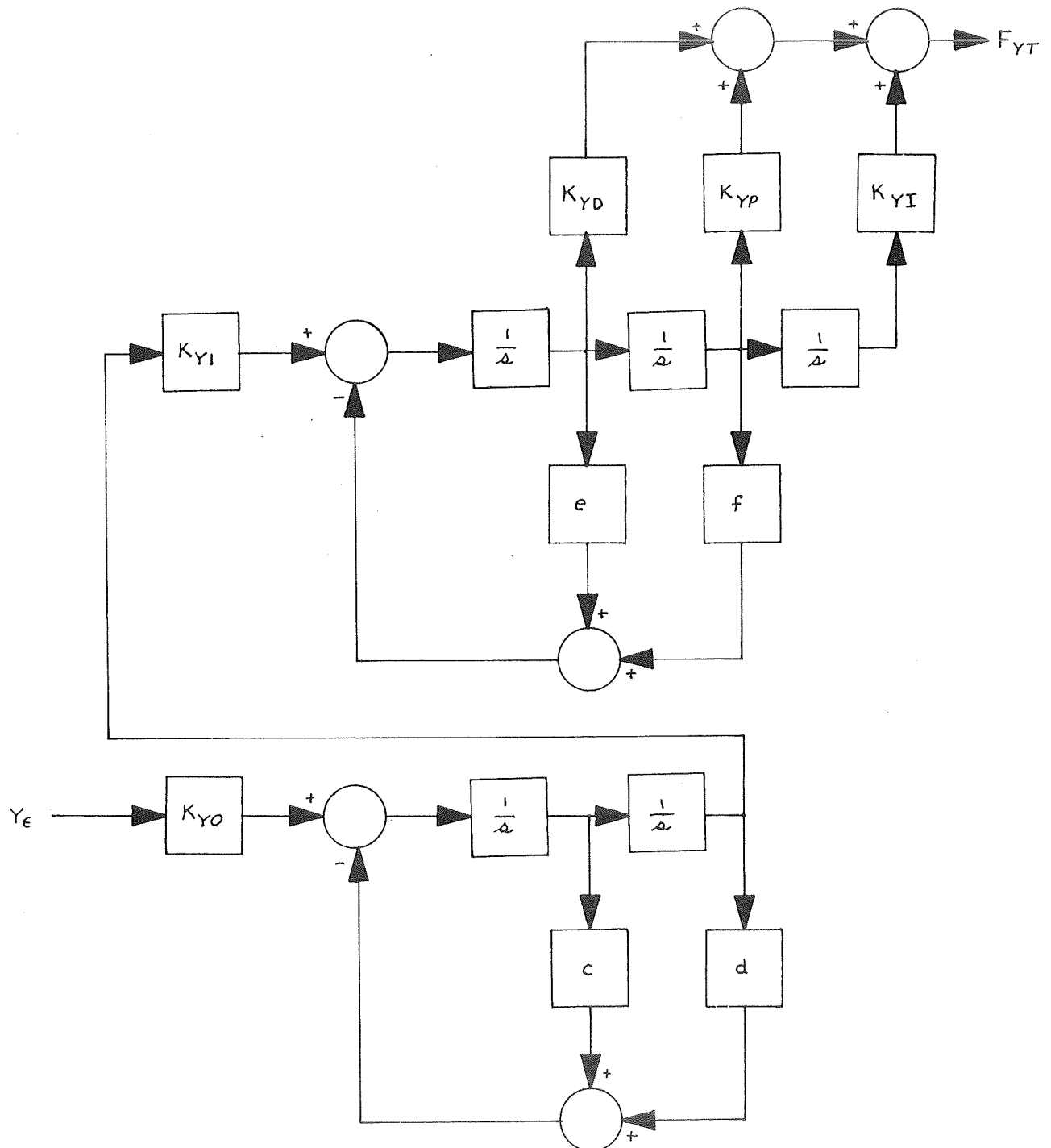
BLOCK DIAGRAM OF
Y-LOOP CONTROL SYSTEM

FIGURE 4.2
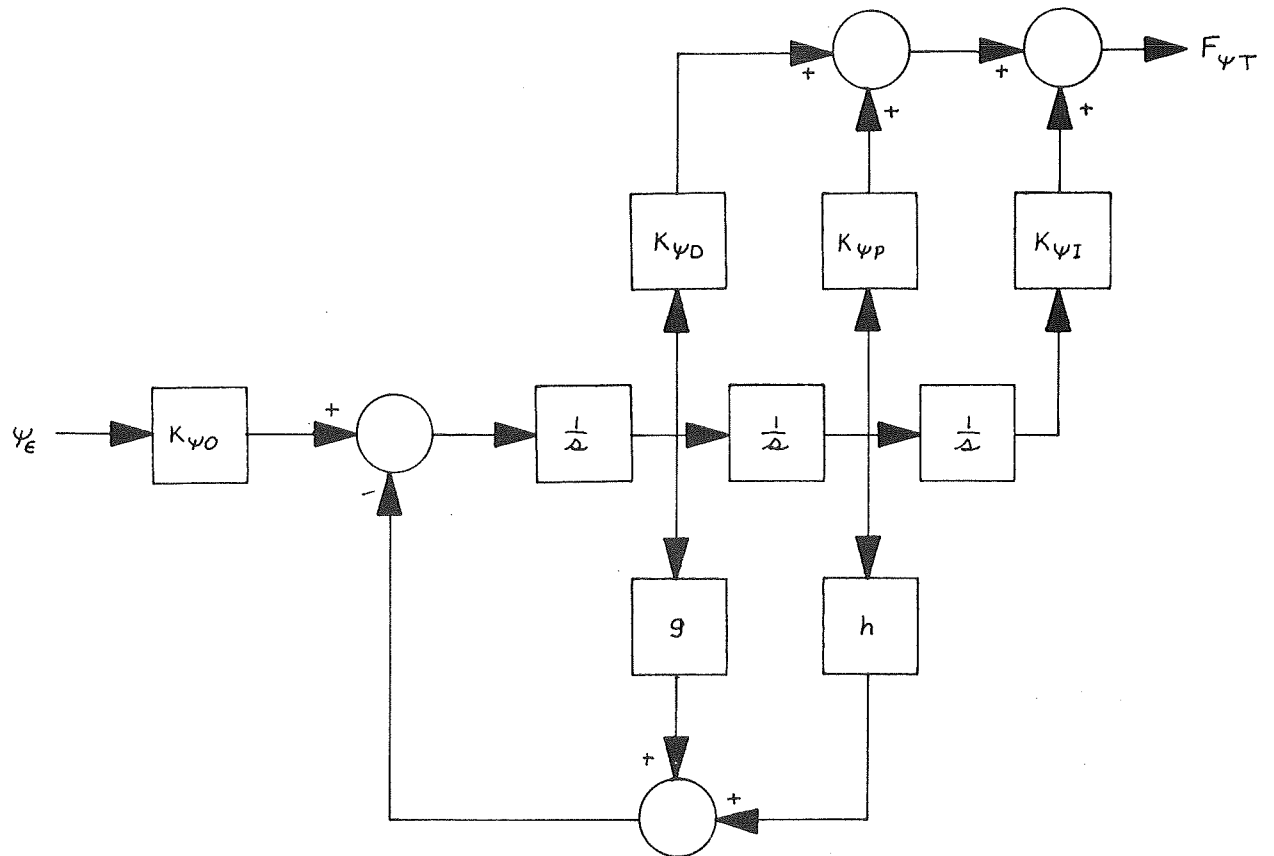
BLOCK DIAGRAM OF

Ψ -LOOP CONTROL SYSTEM

FIGURE 4.3

Equations (2.13) through (2.15) represent the hydro-
dynamic damping force caused by the motion of the vessel
with respect to the water. The velocity functions of these
equations are simulated by using analog comparators and multi-
pliers. The analog comparator senses the sign of the relative
vessel velocity and the output of this comparator controls
a function switch. If the sign of the relative velocity is
negative, the function switch changes state and the multiplier
receives both the positive signal and the negative signal.
The product of the multiplier is the square of the velocity.
However, the product retains the algebraic sign of the relative
vessel velocity.

The multipliers used in the analog section have a
small D. C. offset voltage at their outputs. To compensate
for this offset, the multiplier outputs are summed with the
conjugate of the offset value.

Figures 4.4, 4.5, and 4.6 illustrate the complete
analog computer model for this study. Figure 4.7 is the key
for the analog symbols shown. Table II lists the potentiometer
settings.

Y–POSITION LOOP

FIGURE 4.5

Ψ —HEADING LOOP

FIGURE 4.6

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REFERENCE
VOLTAGE

POTENTIOMETER

SUMMER/INVERTER

SUMMER/INTEGRATOR

MULTIPLIER

COMPARATOR

DIGITAL TO ANALOG
CONVERTOR

ANALOG TO DIGITAL
CONVERTOR

FUNCTION
SWITCH

OPEN

CLOSED
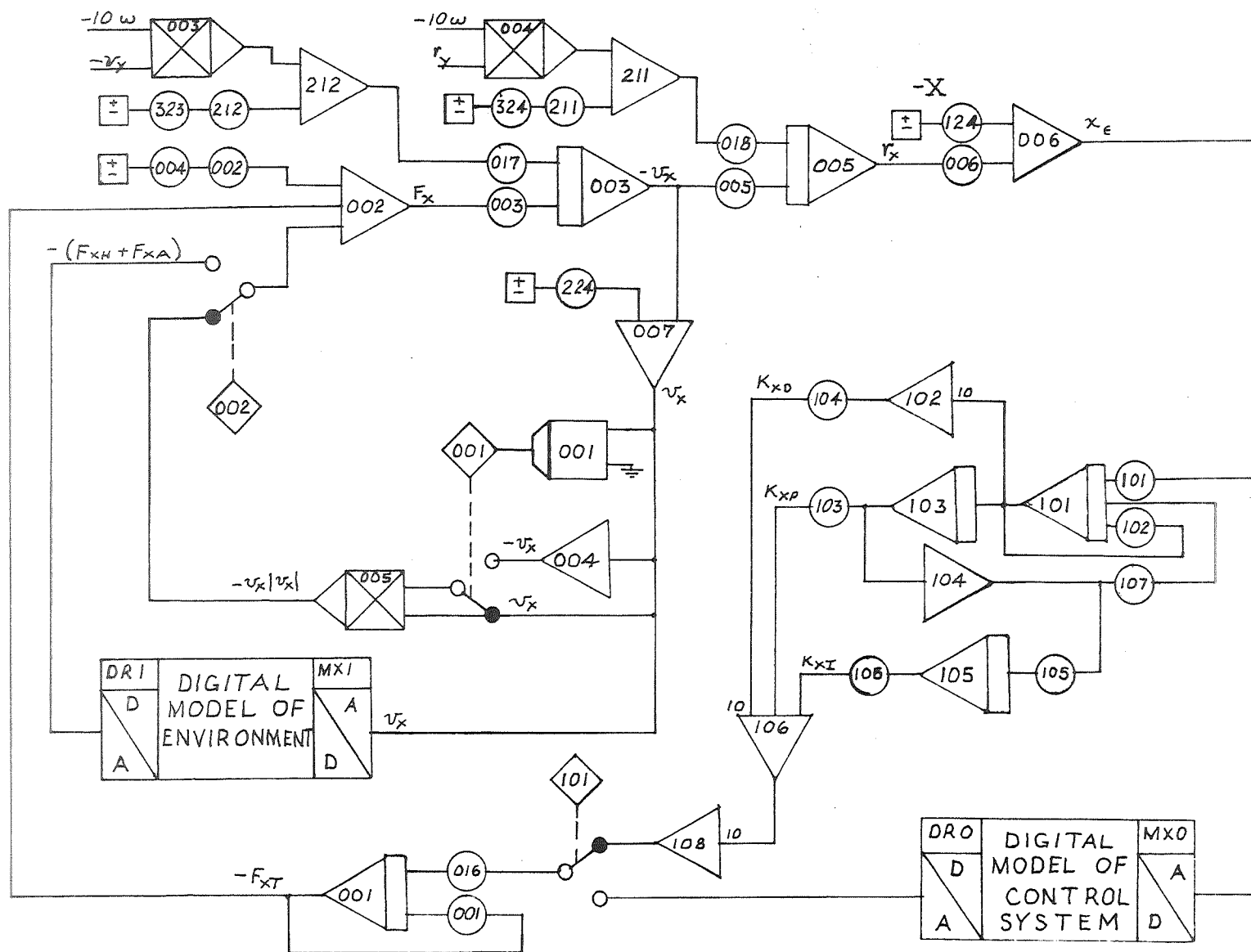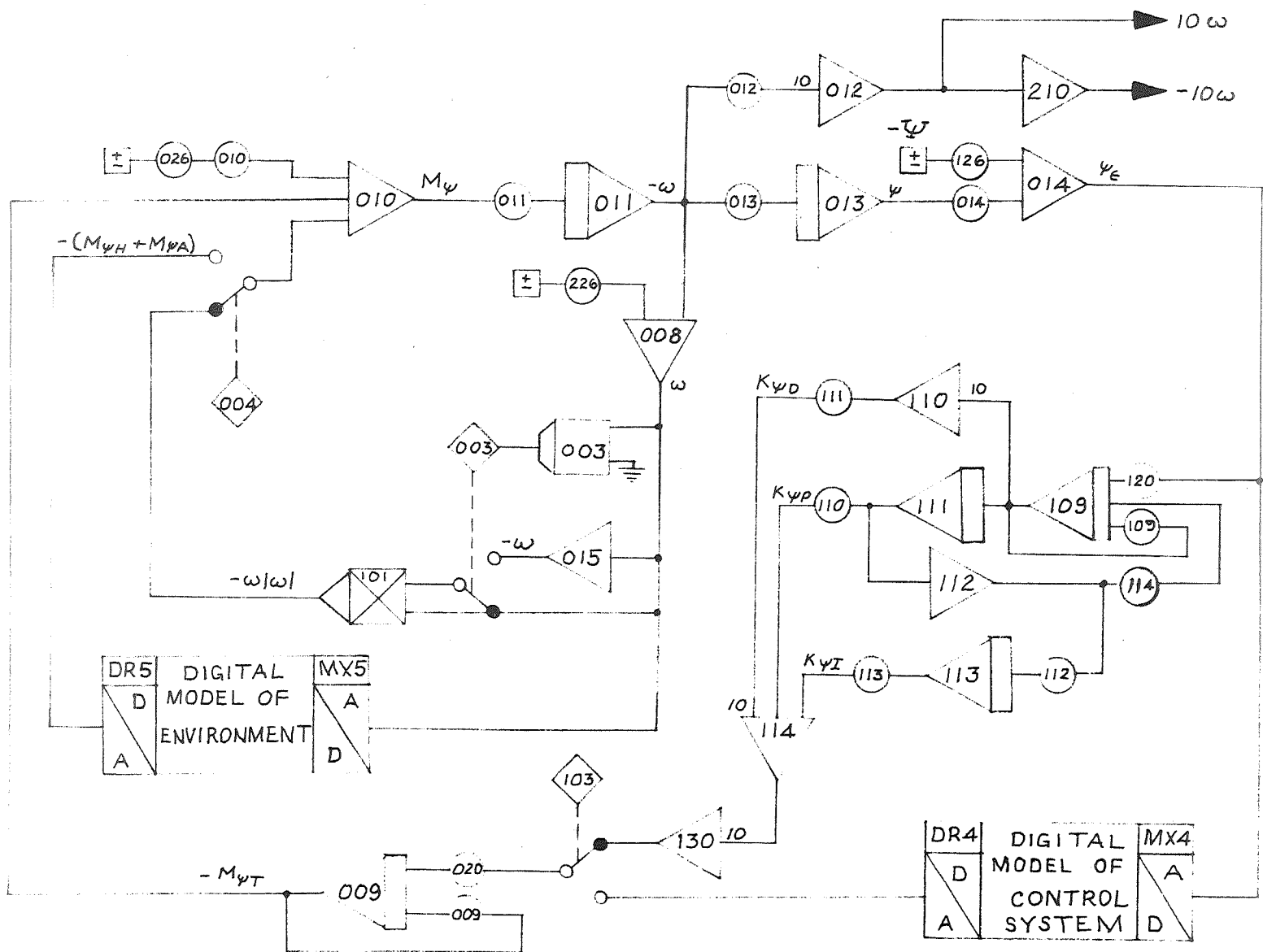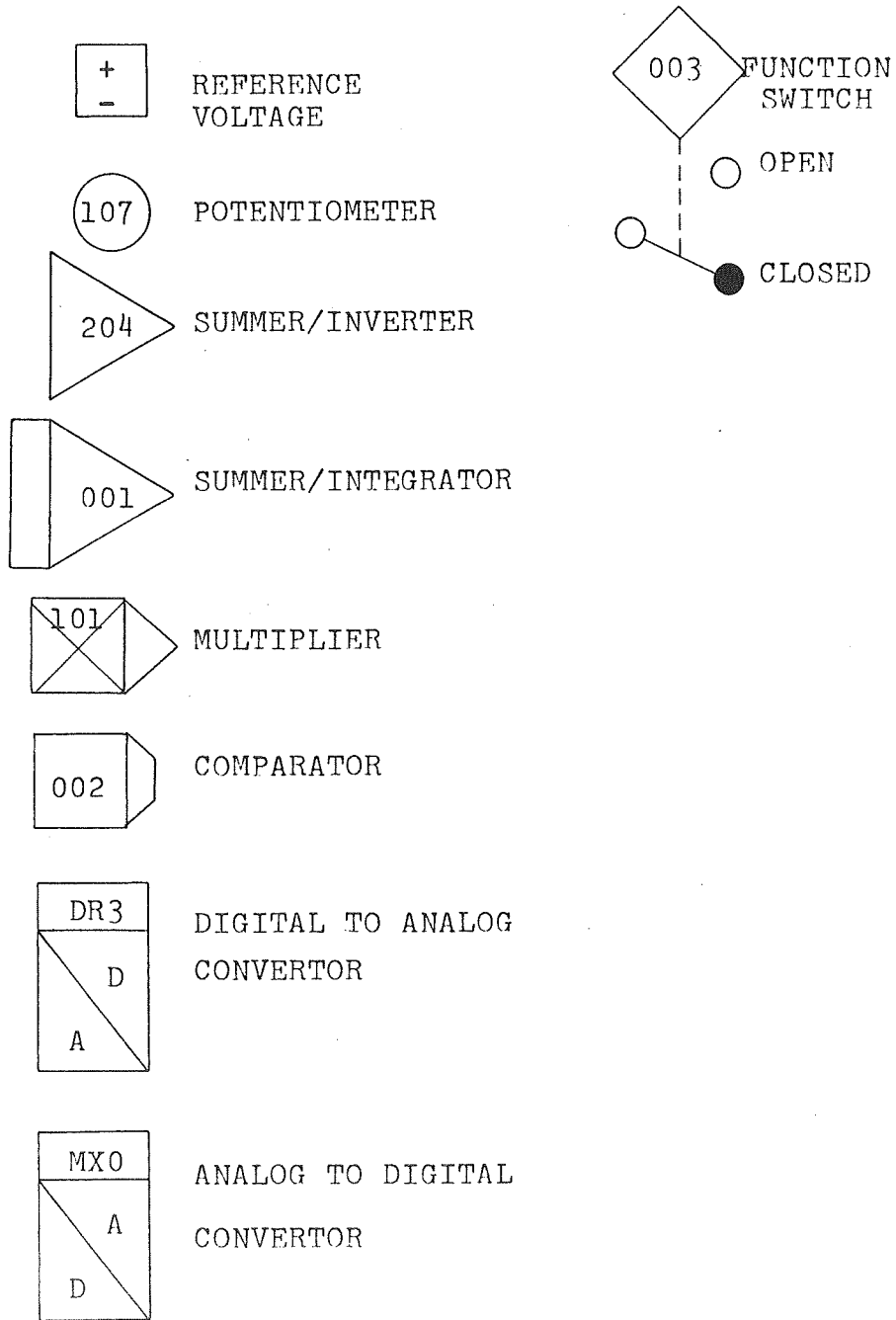
ANALOG KEY

FIGURE 4.7

CHAPTER V

DIGITAL MODEL

The digital model is a FORTRAN computer program which performs three functions:

1. it controls the transfer of information or data between the digital computer and the analog computer;

2. it simulates the controller subsystem; and

3. it generates the hydrodynamic and aerodynamic forces in the case studies.

To simplify the FORTRAN programming, available system subroutines are incorporated in the digital program. A subroutine is a digital computer subprogram which, when called upon by the main program, performs a predefined task. Subroutines from both the Data Acquisition Multiprogramming System (DAMPS) and the Hybrid Executive control the transfer of information between the analog and the digital computer. DAMPS and the Hybrid Executive are collections of subroutines designed for use on the IBM System/360 Model 44--HSI SS-100 Analog/Hybrid computer. Table III lists the subroutines for this study.

The main program begins by calling on various subroutines to establish memory control blocks for each hybrid input/output channel in the simulation. The hybrid I/O channels in this study are:

1. analog to digital input;

2. digital to analog output;

3. sense line input;

4. control line input; and

5. mode control output.

Before each hybrid computer run, the digital line printer lists operating instructions and program options. These instructions and options are:

****

INFORMATION CONCERNING REAL TIME OPERATION OF MAIN PROGRAM

THE FOLLOWING INFORMATION IS REQUESTED BY THE TYPEWRITER TERMINAL
N IS THE NUMBER OF PRINTED OUTPUT SAMPLES
        A SAMPLE IS TAKEN EVERY FIFTH TIME THROUGH THE TIMED
        CONTROL LOOP
        IF N=0 EXIT IS CALLED AND THE PROGRAM CONCLUDED
ISCALE IS THE TIME SCALE FACTOR
LOGIC IS AN INPUT THAT ENABLES PROGRAM OPTIONS
        LOGIC=0 EXISTING GAINS ARE USED AND OPERATION BEGINS
        LOGIC=1 NEW GAINS MAY BE INPUT FOR X-CHANNEL
        LOGIC=2 NEW GAINS MAY BE INPUT FOR Y-CHANNEL
        LOGIC=3 NEW GAINS MAY BE INPUT FOR PSI-CHANNEL
        LOGIC=4 NEW GAINS INPUT FOR X, Y, & PSI-CHANNELS
        LOGIC=5 INPUT CURRENT--POLAR COORDINATES
        LOGIC=6 INPUT SEA STATE (0, 4, 6, OR 8) AND DIRECTION

LOGIC=7 INPUT WIND--POLAR COORDINATES

LOGIC=8 INPUT GUST MAGNITUDE, PERIOD, & VARIATION ANGLE

LOGIC=9 ANALOG CONTROL SYSTEM IS USED--NO GAINS INPUT

THE FOLLOWING RUN OPTIONS ARE AVAILABLE

ENABLE SENSE LINE "1" TO MAKE A PARAMETER CHANGE DURING

A RUN

ENABLE SENSE LINE "0" TO MAKE A CONTINUOUS RUN

****

After the line printer lists the instructions and
options, the digital computer typewriter terminal requests the
run time (N) and the time scale (ISCALE). The values of N and
ISCALE enter the program through the typewriter terminal.

The programmer types the value for LOGIC into the
computer; the computer then requests the corresponding program
option. A case study begins only when LOGIC=0 or LOGIC=9.
For LOGIC=0, the digital computer enables control line "0".
Control line "0" in the enable position causes function switches
in the analog computer to place the digital control system in
the feedback loops. For LOGIC=9, the digital computer disables
control line "0", placing the function switches in position
for the analog control system.

When a case study begins, the parameters of the digital
control system receive their initial values. The digital
computer places the analog computer in the operate mode; starts
the digital timer; and then reads the analog to digital input

lines. Velocity, position, heading, and error information are assigned to these input lines.

The program now directs the error information to the digital model of the control system. This model is a Z-transform representation of the analog control system. From this information the program calculates the level of thrust required to reduce the position and heading errors.

The y-coordinate thrusters supply both the thrust to maintain proper heading and the thrust to maintain proper y-position. The heading thrust requirements have priority on one half of the value of the y-coordinate, or translational thrust. The y-position thrust is at least one half of the translational thrust, plus the difference between one half of the translational thrust and the demanded heading thrust.

The next phase of the program is the simulation of the environmental forces. Sea States are a convenient method of classifying particular combinations of steady wind and wave conditions. The selection of an appropriate Sea State number, gust condition, and ocean current determines the complexity of the environmental model for a particular case study.

The program generates complex ocean waves by adding four sinusoidal wave components. Table V lists the wave components for the simulation of Sea States 4, 6, and 8 used in these case studies. The instantaneous wind velocity corresponding to the selected Sea State is, however, more com-

plicated. It is the sum of the steady state wind velocity
and the gust velocity. The latter is simulated in the program
by modulating both the magnitude and the direction of the wind
as a function of the sine of the gust frequency.

In order to determine the x and y relative velocities
of the vessel, the program transforms the water velocity and
the wind velocity obtained above from the inertial coordinates
to the vessel coordinates. The program then calculates the
hydrodynamic and aerodynamic drag forces using Fourier series
components of the drag force curves shown in Appendix B.
Tables VI and VII list their major Fourier series components.

To normalize the thrust forces and the environmental
forces to levels compatible with the analog model, magnitude
scaling is performed. These normalized forces are then trans-
ferred from the digital computer to the analog computer.

The final phase of the program is the interrogation
of the sense lines for an interrupt message from the analog
computer. If there is no interrupt message, the program checks
the status of run time. If the run time is not yet exceeded,
the program begins again by reading analog to digital values
of velocity, position, heading, and error.

Figure 5.1 is a block diagram flow chart of the digital
computer program. Appendix C is a listing of the program.
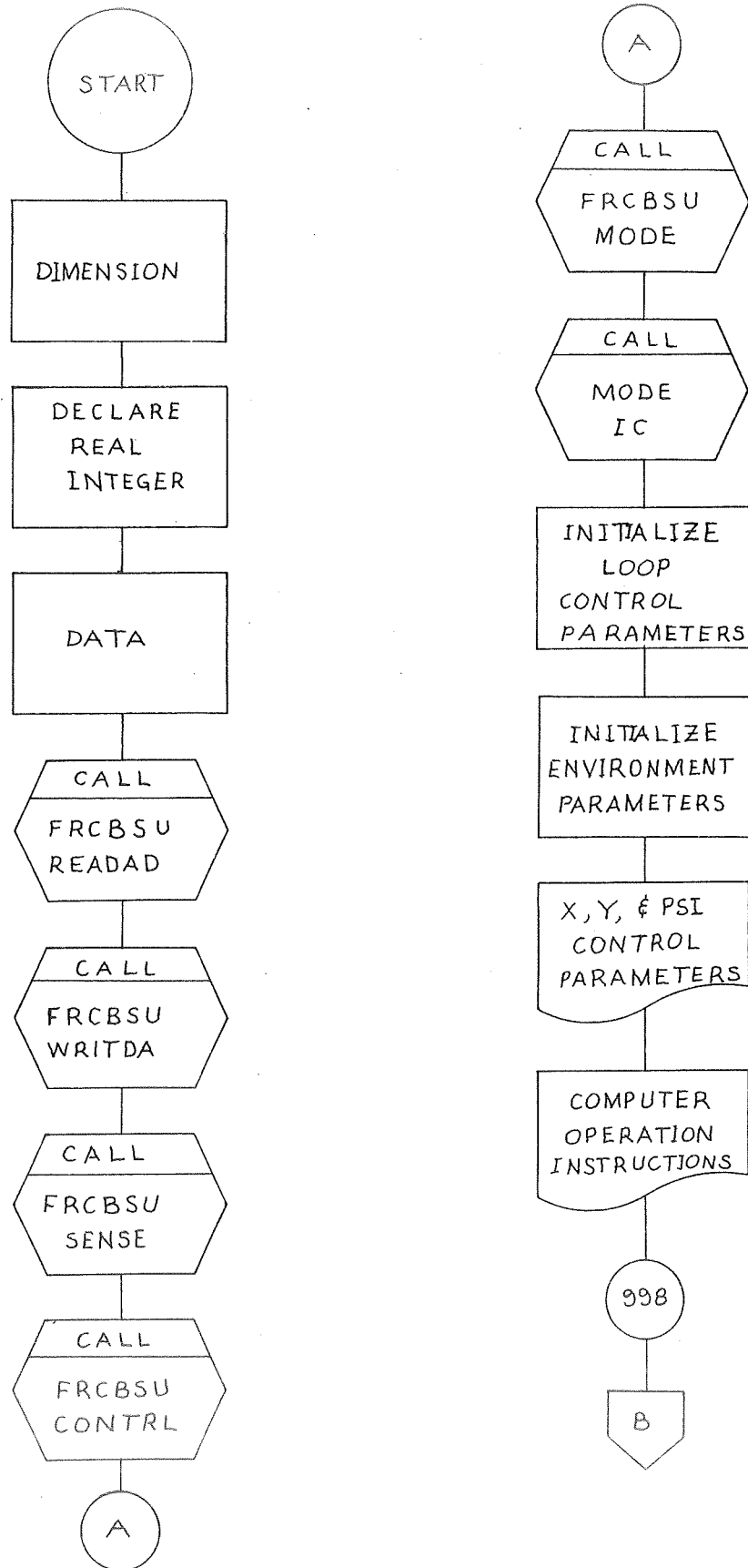
FIGURE 5.1a

FIGURE 5.1b

38
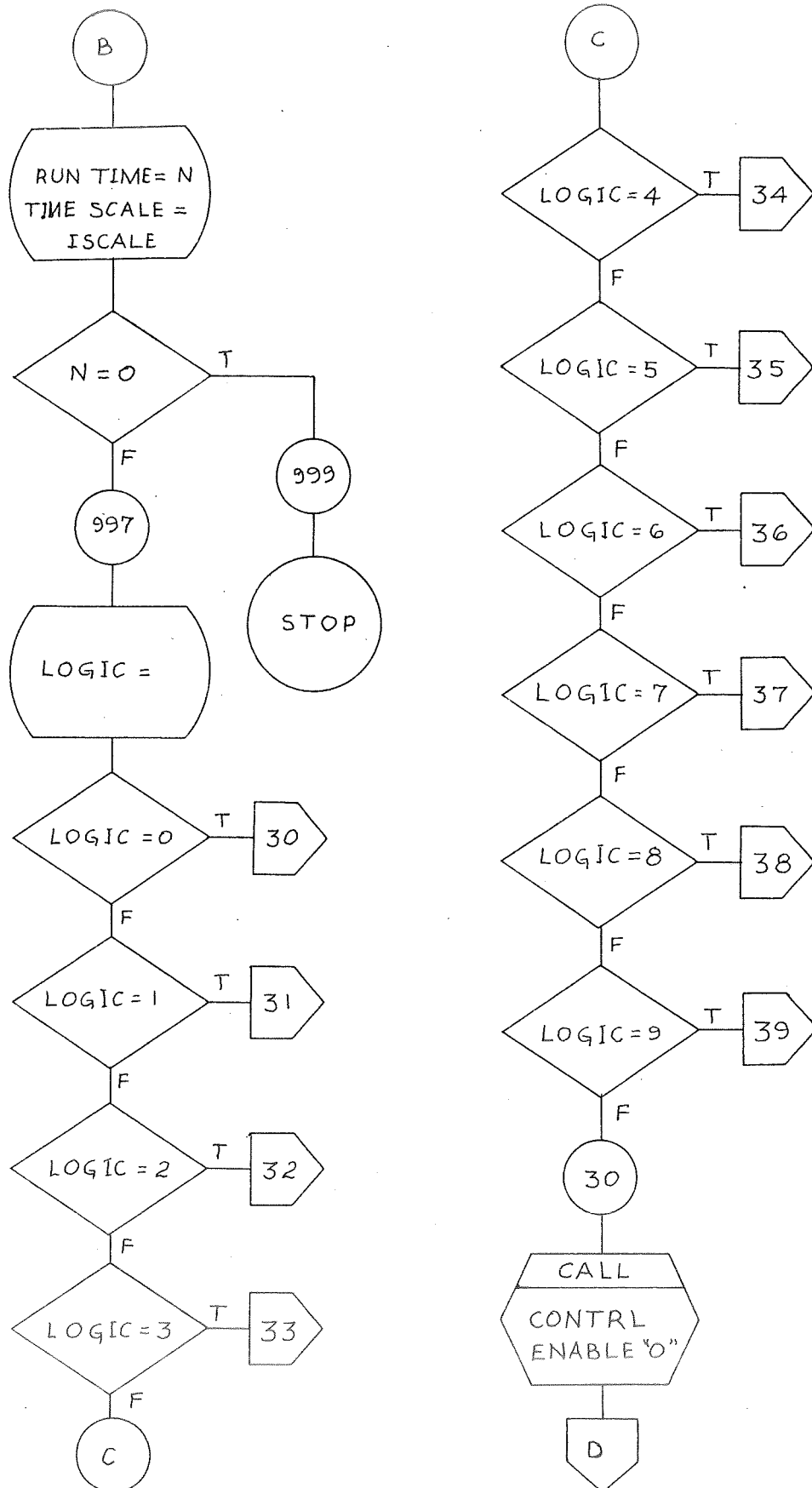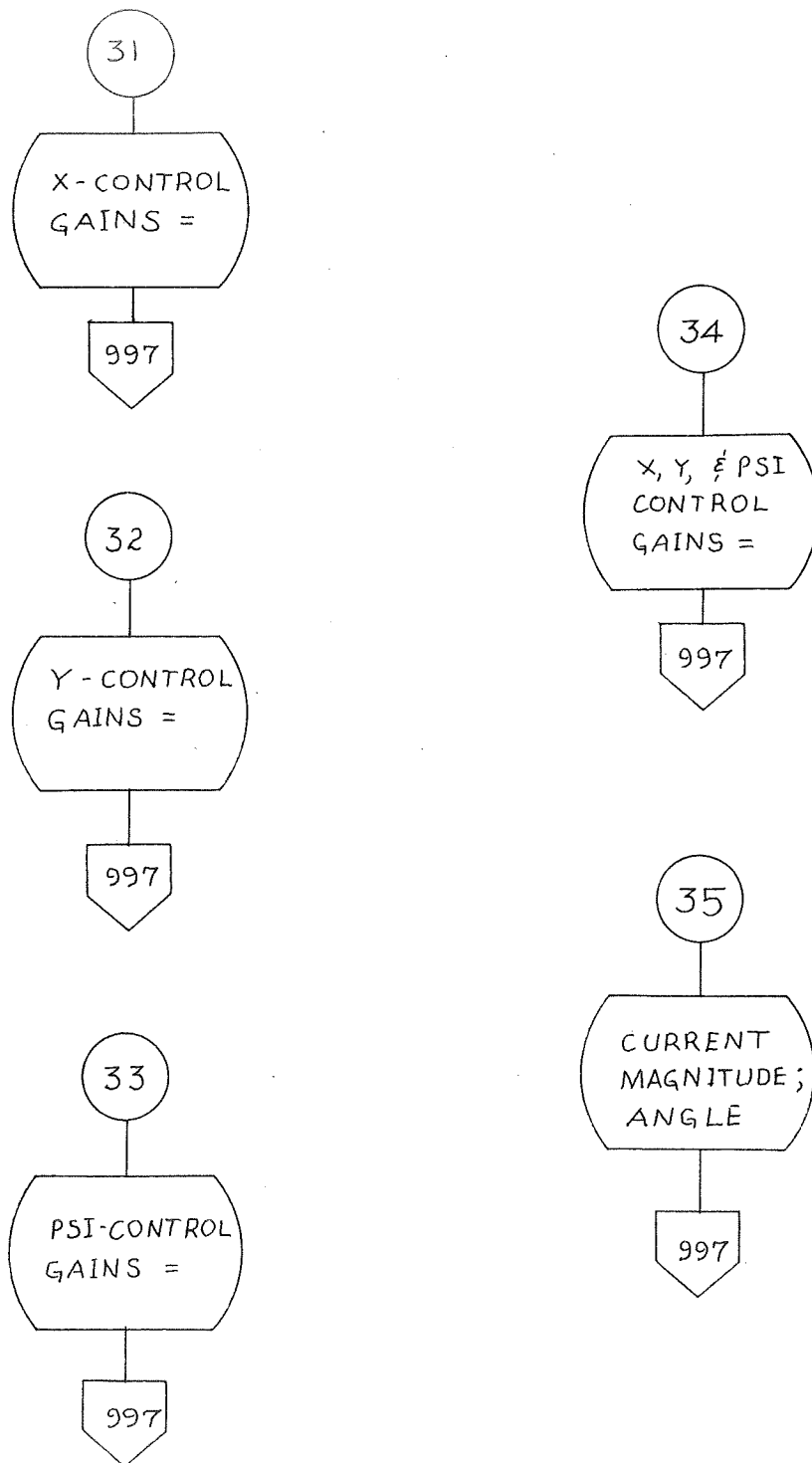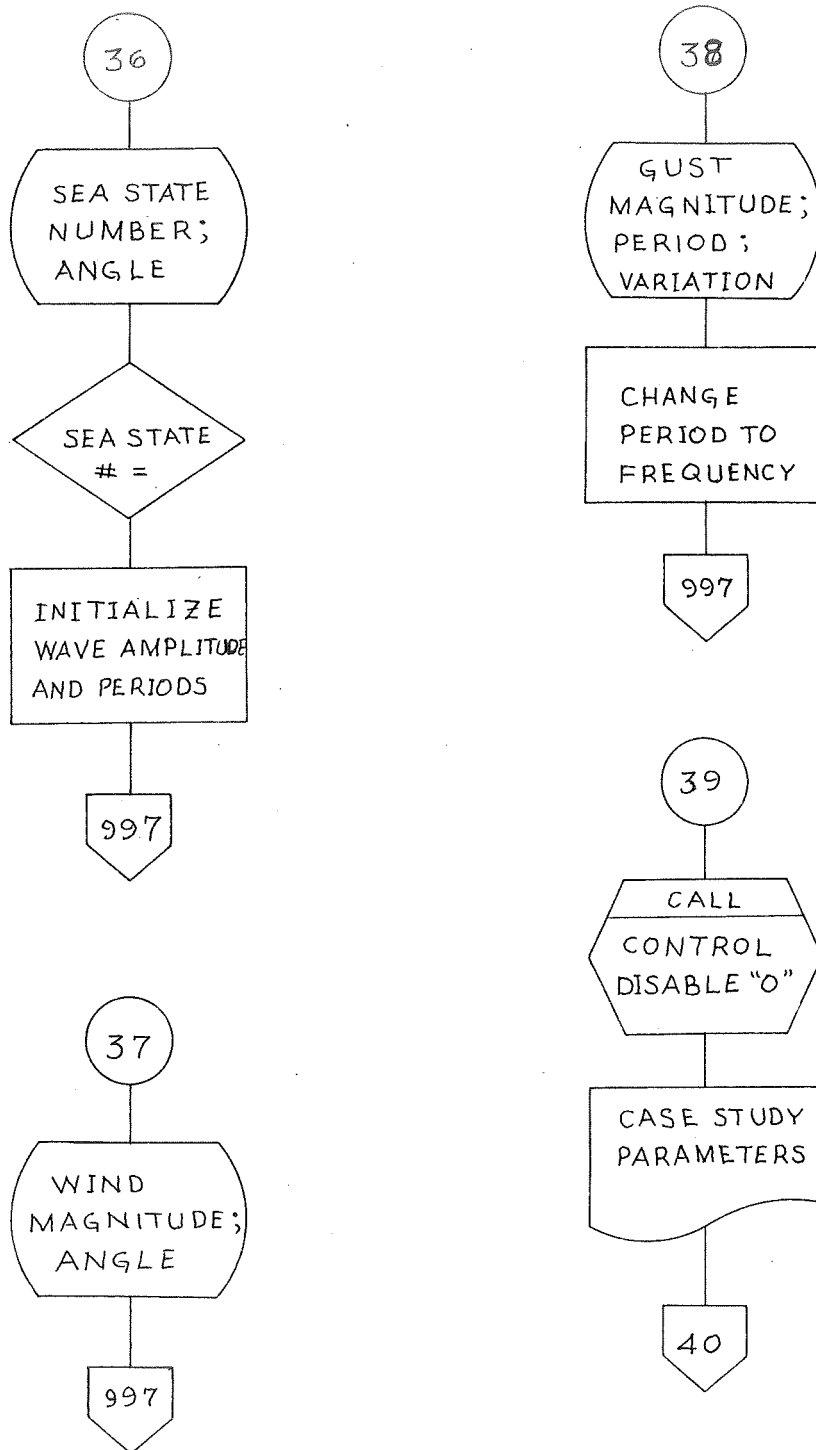
FIGURE 5.1c

FIGURE 5.1d
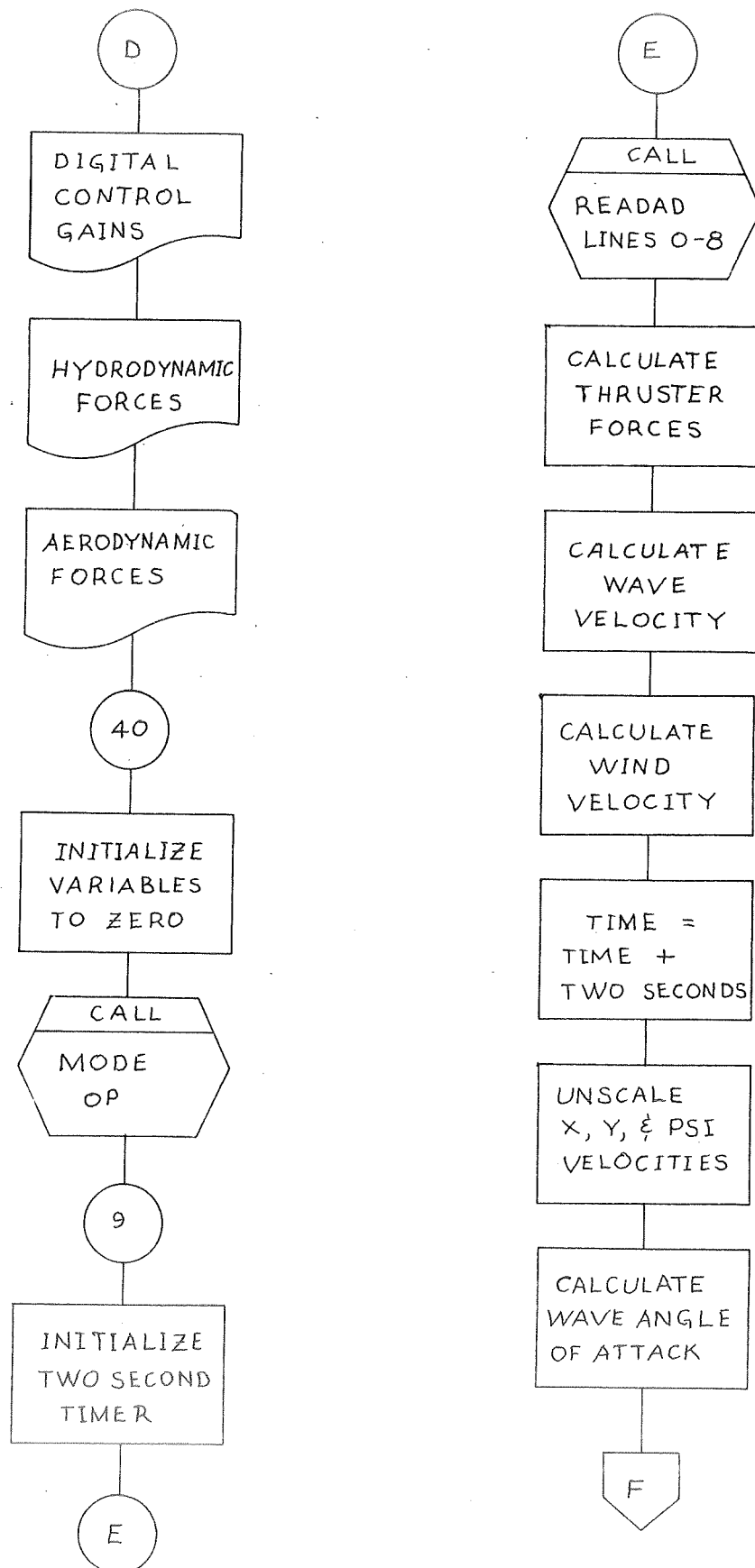
FIGURE 5.1e
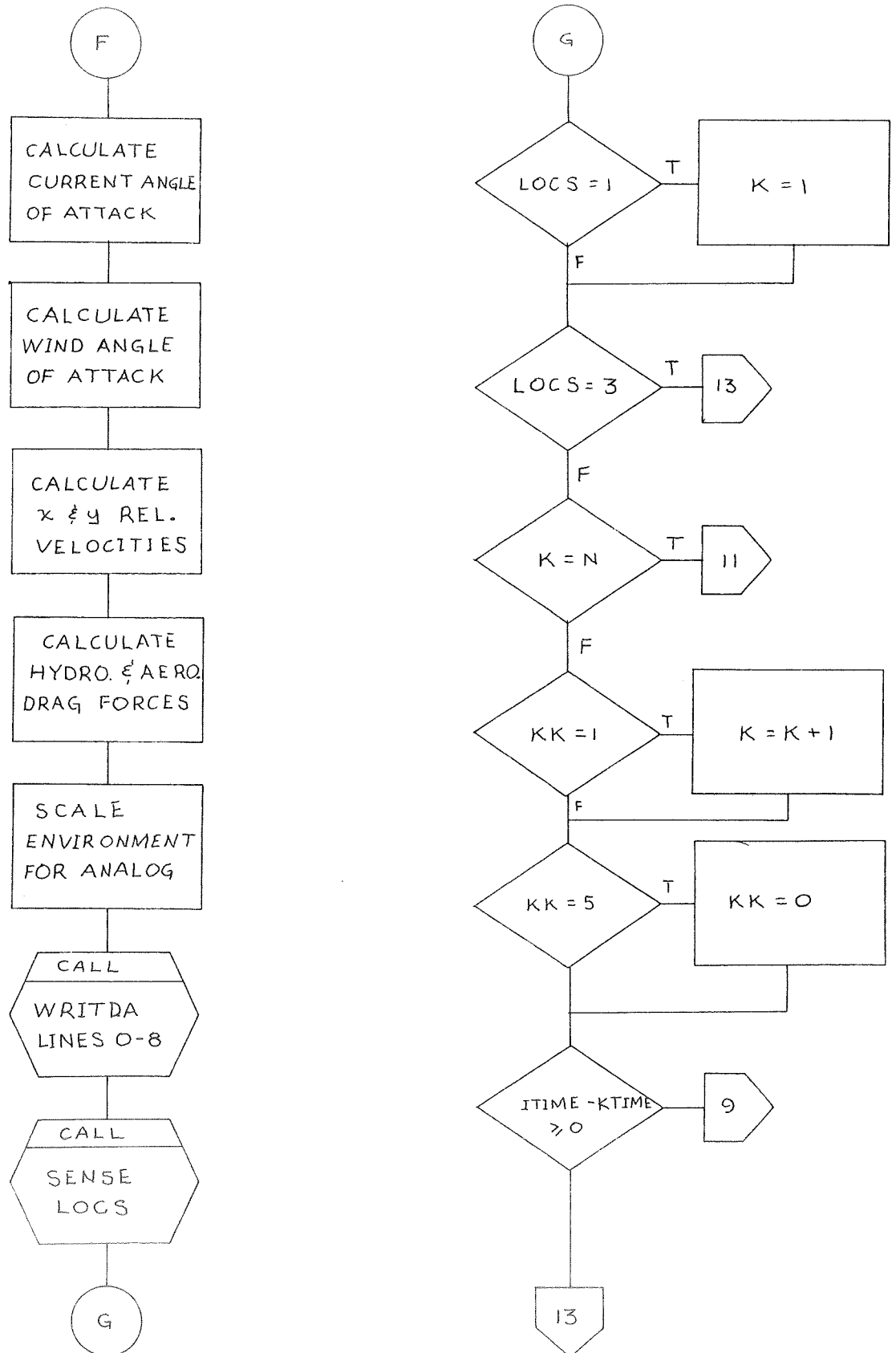
FIGURE 5.1f
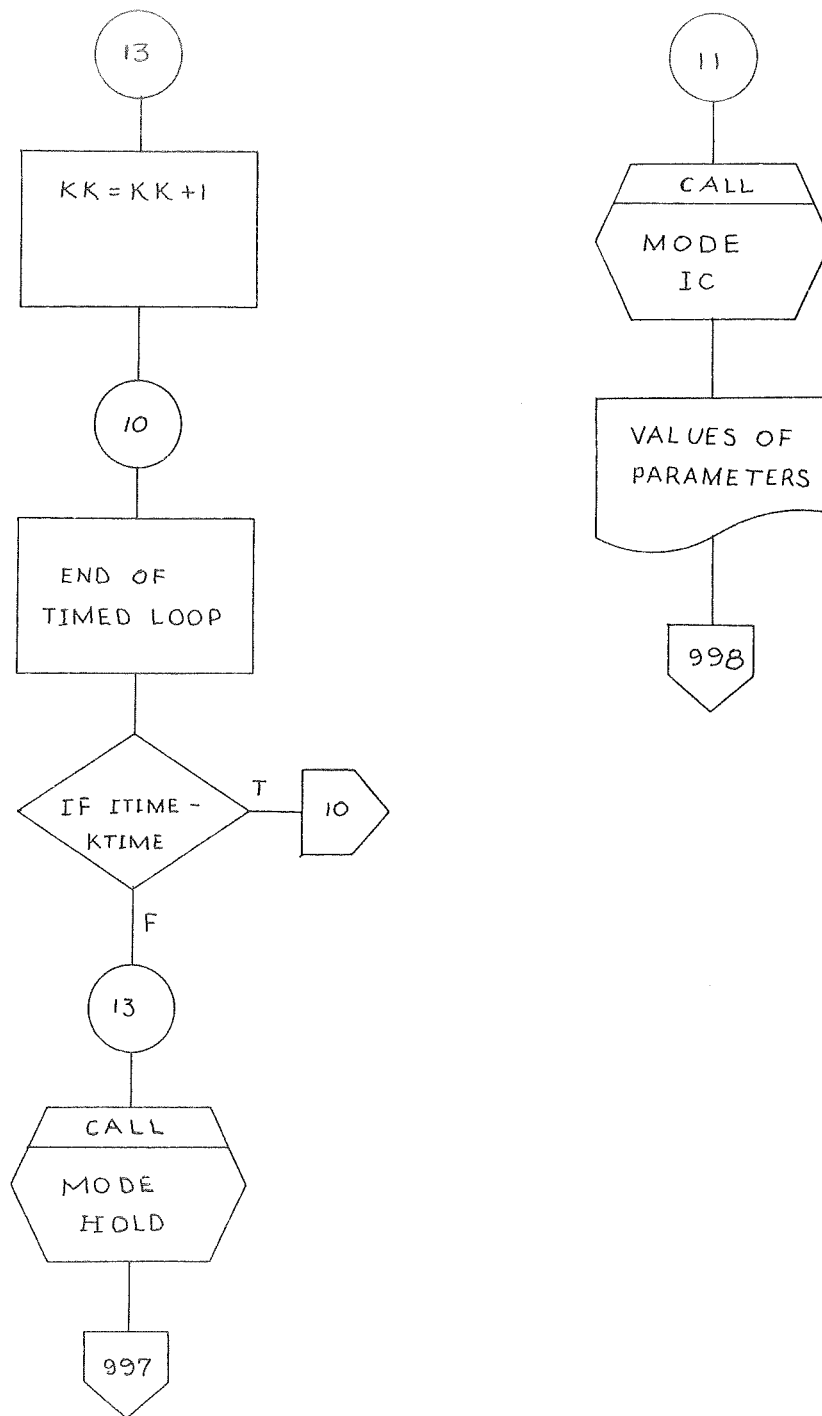
FIGURE 5.1g

CHAPTER VI

CASE STUDIES

This thesis investigates one control gain optimization
study and three case studies for the response of a dynamic
positioning system. There are an infinite combination of
environmental variations on the ocean surface. Three repre-
sentative variations--Sea States 4, 6, and 8--simulate probable
operating conditions for the vessel.

Before a case study begins, it is necessary to select
the computer time scale. Time can be compressed or expanded,
much like an accordian, by altering the time scale. Generally
one wants to compute either as quickly as possible, or, in
certain applications, in real time. For either case, the
upper limit is dictated by the computation cycle time required
by the digital computer program (receive information from the
analog computer, process this information, and transfer results
back to the analog computer). In this case, computation cycle
time is slightly less than twenty milliseconds and therefore
time is compressed by a factor of one hundred so that twenty
milliseconds computer time simulates two seconds actual time.

The first investigation is the vessel response to step
changes in position and heading. A trial and error technique
is used to optimize the control gains. Initial conditions for
the vessel are offsets of 125 feet in the X and Y reference

coordinates and 45 degrees in the heading coordinate. These
offsets produce a 25 per cent error at the output of the
position and heading error comparators. The step response
characteristics of each loop are recorded for a chosen set of
control gains. The gains are then varied, and the step res-
ponse recorded again. This process is repeated until any
further change in gain settings produces less desirable system
response than the previous "best guess" setting. Figures 6.1,
6.2, and 6.3 are typical recordings of the vessel response to
step changes. These recordings are representative of both the
analog and the digital control system models.

Case studies of Sea States 4, 6, and 8 demonstrate
the effects of heading changes on the total magnitude of the
thrust required to maintain a selected position. Table IV
lists the wind and wave conditions associated with these
Sea States. Figures 6.4, 6.5, and 6.6 are illustrations of
the wind velocities and the wave profiles of these Sea States.
The wave profile for Sea State 8 is a record of hurricane
wave data in the Gulf of Mexico. Figures 6.7, 6.9, and 6.11
are illustrations of the environmental force orientation for these
three case studies. Figures 6.8, 6.10, and 6.12 are recordings
of the vessel heading and the total thruster force required
to maintain heading and position.

An oscilliscope monitors the X-position and the Y-
position of the vessel during a case study. The X-position
provides vertical deflection and the Y-position provides
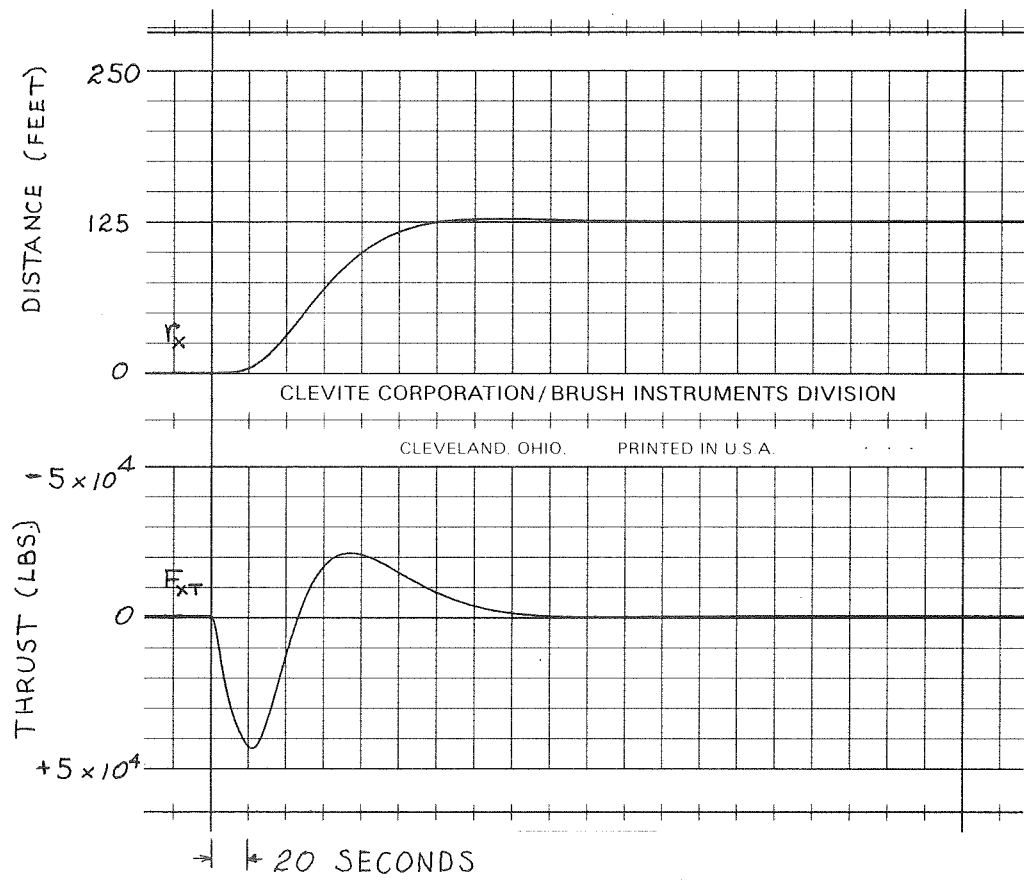
X—LOOP STEP RESPONSE

FIGURE 6.1

46
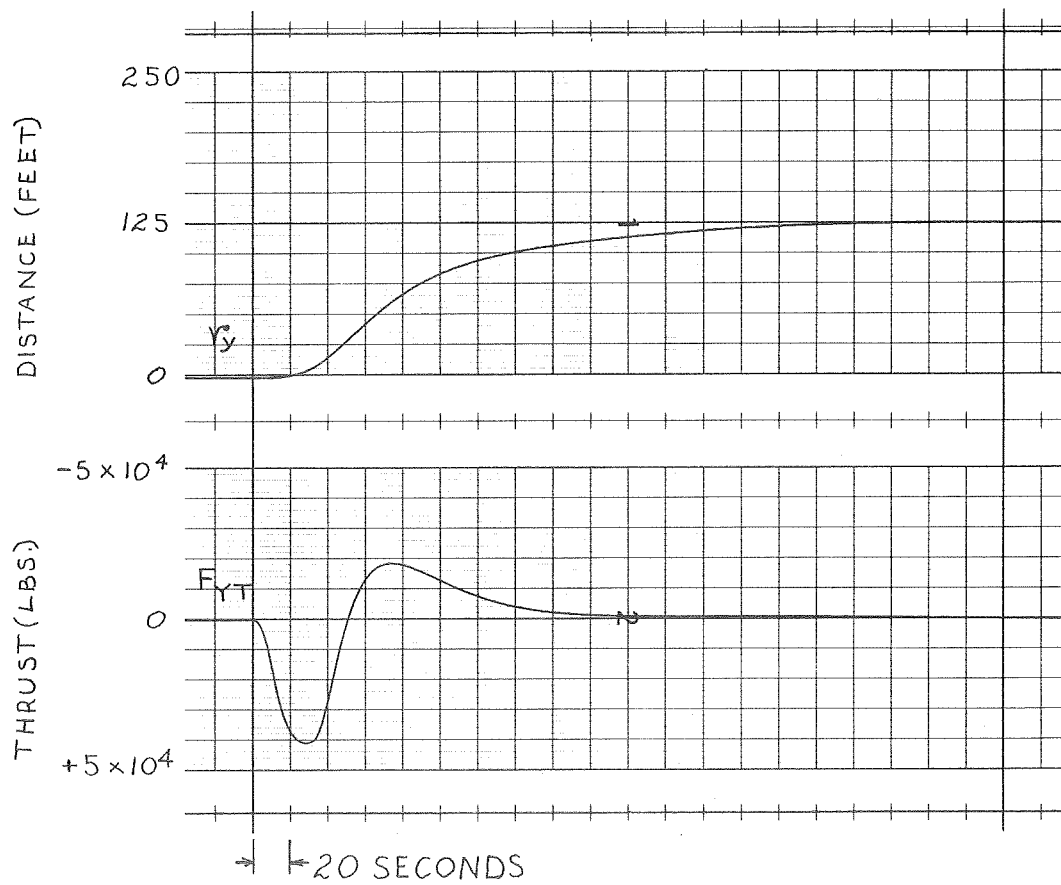
Y-LOOP STEP RESPONSE

FIGURE 6.2
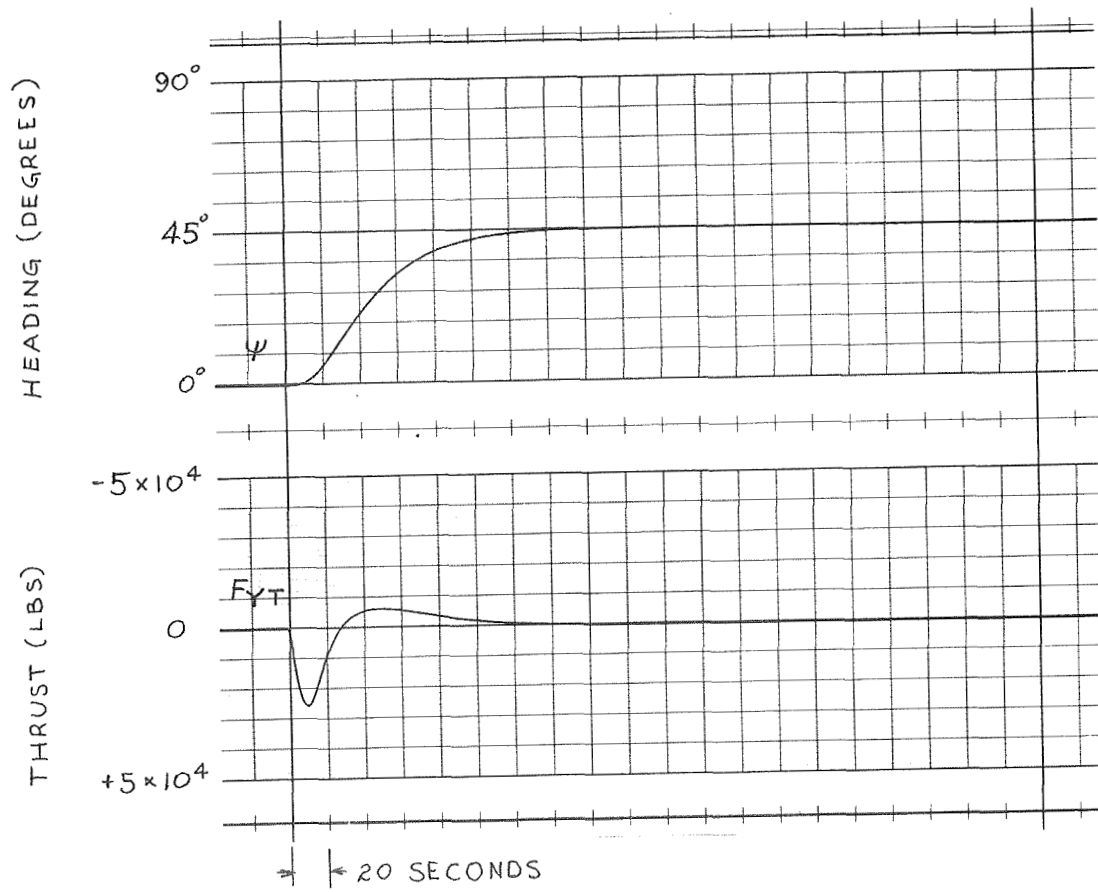
-LOOP STEP RESPONSE

FIGURE 6.3

48
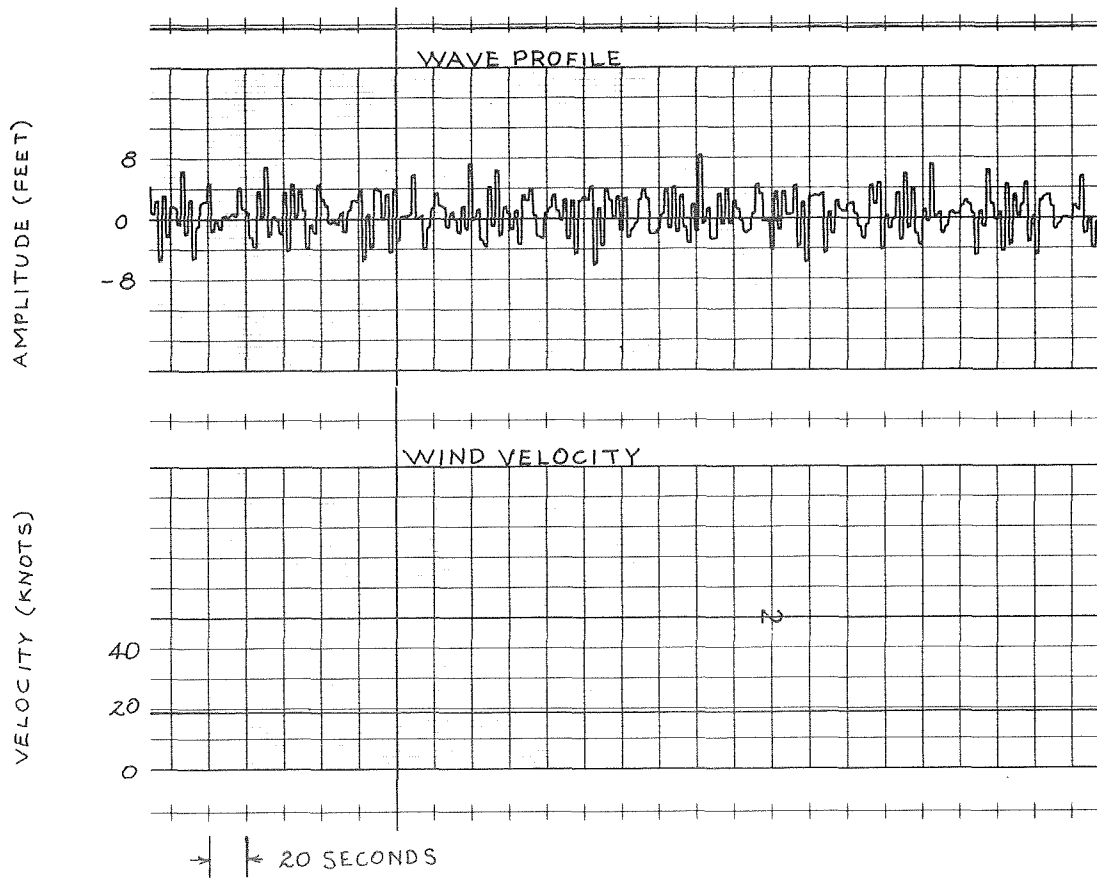
SEA STATE 4

FIGURE 6.4
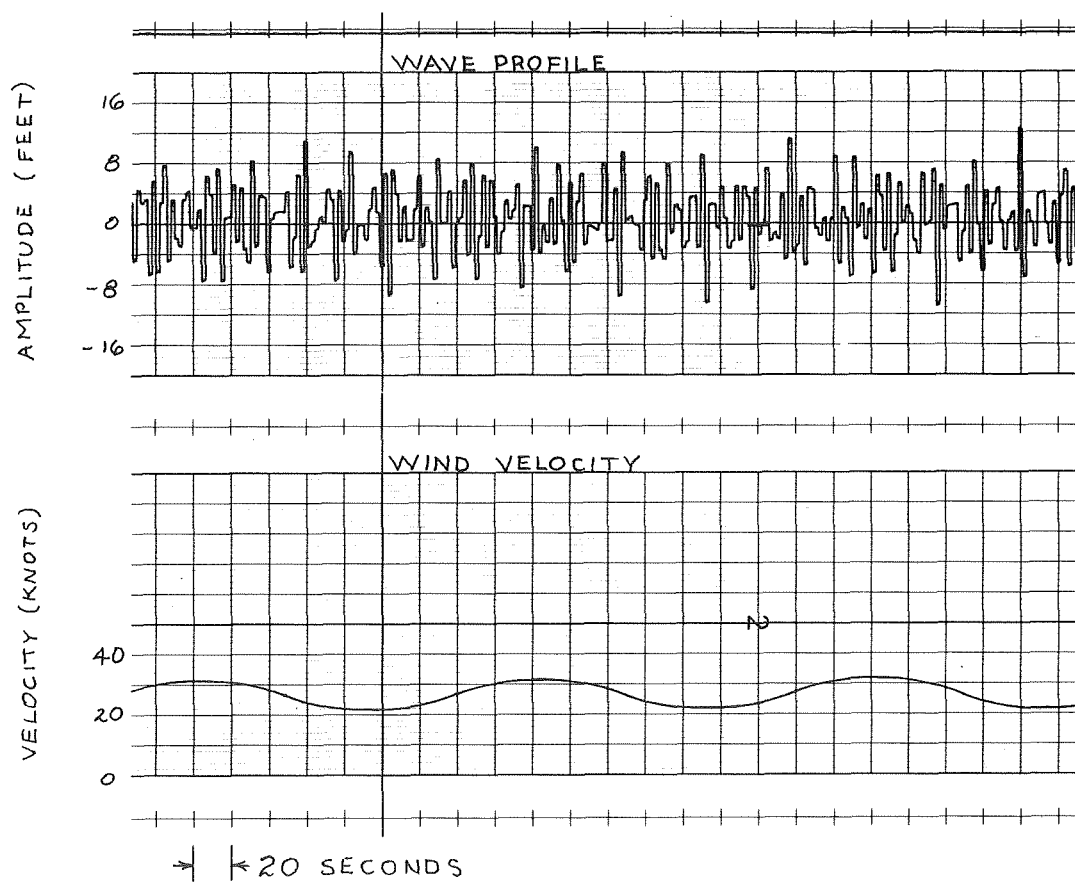
SEA STATE 6

FIGURE 6.5

50
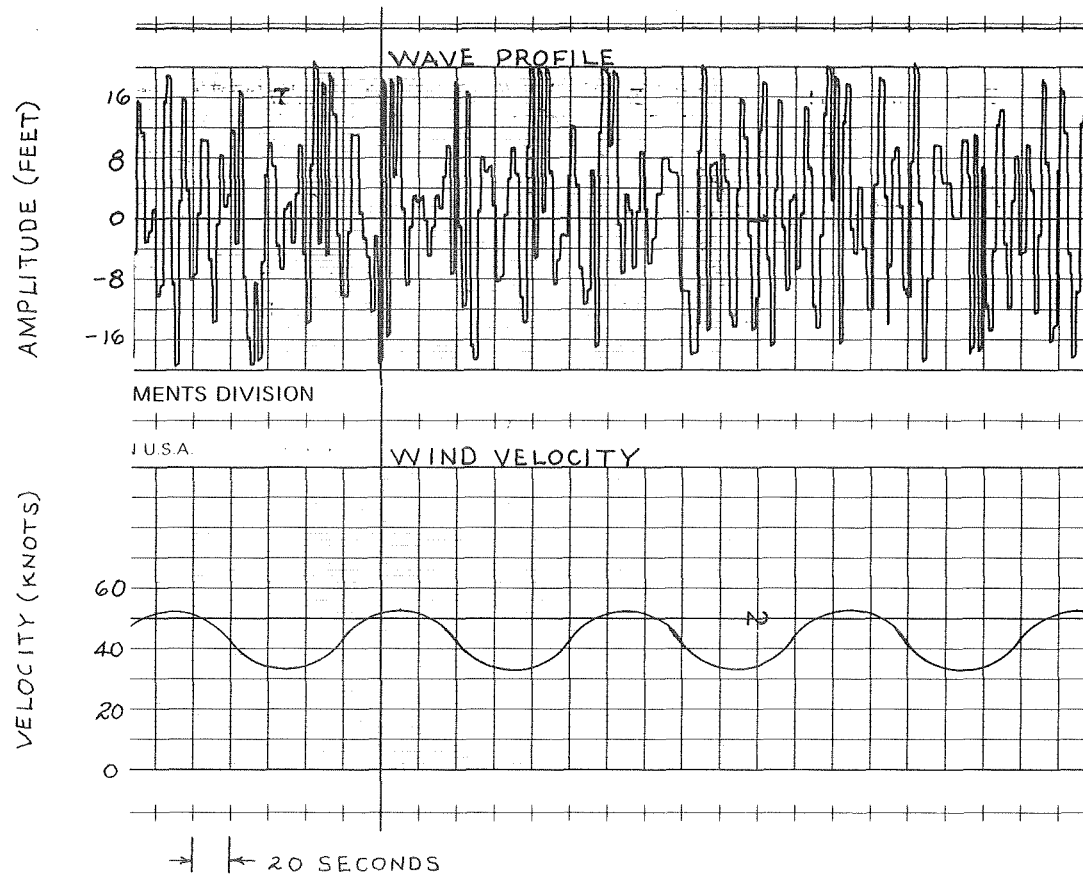
SEA STATE 8

FIGURE 6.6
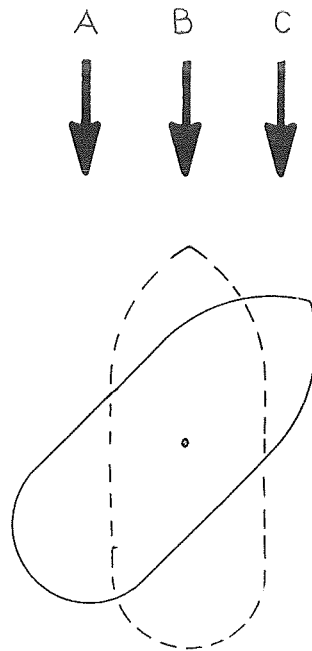
FORCE	DESCRIPTION	HEADING
A	WIND VELOCITY: 19 KNOTS	0 DEGREES
B	WAVES: SEA STATE 4	0 DEGREES
C	CURRENT: 0.5 KNOTS	0 DEGREES

CASE STUDY I

FIGURE 6.7
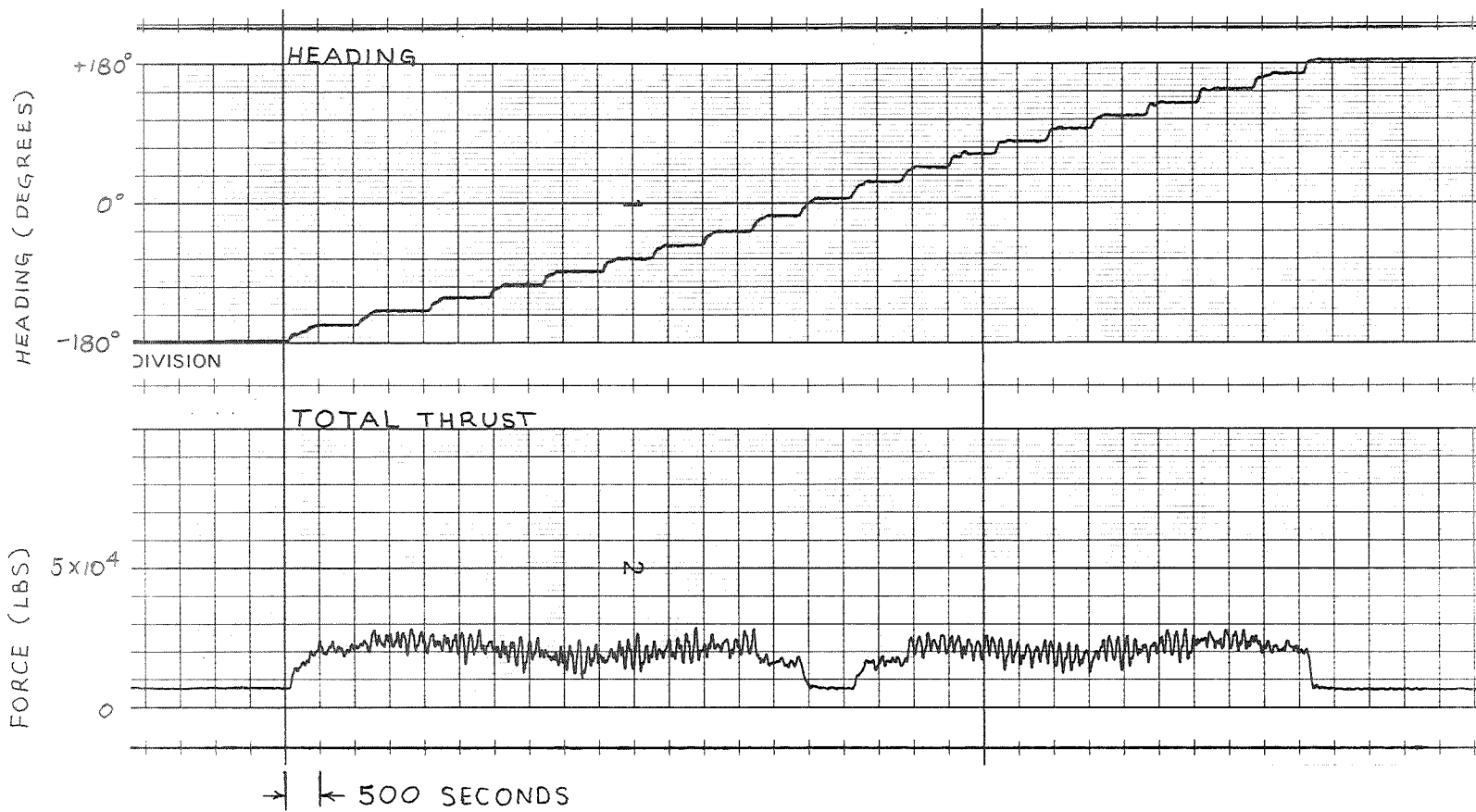
CASE STUDY I

FIGURE 6.8
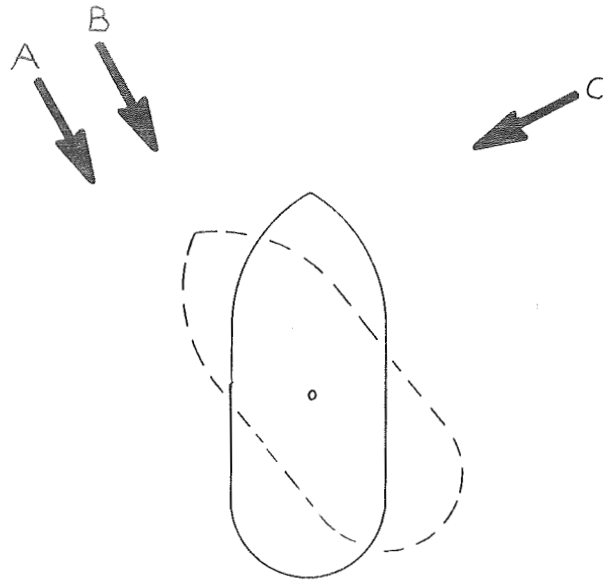
FORCE	DESCRIPTIONS	HEADING
A	WIND VELOCITY: 27 KNOTS GUST VELOCITY: ±5 KNOTS GUST PERIOD: 180 SECONDS	−30 DEGREES ±5 DEGREES
B	WAVES: SEA STATE 6	−30 DEGREES
C	CURRENT: 1 KNOT	+60 DEGREES

CASE STUDY II

FIGURE 6.9
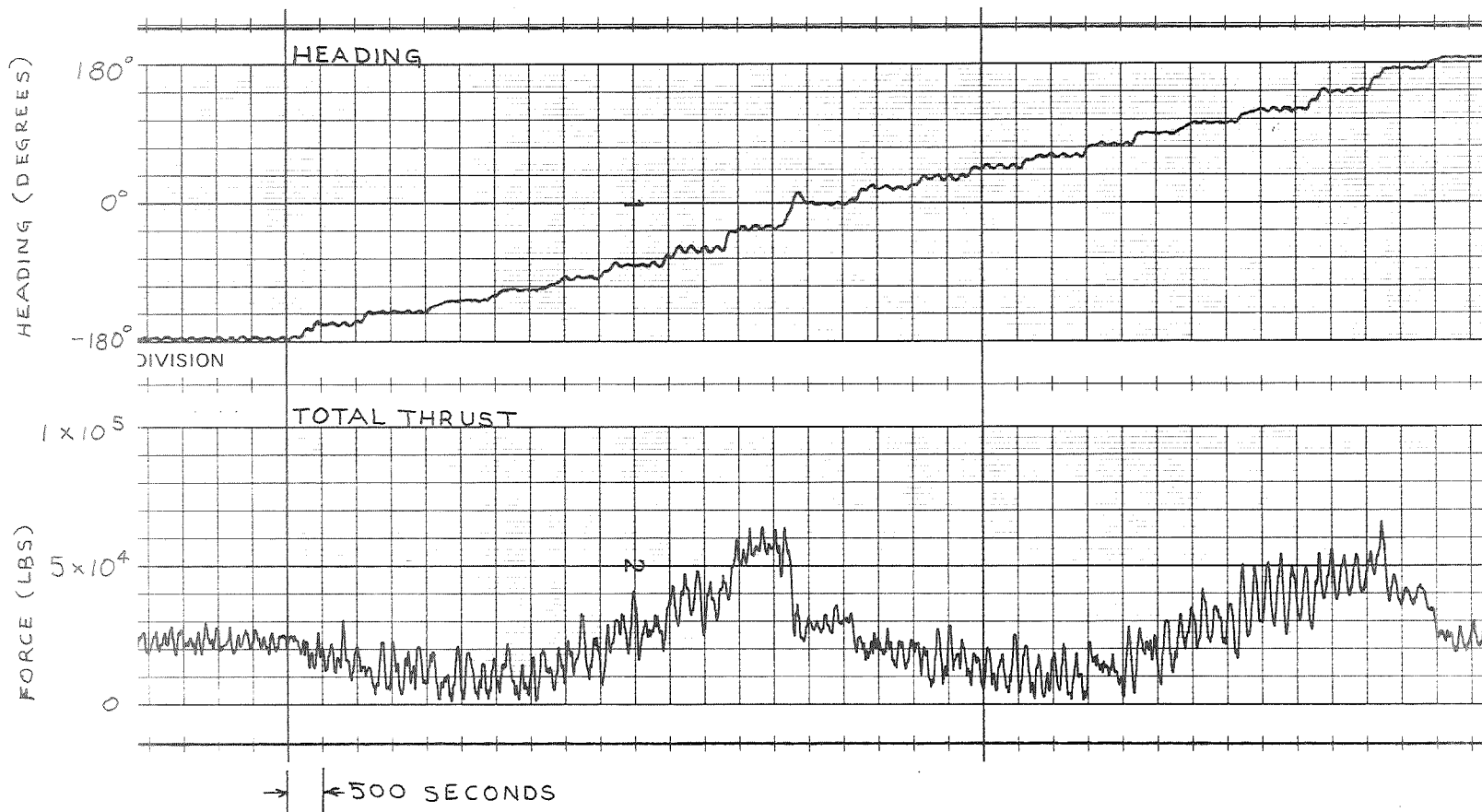
CASE STUDY II

FIGURE 6.10
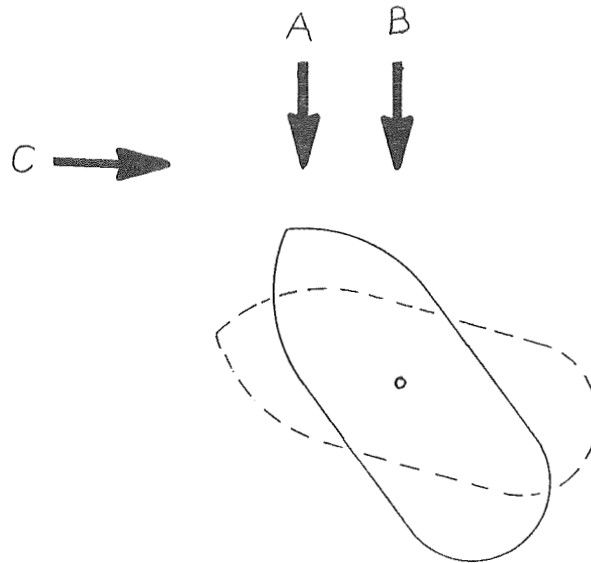
FORCE	DESCRIPTION	HEADING
A	WIND VELOCITY: 43 KNOTS GUST PERIOD: 120 SECONDS GUST VELOCITY: ±10 KNOTS	0 DEGREES ±10 DEGREES
B	WAVES: SEA STATE 8	0 DEGREES
C	CURRENT 2 KNOTS	-90 DEGREES

CASE STUDY III

FIGURE 6.11
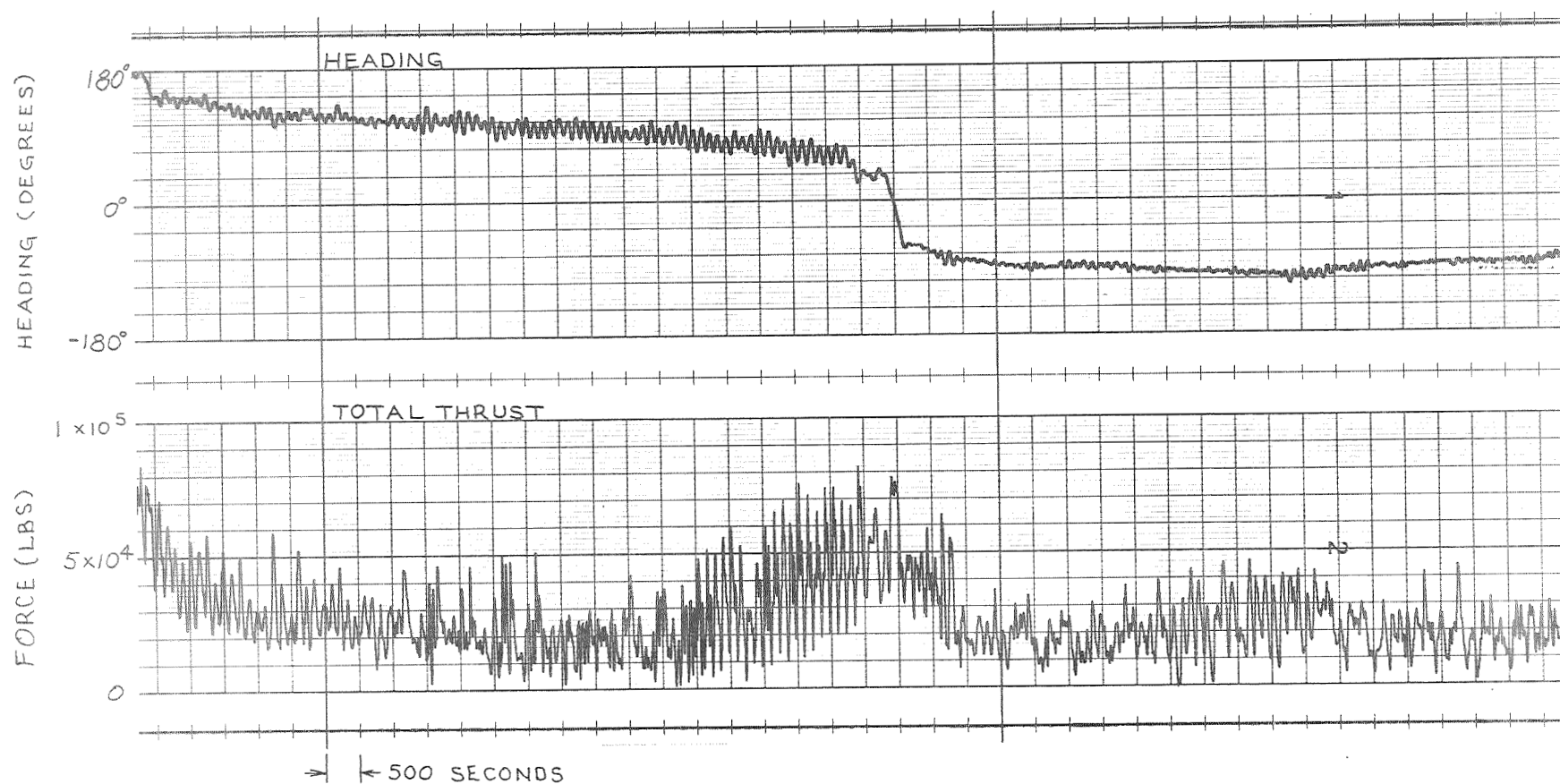
CASE STUDY III

FIGURE 6.12a
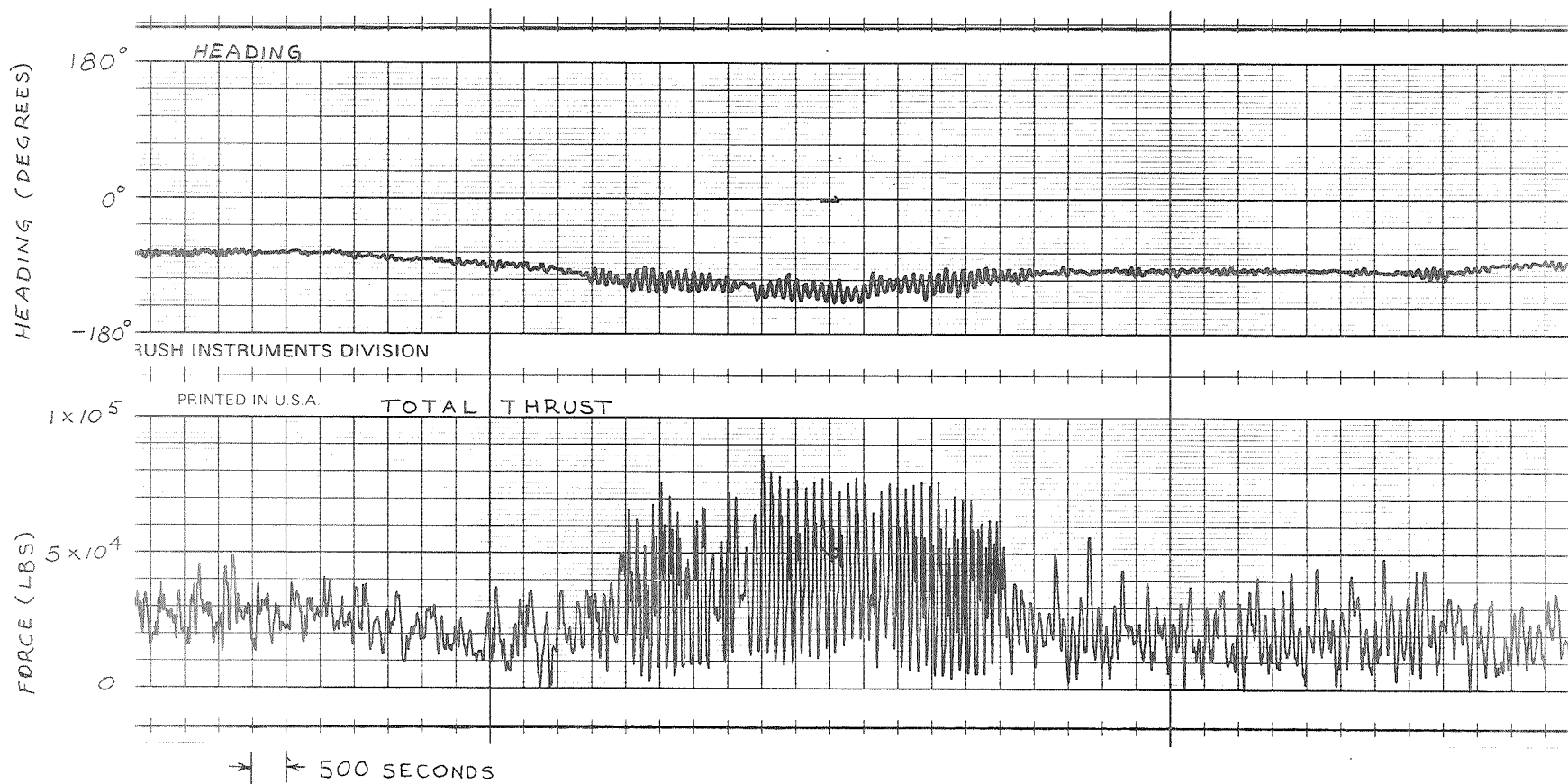
CASE STUDY III

FIGURE 6.12b

horizontal deflection. This monitoring verifies the success of the dynamic positioning system in maintaining position.

For cases I and II, the dynamic positioning system holds the vessel position to within fifty feet of reference zero for all headings.

For case III, X-position errors reach peak values of one hundred feet and Y-position errors reach values as high as 250 feet. Heading errors of fifteen degrees occur in the regions of maximum thrust. The vessel cannot maintain a heading of zero degrees because there is insufficient thrust available to overcome the moment generated at this heading. Headings between -135 degrees and -180 degrees are not shown on the recordings for case III because of insufficient thrust available to maintain position at these angles of attack.

CHAPTER VII

CONCLUSIONS

The hybrid computer model developed for this study
is an efficient research tool. The model permits detailed
investigation of the excitation/response characteristics of
a dynamic ship positioning system.

The results of each case study demonstrate the one-
parameter optimization technique. A close investigation of
the results shows two well-defined optimum headings. These
optimum headings occur in approximately eighteen degree bands
and are always 180 degrees apart. These studies indicate that
for most environmental conditions, the vessel heading will
never be more than ninety degrees away from an optimum.

A practical vessel-search algorithm can be formulated
to locate this optimum. A possible algorithm is to compare
the average thrust level for the present heading with the
average thrust level for the immediate past heading. If the
thrust level increases, the direction of heading change is
reversed. If the thrust decreases, further changes in heading
continue until the thrust is at a minimum level. When incre-
ments in heading change are ten degrees, an optimum heading
results after twelve or fewer changes.

There are two specific problem areas of the present
model. One is the selection of gains for the control system.

The optimum control gains are not obvious because the model
is nonlinear. Future investigations should consider an
adaptive control system which would self-adjust the control
gains in order to minimize position error with minimum thrust.

The other problem area involves the generation of
false position-error signals resulting from the cross product
of r and ω . Small changes in heading introduce large errors
in x and y position which cause needless thruster reversals
and fuel consumption. Future investigations using the present
model should consider the possibility of modifying the control
system to detect and ignore the false signals.

TABLES

Parameter	Description	Maximum Value
F_x	Effective component of X-thruster force	5.0×10^4 lbs.
F_y	Effective component of Y-thruster force	5.0×10^4 lbs.
M_ψ	Effective moment due to thruster force	1.0×10^7 ft.lbs.
V_x	X component of vessel velocity	20.0 ft./sec.
V_y	Y component of vessel velocity	2.0 ft./sec.
ω	Vessel angular velocity	0.1 Rad./sec.
r_x	X coordinate of vessel position	500.0 ft.
r_y	Y coordinate of vessel position	500.0 ft.
ψ	Vessel heading coordinate	π degrees
m_x	Effective longitudinal mass of vessel	7.5×10^5 slugs
m_y	Effective transverse mass of vessel	1.1×10^6 slugs
I_ψ	Effective moment of inertia in yaw	1.375×10^{10} slug-ft.^{2}

MODEL MAXIMUM VALUES

TABLE I

POT	SECT "0" VALUE	SECT "1" VALUE	SECT "2" VALUE	SECT "3" VALUE
P" "01	.1000	.0100	.1000	.0230
02	.0050	.1400	.0050	.1800
03	.0033	.0090	.0227	.1910
04	----	.1325	----	.1840
05	.0400	.0100	.0040	.0200
06	.9999	.0100	.9999	.1000
07	----	.0100	----	.0230
08	----	----	.0500	----
09	.1000	.3500	.0050	----
10	.0050	.2400	----	----
11	.0072	.1640	.0050	----
12	.9999	.1000	.0050	
13	.0318	.0240	.0100	
14	.9999	.0630	.1400	
15	----	----	.0100	
16	.1000	----	.1000	
17	.1000	----	.9999	
18	.9999	----	.9999	
19	----	----	----	
20	.1000	.0630	----	

POTENTIOMETER SETTINGS

TABLE II

HYBRID EXECUTIVE

READAD -- Analog/Digital Conversion

WRITDA -- Digital/Analog Conversion

SENSE --- Read Sense Lines

CONTRL -- Write to Control Lines

MODE ---- Analog Computer Mode Control

POTSS --- Set Potentiometers

ANALOG -- Analog Element Readout

DAMPS

FRCBSU -- Build a Request Control Block, Fortran

FRTIO --- Fortran Real Time I/O

FCHECK -- Check Status of Real Time I/O

SYSTEM SUBROUTINES

TABLE III

SEA STATE	DESCRIPTION	WIND KNOTS	WAVE HEIGHT FEET	WAVE PERIOD SECONDS
0	VERY CALM	0	0	---
4	MODERATE WAVES	17-21	4-6	2.5-10
6	LARGE WAVES	25-30	8-12	4-12
8	DISTURBED SEA	40-47	30-50	7-14

SEA STATE CLASSIFICATION

TABLE IV

SEA STATE	AMPLITUDE				PERIOD			
	A1	A2	A3	A4	T1	T2	T3	T4
0	0	0	0	0	---	---	---	---
4	2.5	1.5	0.75	1.25	10.1	4.9	2.3	3.6
6	5.0	4.0	2.0	1.0	12.2	5.8	3.5	4.2
8	19.1	12.6	9.8	6.8	11.4	8.7	14.05	7.14

WAVE COMPONENTS

TABLE V

	FOURIER COEFFICIENT	FUNCTION
F_x	46.0727	$-\cos(\omega t)$
	9.5869	$\cos(3\omega t)$
	2.2716	$-\cos(7\omega t)$
	2.2570	$\cos(5\omega t)$
	1.8287	$-\cos(9\omega t)$
F_y	100.8445	$-\sin(\omega t)$
	7.2288	$-\sin(3\omega t)$
	2.8212	$\sin(7\omega t)$
	2.4385	$\sin(5\omega t)$
	1.7634	$\sin(9\omega t)$
M_ψ	50.6504×10	$-\sin(2\omega t)$
	27.2316×10	$-\sin(\omega t)$
	7.2552×10	$-\sin(4\omega t)$
	1.2857×10	$\sin(5\omega t)$
	1.2452×10	$\sin(8\omega t)$

AERODYNAMIC DRAG FORCE COEFFICIENTS

TABLE VI

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	FOURIER COEFFICIENT	FUNCTION
F_X	-.1387	DC
	.6200	$-\cos(\omega t)$
	.1809	$-\cos(3\omega t)$
	.1457	$\cos(4\omega t)$
	.0562	$-\cos(5\omega t)$
	.0503	$\cos(7\omega t)$
	.0481	$-\cos(2\omega t)$
	.0372	$-\cos(6\omega t)$
F_Y	.7105	$-\sin(\omega t)$
	.0710	$\sin(2\omega t)$
	.0416	$\sin(3\omega t)$
	.0376	$\sin(5\omega t)$
	.0252	$\sin(7\omega t)$
M_ψ	.5180	$-\sin(2\omega t)$
	.2034	$\sin(\omega t)$
	.0725	$\sin(3\omega t)$
	.0625	$-\sin(5\omega t)$
	.0565	$\sin(6\omega t)$
	.0394	$\sin(7\omega t)$

HYDRODYNAMIC DRAG FORCE COEFFICIENTS

TABLE VII

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APPENDIX A

SMALL AMPLITUDE WAVE THEORY

APPENDIX A

SMALL AMPLITUDE WAVE THEORY

To model the ocean waves, one must understand the
basic premise of the mathematical equations. Small amplitude
wave theory is a particular case of Laplace's potential
flow theory. Figure A.1 shows the coordinate system for
this derivation.

The continuity equation for an incompressible fluid
in steady or unsteady flow is

$$\frac{\partial u}{\partial t} + \frac{\partial v}{\partial t} + \frac{\partial w}{\partial t} = 0 \qquad\qquad (A.1)$$

Two dimensional motion in the X, Y plane reduces equation
(A.1) to

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \qquad\qquad (A.2)$$

$\Phi(x,z,t)$ define a scaler function. The following equations
represent a velocity potential.

$$u = -\frac{\partial \Phi}{\partial x}$$

$$w = -\frac{\partial \Phi}{\partial z} \qquad\qquad (A.3)$$

The combination of equations (A.2) and (A.3) yields

74
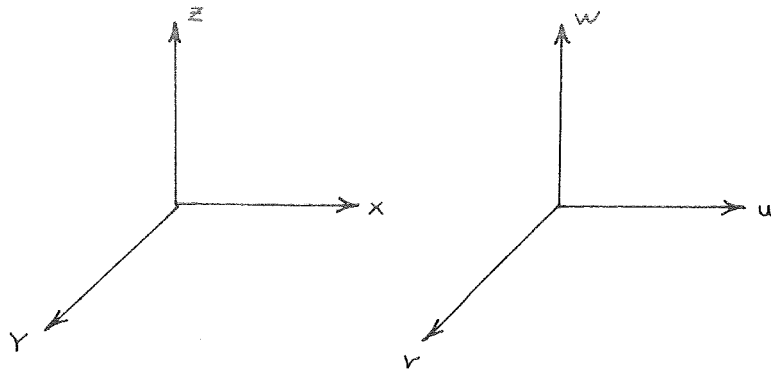
COORDINATE SYSTEM

FIGURE A.1
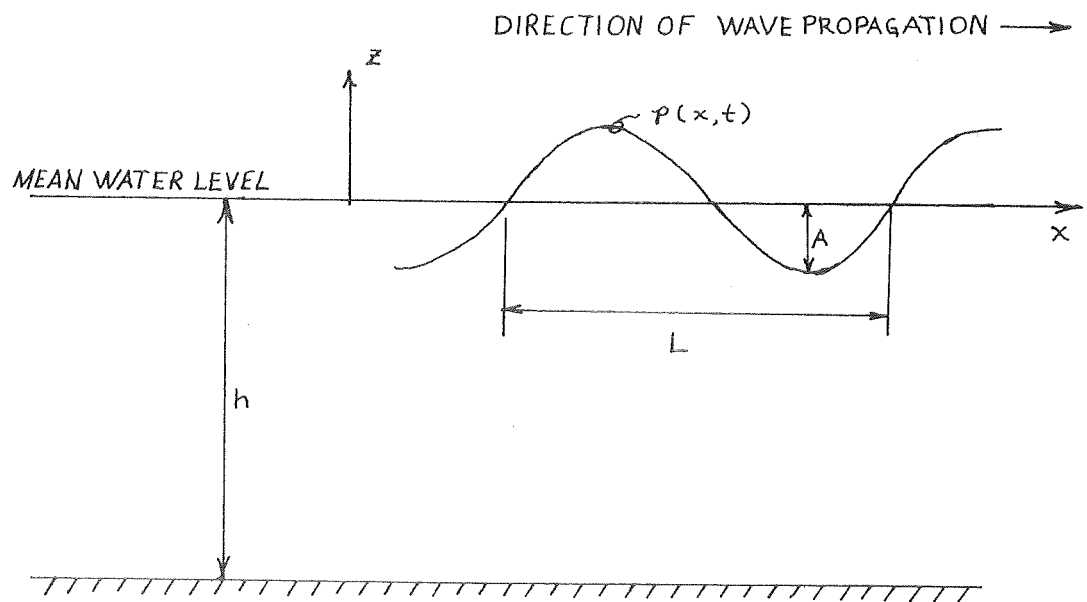
PROFILE OF A SMALL AMPLITUDE WAVE

FIGURE A.2

Laplace's equation.

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial z^2} = 0 \qquad\qquad (A.4)$$

The appropriate boundary conditions of water waves are
necessary to solve this partial differential equation. Figure
A.2 presents a simple harmonic, progressive wave moving in
the +x direction. In Figure A.2, h represents the depth of
the water; A the amplitude of the wave; p(x,t) the wave
profile; and 1 the wave length. Equation (A.4) must be
satisfied in the region

$$-h \leq z \leq p$$

Determination of the boundary conditions at the surface and
the ocean floor is a prerequisite for solving equation (A.4).
If the bottom is a fixed impermeable horizontal boundary,
the first boundary condition is

$$w = -\frac{\partial \Phi}{\partial z} = 0 \qquad (z = -h)$$

$$p(x,t) = \frac{1}{g}\frac{\partial \Phi}{\partial t} \qquad (z = 0) \qquad\qquad (A.6)$$

The acceleration of gravity, g, is the restoring force for
the vertical motion of the wave. It is necessary to solve
equation (A.4) and satisfy the boundary conditions specified
by (A.5) and (A.6) to obtain the mathematical model of an
ocean wave.

$$\Phi = \alpha(x) \times \beta(z) \times \gamma(t) \tag{A.7}$$

Substituting (A.7) in (A.4) yields

$$\alpha''(x)\beta(z)\gamma(t) + \alpha(x)\beta''(z)\gamma(t) = 0 \tag{A.8}$$

Dividing (A.8) by (A.7) yields

$$\frac{\alpha''(x)}{\alpha(x)} + \frac{\beta''(z)}{\beta(z)} = 0 \tag{A.9}$$

It follows that

$$\frac{\alpha''(x)}{\alpha(x)} = -\frac{\beta''(z)}{\beta(z)} = CONSTANT \tag{A.10}$$

If the constant is $-k^2$, equation (A.10) becomes

$$\alpha''(x) + k^2 \alpha(x) = 0 \tag{A.11}$$

$$\beta''(z) - k^2 \beta(z) = 0 \tag{A.12}$$

The solution of (A.11) yields

$$\alpha(x) = c_1 \cos(kx) + c_2 \sin(kx) \tag{A.13}$$

The solution of (A.12) yields

$$\beta(z) = c_3 e^{kz} + c_4 e^{-kz} \tag{A.14}$$

c_1, c_2, c_3, and c_4 are arbitrary constants.
Equation (A.7) becomes

$$\Phi = (c_1 \cos(kx) + c_2 \sin(kx))(c_3 e^{kz} + c_4 e^{-kz}) \gamma(t) \tag{A.15}$$

It is desirable that the solution of (A.15) be simple harmonic in time. Therefore, let (t) be either sin(wt) or cos(wt) where w represents the angular frequency of the wave. Evaluating (A.15) at the boundary values yields the wave equation. Because (A.15) is a linear equation, an elementary set of Φ equations is

$$\Phi_1 = c_1 (c_3 e^{kz} + c_4 e^{-kz}) \cos(kx) \cos(\omega t) \tag{A.16}$$

$$\Phi_2 = c_1 (c_3 e^{kz} + c_4 e^{-kz}) \cos(kx) \sin(\omega t) \tag{A.17}$$

$$\Phi_3 = c_2 (c_3 e^{kz} + c_4 e^{-kz}) \sin(kx) \cos(\omega t) \tag{A.18}$$

$$\Phi_4 = c_2 (c_3 e^{kz} + c_4 e^{-kz}) \sin(kx) \cos(\omega t) \tag{A.19}$$

Applying (A.5) to (A.16)

$$\left[\frac{\partial \Phi_1}{\partial z} \right]_{z=-h} = 0 = c_1 \cos(kx) \cos(\omega t) \left[c_3 k e^{-kh} - c_4 k e^{kh} \right] \tag{A.20}$$

$$c_4 k e^{kh} = c_3 k e^{-kh}$$

$$c_4 = c_3 e^{-2kh} \tag{A.21}$$

Substituting (A.21) into (A.16) and rewriting the result yields

$$\Phi_1 = 2c_1 c_3 e^{kh} \left[\frac{e^{k(h+z)} + e^{-k(h+z)}}{2} \right] \cos(kx) \cos(\omega t) \tag{A.22}$$

$$\Phi_1 = 2c_1 c_3 e^{kh} \cosh\left[k(h+z)\right] \cos(kx) \cos(\omega t) \tag{A.23}$$

Now applying (A.6) to (A.23) yields

$$\frac{1}{g}\left[\frac{\partial \Phi_1}{\partial t}\right]_{z=0} = p(x,t) = \frac{-2\omega c_1 c_3}{g} e^{kh} \cosh(kh) \cos(kx) \sin(\omega t) \tag{A.24}$$

The maximum value p(x,t) can have is A, the wave height. The maximum for (A.24) occurs only when cos(kx)sin(wt)=1. Making these substitutions yields

$$c_1 c_3 e^{kh} = -\frac{Ag}{2\omega \cosh(kh)} \tag{A.25}$$

The constants in the remaining elementary equations are obtained in a similar manner. The results are summarized below.

$$\Phi_1 = -\frac{Ag \cosh\left[k(h+z)\right]}{\omega \cosh\left[kh\right]} \cos(kx) \cos(\omega t) \tag{A.26}$$

$$\Phi_2 = \frac{Ag \cosh[k(h+z)]}{\omega \cosh(kh)} \sin(kx) \sin(\omega t) \tag{A.27}$$

$$\Phi_3 = -\frac{Ag \cosh[k(h+z)]}{\omega \cosh(kh)} \sin(kx) \cos(\omega t) \tag{A.28}$$

$$\Phi_4 = \frac{Ag \cosh[k(h+z)]}{\omega \cosh(kh)} \cos(kx) \sin(\omega t) \tag{A.29}$$

Since Laplace's equation is linear, we can linearly combine its solutions to form other solutions. By adding (A.28) and (A.29) and substituting the trigonometric identity, sin(wt-kx)= sin(wt)cos(kx)-cos(wt)sin(kx), the result is

$$\Phi = \Phi_3 + \Phi_4 = \frac{Ag \cosh[k(h+z)]}{\omega \cosh(kh)} \sin(\omega t - kx) \tag{A.30}$$

From (A.6) we obtain the equation for the surface of a wave

$$\rho(x,t) = \frac{1}{g}\left[\frac{\partial \Phi}{\partial t}\right]_{z=0} = A\cos(\omega t - kx) \tag{A.31}$$

To solve for k, we make use of the fact that p is periodic in x and t. If we choose some constant position on the wave profile and travel with the wave keeping this same position, then equation (A.31) reduces to

$$\rho(x,t) = CONSTANT = A\cos(\omega t - kx)$$
$$\omega t - kx = CONSTANT$$

and the wave's propagational velocity is

$$\frac{L}{T} = \frac{dx}{dt} = \frac{\omega}{k} \qquad (A.32)$$

Solving for k yields

$$k = \frac{\omega T}{L} = \frac{2\pi}{L} \qquad (A.33)$$

Substituting (A.33) into (A.31) and (A.30) yields the wave profile equation

$$\rho(x,t) = A \cos\left(\omega t - \frac{2\pi x}{L}\right) \qquad (A.34)$$

and the velocity potential equation

$$\Phi(x,z,t) = \frac{Ag}{\omega} \frac{\cosh\left[\frac{2\pi}{L}(h+z)\right]}{\cosh\left[\frac{2\pi h}{L}\right]} \sin\left(\omega t - \frac{2\pi x}{L}\right) \qquad (A.35)$$

From the velocity potential equation, the component particle velocities of the wave are found. First, the relationship between period, wave length, and propagational velocity must be determined. Equation (A.32) describes the propagational velocity. The vertical velocity component, w, is

$$w = \frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x}\frac{\partial x}{\partial t} \overset{\approx 0}{\diagup} \qquad (A.36)$$

Because the wave amplitude is very small, equation (A.36) is approximated by

$$w = -\frac{\partial P}{\partial z} \tag{A.37}$$

Because of the properties of the velocity potential equation, w also takes the form

$$w = -\frac{\partial \Phi}{\partial z} \tag{A.38}$$

Equating (A.27) and (A.38) yields

$$-\frac{\partial \Phi}{\partial z} = \frac{\partial P}{\partial t} \tag{A.39}$$

Substituting (A.6) yields

$$\frac{\partial \Phi}{\partial z} = \frac{1}{g}\frac{\partial^2 \Phi}{\partial t^2} \qquad (z = 0) \tag{A.40}$$

Applying (A.35) yields

$$-\frac{\partial \Phi}{\partial z} = -\frac{Ag2\pi}{\omega L} \tanh \frac{2\pi h}{L} \sin\left(\omega t - \frac{2\pi x}{L}\right) \tag{A.41}$$

$$\frac{1}{g}\left[\frac{\partial^2 \Phi}{\partial t^2}\right]_{z=0} = -A\omega \sin\left(\omega t - \frac{2\pi x}{L}\right) \tag{A.42}$$

Substituting (A.41) and (A.42) into (A.40) yields

$$\omega^2 = \frac{2\pi}{L} g \tanh \frac{2\pi h}{L} \tag{A.43}$$

$$L = \frac{2\pi}{\omega^2} g \tanh \frac{2\pi h}{L}$$

$$L = \frac{gT^2}{2\pi} \tanh \frac{2\pi h}{L} \tag{A.43}$$

The horizontal velocity, u, is

$$u = -\frac{\partial \Phi}{\partial x}$$

$$u = \frac{2\pi A g}{\omega L} \frac{\cosh\left[\frac{2\pi}{L}(h+z)\right]}{\cosh\left[\frac{2\pi h}{L}\right]} \cos\left(\omega t - \frac{2\pi x}{L}\right) \tag{A.44}$$

Substituting (A.43) into (A.44) yields

$$u = A\omega \cos\left(\omega t - \frac{2\pi x}{L}\right) \frac{\cosh\left[\frac{2\pi}{L}(h+z)\right]}{\sinh\left[\frac{2\pi h}{L}\right]} \tag{A.45}$$

Evaluating u at the surface, (z=0); in deep water with small amplitude waves $\frac{h}{L} \geq \frac{1}{2}$

Equation (A.45) becomes

$$u = A\omega \cos\left(\omega t - \frac{2\pi x}{L}\right) \tanh \frac{2\pi h}{L} \nearrow \approx 1 \tag{A.46}$$

$$u = A\omega \cos\left(\omega t - \frac{2\pi x}{L}\right)$$

Using (x=0) as the reference point, equation (A.46) becomes

$$u = A\omega \cos(\omega t) \tag{A.47}$$

Differentiating equation (A.47) yields the horizontal particle

acceleration.

$$\frac{\partial u}{\partial t} = -A \omega^2 \sin(\omega t) \tag{A.48}$$

Equations (A.47) and (A.48) represent a simple one component wave. Because Laplace's equation is linear, a linear superposition of simple one component waves produces a multicomponent complex wave. The complex wave equations are

$$u(x,t) = \sum_{i=1}^{n} A_i \omega_i \cos\left(\omega_i t - \frac{2\pi x_i}{L_i}\right) \frac{\cosh\left[\frac{2\pi(h+z)}{L_i}\right]}{\sinh\left[\frac{2\pi h}{L_i}\right]} \tag{A.49}$$

$$\frac{\partial u}{\partial t} = \sum_{i=1}^{n} -A_i \omega_i^2 \sin\left(\omega_i t - \frac{2\pi x_i}{L_i}\right) \frac{\cosh\left[\frac{2\pi(h+z)}{L_i}\right]}{\sinh\left[\frac{2\pi h}{L_i}\right]} \tag{A.50}$$

Applying the same small amplitude, deep water relationships used to reduce equations (A.45) to (A.47), the reduced complex wave equations are

$$u(t) = \sum_{i=1}^{n} A_i \omega_i \cos(\omega_i t) \tag{A.51}$$

$$\frac{\partial u}{\partial t} = \sum_{i=1}^{n} -A_i \omega_i^2 \sin(\omega_i t) \tag{A.52}$$

APPENDIX B

HYDRODYNAMIC AND AERODYNAMIC
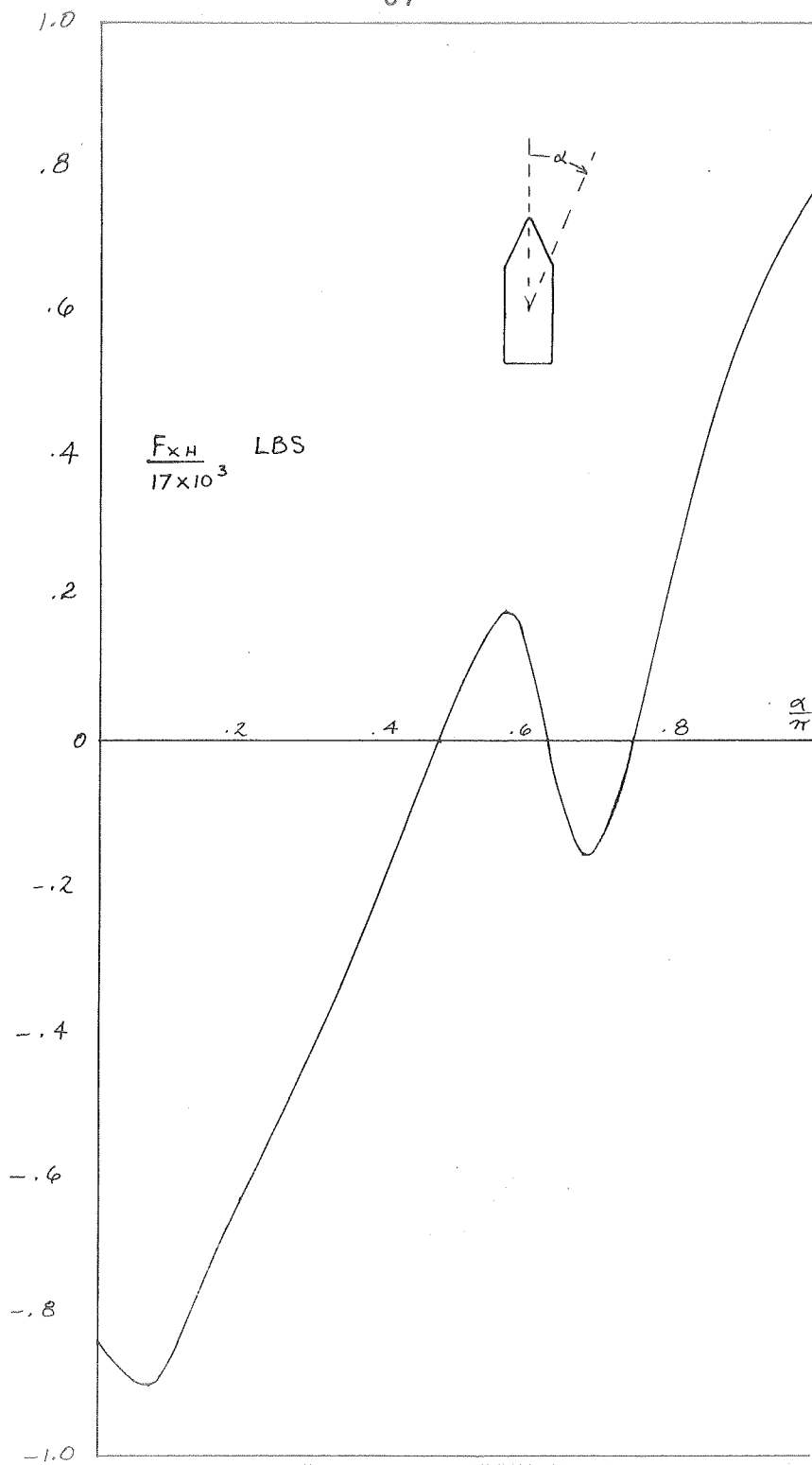
DRAG FORCE DATA

X-HYDRODYNAMIC DRAG FORCE

FIGURE B.1

$\dfrac{F_{YH}}{18 \times 10^{5}}$ LBS

$\dfrac{\alpha}{\pi}$
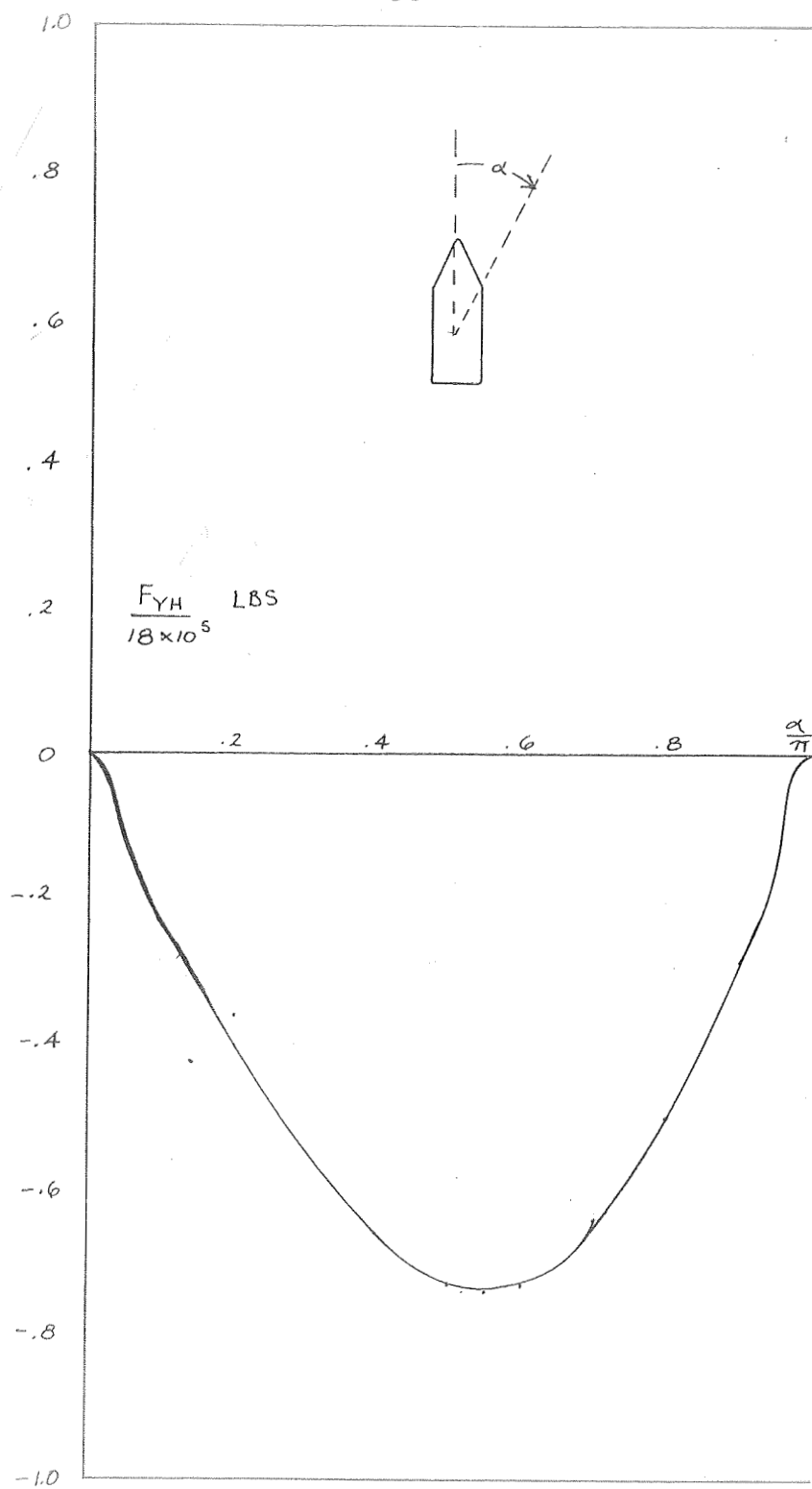
Y-HYDRODYNAMIC DRAG FORCE

FIGURE B.2
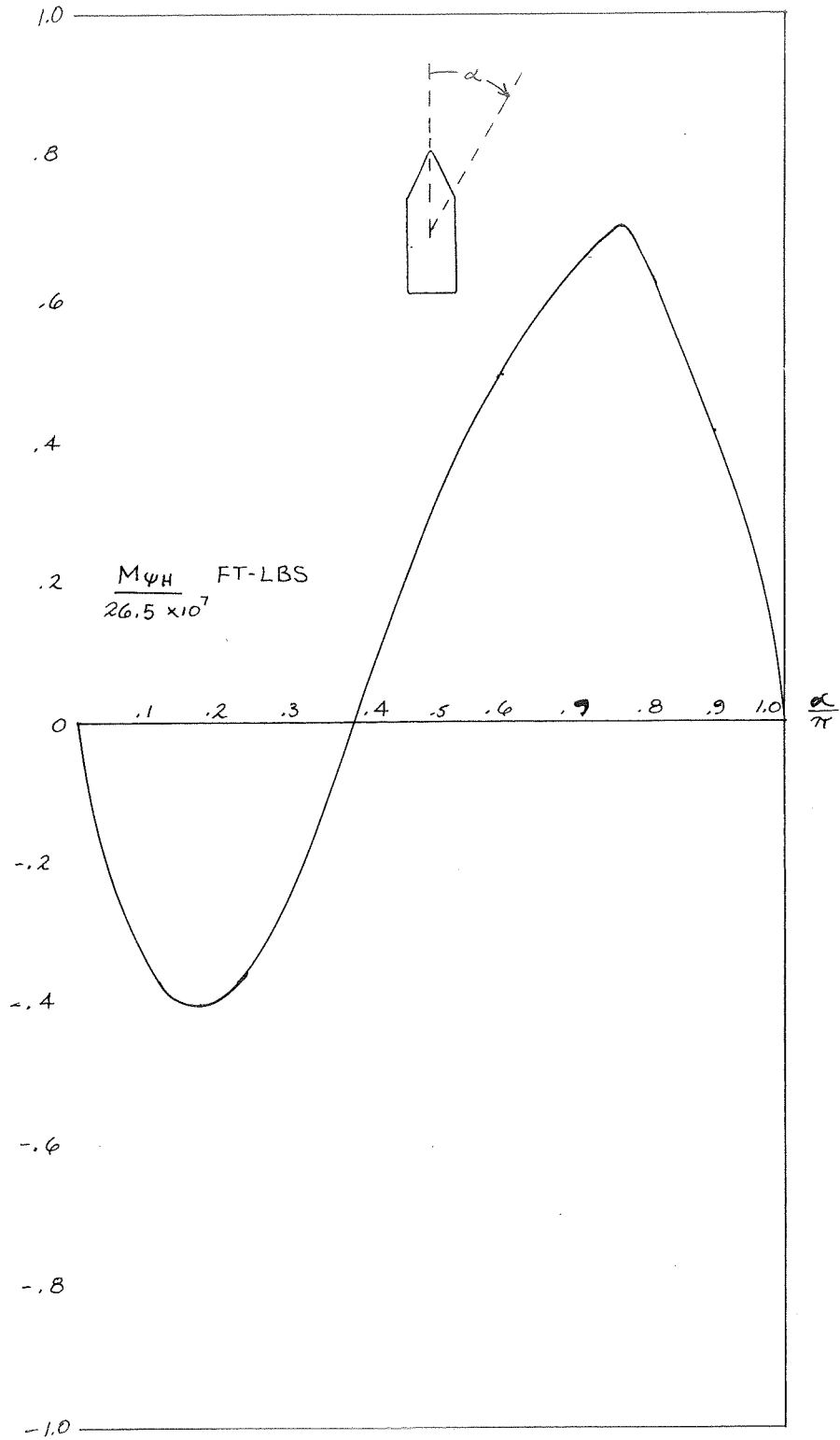
Ψ —HYDRODYNAMIC DRAG FORCE

FIGURE B.3
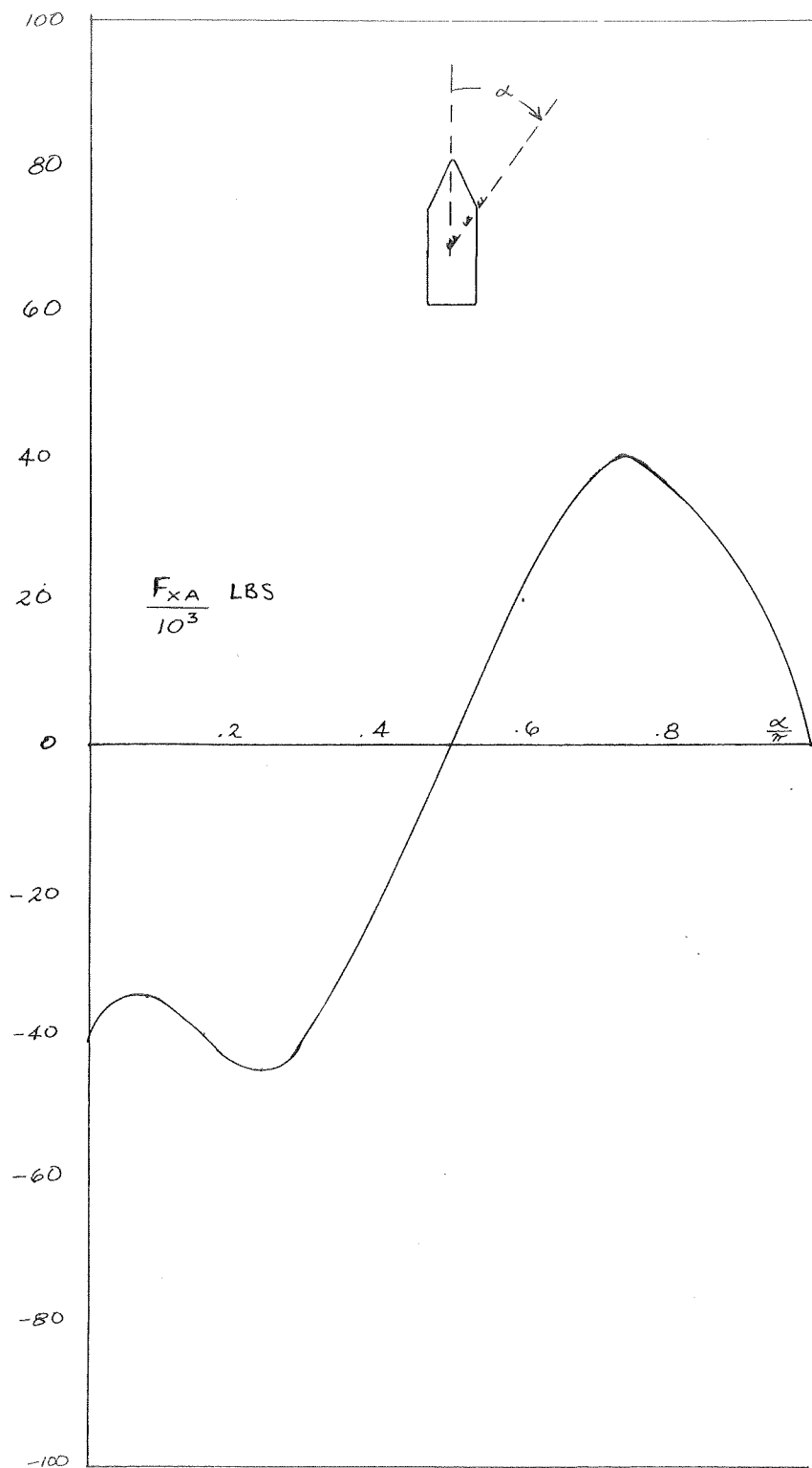
X—AERODYNAMIC DRAG FORCE

FIGURE B.4
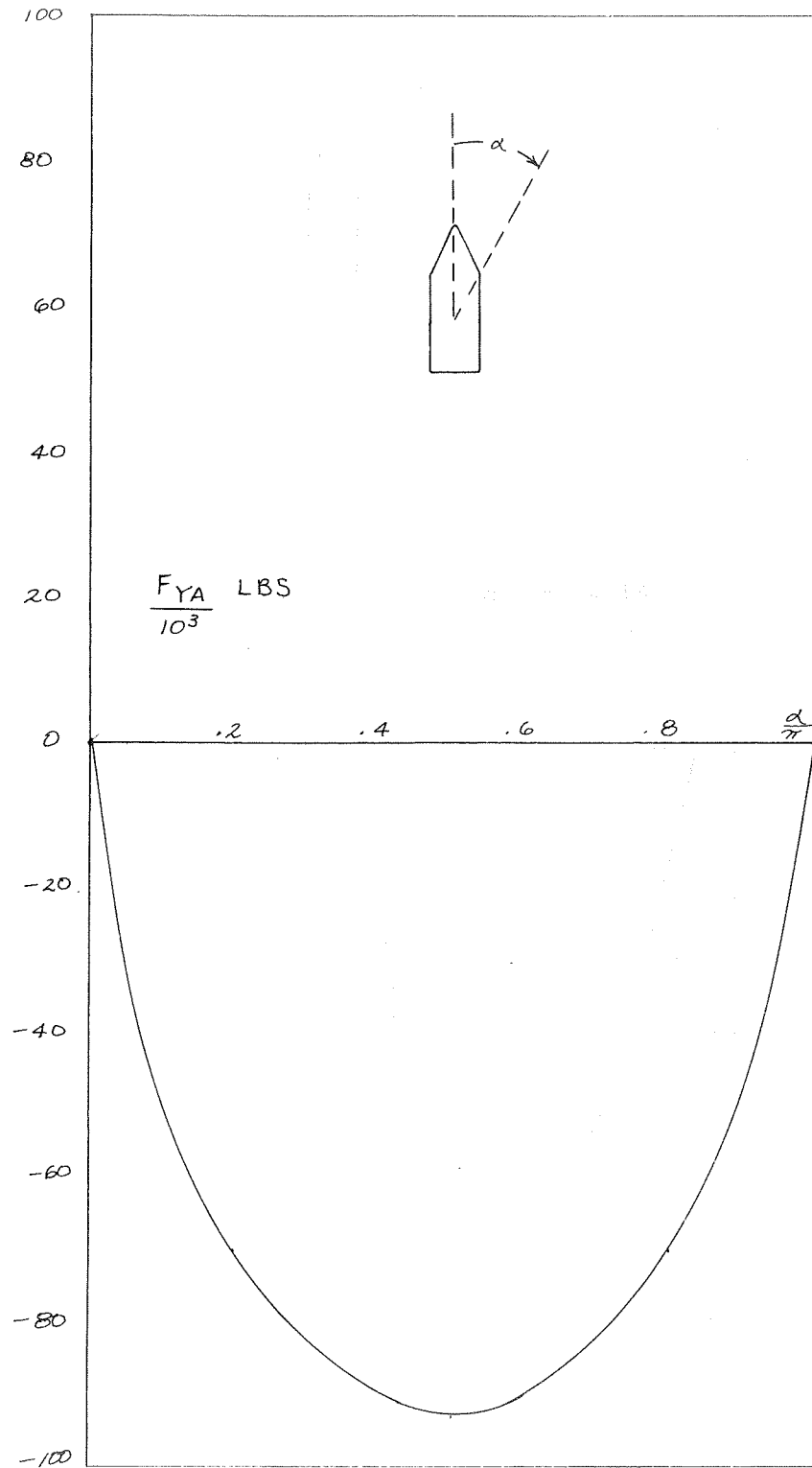
Y-AERODYNAMIC DRAG FORCE

FIGURE B.5
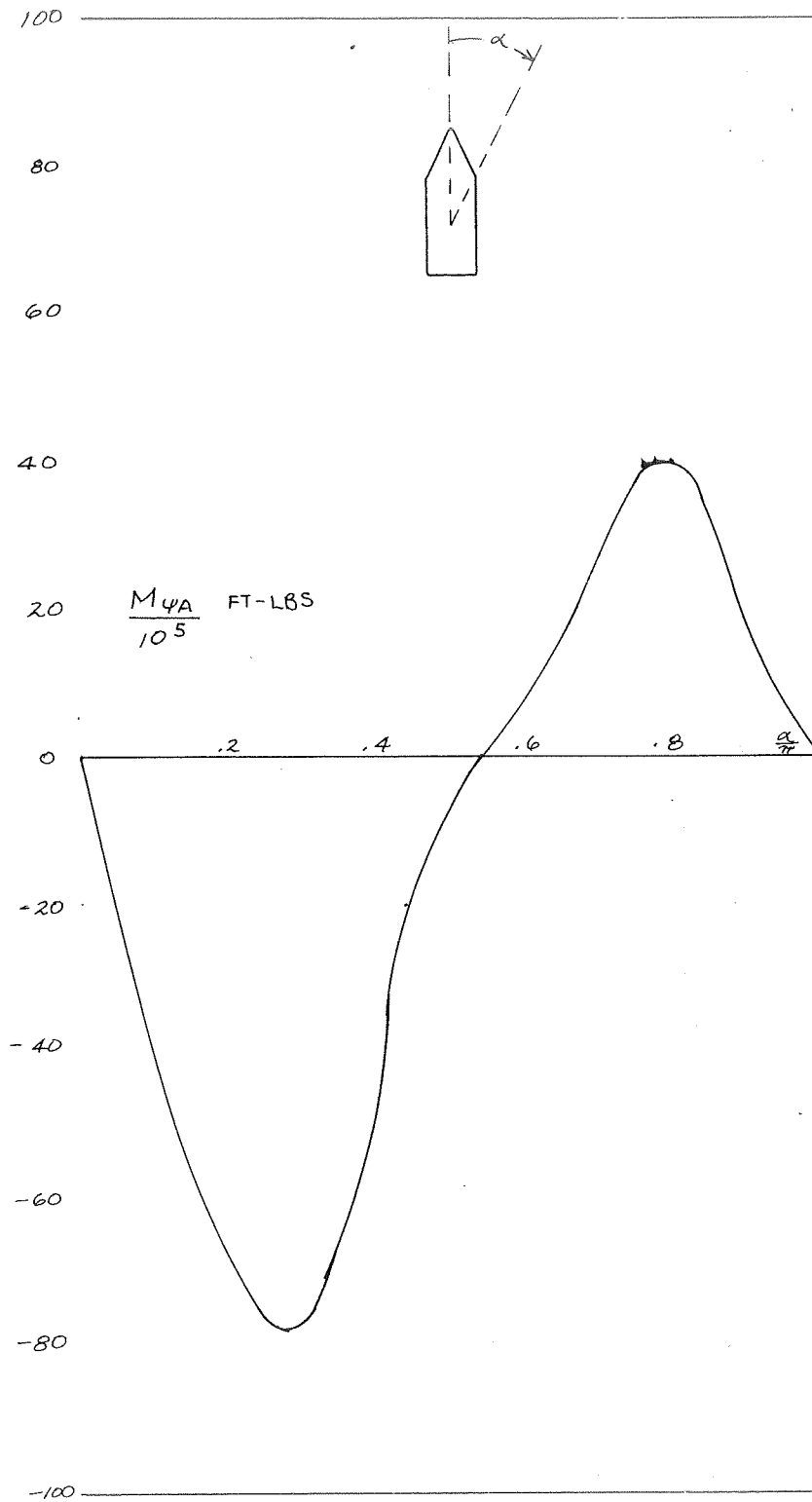
ψ –AERODYNAMIC DRAG FORCE

FIGURE B.6

APPENDIX C

DIGITAL PROGRAM

```
      DIMENSION XLOCA(250,10),ID(250),TEST(250,5)
      REAL*8 RCBAD(4),CCWAD(2),RCBDA(4),CCWDA(2),RCBSN(4),CCWSN
      REAL*8 RCBMD(4),CCWMD   ,RCBCN(4),CCWCN
      INTEGER*2 LOCR(12),LOCW(15)
      INTEGER*2 LOCS,ICONO,ICON1
      INTEGER*2 MIC,MOP,MHLD
      DATA ICONO,ICON1/0,1/,NB/2/
      DATA MIC,MOP,MHLD/16,8,4/
      DATA LOCR(1),NRD/09,10/,LOCW(1),NWR/11,12/
      DATA T,XA,XB/2.,.07,.0714/,YA,YB/.09,.12207/,SA,SB/.175,.17993/
      DATA AMAX,AMIN/8191.,-8191./,KSEC/38400/
      DATA TWOPI/6.28318/,RAD/57.296/
      DATA H41,H42,H43,H44/2.5,1.5,.75,1.25/
      DATA P41,P42,P43,P44/10.1,4.9,2.3,3.6/
      DATA H61,H62,H63,H64/5.,4.,2.,1./
      DATA P61,P62,P63,P64/ 12.2,5.8,3.5,4.2/
      DATA H81,H82,H83,H84/19.1,12.6,9.8,6.8/
      DATA P81,P82,P83,P84/11.4,8.7,14.05,7.14/
      DATA FYA1,FYA2,FYA3,FYA4,FYA5/-100.8,-7.229,2.821,2.438,1.763/
      DATA FXA1,FXA2,FXA3,FXA4,FXA5/-46.07,9.587,-2.272,2.257,-1.829/
      DATA FMA1,FMA2,FMA3,FMA4,FMA5/-506.5,-272.3,-72.55,12.86,12.45/
      DATA FYH1,FYH2,FYH3,FYH4,FYH5/-.7105,.0710,.0416,.0376,.0252/
      DATA FXH0,FXH1,FXH2,FXH3,FXH4/-.1387,-.6200,-.1809,.1457,-.0562/
      DATA FXH5,FXH6,FXH7/.0503,-.0481,-.0372/
      DATA FMH1,FMH2,FMH3,FMH4,FMH5/-.5180,.2034,.0725,-.0654,.0565/
      DATA FMH6/.0394/
C *** SET UP VARIOUS REMOTE CONTROL BLOCKS AND CHANNEL CONTROL WORDS ***
      CALL FRCBSU (RCBAD,29,CCWAD)
      CALL READAD (CCWAD,NRD,0,LOCR)
      CALL FRCBSU (RCBDA,30,CCWDA)
      CALL WRITDA (CCWDA,0,NWR,LOCW)
      CALL FRCBSU (RCBSN,28,CCWSN)
      CALL SENSE  (CCWSN,LOCS,NB)
      CALL FRCBSU (RCBCN,28,CCWCN)
      CALL CONTRL (CCWCN,LOCS,NB)
      CALL FRCBSU (RCBMD,28,CCWMD)
C *** PLACE ANALOG COMPUTER IN INITIAL CONDITION MODE *****************
      CALL MODE   (CCWMD,MIC)
      CALL FRTIO  (RCBMD)
      CALL FCHECK (RCBMD,IRET,1)
C *** INITIALIZE VARIOUS CONTROL SYSTEM CONSTANTS ********************
      XW=XB*T
      XTAU=-XA*T
      XK1=2.*EXP(XTAU)*COS(XW)
      XK2=-EXP(2.*XTAU)
      XK3=EXP(XTAU)*SIN(XW)/XB
      XIK1=(1.-XK1/2.-2.*XA*XK3)/(XA*XA+XB*XB)
      XIK2=(-XK2-XK1/2.+2.*XA*XK3)/(XA*XA+XB*XB)
      XIK3=1.+XK1
```

```
      XIK4=XK2-XK1
      XGAIN=XK3/(1.-XK1-XK2)
      YW=YB*T
      YTAU=-YA*T
      YK1=2.*EXP(YTAU)*COS(YW)
      YK2=-EXP(2.*YTAU)
      YK3=EXP(YTAU)*SIN(YW)/YB
      YIK1=(1.-YK1/2.-2.*YA*YK3)/(YA*YA+YB*YB)
      YIK2=(-YK2-YK1/2.+2.*YA*YK3)/(YA*YA+YB*YB)
      YIK3=1.+YK1
      YIK4=YK2-YK1
      YGAIN=YK3/(1.-YK1-YK2)
      SW=SB*T
      STAU=-SA*T
      SK1=2.*EXP(STAU)*COS(SW)
      SK2=-EXP(2.*STAU)
      SK3=EXP(STAU)*SIN(SW)/SB
      SIK1=(1.-SK1/2.-2.*SA*SK3)/(SA*SA+SB*SB)
      SIK2=(-SK2-SK1/2.+2.*SA*SK3)/(SA*SA+SB*SB)
      SIK3=1.+SK1
      SIK4=SK2-SK1
      SGAIN=SK3/(1.-SK1-SK2)
      XPGAIN=.8
      XDGAIN=140.
      XIGAIN=.0008
      YPGAIN=108.
      YDGAIN=7000.
      YIGAIN=.0108
      SPGAIN=3.5
      SDGAIN=132.
      SIGAIN=.0005
C *** INITIALIZE ENVIRONMENTAL PARAMETERS ******************************
      WINDV=0.
      GUSTV=0.
      ALPHA=0.
      VELMAG=0.
      THETA=0.
      WH1=0.
      WH2=0.
      WH3=0.
      WH4=0.
      WP1=0.
      WP2=0.
      WP3=0.
      WP4=C.
C *** LIST OPERATING INSTRUCTIONS FOR PROGRAM ************************
      WRITE(6,301)
  301 FORMAT(1H1//10X'***** INFORMATION CONCERNING REAL TIME OPERATION C
     1F MAIN PROGRAM *****'///10X'THE FOLLOWING INFORMATION IS REQUESTED
```

```
     2 BY THE TYPEWRITER TERMINAL'//
     315X'N IS THE NUMBER OF PRINTED OUTPUT SAMPLES'//
     420X'A SAMPLE IS TAKEN EVERY FIFTH TIME THROUGH THE TIMED CONTROL L
     5UOP'//20X'IF N = 0 EXIT IS CALLED AND THE PROGRAM CONCLUDED'//
     615X'ISCALE IS THE TIME SCALE FACTOR'//
     715X'LOGIC IS AN INPUT THAT ENABLES PROGRAM OPTIONS'//
     820X'LOGIC = 0 - EXISTING GAINS ARE USED AND OPERATION BEGINS'//
     920X'LOGIC = 1 - NEW GAINS MAY BE INPUT FOR X-CHANNEL'//
     A20X'LOGIC = 2 - NEW GAINS MAY BE INPUT FOR Y-CHANNEL'//
     B20X'LOGIC = 3 - NEW GAINS MAY BE INPUT FOR PSI-CHANNEL'//
     C20X'LOGIC = 4 - NEW GAINS INPUT FOR X,Y & PSI-CHANNELS'//
     D20X'LOGIC = 5 - INPUT CURRENT - POLAR COORDINATES'//
     E20X'LOGIC = 6 - INPUT SEA STATE (0,4,6,OR 8) AND DIRECTION'//
     F20X'LOGIC = 7 - INPUT WIND - POLAR COORDINATES'//
     G20X'LOGIC = 8 - INPUT GUST MAGNITUDE, PERIOD & VARIATION ANGLE'//
     H20X'LOGIC = 9 - ANALOG CONTROL SYSTEM IS USED - NO GAINS INPUT'//
     I15X'THE FOLLOWING RUN OPTIONS ARE AVAILABLE'//
     J20X'USE SENSE LINE "1" TO MAKE A PARAMETER CHANGE DURING A RUN'//
     K20X'USE SENSE LINE"0" TO MAKE A CONTINUOUS RUN'//)
C *** START OF MAIN PROGRAM LOOP *****************************************
 998    CONTINUE
C *** I/O FOR PROGRAM OPTIONS AND ENVIRONMENTAL DATA ********************
        WRITE(15,304)
 304    FORMAT(1X'INPUT N & ISCALE - 2I5')
        READ(15,305) N,ISCALE
 305    FORMAT(2I5)
        IF(N.EQ.0) GO TO 999
        WRITE(6,306) N,ISCALE
 306    FORMAT(1H19X'NO. OF ITERATIONS...'I5,5X'TIME SCALED BY...'I5/)
 997    WRITE(15,302)
 302    FORMAT(1X'INPUT LOGIC - I1')
        READ(15,303) LOGIC
 303    FORMAT(I1)
        LOGIC=LOGIC+1
        GO TO (30,31,32,33,34,35,36,37,38,39),LOGIC
 31     WRITE(15,331)
 331    FORMAT(1X'XP,XD & XI GAINS - 3F5.2')
        READ(15,330) XPGAIN,XDGAIN,XIGAIN
 330    FORMAT(3F5.2)
        GO TO 997
 32     WRITE(15,332)
 332    FORMAT(1X'YP,YD & YI GAINS - 3F5.2')
        READ(15,330) YPGAIN,YDGAIN,YIGAIN
        GO TO 997
 33     WRITE(15,333)
 333    FORMAT(1X'SP,SD & SI GAINS - 3F5.2')
        READ(15,330) SPGAIN,SDGAIN,SIGAIN
        GO TO 997
 34     WRITE(15,334)
```

```
334    FORMAT(1X'XP,XD,XI,YP,YD,YI,SP,SD & SI GAINS - 3(3F5.20)')
       READ(15,330) XPGAIN,XDGAIN,XIGAIN
       READ(15,330) YPGAIN,YDGAIN,YIGAIN
       READ(15,330) SPGAIN,SDGAIN,SIGAIN
       GO TO 997
35     WRITE(15,335)
335    FORMAT(1X'CURRENT - POLAR COORDINATES - 2F5.2')
       READ(15,330) VELMAG,ATHET
       THETA=ATHET/RAD
       GO TO 997
36     WRITE(15,336)
336    FORMAT(1X'SEA STATE & DIRECTION - I1,F5.2')
       READ(15,326) ISEA,ABET
326    FORMAT(I1F5.2)
       BETA=ABET/RAD
       IF(ISEA.EQ.0) GO TO 324
       IF(ISEA-6) 327,328,329
C ***  INITIALIZE A'S & W'S FOR SEA STATE 4 ******************************
327    WH1=H41
       WH2=H42
       WH3=H43
       WH4=H44
       WP1=P41
       WP2=P42
       WP3=P43
       WP4=P44
       GO TO 325
C ***  INITIALIZE A'S & W'S FOR SEA STATE 6 ******************************
328    WH1=H61
       WH2=H62
       WH3=H63
       WH4=H64
       WP1=P61
       WP2=P62
       WP3=P63
       WP4=P64
       GO TO 325
C ***  INITIALIZE A'S & W'S FOR SEA STATE 8 ******************************
329    WH1=H81
       WH2=H82
       WH3=H83
       WH4=H84
       WP1=P81
       WP2=P82
       WP3=P83
       WP4=P84
       GO TO 325
C ***  SET A'S & W'S TO ZERO *********************************************
324    WH1=0.
```

```
           WH2=0.
           WH3=0.
           WH4=0.
           WP1=0.
           WP2=0.
           WP3=0.
           WP4=0.
    325    W1=TWOPI/(WP1+1.E-10)
           W2=TWOPI/(WP2+1.E-10)
           W3=TWOPI/(WP3+1.E-10)
           W4=TWOPI/(WP4+1.E-10)
           WA1=WH1*W1
           WA2=WH2*W2
           WA3=WH3*W3
           WA4=WH4*W4
           GO TO 997
    37     WRITE(15,337)
    337    FORMAT(1X'INPUT WIND DATA - 2F5.2')
           READ(15,330) WIN,AALPH
           ALP=AALPH/RAD
           GO TO 997
    38     WRITE(15,338)
    338    FORMAT(1X'INPUT WIND GUST DATA - 3F5.2')
           READ(15,330) GUSTV,GUSTP,ADALPH
           DALPHA=ADALPH/RAD
           WGP=TWOPI/GUSTP
           GO TO 997
    39     CALL CONTRL (CCWCN,ICONO,NB)
           CALL FRTIO  (RCBCN)
           CALL FCHECK (RCBCN,IRET,1)
           WRITE(6,339)
    339    FORMAT(10X'THIS RUN USES THE ANALOG CONTROL SYSTEM WITH DIGITAL US
           1ED FOR SAMPLING PURPOSES ONLY'/)
           GO TO 40
    30     CALL CONTRL (CCWCN,ICON1,NB)
           CALL FRTIO  (RCBCN)
           CALL FCHECK (RCBCN,IRET,1)
           WRITE(6,340) XPGAIN,XDGAIN,XIGAIN,YPGAIN,YDGAIN,YIGAIN,SPGAIN,
           1SDGAIN,SIGAIN
    340    FORMAT(10X'XPGAIN'5X'XDGAIN'5X'XIGAIN'5X'YPGAIN'5X'YDGAIN'5X'YIGAI
           1N'5X'SPGAIN'5X'SDGAIN'5X'SIGAIN'/6X9(1X,F10.4))
           WRITE(6,341) VELMAG,ATHET
    341    FORMAT(/10X'CURRENT DATA - VELOCITY MAGNITUDE = 'F10.4,5X'DIRECTIO
           1N = 'F10.4)
           WRITE(6,342) WH1,WP1,WH2,WP2,WH3,WP3,WH4,WP4,ABET
    342    FORMAT(/10X'THE WAVE COMPONENTS ARE AS FOLLOWS'/10X'1 - AMPLITUDE
           1& PERIOD'5X'2 - AMPLITUDE & PERIOD'5X'3 - AMPLITUDE & PERIOD'5X'4
           2- AMPLITUDE & PERIOD'5X'DIRECTION'/16XF5.2,6XF5.2,11XF5.2,6XF5.2,1
           31XF5.2,6XF5.2,11XF5.2,6XF5.2,7XF6.2/)
```

```
      WRITE(6,343) WIN,AALPH,GUSTV,GUSTP,ADALPH
  343 FORMAT(10X'WIND DATA IS AS FOLLOWS'/10X'WIND MAGNITUDE'5X'DIRECTIO
     1N'5X'GUST MAGNITUDE'5X'GUST PERIOD'5X'GUST ANGLE'/12XF10.4,6XF10.4
     1,7XF10.4,8XF10.4,5XF10.4/)
   40 CONTINUE
      X1=0.
      XC=0.
      X1P=0.
      XCP=0.
      X1D=0.
      XCD=0.
      X2I=0.
      X1I=0.
      XCI=0.
      Y1F=0.
      YCF=0.
      Y1=0.
      YC=0.
      Y1P=0.
      YCP=0.
      Y1D=0.
      YCD=0.
      Y2I=0.
      Y1I=0.
      YCI=0.
      S1=0.
      SC=0.
      S1P=0.
      SCP=0.
      S1D=0.
      SCD=0.
      S2I=0.
      S1I=0.
      SCI=0.
      TW=0.
      IDELT=KSEC/ISCALE-9
      KK=1
      K=1
      CALL MODE(CCWMD,MOP)
      CALL FRTIO(RCBMD)
      CALL FCHECK(RCBMD,IRET,1)
C#### ENTER TIMED CONTROL LOOP ########################################
    9 KSTORE=ITIME(3)+IDELT                                            #
      IF(KK.EQ.1.AND.K.EQ.1) KDIF=ITIME(3)                            #
      IF(K.GT.1) ID(K)=KSTORE-KTIME                                   #
      KTIME=KSTORE                                                    #
C#### READ VELOCITY, POSITION, & POSITION ERROR FROM ANALOG ##########
      CALL FRTIO (RCBAD)                                              #
      CALL FCHECK (RCBAD,IRET,1)                                      #
```

```
      DO 12 I=1,NRD                                                         #
 12    XLOCA(K,I)=LOCR(I+1)/81.92                                           #
C#### X CONTROL LOOP #####################################################
      X2=X1                                                                 #
      X1=XC                                                                 #
      XC=LOCR(2)/XGAIN                                                      #
      X2P=X1P                                                               #
      X1P=XCP                                                               #
      XCP=XK3*X1+XK1*X1P+XK2*X2P                                            #
      X2D=X1D                                                               #
      X1D=XCD                                                               #
      XCD=X1-X2+XK1*X1D+XK2*X2D                                             #
      X3I=X2I                                                               #
      X2I=X1I                                                               #
      X1I=XCI                                                               #
      XCI=XIK1*X1+XIK2*X2+XIK3*X1I+XIK4*X2I-XK2*X3I                         #
C#### X-THRUSTER FORCE ###################################################
      XCONF=XPGAIN*XCP+XDGAIN*XCD+XIGAIN*XCI                                #
      IF(XCONF.GT.AMAX) XCONF=AMAX                                          #
      IF(XCONF.LT.AMIN) XCONF=AMIN                                          #
      LOCW(2)=XCONF                                                         #
      TEST(K,1)=XCONF
C#### PSI CONTROL LOOP ###################################################
      S2=S1                                                                 #
      S1=SC                                                                 #
      SC=LOCR(8)/SGAIN                                                      #
      S2P=S1P                                                               #
      S1P=SCP                                                               #
      SCP=SK3*S1+SK1*S1P+SK2*S2P                                            #
      S2D=S1D                                                               #
      S1D=SCD                                                               #
      SCD=S1-S2+SK1*S1D+SK2*S2D                                             #
      S3I=S2I                                                               #
      S2I=S1I                                                               #
      S1I=SCI                                                               #
      SCI=SIK1*S1+SIK2*S2+SIK3*S1I+SIK4*S2I-SK2*S3I                         #
C#### PSI MOMENT FORCE ###################################################
      SCONF=SPGAIN*SCP+SDGAIN*SCD+SIGAIN*SCI                                #
      IF(SCONF.GT.AMAX) SCONF=AMAX                                          #
      IF(SCONF.LT.AMIN) SCONF=AMIN                                          #
      LOCW(6)=SCONF                                                         #
      TEST(K,3)=SCONF
C#### Y CONTROL LOOP #####################################################
      Y2F=Y1F                                                               #
      Y1F=YCF                                                               #
      YCF=LOCR(5)/XGAIN                                                     #
      Y2=Y1                                                                 #
      Y1=YC                                                                 #
      YC=XK3*Y1F+XK1*Y1+XK2*Y2                                              #
```

```
      YC=YC/YGAIN                                                          #
      Y2P=Y1P                                                              #
      Y1P=YCP                                                              #
      YCP=YK3*Y1+YK1*Y1P+YK2*Y2P                                           #
      Y2D=Y1D                                                              #
      Y1D=YCD                                                              #
      YCD=Y1-Y2+YK1*Y1D+YK2*Y2D                                            #
      Y3I=Y2I                                                              #
      Y2I=Y1I                                                              #
      Y1I=YCI                                                              #
      YCI=YIK1*Y1+YIK2*Y2+YIK3*Y1I+YIK4*Y2I-YK2*Y3I                        #
C#### Y-THRUSTER FORCE ################################################
      YCONF=YPGAIN*YCP+YDGAIN*YCD+YIGAIN*YCI                               #
      YMAX=AMAX-ABS(SCONF)                                                 #
      YMIN=-YMAX                                                           #
      IF(YCONF.GT.YMAX) YCONF=YMAX
      IF(YCONF.LT.YMIN) YCONF=YMIN                                         #
      LOCW(4)=YCONF                                                        #
      TEST(K,2)=YCONF
C#### CALCULATE WAVE AND WIND VELOCITY ###############################
      WAVEL=WA1*COS(W1*TW)+WA2*COS(W2*TW)+WA3*COS(W3*TW)+WA4*COS(W4*TW)  #
      LOCW(8)=WAVEL*81.92*5.
      DELTA=SIN(WGP*TW)                                                    #
      ALPHA=ALP+DALPHA*DELTA                                               #
      WINDV=WIN+GUSTV*DELTA                                                #
C#### INCREMENT REAL TIME BY 2 SECONDS ###############################
      TW=TW+2.                                                             #
C#### UNSCALE VESSEL VELOCITIES AND CORRECT SIGN #####################
      XVEL=-LOCR(4)/(81.92*5.)                                            #
      YVEL=-LOCR(7)/(81.92*50.)                                           #
      SVEL=-LOCR(10)/(81.92*1000.)                                        #
      SI=LOCR(9)*.031428/81.92                                            #
C#### CHANGE ANGLE OF WAVES, CURRENT & WIND TO VESSEL COORDINATES #######
      BET=BETA-SI                                                          #
      THET=THETA-SI                                                        #
      ALPH=ALPHA-SI                                                        #
C#### CURRENT AND WAVE COMPONENT VELOCITIES ###########################
      XCURV=-VELMAG*COS(THET)                                              #
      YCURV=-VELMAG*SIN(THET)                                              #
      XWAVE=-WAVEL*COS(BET)                                                #
      YWAVE=-WAVEL*SIN(BET)                                                #
C#### VESSEL RELATIVE VELOCITIES #####################################
      XRELV=XVEL-XCURV-XWAVE                                               #
      YRELV=YVEL-YCURV-YWAVE                                               #
      MXRV=XVEL-XCURV                                                      #
      MYRV=YVEL-YCURV                                                      #
C#### VESSEL RESULTANT VELOCITY ######################################
      RVNET=YRELV**2+XRELV**2                                              #
      GAM=ATAN2(YRELV,XRELV)                                               #
```

```
      MNETV=MXRV**2+MYRV**2                                                    #
      TEST(K,4)=RVNET                                                          #
      TEST(K,5)=GAM*RAD                                                        #
C#### HYDRODYNAMIC AND AERODYNAMIC DRAG COEFFICIENTS ###################
      SIN1=SIN(GAM)                                                            #
      SIN2=SIN(2.*GAM)                                                         #
      SIN3=SIN(3.*GAM)                                                         #
      SIN5=SIN(5.*GAM)                                                         #
      FYHYD=FYH1*SIN1+FYH2*SIN2+FYH3*SIN3+FYH4*SIN5+FYH5*SIN(7.*GAM)           #
      FXHYD=FXH0+FXH1*COS(GAM)+FXH2*COS(3.*GAM)+FXH3*COS(4.*GAM)+              #
     1      FXH4*COS(5.*GAM)+FXH5*COS(7.*GAM)                                  #
      FMHYD=FMH1*SIN2+FMH2*SIN1+FMH3*SIN3+FMH4*SIN5+FMH5*SIN(6.*GAM)           #
      FXAER=FXA1*COS(ALPH)+FXA2*COS(3.*ALPH)+FXA3*COS(7.*ALPH)+               #
     1      FXA4*COS(5.*ALPH)+FXA5*COS(9.*ALPH)                                #
      FYAER=FYA1*SIN(ALPH)+FYA2*SIN(3.*ALPH)+FYA3*SIN(7.*ALPH)                #
      FMAER=FMA1*SIN(2.*ALPH)+FMA2*SIN(ALPH)+FMA3*SIN(4.*ALPH)                #
C#### WIND AND WATER DRAG FORCE CALCULATIONS #########################
      FADX=WINDV**2*FXAER*.4                                                   #
      FADY=WINDV**2*FYAER*.4                                                   #
      FADM=WINDV**2*FMAER*4.                                                   #
      FHDX= RVNET*FXHYD*149.                                                   #
      FHDY= RVNET*FYHYD*1.7E4                                                  #
      FHWM=-SVEL*ABS(SVEL)*1.E9                                                #
      FHDM=MNETV*FMHYD*2.65E6                                                  #
C#### SUM ENVIRONMENTAL FORCES ######################################
      FTDX=FHDX+FADX                                                           #
      FTDY=FHDY+FADY                                                           #
      FTDM=FADM+FHWM+FHDM                                                      #
C#### SCALE ENVIRONMENTAL FORCES FOR ANALOG #########################
      FTDY=FTDY*81.92*.002                                                     #
      FTDX=FTDX*81.92*.002                                                     #
      FTDM=FTDM*81.92*1.E-5                                                    #
      IF(FTDX.LT.AMIN)  FTDX=AMIN                                              #
      IF(FTDY.LT.AMIN)  FTDY=AMIN                                              #
      IF(FTDM.LT.AMIN)  FTDM=AMIN                                              #
      IF(FTDX.GT.AMAX)  FTDX=AMAX                                              #
      IF(FTDY.GT.AMAX)  FTDY=AMAX                                              #
      IF(FTDM.GT.AMAX)  FTDM=AMAX                                              #
C#### RESULTANT THRUSTER FORCE MAGNITUDE ############################
      RTHF=-(ABS(XCONF)+ABS(YCONF)+ABS(SCONF/200.))/2.                        #
      LOCW(3)=-FTDX                                                            #
      LOCW(5)=-FTDY                                                            #
      LOCW(7)=-FTDM                                                            #
      LOCW(10)=RTHF                                                            #
C#### SEND CONTOL & ENVIRONMENTAL FORCES TO ANALOG #################
      CALL FRTIO(RCBDA)                                                        #
      CALL FCHECK(RCBDA,IRET,1)                                                #
C#### INTERROGATE SENSE LINES ######################################
      CALL FRTIO (RCBSN)                                                       #
```

```
      CALL FCHECK(RCBSN,IRET,1)                                              #
      IF(LOCS.EQ.1) K=1                                                      #
      IF(LOCS.EQ.3) GO TO 13                                                 #
C#### UPDATE VARIOUS COUNTERS ###############################################
      IF(K.EQ.N) GO TO 11                                                    #
      IF(KK.EQ.1) K=K+1                                                      #
      IF(KK.EQ.05) KK=0                                                      #
      KK=KK+1                                                                #
      IF(KK.EQ.2.AND.K.EQ.2) KDIF=ITIME(3)-KDIF                             #
  10  IF(ITIME(3)-KTIME) 10,9,9                                             #
C#### END OF TIMED CONTROL LOOP #############################################
  13  CALL MODE  (CCWMD,MHLD)
      CALL FRTIO (RCBMD)
      CALL FCHECK (RCBMD,IRET,1)
      GO TO 997
  11  CONTINUE
      CALL MODE(CCWMD,MIC)
      CALL FRTIO(RCBMD)
      CALL FCHECK(RCBMD,IRET,1)
C *** WRITE VALUES OF PARAMETERS FROM REAL TIME RUN *********************
      WRITE(6,382) KDIF
 382  FORMAT(10X'KDIF...'I10/)
      WRITE(6,381)
 381  FORMAT(3X'TIMUN'2X'K'4X'MX0'3X'MX1'3X'MX2'3X'MX3'3X'MX4'3X'MX5'3X
     1'MX6'3X'MX7'3X'MX8'3X'MX9'5X'TEST1'6X'TEST2'6X'TEST3'6X'TEST4'6X
     2'TEST5'/)
      DO 16 K=1,N
  16  WRITE(6,380) ID(K),K,(XLOCA(K,I),I=1,NRD),(TEST(K,I),I=1,5)
 380  FORMAT(3XI5,1XI3,1X10F6.1,5(1X,E10.4))
      GO TO 998
 999  CALL EXIT
      END
```

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13. ABSTRACT

Dynamic positioning is a method of anchoring a vessel in deep areas of the ocean. The essential components of a dynamic positioning system are a vessel with positioning forces; a position measuring system; a comparator; and a controller. These components position a vessel by interacting with each other and with the environment.

Mathematical models define each component of the positioning system. The hybrid computer simulates the positioning system, and the aerodynamic and hydrodynamic forces present on the ocean's surface.

This report investigates the excitation/response characteristics of the model for a variety of environment conditions. Optimum headings with respect to positioning thrust result for each environmental case. A vessel search algorithm is developed to locate an optimum heading.

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