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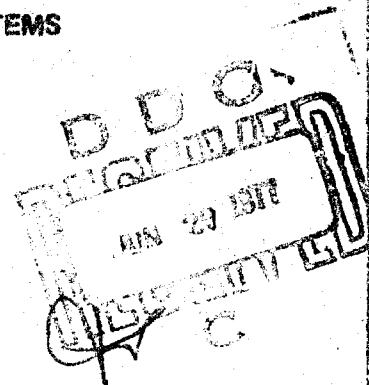


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A FORTRAN IV COMPUTER PROGRAM FOR THE TIME DOMAIN ANALYSIS
OF THE TWO-DIMENSIONAL DYNAMIC MOTIONS
OF GENERAL BUOY-CABLE-BODY SYSTEMS

by

Henry T. Wang



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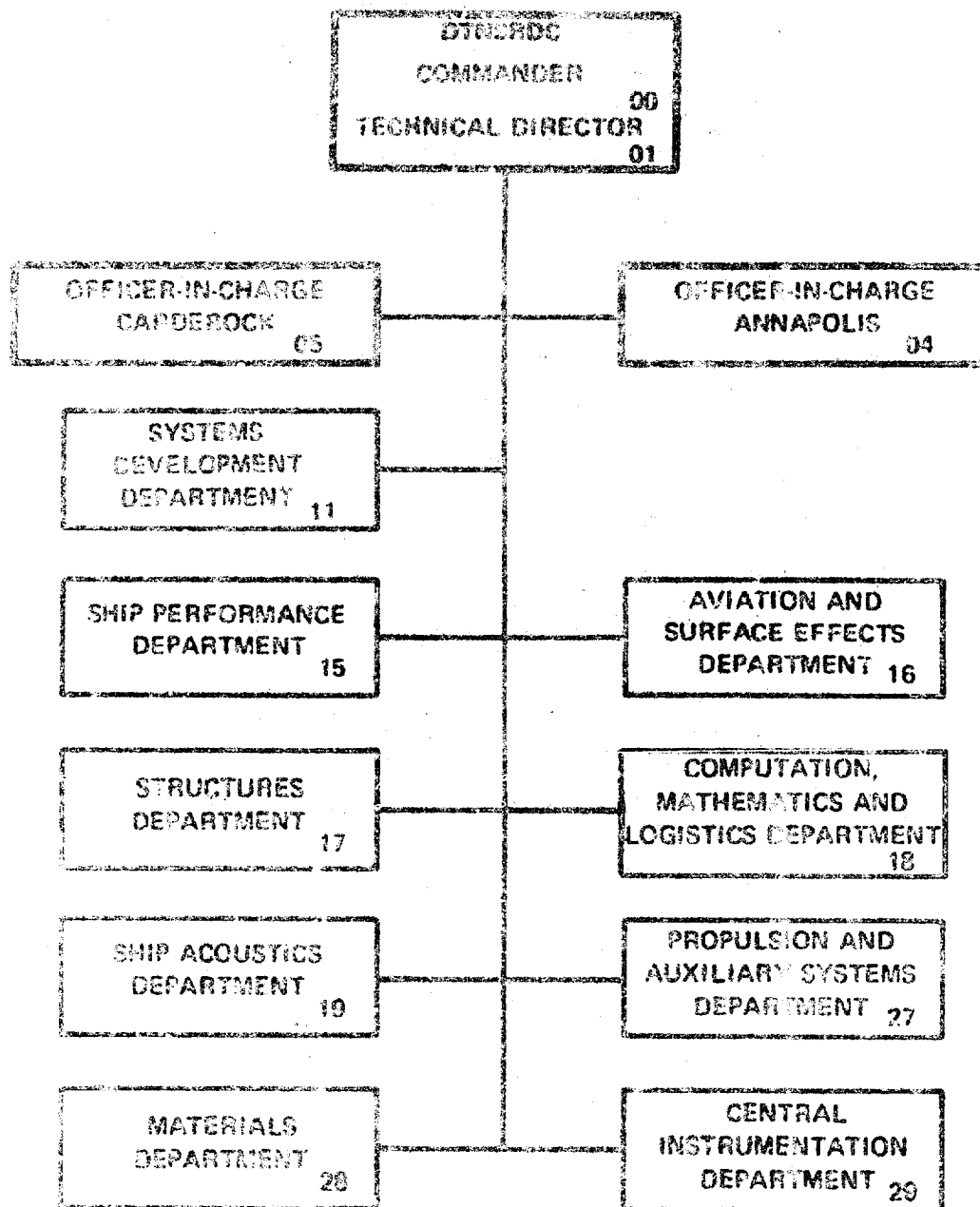
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TABLE OF CONTENTS

	Page
ABSTRACT	1
ADMINISTRATIVE INFORMATION	1
INTRODUCTION	1
STEADY-STATE CALCULATIONS	3
CABLE EQUATIONS	3
INTERMEDIATE BODIES	5
BOUNDARY CONDITIONS	6
OCEAN SURFACE WAVES	7
DESCRIPTION OF MOTION	7
CHOICE OF COMPONENTS	8
PREScribed SURFACE MOTIONS	9
SURFACE BUOY EQUATIONS	10
GENERAL CONSIDERATIONS	10
DIFFERENTIAL EQUATIONS OF MOTION	12
SPAR BUOYS	15
SMALL SPHEROIDAL BUOYS	17
DYNAMIC CABLE EQUATIONS	19
GENERAL CONSIDERATIONS	19
PRELIMINARY APPROACHES	20
FINAL FORMULATION	22
DEFINITION OF CABLE FORCES	23
INTERMEDIATE BODIES	27
CONSTANT COEFFICIENTS	27
VARIABLE COEFFICIENTS FOR CIRCULAR DISK	28
DESCRIPTION OF COMPUTER PROGRAM	30
MAIN PROGRAM	30
SUBROUTINE STAT	30
SUBROUTINE DYNA	30
SUBROUTINE CUR	31
SUBROUTINE SPECT	31
SUBROUTINE BUOY	31
SUBROUTINE ITERA	31
SUBROUTINE KUTMER	31

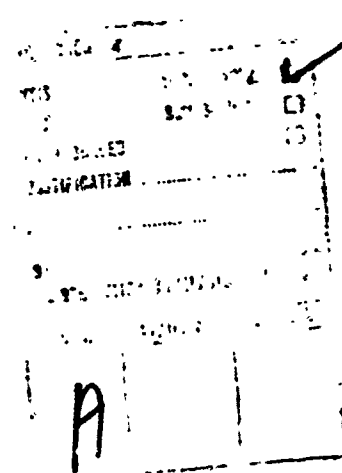
	Page
INPUT INSTRUCTIONS	32
READ STATEMENTS	32
DEFINITION OF INPUT VARIABLES FOR MAIN PROGRAM	33
DEFINITION OF INPUT VARIABLES FOR SURFACE BUOY	35
EXPLANATORY NOTES	35
PROGRAM STORAGE AND TIME REQUIREMENTS	37
SAMPLE PROBLEMS	38
PROBLEM 1 – UNIFORM CABLE WITH VARIOUS TENSION-STRAIN RELATIONS	38
PROBLEM 2 – UNIFORM CABLE PRESENTED BY VARIOUS NUMBERS OF SEGMENTS	51
PROBLEM 3 – DEPLOYMENT OF SUSPENDED CABLE IN CIRCULATING WATER CHANNEL	53
PROBLEM 4 – COMPLETE MOORED BUOY-CABLE-BODY SYSTEM	56
ACKNOWLEDGMENTS	61
REFERENCES	62
APPENDIX - LISTING OF COMPUTER PROGRAM	65

LIST OF FIGURES

1 – Definition of Coordinate System	3
2 – Definition of Forces Acting on Surface Buoy	13
3 – Finite Element with Intermediate Nodes	21
4 – Final Finite Element Model	22
5 – Tension in Upper Cable Segment for Various Values of C_1	50
6 – Steady-State Location of Lower Weight for Various Numbers of Nodes	52
7 – Velocity of Lower Weight for Various Numbers of Nodes	52
8 – Configuration of Nodes at Various Times during Deployment, $C = 1$ Knot	55
9 – Configuration of Nodes at Various Times during Deployment, $C = 2$ Knots	55
10 – Configuration of Nodes at Various Times during Deployment, $C = 4$ Knots	56
11 – Pitch of Surface Buoy	61

LIST OF TABLES

	Page
1 - Values of Added Inertia Coefficients for Spheroidal Buoys at Zero Reduced Frequency	18
2 - Computer Execution Times and Cost for All the Sample Problems	38
3 - Input Data for Sample Problem 1	40
4 - Program Output for Problem 1D	42
5 - Input Data for Sample Problem 2	51
6 - Input Data for Sample Problem 3	54
7 - Parameters for Moored Buoy-Cable-Body System	57
8 - Input Data for Sample Problem 4	59



ABSTRACT

The present report gives a detailed description of Program CABUOY, which analyzes in the time domain the two dimensional dynamic behavior of general ocean cable systems consisting of a surface buoy, connecting cable, and intermediate bodies. The equations which model the motions of the surface waves and the various components of the cable system are presented, and the subroutines of the program are briefly outlined. Instructions on use of the program include a listing of the input READ statements, definitions of the input variables, and a number of comments on the entering of input data. Several sample problems are given to illustrate use of the program, the output of the program, and computer costs for a range of cases. The listing of the program is given in the appendix.

ADMINISTRATIVE INFORMATION

The work described in this report was authorized by the Naval Air Development Center under Project Orders 4-0601 and 0-0611 respectively dated 5 March 1974 and 13 February 1976. The work was performed under internal Work Units 1-1552-130 and 1-1552-145.

INTRODUCTION

The dynamic motion characteristics of cable systems are currently of extreme interest, and several major surveys of cable dynamics studies have been made in recent years ¹⁻³

An ocean cable system generally consists of the following three components:

1. A ship or surface float at the upper end.
2. A cable whose properties may vary along its length.
3. Intermediate bodies along the cable, including the possibility of a body at the lower end.

Previous studies have usually focused on only one of the above components. For example, the principal emphasis in many studies is on the dynamic characteristics of the cable itself.

¹Dillon, D.B., "An Inventory of Current Mathematical Models of Scientific Data - Gathering Moors," Hydrospace-Challenger, Inc. TR 4450 0001 (Feb 1973).
A complete list of references is given on pages 61-63.

²Choo, Y.I. and M.J. Casarella, "A Survey of Analytical Methods for Dynamic Simulation of Cable-Body Systems," Journal of Hydronautics, Vol. 7, No. 4, pp. 137-144 (Oct 1973).

³Albertsen, N.D., "A Survey of Techniques for the Analysis and Design of Submerged Mooring Systems," Civil Engineering Laboratory Technical Report R-815 (Aug 1974).

Conditions at the ends of the cable are then either those of prescribed motions or simple representations of the surface buoy or lower body. It appears that such studies were carried out mainly to demonstrate the feasibility of a particular method of solving for the dynamic characteristics of the cable. Choo and Casarella² discuss the merits and drawbacks of the three principal analytical methods: linearized frequency-domain method, method of characteristics, and finite element method. In other studies, the principal emphasis is on the dynamic characteristics of the surface buoy or the lower body and the effect of the cable is then approximated in various ways. It is clear that these studies are suitable only for analyzing particular types of cable systems, also, only the dynamic characteristics of certain components are accurately described.

The present report gives details on Program CABUOY, which analyzes in the time domain the two-dimensional dynamic behavior of all three components of a general cable system. This program has already been briefly described.⁴ Although it was developed principally to analyze the dynamic behavior of sonobuoy systems, for which it is of interest to know the dynamic behavior of the surface buoy, connecting cable, and lower acoustic detection units, the great generality and versatility of the program make it useful for a wide variety of other cable systems.

The report first presents in detail the equations which form the basis of the program. These include equations for the steady-state cable configuration and for the dynamic motions of the surface waves, surface buoy, cable, and intermediate bodies. Each of the program subroutines is briefly described. Detailed input instructions include a listing of the input FORTRAN READ statements, definition of the input variables contained in these READ statements, and comments on the entry of input data. Several sample problems serve to illustrate program use, output, and computer costs. The program is listed in the appendix.

Both the input instructions and the sample problems illustrate the wide applicability of the program. The sample problems range from a parametric study of the accuracy and computer cost of various finite element representations of the cable to the analysis of a complete buoy-cable-body system moored in the presence of typical ocean waves and current profiles. The characteristics of each component of the ocean surface waves may be specified by the user or may be internally generated by the program by means of the Pierson-Moskowitz spectrum. The surface buoy at the top of the cable may have a relatively wide range of sizes and shapes. It may be a prolate or oblate spheroid of any aspect ratio provided its horizontal

⁴Wang, H.T., "Preliminary Report on a Fortran IV Computer Program for the Two-Dimensional Dynamic Behavior of General Ocean Cable Systems," DTNSRDC Departmental Report SPD-633-01 (Aug 1975).

length is small compared to the wavelengths of the significant ocean waves, or it may be a spar buoy of any size. The reasons for these particular choices of buoy shapes and sizes are given in the section on surface buoys. Alternatively, motions may be prescribed at the upper end. The user determines the accuracy and computer cost of the dynamic analysis of the cable by specifying the total number of cable segments as well as the length of each segment. Several different formulations are given for the added masses and drag coefficients of the intermediate bodies.

STEADY-STATE CALCULATIONS

CABLE EQUATIONS

The program first calculates the configuration of the cable system in the presence of a steady-state current* alone, in the absence of any time-dependent excitations. The differential equations for the steady-state configuration of the cable are well known and take the following form for the coordinate system shown in Figure 1; for example, see Springston.⁵

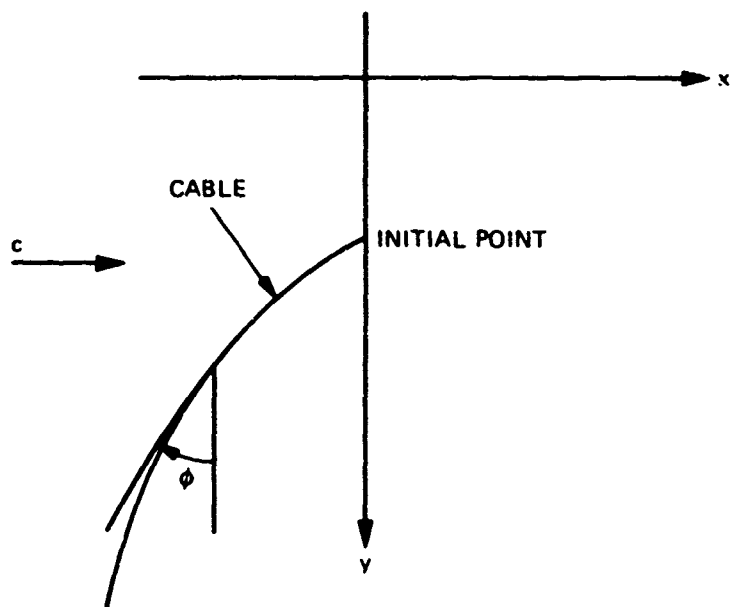


Figure 1 – Definition of Coordinate System

*The term current is used to denote the steady-state fluid velocity relative to the cable. For the case of a cable towed in still water, the current has magnitude equal to and direction opposite to the towing velocity.

⁵Springston, G.B. Jr., "Generalized Hydrodynamic Loading Functions for Bare and Faired Cables in Two-Dimensional Steady-State Cable Configurations," NSRDC Report 7424 (Jun 1967).

$$-T \frac{d\phi}{ds_0} + I + \sin \phi W = 0 \quad (1)$$

$$\frac{dT}{ds_0} + G + \cos \phi W = 0 \quad (2)$$

$$\frac{ds}{ds_0} = 1 + \epsilon \quad (3)$$

$$\frac{dx}{ds_0} = (1 + \epsilon) \sin \phi \quad (4)$$

$$\frac{dy}{ds_0} = (1 + \epsilon) \cos \phi \quad (5)$$

where T = cable tension
 ϕ = angle of the cable segment with the vertical (see Figure 1)
 s_0 = reference cable length (when $T = T_0$) measured from the initial point
 T_0 = reference tension
 I, G = normal and tangential drag forces, respectively, per unit length acting on the cable
 W = weight in fluid per unit length of the cable
 s = stretched cable length measured from the initial point
 ϵ = cable strain; $\epsilon = 0$ at $T = T_0$
 x = horizontal displacement, positive to the right
 y = vertical displacement, positive downward

For smooth, approximately round cables, the normal and tangential drags may be taken as respectively proportional to the squares of the velocities normal and tangential to the cable⁵

$$I = \frac{1}{2} \rho C_D d c_n |c_n| \quad (6)$$

$$G = \frac{1}{2} \rho C_T d c_t |c_t| \quad (7)$$

where ρ = fluid density
 C_D, C_T = normal and tangential drag coefficients respectively
 d = cable diameter
 c_n = component of the current normal to the cable = $c \cos \phi$
 c_t = component of the current tangential to the cable = $-c \sin \phi$
 c = magnitude of the current, taken to act only in the x -direction

The tension-strain function is assumed to be of the form⁶

$$T - T_0 = C_1 \epsilon^{C_2} \quad (8)$$

where C_1 = constant of elasticity; $C_1 = AE$ for a linearly elastic cable
 A = cross-sectional area = $\pi d^2/4$ for a round cable
 E = modulus of elasticity
 C_2 = an exponent; $C_2 = 1$ for a linearly elastic cable

Equation (8) enables a nonlinear tension-strain relation to be modeled by only two input variables, C_1 and C_2 . It is more convenient to express ϵ as a function of $(T - T_0)$ in order to eliminate it in Equations (3) through (5):

$$\epsilon = \left(\frac{T - T_0}{C_1} \right)^{1/C_2} \quad (9)$$

INTERMEDIATE BODIES

It is assumed that conditions at the top of the cable are known and the integration of Equations (1) through (5) proceeds down the cable. At an intermediate body, the integration must be interrupted and the unknown cable variables T_u and ϕ_u below the body must be related to the known variables T_k and ϕ_k above the body. Reducing the three-dimensional equations contained in References 7 and 8 to the present two-dimensional case results in the following two equations for T_u and ϕ_u :

$$T_u = \sqrt{(\sin \phi_k T_k + D_x)^2 + (-\cos \phi_k T_k + W_B)^2} \quad (10)$$

$$\phi_u = \tan^{-1} \frac{\sin \phi_k T_k + D_x}{-\cos \phi_k T_k + W_B} \quad (11)$$

where D_x is the drag on the body and

⁶Thresher, R.W. and J.H. Nath, "Anchor-Last Deployment Procedure for Mooring," Oregon State University Report 73-5 (Jun 1973).

⁷Wang, H.T., "Effect of Nonplanar Current Profiles on the Configuration of Moored Cable Systems," NSRDC Report 3692 (Oct 1971).

⁸Wang, H.T., "A FORTRAN IV Program for the Three-Dimensional Steady-State Configuration of Extensible Flexible Cable Systems," NSRDC Report 4384 (Sep 1974).

$$D_x = \frac{1}{2} \rho C_D A_x |c|c| \quad (12)$$

Here also, $C_D A_x$ is the drag area of the body for flow in the x-direction and W_B is the weight of the body in fluid.

BOUNDARY CONDITIONS

Initial Value Cases

The integration of the above differential equations is most convenient when the tension T and the angle ϕ are known at one end of the cable. These are known for certain cases of single-point moored cables and towing cables. For the moored cases, the program starts with the known conditions at the top of the cable and integrates the five differential equations until the lower end of the cable is reached. This is the simplest case for the program since the numbering of the cable segments and intermediate bodies starts at the top of the cable. For towing cable cases, where the conditions are known at the lower towed body, the program integrates the differential equations twice. They are first integrated from the towed body to the upper point, thus fixing the conditions at this point. Then, in order to conform to the numbering system which is used for the dynamic calculations, the equations are integrated once again from the upper point down to the lower towed body.

Boundary Value Cases

In many applications the values of T and ϕ are not known *a priori* at any point along the cable. It is necessary to treat these cases as boundary value problems and use iteration techniques to obtain the solution. The present program contains the iteration schemes for two cases of particular interest for monobuoy systems: a cable of given length moored in a given ocean depth⁹ and a free-floating cable system.¹⁰ The iteration subroutine is written so that the user may conveniently implement iteration schemes for other applications.

⁹Wang, H.T. and B.L. Webster, "Current Profiles Which Give Rise to Nonunique Solutions of Moored Cable Systems," Paper OTC 1538, Fourth Annual Offshore Technology Conference, Houston, Texas (May 1972).

¹⁰Wang, H.T. and T.L. Moran, "Analysis of the Two-Dimensional Steady-State Behavior of Extensible Free-Floating Cable Systems," NSRDC Report 3721 (Oct 1971)

OCEAN SURFACE WAVES

DESCRIPTION OF MOTION

For ocean depths greater than one-half the wavelength,¹¹ the water particle trajectories due to a single progressive wave are, according to linearized first-order theory, given by^{11,12}

$$x_w = a_w e^{-ky} \cos(kx - \sigma t + \theta_w) \quad (13a)$$

$$y_w = -a_w e^{-ky} \sin(kx - \sigma t + \theta_w) \quad (13b)$$

where x_w, y_w = water particle displacements in the (x, y) directions, respectively
 a_w = wave amplitude
 k = wave number = $2\pi/\lambda$
 λ = wavelength
 σ = circular frequency = $\sqrt{2\pi g/\lambda} = 2\pi f$
 f = frequency
 t = time
 g = gravity constant = 32.2 ft/sec² (9.81 m/sec²)
 θ_w = phase angle

It is of interest to note that the trajectories describe circular orbits with a radius which decays exponentially with depth.

For an irregular sea consisting of N distinct components, the resultant water particle displacements are obtained by a summation of the above expressions, resulting in

$$x_w = \sum_{i=1}^N a_{wi} e^{-k_i y} \cos(k_i x - \sigma_i t + \theta_{wi}) \quad (14a)$$

$$y_w = - \sum_{i=1}^N a_{wi} e^{-k_i y} \sin(k_i x - \sigma_i t + \theta_{wi}) \quad (14b)$$

Differentiations with respect to time yield the following results for water particle velocities and accelerations

¹¹Lamb, H., "Hydrodynamics," Sixth Edition, Dover Publications, New York (1945), pp. 363-370, pp. 152-155.

¹²Wehausen, J.V. and E.V. Laitone, "Surface Waves," in "Handbuch der Physik," Vol. 9, Springer Verlag, Berlin (1960), pp. 446-778.

$$\dot{x}_w = \sum_{i=1}^N \sigma_i a_{wi} e^{-k_i y} \sin(k_i x - \sigma_i t + \theta_{wi}) \quad (15a)$$

$$\dot{y}_w = \sum_{i=1}^N \sigma_i a_{wi} e^{-k_i y} \cos(k_i x - \sigma_i t + \theta_{wi}) \quad (15b)$$

$$\ddot{x}_w = \sum_{i=1}^N -\sigma_i^2 a_{wi} e^{-k_i y} \cos(k_i x - \sigma_i t + \theta_{wi}) \quad (16a)$$

$$\ddot{y}_w = \sum_{i=1}^N \sigma_i^2 a_{wi} e^{-k_i y} \sin(k_i x - \sigma_i t + \theta_{wi}) \quad (16b)$$

CHOICE OF COMPONENTS

The computer program allows the user two options for describing an irregular sea. He may specify the values of N , a_{wi} , σ_i , and θ_{wi} or he may use an energy spectrum $S_S(\sigma)$ to define the wave amplitudes

$$a_{wi} = \sqrt{S_S(\sigma_i) \Delta\sigma} \quad (17)$$

where $\sigma_i = \sigma_{i-1} + \Delta\sigma$
 $\Delta\sigma = (\sigma_u - \sigma_l)/N$
 σ_u = upper limit of the significant range of σ 's
 σ_l = lower limit of the significant range of σ 's

The program uses the Pierson-Moskowitz energy sea spectrum of the form

$$S_S(\sigma) = \frac{A}{\sigma^5} e^{-B/\sigma^4} \quad (18)$$

where $A = 0.0081 g^2$ and $B = 33.56 h_{1/3}^2$. Here $h_{1/3}$ is the significant wave height, the average of the one-third highest peak-to-trough heights. As reported by Frank and Salvesen,¹³ the 11th International Towing Tank Conference (Tokyo) (1966) recommended the spectrum in this form for computations when information is not available on typical sea spectra.

¹³Frank, W. and N. Salvesen, "The Frank Close-Fit Ship-Motion Computer Program," NSRDC Report 3289 (Jun 1970).

Other forms for $S_5(\sigma)$ can, of course, be conveniently programmed. Values for $h_{1/3}$, σ_u , and σ_ϕ for State 0 to 9 seas may be found in Table 1 of Reference 13. The program sets the values of θ_{w1} to be evenly spaced from θ_{w1} to $360-\theta_{w1}$ degrees.

PREScribed SURFACE MOTIONS

The program allows the user either to prescribe the motion at the surface or to describe it by means of differential equations of motion for a surface buoy.

If the surface buoy or ship is sufficiently large that its motions are not appreciably affected by the presence of the cable, these motions may be calculated separately and used as input for the present program. Several programs are available to calculate the pitch and heave motion responses of surface ships, for example, the Frank Close-Fit Ship Motion Computer Program.¹³ This approach is also valid for laboratory simulations of cable dynamics where the motions at the upper end of the cable are often prescribed. A third area of application could be a full-scale trial where the motions of the surface ship or platform can be readily measured.

The program considers the prescribed motion of the end of the cable as composed of a series of sinusoidal components in the horizontal and vertical directions

$$x_s = \sum_{i=1}^N a_{xi} \cos (-2\pi f_i t + \theta_{si}) \quad (19)$$

$$y_s = \sum_{i=1}^N -a_{yi} \sin (-2\pi f_i t + \theta_{si}) \quad (20)$$

where x_s, y_s = horizontal and vertical components of the surface motion, respectively

a_{xi}, a_{yi} = amplitudes for the i th component of x_s and y_s , respectively

f_i, θ_{si} = frequency and phase angle for the i th component, respectively

If so desired, other forms for the prescribed motion may be conveniently added to the program, e.g., other functions of time such as powers of t or exponentials

SURFACE BUOY EQUATIONS

GENERAL CONSIDERATIONS

It is well known that the added mass and damping coefficients of surface buoys are, in general, functions of the frequency of the oscillation.^{14 15} In the time domain, this requires the solution of integrodifferential equations which contain convolution integrals. Alternatively, if the frequency-dependent coefficients can be expressed as simple polynomials of the frequency, the integrodifferential equations may be replaced by a set of higher order differential equations.¹⁴ In either case, the solutions are complex and/or time-consuming in the time domain. Thus, surface buoy motions have usually been solved in the frequency domain. In this approach, the steady-state harmonic response is obtained for each frequency component of the exciting surface waves. The total response to the sum of the individual wave components is then obtained by linear superposition. Experiments have shown that this procedure generally yields satisfactory results for pitch and heave motions of surface ships.

Because of difficulties in solving buoy equations in the time domain, the frequency domain approach has also been used to study the motion of cable-buoy systems. Perhaps the most comprehensive of these studies is the Goodman et al. computer program¹⁶ which considers four different buoy shapes. In addition to facilitating the solution for general buoy shapes, the frequency domain approach has the additional advantages of immediately giving the steady-state harmonic response (no need to wait for the transient response to die down) and of reducing the computer time required to obtain cable motions.¹⁷ However, the drawbacks to this approach include neglect of all nonlinearities and the assumption that all the dynamic response variables are small compared to their steady-state values. This approach would not be able to predict, for example, the large dynamic snap loads which occur when the cable goes slack.

In view of the above drawbacks and also in view of the existence of the comprehensive frequency-domain computer program described in Goodman et al.,¹⁶ it was decided to use a

¹⁴Tick, I.J., "Differential Equations with Frequency-Dependent Coefficients," *Journal of Ship Research*, Vol. 3, No. 2, pp. 45-46 (Oct 1959).

¹⁵Ogilvie, T.F., "Recent Progress toward the Understanding and Prediction of Ship Motions," *Fifth Symposium of Naval Hydrodynamics*, Bergen, Norway, pp. 3-128 (Sep 1964).

¹⁶Goodman, T.R. et al., "Static and Dynamic Analysis of a Moored Buoy System," *National Data Buoy Center Report 6113.1* (Apr 1972).

¹⁷Wang, H.T., "A Two-Degree-of-Freedom Model for the Two-Dimensional Dynamic Motions of Suspended Extensible Cable Systems," *NSRDC Report 3663* (Oct 1971).

time domain approach in the present study. In order to make this approach feasible, it was important to find classes of buoys which did not have frequency-dependent added mass and damping coefficients. A literature search revealed two such classes: spar buoys^{18,19} and small buoys. Spar buoys are buoys with circular cross sections and large draft-to-diameter ratios H/b . Because of their slenderness, the added inertia terms of these buoys are essentially those for infinite fluid, and the frequency-dependent wave damping coefficients are zero to first order approximation.¹⁸ The other class corresponds to buoys whose typical dimension a is so small compared to the ocean wavelengths λ that the reduced frequency $\bar{\sigma}$ given by

$$\bar{\sigma} = 2\pi \frac{a}{\lambda} \ll 1 \quad (21)$$

is much less than unity for the range of λ values corresponding to ocean waves of interest.

For surface buoys of sonobuoy systems, whose typical dimension is of the order of 1 ft (0.305 m), the above condition holds for the large majority of sea states. When Equation (21) holds, the wave damping terms go to zero and the added inertia terms for $\bar{\sigma} = 0$ may be used. In this case, the ocean surface behaves essentially as a rigid plane,²⁰ and for the case of a buoy whose axis of symmetry is aligned with the y-axis, the added mass in surge is equal to the infinite fluid value. The added mass coefficients for pitch and heave must be calculated separately for each shape considered. Since these coefficients have been studied for several cases of oblate and prolate spheroids,²¹⁻²⁴ and also because they represent mathematical shapes which are similar to surface buoys of sonobuoy systems, it was decided to represent the small buoys by prolate and oblate spheroids. Both types of spheroids are characterized by having two of their three axes equal in length. The limiting cases for a prolate spheroid are a

¹⁸Newman, J.N., "The Motions of a Spar Buoy in Regular Waves," David Taylor Model Basin Report 1499 (May 1963).

¹⁹Rudnick, P., "Motion of A Large Spar Buoy in Sea Waves," Journal of Ship Research, Vol. 11, No. 4, pp. 257-267 (Dec 1967).

²⁰Newman, J.N., "Marine Hydrodynamics (Lecture Notes)," M.I.T. Dept. Nav. Arch. and Mar. Eng. (Spring Term 1971).

²¹Havelock, T., "Waves due to a Floating Sphere Making Periodic Heaving Oscillations," Proceedings of the Royal Society, Vol. 231, Series A, pp. 1-7 (Jul 1955).

²²MacCamy, R.C., "On the Heaving Motion of Cylinders of Shallow Draft," Journal of Ship Research, Vol. 7, No. 3, pp. 34-43 (Dec 1961).

²³Kim, W.D., "On the Forced Oscillations of Shallow-Draft Ships," Journal of Ship Research, Vol. 7, No. 2, pp. 7-18 (Oct 1963).

²⁴Kim, W.D., "On a Free-Floating Ship in Waves," Journal of Ship Research, Vol. 10, No. 3, pp. 182-191 (Sep 1966).

long thin cylinder and a sphere, and the limiting cases for an oblate spheroid are a thin circular disk and again a sphere. It can be seen from these limiting cases, that prolate and oblate spheroids can be used to generate a wide range of shapes.

DIFFERENTIAL EQUATIONS OF MOTION

The linearized differential equations for the surge, heave, and pitch motions of a surface buoy or ship freely floating in an inviscid fluid are well known; see, for example, Frank and Salvesen¹³ and Newman.¹⁸ These equations usually contain the inertia forces (including the added hydrodynamic inertia forces), the wave-damping forces, the exciting forces due to the incoming ocean waves, and the restoring forces due to buoyancy. The resulting equations are usually solved in the frequency domain. As mentioned previously, the wave-damping forces may be neglected, to first order, for the two types of buoys considered in the present report. The forces due to viscous drag and cable tension, which are not usually considered in the above studies, are included in the present formulation. The viscous drag forces which are quadratic in the motion velocities of the float, are usually omitted since they make the equations nonlinear and complicate solutions in the frequency domain. The inclusion of these forces poses no problem in a time-domain analysis. The cable forces are, of course, zero for a freely floating buoy.

If the above forces acting on the buoy (shown in Figure 2) are considered and the pitch angle ψ is taken to be small such that

$$\sin \psi \approx \psi \quad (22a)$$

$$\cos \psi \approx 1, \quad (22b)$$

the three differential equations for the surge ξ , heave ζ , and pitch ψ are as follows

$$\left[A_{\xi\xi} = (m + K_S \rho V) \right] \ddot{\xi} + \left[A_{\xi\psi} = -\rho \int_0^H (y - y_G) k_S(y) S(y) dy \right] \ddot{\psi} = FK_x + D_x + T_x + T_{lw x} \quad (23)$$

$$\left[A_{\eta\eta} = (m + K_H \rho V) \right] \ddot{\zeta} = -\rho g S_w (\zeta - y_w) + FK_v + D_y + T_y - T_{ys} \quad (24)$$

$$\begin{aligned} A_{\xi\psi} \ddot{\xi} + \left\{ A_{\psi\psi} = \left[1 + \rho \int_0^H (y - y_G)^2 k_S(y) S(y) dy \right] \right\} \ddot{\psi} = \rho g V \overline{BG} \psi + FK_\psi \\ - \overline{BG} D_x + (-r_y \psi + r_x) T_y - (r_x \psi + r_y) T_x - r_{wy} T_{lw x} \end{aligned} \quad (25)$$

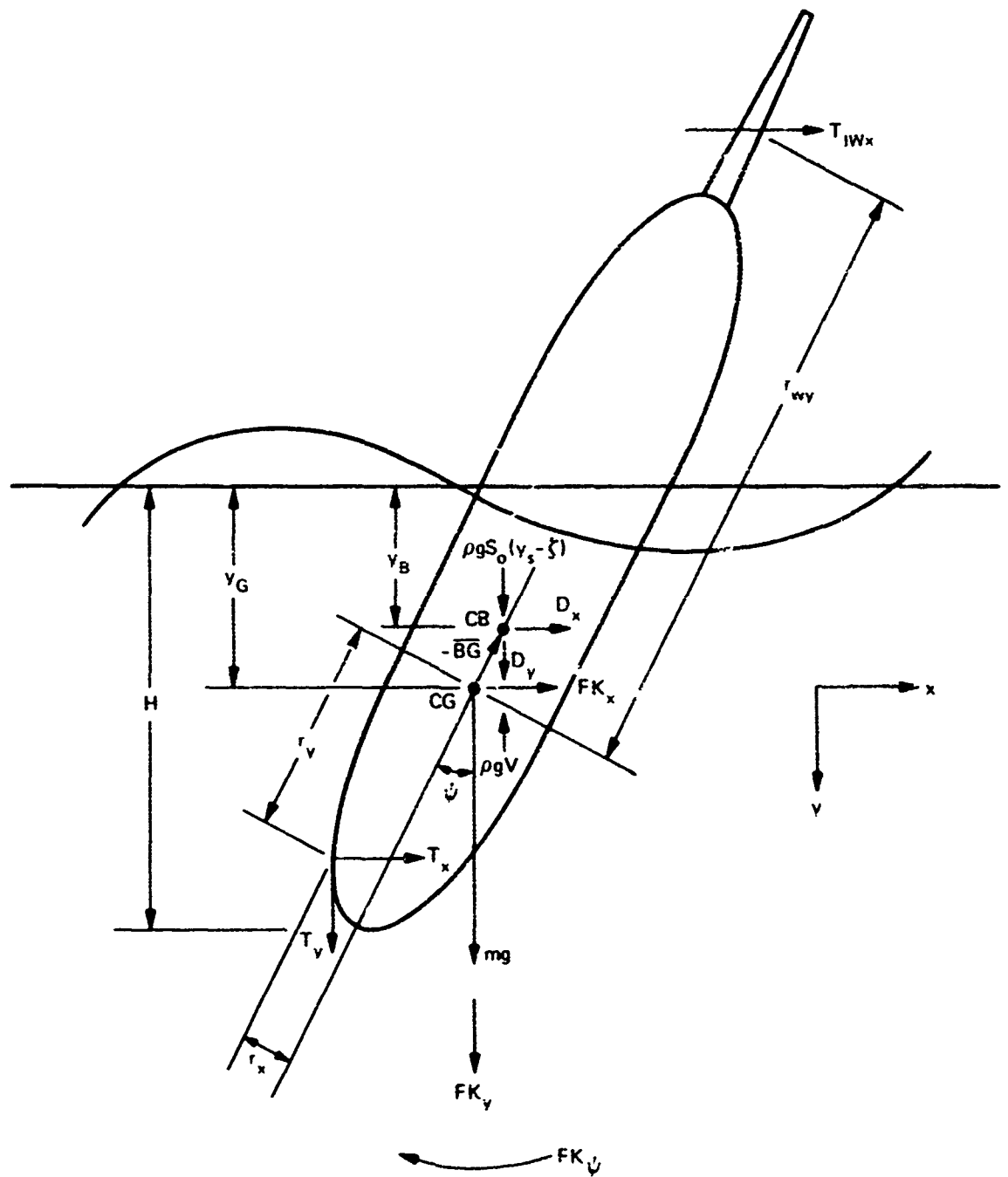


Figure 2 – Definition of Forces Acting on Surface Buoy

where	$A_{\xi\xi}, A_{\xi\psi}, A_{\eta\eta},$ and $A_{\psi\psi}$	= inertia coefficients defined above
	m	= mass of the buoy
	K_S and K_H	= added mass coefficients for surge and heave, respectively
	V	= submerged volume
	H	= draft
	y_G	= distance of the center of gravity below the undisturbed free surface
	$k_S(y)$	= local added mass coefficient for surge
	$S(y)$	= local cross-sectional area
	FK_x, FK_y	= exciting forces due to surface waves in the x- and y-directions, respectively
	FK_ψ	= exciting moment about the center of gravity due to surface waves
	D_x, D_y	= viscous drag forces in the x- and y-directions, respectively
	T_x, T_y	= components of the cable tension in the x- and y-directions, respectively, at the attachment point to the buoy
	T_{1wx}	= wind loading on the buoy in the x-direction
	T_{ys}	= steady-state component of tension in the y-direction at the attachment point to the buoy
	S_w	= waterplane area of the buoy
	y_w	= vertical displacement of the ocean surface, defined in Equation (14b)
	I	= moment of inertia about the center of gravity
	$-y_B$	= $y_B - y_G$
	y_B	= distance of the center of buoyancy below the undisturbed free surface
	r_{cx}, r_{cy}	= horizontal and vertical distances measured from the center of gravity to the cable attachment point
	r_{wy}	= vertical distance measured from the center of gravity to the center of the wind loading force

In Equations (23)–(25), a dot denotes differentiation with respect to time.

The added inertia coefficients, presented below, are all calculated for the case $\psi \equiv 0$. It should be noted that the moment terms on the right-hand side of Equation (25) may be readily changed to account for large values of ψ which negate approximations (22a) and (22b). However, the added inertia terms on the left-hand side of Equations (23) through (25) must be calculated (by potential flow methods) for each new value of ψ . For example, for a large value of ψ , the added mass in surge for a small spheroidal buoy is no longer equal to the infinite fluid value since in this case, there will be motion of the fluid perpendicular to the free surface.

Under static conditions, the submerged volume V must support both the weight of the buoy in air (mg) and the vertical component of the steady-state tension (T_{ys})

$$\rho g V = mg + T_{ys} \quad (26a)$$

$$V = \frac{m}{\rho} + \frac{T_{ys}}{\rho g} \quad (26b)$$

If the input dimensions for the draft and cross-sectional areas of the buoy are such that the submerged volume does not equal the value given in Equation (26b), the program internally multiplies the cross-sectional areas by a constant factor so that the submerged volume becomes exactly equal to the value given by this equation. All of the added inertia and wave-exciting forces given in the following sections are based on this volume.

The following two sections present derivations for the added inertia coefficients K_S , K_H , k_S and the wave-exciting forces FK_x , FK_y , FK_ψ for the two classes of buoys considered: spar buoys and small spheroidal buoys.

SPAR BUOYS

Because of the slenderness of the spar buoy, Newman¹⁸ shows that its added inertias for surge and pitch are identical to those in infinite fluid. Since the spar buoy has a circular cross section, the surge inertia coefficients k_S and K_S are both equal to 1, leading to the following definitions for the added surge and pitch inertia terms in Equations (23) through (25):

$$K_S = k_S = 1 \quad (27a)$$

$$m + K_S \rho V = m + \rho V \quad (27b)$$

$$\rho \int_0^H (y - y_G) k_S(y) S(y) dy = \rho \int_0^H (y - y_G) S(y) dy \quad (27c)$$

$$\rho \int_0^H (y - y_G)^2 k_S(y) S(y) dy = \rho \int_0^H (y - y_G)^2 S(y) dy \quad (27d)$$

Newman takes the buoy to be sufficiently slender so that the added mass for heave may be neglected. Adeo and Bai²⁵ have shown experimentally that for the case of a circular cylinder, it is more accurate to add a term corresponding to one-half the added mass of a circular disk (with the same diameter as that of the cylinder) heaving in infinite fluid.

²⁵ Adeo, B.H. and K.J. Bai, "Experimental Studies of the Behavior of Spar Type Stable Platforms in Waves." University of California (Berkeley) Report NA-70-4 (Jul 1970).

This correction term has been incorporated into the present formulation by taking the radius of the disk to be the mean radius of the spar buoy $\bar{r}$, defined by

$$\pi \bar{r}^2 H = V, \quad \bar{r} = \sqrt{\frac{V}{\pi H}}$$

Since one-half of the added inertia of a circular disk heaving in infinite fluid¹¹ is $(4/3) \rho \bar{r}^3$, the following expression is obtained for K_H in Equation (24)

$$K_H = \frac{4}{3} \frac{1}{V} \bar{r}^3 = \frac{4}{3} \frac{1}{V} \left(\frac{V}{\pi H} \right)^{3/2} \quad (28)$$

Newman shows that the wave-exciting forces are simply the Froude-Krylov forces, which may be obtained by integrating the pressure field generated by the ocean waves around the contour of the buoy. The following expressions are obtained for FK_x and FK_ψ

$$FK_x = -2 \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) Q_0(k_i) \right] \quad (29)$$

$$FK_\psi = 2 \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) Q_1(k_i) \right] \quad (30)$$

where

$$Q_0(k_i) = \rho \int_0^H e^{-k_i y} S(y) dy$$

$$Q_1(k_i) = \rho \int_0^H e^{-k_i y} (y - y_G) S(y) dy$$

For the heave motion, the Froude-Krylov force given by Newman has been modified to account for the additional heave added-mass term given in Equation (28). This modification has been so made that in the limiting case of a very small spar buoy (which would follow the motions of the waves in the absence of cable forces), the wave-exciting term in Equation (24) would be exactly equal to the inertia term on the left-hand side of the equation. The resulting force has the form

$$FK_y = \left[1 + \frac{4}{3} \rho \left(\frac{V}{\pi H} \right)^{3/2} \right] \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \sin(k_i x - \sigma_i t + \theta_{wi}) Q_0(k_i) \right] \quad (31)$$

The expression given by Newman does not contain the correction term $(4/3) \rho (V/\pi H)^{3/2}$.

SMALL SPHEROIDAL BUOYS

As mentioned previously, for the limiting case of zero reduced frequency where the free surface behaves as a rigid plane, the coefficient for the surge added mass K_S is equal to the infinite fluid value. These coefficients may be calculated by the formulas and tables given in Lamb.¹¹

The added inertia coefficients for heave, pitch, and coupled pitch-surge motions which have components normal to the free surface are not the same as the coefficients for infinite fluid. Instead, they must be calculated separately to incorporate the rigid free-surface condition. Inspection of Equations (23) and (25) shows that the added inertia terms for pitch and coupled pitch-surge motions may be defined as follows

$$\begin{aligned} \int_0^H (y - y_G)^2 k_S(y) S(y) dy &= \int_0^H (y^2 - 2yy_G + y_G^2) k_S(y) S(y) dy \\ &= \mu_{55} r_w^2 V - 2y_G (-\mu_{15}) r_w V + y_G^2 K_S V \end{aligned} \quad (32a)$$

$$- \int_0^H (y - y_G) k_S(y) S(y) dy = \mu_{15} r_w V + y_G K_S V \quad (32b)$$

where r_w is the maximum radius of the buoy and is used to render the coefficients μ_{55} and μ_{15} dimensionless.

Thus, a calculation of μ_{55} , μ_{15} , and K_H , along with the values of K_S for infinite fluid as given in Lamb, completely determines all the added inertia terms in Equations (23) through (25). Bai²⁶ has used a finite element approach to calculate coefficients μ_{55} , μ_{15} , and K_H for spheroids with draft to maximum radius ratios (H/r_w) ranging from 0.1 to 10. His results agree well with previous results²¹⁻²⁴ for corresponding cases at the zero reduced frequency limit.

Principally for the sake of programming ease, the present program considers only the results for the case where the maximum radius lies at the free surface. Consideration of other radii at the free surface would introduce additional parameters to a description of the submerged buoy. In addition, it is expected that in most cases the maximum radius will be close to the free surface because most of the volume (and hence buoyancy capability) of the spheroid is concentrated in the region around the maximum radius. Results for several cases where the waterline does not occur at the maximum radius are presented in Bai.²⁶

²⁶Bai, K.J., "The Zero-Frequency Hydrodynamic Coefficients of Vertical Axisymmetric Bodies at a Free Surface," *Journal of Hydronautics* (Jan 1977).

In the range $0.1 \leq H/r_w \leq 10.$, the coefficients μ_{15} , μ_{55} , K_H , and K_S are obtained by linearly interpolating between the values shown in Table 1.

**TABLE 1 – VALUES OF ADDED INERTIA COEFFICIENTS
FOR SPHEROIDAL BUOYS AT ZERO REDUCED FREQUENCY**

H/r_w	K_S	K_H	μ_{55}	μ_{15}
0.1	0.074	12.84	1.27	0.3
0.2	0.143	5.84	0.55	0.264
0.3	0.207	3.672	0.312	0.237
0.5	0.31	2.005	0.117	0.177
0.7	0.397	1.323	0.0358	0.11
0.9	0.469	0.96	0.0038	0.0039
1.0	0.50	0.836	0.	0.
1.5	0.622	0.484	0.0731	-0.191
2.	0.704	0.323	0.272	-0.391
3.	0.804	0.18	0.993	-0.788
5.	0.894	0.082	3.65	-1.565
7.	0.933	0.049	8.20	-2.38
10.	0.96	0.028	20.0	-3.75

The values of K_S are those given by Lamb,¹¹ and the values of μ_{15} , μ_{55} , and K_H are the values given by Bai,²⁶ subject to two modifications at $H/r_w = 10.0$. The values of μ_{15} and μ_{55} for $H/r_w = 10$, respectively 20.0 and -3.75, correspond to those obtained by simply using strip theory with $k_s(y) = 1$ for $0 \leq y \leq H$. The corresponding values of μ_{15} and μ_{55} obtained by Bai are respectively 17.84 and -3.53. These modifications were made principally for the sake of providing continuity with the approximation used in the range $H/r_w > 10.0$, where the buoy is treated essentially as a spar buoy. There are two reasons for the differences between the strip theory and theoretical finite element calculations.²⁶ First, the strip theory approach neglects the flow around the lower end of the buoy, where $k_s(y) < 1$. Second, the finite element representation, where only the nodes of the elements are on the surface of the buoy, effectively models a smaller buoy. Both of these effects serve to make the strip theory values higher than the corresponding finite element results.

Wave-Exciting Forces

The exciting forces FK_x and FK_y in Equations (23) and (24) were written in a form which assumes that the buoy follows the wave motion in the absence of cable forces and

coupling between pitch and surge motions. This is the case for buoys with dimensions which are small compared to the lengths of the exciting waves. The resulting equations take the form

$$FK_x = (1 + K_S) \rho V \ddot{x}_w = -(1 + K_S) \rho V \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) \right] \quad (33)$$

$$FK_y = (1 + K_H) \rho V \ddot{y}_w = (1 + K_H) \rho V \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \sin(k_i x - \sigma_i t + \theta_{wi}) \right] \quad (34)$$

The term $e^{-k_i y}$ which appears in Equations (16a) and (16b) for $\ddot{x}_w$ and $\ddot{y}_w$ has been omitted in the above equations since it is ≈ 1 under the assumption of small reduced frequency, Equation (21).

The pitch-exciting moment is computed by noting that because of the symmetry of the buoy about the vertical axis, only the horizontal wave motions make a contribution to pitch, resulting in

$$\begin{aligned} FK_\psi &= -\rho \int_0^H (y - y_G) \ddot{x}_w [1 + k_S(y)] S(y) dy \\ &= \rho (-\overline{BG} V + \mu_{15} r_w V + y_G K_S V) \ddot{x}_w \\ &= -\rho V (-\overline{BG} + \mu_{15} r_w + y_G K_S) \sum_{i=1}^N \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) \right] \end{aligned} \quad (35)$$

Again, under the assumption of small reduced frequency, the term $e^{-k_i y}$ has been set equal to 1 in the expression for $\ddot{x}_w$.

DYNAMIC CABLE EQUATIONS

GENERAL CONSIDERATIONS

As mentioned previously, equations for the present study are solved in the time domain. Previous cable studies have considered two major approaches in the time domain: the method of characteristics and the finite element method. The method of characteristics is an elegant method which reduces the original set of partial differential equations to a set of ordinary differential equations which are integrated along characteristic lines or wavefronts. This method furnishes valuable insight into the various modes of cable motion but solution times are typically very large.²

The finite element method seeks to represent the actual cable system by a series of segments and nodes. The original set of partial differential equations is then reduced to a set of ordinary differential equations of motion for the nodes. This method facilitates the modeling of nonuniform properties along the cable as well as the presence of intermediate bodies. The method is also quite flexible in that the number and location of nodes is left to the judgment of the user. In arriving at his selection of nodes, he may consider such factors as the type and accuracy of the dynamic information desired, the amount of computer time available, the complexity of the cable system, and the spatial variation of the environmental velocity profiles.

Principally for reasons of generality and flexibility, the finite element approach was used to model the cable. Straight elements are used in the present formulation. Webster²⁷ studied the use of higher order curved elements to model cable shape and concluded that the first order straight element appears to be the most cost-effective. In particular, he showed that one second-order quadratic element would have to be as accurate as at least eight straight elements before its use would be economical.

Before deciding on the final formulation, a number of preliminary approaches for obtaining the differential equations of motion for the nodes were explored. Two approaches in particular were considered in some detail.

PRELIMINARY APPROACHES

In one approach, the equations were formulated in a coordinate system aligned with the cable segment. This is the approach used by Rupe and Thresher²⁸ to obtain the dynamic motions of an inextensible, uniform cable. For the present case of an extensible cable, the two unknowns are the inclination and stretch of each segment. This is the most natural way of describing the configuration of a segment. In addition, certain cable forces such as tension, added inertia, and drag forces are most conveniently expressed in directions normal and tangential to a cable segment. However, in the presence of intermediate bodies along the cable, for which the inertia and drag are most conveniently expressed in the spatial x - and y -directions, the resulting equations are greatly complicated by the transformation required to express the body forces in the cable coordinate system. The cable system considered by Rupe and Thresher is free of intermediate bodies.

²⁷Webster, R.L., "An Application of the Finite Element Method to the Determination of Nonlinear Static and Dynamic Responses of Underwater Cable Structures," General Electric Report R76EMH2 (Jan 1976).

²⁸Rupe, R.C. and Thresher, R.W., "The Anchor-Last Deployment Problem for Inextensible Mooring Lines," ASME Paper 74-WA/O&T-5 (Dec 1974).

Wang²⁹ has shown that relatively few segments are required to accurately describe the overall steady-state configuration of a cable; these results suggested a second novel approach. The cable was conventionally divided into a number of straight segments and two differential equations in the x- and y-directions were written for the nodes at the ends of the segments. However, each straight segment was subdivided into a number of intermediate nodes, as shown in Figure 3.

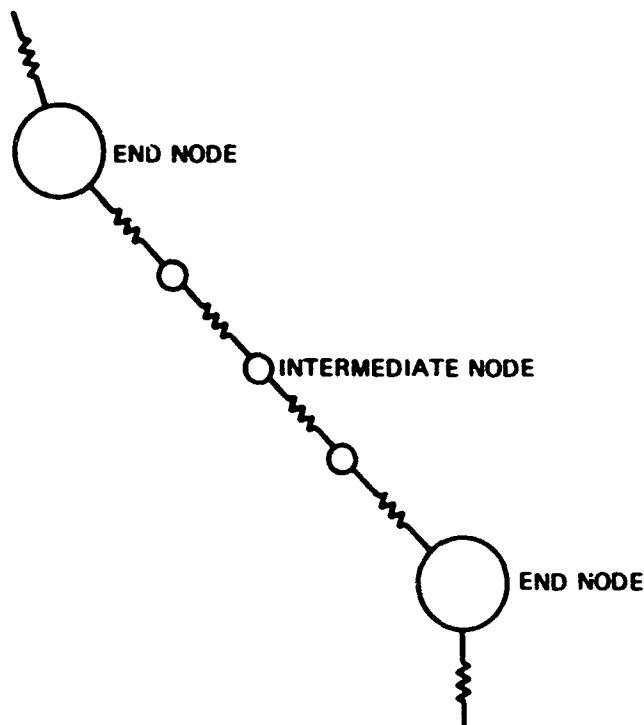


Figure 3 – Finite Element with Intermediate Nodes

Since these intermediate nodes were forced to move along the straight cable segment, only one differential equation was needed to describe their longitudinal motion. The principal intention of this approach was to have the end nodes describe the overall cable configuration and the intermediate nodes describe the variation of tension along a cable segment. There was not sufficient time in the present study to fully explore this approach. However, it was found that a certain amount of bookkeeping was required in the program to differentiate between the "end" and "intermediate" nodes. Also, although this approach reduces the total number of differential equations from that required by more conventional approaches, the

²⁹Wang, H.T., "Determination of the Accuracy of Segmented Representations of Cable Shape," Journal of Engineering for Industry, Vol. 97, No. 2, Series B, pp. 472-478 (May 1975).

integration time step still depends on the distance between intermediate nodes and the elastic modulus of the cable. For short distances and nearly inextensible cables, the size of the integration steps becomes very small, which increases computer time.

FINAL FORMULATION

In view of the above, selection of the final finite element model was as shown in Figure 4. The continuous cable is divided into a number of massless straight elastic segments. The inertia, weight, and drag forces acting on each cable segment are equally divided between the two nodes at the ends of the segment.

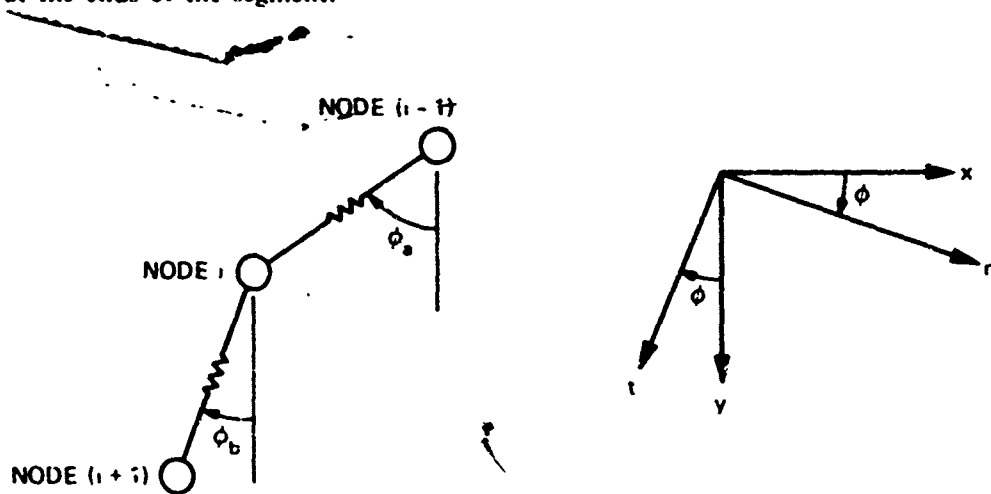


Figure 4 - Final Finite Element Model

Two second-order differential equations of motion are written in the spatial x- and y-directions for each node i, as follows

$$J_{x_i} \ddot{x}_i + K_i \ddot{y}_i = F_{x_i} = T_{x_i} + D_{nx_i} + D_{tx_i} + D_{Bx_i} \quad (36)$$

$$K_i \ddot{x}_i + J_{y_i} \ddot{y}_i = F_{y_i} = T_{y_i} + D_{ny_i} + D_{ty_i} + D_{By_i} + W_{C_i} + W_{B_i} \quad (37)$$

$$i = 1, 2, \dots, M$$

where J_x, J_y, K = inertia coefficients defined below in Equation (43)
 x, y = subscripts denoting the x- and y-directions, respectively
 F = sum of the tension, drag, and gravity forces acting on the node
 T = tension in the cable due to stretch and internal damping
 D_n = normal drag force acting on the cable

- D_t = tangential drag force acting on the cable
 D_b = drag force acting on the intermediate body
 W_c = weight of the cable in fluid
 W_b = weight of the intermediate body in fluid
 M = total number of nodes

Detailed definitions of the cable forces are now given, and the drag and inertia forces for the intermediate bodies are defined in the next major section.

It is most convenient to solve the set of $2M$ differential equations (36) and (37) with $\ddot{x}_i$ and $\ddot{y}_i$ uncoupled, as follows

$$\ddot{x}_i = (J_{y_i} F_{x_i} - K_i F_{y_i}) / (J_{x_i} J_{y_i} - K_i^2) \quad (38a)$$

$$\ddot{y}_i = (J_{x_i} F_{y_i} - K_i F_{x_i}) / (J_{x_i} J_{y_i} - K_i^2) \quad (38b)$$

DEFINITION OF CABLE FORCES

Inertia Forces

Each cable segment is taken to be a long thin cylinder for which fluid inertia is added only for acceleration normal to the segment. Thus, in a coordinate system aligned with the segment, the inertia force $\vec{F}_{IC}$ for the cable segment is simply given by

$$\vec{F}_{IC} = (\mu \ell_0 + \alpha \rho A \ell_0) \vec{a}_n + \mu \ell_0 \vec{a}_t \quad (39)$$

- where
- μ = mass per unit length of the cable
 - ℓ_0 = reference length of the cable segment
 - α = added mass coefficient = 1.0 for a round cable
 - A = cross-sectional area of the cable
 - $\vec{a}_n, \vec{a}_t$ = accelerations respectively normal and tangential to the cable segment

In this equation, an arrow denotes a vector.

In the fixed x- and y-directions, for which the differential equations are written, the inertia coefficients are not constants but rather are functions of cable inclination ϕ . For the coordinate systems shown in Figure 4, a_n and a_t are related to $\ddot{x}$ and $\ddot{y}$, respectively the accelerations in the x- and y-directions, by

$$a_n = \ddot{x} \cos \phi - \ddot{y} \sin \phi \quad (40a)$$

$$a_t = -\ddot{x} \sin \phi + \ddot{y} \cos \phi \quad (40b)$$

The x- and y-components of a_n and a_t are, in turn, given by

$$a_{nx} = a_n \cos \phi = \ddot{x} \cos^2 \phi + \ddot{y} \sin \phi \cos \phi \quad (41a)$$

$$a_{ny} = a_n \sin \phi = \ddot{x} \sin \phi \cos \phi + \ddot{y} \sin^2 \phi \quad (41b)$$

$$a_{tx} = -a_t \sin \phi = \ddot{x} \sin^2 \phi - \ddot{y} \sin \phi \cos \phi \quad (41c)$$

$$a_{ty} = a_t \cos \phi = -\ddot{x} \sin \phi \cos \phi + \ddot{y} \cos^2 \phi \quad (41d)$$

The inertia force for the cable segment in the spatial coordinates x and y takes the form

$$\begin{aligned} \vec{F}_{IC} = & [(\mu \ell_o + \alpha \rho A \ell_o) a_{nx} + \mu \ell_o a_{tx}] \vec{i} \\ & + [(\mu \ell_o + \alpha \rho A \ell_o) a_{ny} + \mu \ell_o a_{ty}] \vec{j} \end{aligned} \quad (42)$$

where $\vec{i}, \vec{j}$ are unit vectors in the x- and y-directions, respectively.

If one-half of the inertia force of the cable segments above and below the node are summed and the possible presence of an intermediate body at the node is taken into account, Equations (39) to (42) yield the following equation for the total inertia force $\vec{F}_I$ at the node

$$\begin{aligned} \vec{F}_I = & \left[\left(\frac{\mu_a \ell_{oa} + \mu_b \ell_{ob}}{2} + \frac{\alpha \rho A_a \ell_{oa}}{2} \cos^2 \phi_a + \frac{\alpha \rho A_b \ell_{ob}}{2} \cos^2 \phi_b + M_{BVx} \right) \ddot{x} \right. \\ & + \left. \left(\frac{-\alpha \rho A_a \ell_{oa}}{2} \sin \phi_a \cos \phi_a - \frac{\alpha \rho A_b \ell_{ob}}{2} \sin \phi_b \cos \phi_b \right) \ddot{y} \right] \vec{i} \\ & + \left[\left(\frac{-\alpha \rho A_a \ell_{oa}}{2} \sin \phi_a \cos \phi_a - \frac{\alpha \rho A_b \ell_{ob}}{2} \sin \phi_b \cos \phi_b \right) \ddot{x} \right. \\ & + \left. \left(\frac{\mu_a \ell_{oa} + \mu_b \ell_{ob}}{2} + \alpha \rho A_a \ell_{oa} \sin^2 \phi_a + \alpha \rho A_b \ell_{ob} \sin^2 \phi_b + M_{BVy} \right) \ddot{y} \right] \vec{j} \\ = & (J_x \ddot{x} + K \ddot{y}) \vec{i} + (K \ddot{x} + J_y \ddot{y}) \vec{j} \end{aligned} \quad (43)$$

where subscripts a and b respectively denote the cable segments above and below the node and M_{BVx} and M_{BVy} are respectively the virtual mass, the mass plus the added mass, of the intermediate body for motions in the x- and y-directions.

Tension Force

For an extensible cable segment, the tension force T depends on the strain ϵ and the strain rate $\dot{\epsilon}$

$$T = T(\epsilon, \dot{\epsilon}) \quad (44)$$

where

$$\epsilon = \frac{\Delta \ell}{\ell_0} = \frac{\ell}{\ell_0} - 1 = \frac{\sqrt{(x_\ell - x_u)^2 + (y_\ell - y_u)^2}}{\ell_0} - 1 \quad (45)$$

$$\dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{(\dot{x}_\ell - \dot{x}_u)(x_\ell - x_u) + (\dot{y}_\ell - \dot{y}_u)(y_\ell - y_u)}{\ell \ell_0} \quad (46)$$

Here ℓ is the stretched length of the cable segment and the subscripts ℓ and u respectively refer to the lower and upper ends of the cable segment.

Several relationships have been proposed in the literature for the form of this dependence. In the present study, the following relatively simple yet general relationship is used

$$T = T_0 + C_I \epsilon^2 + C_I \dot{\epsilon} \quad (47)$$

where C_I is the internal damping coefficient. Note that the above dynamic tension differs from the static tension, Equation (8), by the addition of the linear internal structural damping term $C_I \dot{\epsilon}$. This model, commonly referred to as the Voigt model, has been used in previous cable studies, for example, by Huffman³⁰ and by Goeller and Laura³¹. Goeller and Laura show experimentally that this model adequately describes internal damping for nylon ropes except for frequencies significantly higher than the resonance frequency of the cable. Other more complex forms for the internal structural damping, such as those proposed by Reid,³² can be conveniently incorporated into the program.

Since the cable segments above and below the node act on it, the following two expressions are obtained for T_x and T_y (respectively the x - and y -components of the resultant forces due to cable tension).

$$T_x = T_{ax} + T_{bx} = T_a \sin \phi_a - T_b \sin \phi_b \quad (48a)$$

$$T_y = T_{ay} + T_{by} = -T_a \cos \phi_a + T_b \cos \phi_b \quad (48b)$$

³⁰Huffman, R.R., "The Dynamical Behavior of Extensible Cable in a Uniform Flow Field (An Investigation of the Towed Vehicle Problem)," Ph.D. Thesis, Purdue University (Jan 1969).

³¹Goeller, J.F. and P.A. Laura, "Analytical and Experimental Study of the Dynamic Response of Cable Systems," The Catholic University of America, Department of Mechanical Engineering, Thesis Program 893, Report 70-3 (Apr 1970).

³²Reid, R.D., "Dynamics of Deep-Sea Mooring Lines," Texas A&M University, Department of Oceanography, M&M Project 204, Reference 68-11F (Jul 1968).

Drag Forces

As shown previously in Equations (6) and (7), the static normal and tangential cable drags are taken to be respectively proportional to the squares of the normal and tangential components of the current velocity $\vec{c}$. In the dynamic case, the fluid velocity relative to the cable must include the ocean wave particle velocities $\dot{x}_w$ and $\dot{y}_w$ as well as the velocities $\dot{x}$ and $\dot{y}$ of the cable. The resultant expressions v_{rn} and v_{rt} for the relative velocities normal and tangential to the cable then take the form

$$v_{rn} = (c + \dot{x}_w - \dot{x}) \cos \phi + (\dot{y}_w - \dot{y}) \sin \phi = \dot{x}_r \cos \phi + \dot{y}_r \sin \phi \quad (49a)$$

$$v_{rt} = -(c + \dot{x}_w - \dot{x}) \sin \phi + (\dot{y}_w - \dot{y}) \cos \phi = -\dot{x}_r \sin \phi + \dot{y}_r \cos \phi \quad (49b)$$

where $\dot{x}_r = c + \dot{x}_w - \dot{x}$ and $\dot{y}_r = \dot{y}_w - \dot{y}$.

If one-half of the drag forces acting on the cable segments above and below the node are summed, the following equations are obtained for the resultant forces D_{nx} , D_{ny} , D_{tx} , and D_{ty} acting on the node

$$D_{nx} = \frac{1}{2} D_{na} \cos \phi_a + \frac{1}{2} D_{nb} \cos \phi_b \quad (50a)$$

$$D_{ny} = \frac{1}{2} D_{na} \sin \phi_a + \frac{1}{2} D_{nb} \sin \phi_b \quad (50b)$$

$$D_{tx} = -\frac{1}{2} D_{ta} \sin \phi_a - \frac{1}{2} D_{tb} \sin \phi_b \quad (50c)$$

$$D_{ty} = \frac{1}{2} D_{ta} \cos \phi_a + \frac{1}{2} D_{tb} \cos \phi_b \quad (50d)$$

where

$$D_{n(a,b)} = \frac{1}{2} \rho C_{D(a,b)} d_{(a,b)} \ell_{\alpha(a,b)} v_{rn(a,b)} |v_{rn(a,b)}|$$

$$D_{t(a,b)} = \frac{1}{2} \rho C_{T(a,b)} d_{(a,b)} \ell_{\alpha(a,b)} v_{rt(a,b)} |v_{rt(a,b)}|$$

$$v_{rn(a,b)} = \dot{x}_r \cos \phi_{(a,b)} + \dot{y}_r \sin \phi_{(a,b)}$$

$$v_{rt(a,b)} = -\dot{x}_r \sin \phi_{(a,b)} + \dot{y}_r \cos \phi_{(a,b)}$$

INTERMEDIATE BODIES

The magnitude and direction of the added inertia and drag forces for an arbitrary body depend, in general, in a complex manner on body shape and orientation relative to the flow. The modeling of intermediate bodies in previous cable studies has ranged from the very simple to the very complex. At one extreme, the presence of intermediate bodies has been neglected altogether, leading to a cable-only system. At the other extreme, some studies have paid very careful attention to a particular body, often the lower body of the system, and approximated the rest of the cable system in a simple manner.

After careful review of previous studies, formulations were selected for the present study which although relatively simple, can model most bodies of interest for sonobuoy systems. They are also applicable to other cable systems where the bodies are relatively small and/or conform to the shape limitations given below.

CONSTANT COEFFICIENTS

Inertia Forces

The inertia forces in the x- and y-directions are expressed as the virtual mass times the acceleration in these directions, where the virtual mass is the sum of the mass of the body M_B and the constant infinite fluid added mass. Thus, the virtual masses M_{BVx} and M_{Bvy} which appear in Equation (43) are given by

$$M_{BVx} = M_B + K_x \rho V_B \quad (51a)$$

$$M_{Bvy} = M_B + K_y \rho V_B \quad (51b)$$

where K_x , K_y are respectively the added mass coefficients for motions in the x- and y-directions and V_B is the reference volume, usually the volume of the body.

Drag Forces

Two formulations are used to describe the drag forces. In one, the drag components D_{Bx} and D_{By} are taken to have the form

$$D_{Bx} = \frac{1}{2} \rho C_{DAx} v_r \dot{x}_r \quad (52a)$$

$$D_{By} = \frac{1}{2} \rho C_{DAy} v_r \dot{y}_r \quad (52b)$$

where C_{DAx} , C_{DAy} are respectively the drag areas in the x- and y-directions and $v_r = \sqrt{\dot{x}_r^2 + \dot{y}_r^2}$ is the resultant fluid velocity relative to the body. This approach has been used by Walton and Polachek³³ and is exact for the case of a sphere. In this case, where $C_{DAx} = C_{DAy} = C_{DA}$, the resultant drag D_B is parallel to the resultant fluid velocity v_r

$$\vec{D}_B = D_{Bx} \vec{i} + D_{By} \vec{j} = \frac{1}{2} \rho C_{DA} v_r (\dot{x}_r \vec{i} + \dot{y}_r \vec{j}) = \frac{1}{2} \rho C_{DA} v_r \vec{v}_r$$

This approach may also be used to approximate the drag for other blunt shapes for which the drag areas for different flow directions do not differ greatly, e.g., near-cubes or circular cylinders with length to diameter ratios of approximately 1.

In the second approach, D_{Bx} and D_{By} are taken as proportional to the squares of the components of the relative fluid velocities in these respective directions

$$D_{Bx} = \frac{1}{2} \rho C_{DAx} \dot{x}_r |\dot{x}_r| \quad (53a)$$

$$D_{By} = \frac{1}{2} \rho C_{DAy} \dot{y}_r |\dot{y}_r| \quad (53b)$$

This is a good approximation for long cylinders or thin disks with axes parallel to the x- or y-directions. In these cases, where there is a large difference between the drag areas, the drag in one direction is essentially pressure drag whereas the much smaller drag in the other direction is essentially due to fluid friction.

In the present program, the choice of whether to use Equation (52) or (53) to compute the drag is determined by the value of the ratio C_{DAx}/C_{DAy} . It was somewhat arbitrarily decided that in the range

$$0.5 \leq C_{DAx}/C_{DAy} \leq 2.0 \quad (54)$$

Equations (52a) and (52b) would be used to compute D_{Bx} and D_{By} . Outside this range, Equations (53a) and (53b) are used to compute D_{Bx} and D_{By} .

VARIABLE COEFFICIENTS FOR CIRCULAR DISK

When a body is executing dynamic oscillations such that it periodically traverses its own viscous wake, the added mass and drag coefficients are more correctly expressed as functions

³³Walton, T.S. and H. Polachek, "Calculation of Transient Motion of Submerged Cables," *Mathematical Tables and Other Aids to Computation*, Vol. 14, No. 69, pp. 27-46 (Jan 1960).

of the dynamic motion. Drag coefficients are usually obtained for steady flow and added mass coefficients are often computed for an inviscid fluid. The reviews by Wiegel³⁴ and Holler³⁵ show that nearly all of the measurements of the dynamic coefficients for various bodies have been conducted for dynamic oscillation in one direction only and in the absence of any steady-state fluid velocity. Thus, the results from these studies should be used with caution in the present case where the cable system will generally undergo dynamic motions in both directions in the presence of a steady-state current profile.

For the particular case of a circular disk, which is commonly used in sonobuoy systems to damp out the motions of the lower acoustic units, the user may either employ the constant coefficient approach (described previously) or have the program internally compute the dynamic added mass and drag coefficients for the direction normal to the disk plane, as based on the experimental relationships given by Holler.³⁵ The coefficients are related to the dynamic motions as follows³⁵

$$C_{DA n} = \frac{\pi d_B^2}{4} \frac{2.2}{\gamma} \quad (55a)$$

$$M_{BV n} = M_B + 1.2 \gamma \rho d_B^2 = M_B + M_A \quad (55b)$$

$$\begin{aligned} \gamma &= \sqrt{\beta} = \sqrt{\frac{\dot{n}^2}{\ddot{n} d_B}} \text{ for } 0.077 \leq \beta \leq 3.84 \\ &= \sqrt{3.84} = 1.96 \text{ for } \beta > 3.84 \\ &= \sqrt{0.077} = 0.278 \text{ for } \beta < 0.077 \end{aligned}$$

where n = direction normal to the disk plane, either x or y

M_A = added mass

$\dot{n}, \ddot{n}$ = the velocity and acceleration, respectively, of the disk in this direction, either $(\dot{x}, \ddot{x})$ or $(\dot{y}, \ddot{y})$

The above formulas show how the drag area and the added mass vary with β , which is a measure of the ratio of relative magnitudes of the velocity and acceleration. At low values of β , where the acceleration is much higher than the velocity (e.g., during the initial instants of

³⁴Wiegel, R.L., "Oceanographical Engineering," Prentice Hall, Inc., Englewood Cliffs, N.J., (1964), Chapter 11.

³⁵Holler, R.A., "Hydrodynamic Effects of Harmonic Acceleration," Naval Air Development Center Report AE-7120 (Jan 1972).

a body starting from rest), the formulas show that $C_{DA n}$ has a high value and that the added mass is given by $M_A = \rho d_B^3/3$, the potential flow result. At the other extreme of high values of β , where the velocity is much higher than the acceleration, the added mass has a high value and the drag area is given by $C_{DA n} = 1.12 \pi d_B^2/4$, the steady-state value.

The added mass and drag in the direction tangent to the disk plane, which are much smaller, are computed by the constant coefficient approach outlined previously.

DESCRIPTION OF COMPUTER PROGRAM

Program CABUOY consists of a main program and six subroutines.

MAIN PROGRAM

The main program accepts input data for the cable system, surface waves, current profile, and the initial conditions for the dynamic calculations. If a surface buoy is present, input data are read in by Subroutine BUOY, described below. Data may be entered in either English or metric units. A detailed description of input instructions is given later.

The program is currently written to accept up to 50 cable segments and 49 intermediate bodies. This number can be conveniently increased by changing a few DIMENSION and COMMON statements, but it should be noted that dynamic calculations for more than 50 nodes are likely to require prohibitively large amounts of computer time.

The main program prints out the input data and then calls on various subroutines to calculate the ocean wave spectrum, certain constants for the surface buoy, the steady-state configuration of the cable system, and finally the dynamic motions of the system at prescribed time intervals. The output from the steady-state and dynamic calculations are also printed by this program.

SUBROUTINE STAT

This subroutine defines the five steady-state differential equations, (1) to (5), for the cable.

SUBROUTINE DYNA

This subroutine defines the dynamic differential equations, (36) and (37), for each of the M nodes. For cases where a buoy is present, this subroutine also defines the three differential equations of motion for the surface buoy, namely (23) to (25).

SUBROUTINE CUR

This subroutine furnishes the steady-state current profile relative to the cable system. For a free-floating cable system, this would be the actual current profile minus the drift velocity of the cable system. For a given value of the vertical distance y , this subroutine linearly interpolates between the input velocities which are read in as a function of y . For cases where the given value of y is greater (less) than the largest (smallest) value of y which is read in, the subroutine takes the velocity to be the value at the largest (smallest) algebraic value of y which is read in.

SUBROUTINE SPECT

This subroutine is employed when the user wishes the program to internally generate the surface wave components. In this case, the subroutine defines the amplitudes of the surface wave components by using the Pierson-Moskowitz energy sea spectrum, Equation (18). Provision is left at the end of the subroutine for implementing other forms for the sea spectrum.

SUBROUTINE BUOY

This subroutine is used when a surface buoy is present. After reading input data for the surface buoy, the subroutine calculates the various buoy geometrical and added inertia coefficients which appear in Equations (27) to (35). It concludes by calculating the steady-state pitch angle of the buoy, in the absence of any dynamic excitation due to surface waves.

SUBROUTINE ITERA

This subroutine is used for boundary value cases when iteration schemes are required to obtain the steady-state configuration of the cable system. It contains iteration schemes which are applicable for free-floating cable systems and a cable of given length moored in a given ocean depth. Provision is made at the end of the subroutine for implementing iteration schemes for other applications.

SUBROUTINE KUTMER

This subroutine uses the Kutta-Merson method to numerically integrate the steady-state differential equations defined in Subroutine STAT and the dynamic differential equations of

motion defined in Subroutine DYNA. The subroutine automatically reduces the integration step size until specified error criteria are met.

INPUT INSTRUCTIONS

READ STATEMENTS

Input data are entered into the program by means of the following READ statements contained in Program MAIN and Subroutine BUOY. These statements are given numbers simply for identification purposes.

MAIN Program

READ (5,1) NCASES	Card 1
DO 1000 MC=1, NCASES	
READ (5,301) TITLE	Card 2
READ (5,1) NSM, NSW, NCAB, NCUR, ITER, MTRC	Card 3
READ (5,2) (FSM (K), K=1, NSM)	Card 4
READ (5,2) (AXSM (K), K=1, NSM)	Card 5
READ (5,2) (AYSM (K), K=1, NSM)	Card 6
READ (5,2) (FIDSM (K), K=1, NSM)	Card 7
READ (5,2) (ASW (K), K=1, NSW)	Card 8
READ (5,2) (FRSW (K), K=1, NSW)	Card 9
READ (5,2) (FIDSW (K), K=1, NSW)	Card 10
READ (5,2) RHO, SUBM, TWX, TIY, CDASX, AMC, AFAC, TMIN	Card 11
READ (5,2) TINV1, DT1, TOTT, DT2, DIR, TBH, TBYMX	Card 12
READ (5,3) (FLC (K), K=1, NCAB)	Card 13
READ (5,2) (DCI (K), K=1, NCAB)	Card 14
READ (5,2) (CDN (K), K=1, NCAB)	Card 15
READ (5,2) (CDT (K), K=1, NCAB)	Card 16
READ (5,2) (WC (K), K=1, NCAB)	Card 17
READ (5,4) (CM (K), K=1, NCAB)	Card 18
READ (5,3) (TREF (K), K=1, NCAB)	Card 19
READ (5,5) (C1 (K), K=1, NCAB)	Card 20
READ (5,2) (C2 (K), K=1, NCAB)	Card 21
READ (5,2) (CINT (K), K=1, NCAB)	Card 22
READ (5,2) (WBD (K), K=1, NCAB)	Card 23
READ (5,2) (CDABX (K), K=1, NCAB)	Card 24
READ (5,2) (CDABY (K), K=1, NCAB)	Card 25
READ (5,2) (XMBV (K), K=1, NCAB)	Card 26
READ (5,2) (YMBV (K), K=1, NCAB)	Card 27
READ (5,3) (YY (I), I=1, NCUR)	Card 28
READ (5,3) (CCK (I), I=1, NCUR)	Card 29
READ (5,2) (PHID (I), I=1, NCAB)	Card 30

READ (5,3) (TENI (I), I=1, NCAB)	Card 31
READ (5,2) (XPI (I), I=1, NCAB)	Card 32
READ (5,2) (YPI (I), I=1, NCAB)	Card 33

1000 CONTINUE

The corresponding FORMAT statements are:

```

1  FORMAT (24I3)
2  FORMAT (8F10.4)
3  FORMAT (8F10.2)
4  FORMAT (8F10.6)
5  FORMAT (8F10.0)
301 FORMAT (20A4)

```

Subroutine BUOY

READ (5,1) C0ASY, WAS, RWY, RTX, RTY, YCG, BIN	Card 34
READ (5,1) XSI, ZETI, SYDI, XPSI, ZTPI, SYPDI	Card 35

The corresponding FORMAT statement is:

```

1  FORMAT (8F10.4)

```

DEFINITION OF INPUT VARIABLES FOR MAIN PROGRAM

NCASES	Number of cases, NCASES ≥ 1
TITLE	Title
NSM ²	Number of surface motion components, $1 \leq \text{NSM} \leq 20$
NSW ³	Number of surface wave components, $1 \leq \text{NSW} \leq 20$
NCAB	Number of cable segments, $2 \leq \text{NCAB} \leq 50$
NCUR	Number of current profile points, $2 \leq \text{NCUR} \leq 10$
MTRC	MTRC ≤ 0 if input data are entered in English units; MTRC ≥ 1 if input data are entered in metric units
ITER	Iteration index
FSM(K) ²	$x_{SM} = \sum_{k=1}^{\text{NSM}} \text{AXSM}(K) * \cos (-2\pi * \text{FSM}(K) * t + \text{FIDSM}(K) * \pi * 180.)$
AXSM(K) ²	
AYSM(K) ²	$y_{SM} = \sum_{k=1}^{\text{NSM}} -\text{AYSM}(K) * \sin (-2\pi * \text{FSM}(K) * t + \text{FIDSM}(K) * \pi * 180.)$
FIDSM(K) ²	
ASW(K) ³	$x_{SW} = \sum_{k=1}^{\text{NSW}} \text{ASW}(K) * \cos (-2\pi * \text{FRSW}(K) * t + \text{FIDSW}(K) * \pi * 180.)$

FRSW(K) ³	$y_{sw} = \sum_{k=1}^{NSW} -ASW(K) * \sin(-2\pi * FRSW(K) * t + FIDSW(K) * \pi / 180.)$
FIDSW(K) ³	
RHO	Fluid density in slugs/feet ³ (kilograms/meters ³)
SUBM ⁴	Submergence of top point of cable below free surface in feet (meters)
TWX ⁴	Horizontal force acting at top of cable in pounds (newtons)
TIY	Vertical component of tension at top of cable in pounds (newtons)
CDASX ⁴	Drag area of surface buoy perpendicular to the x-axis in feet ² (meters ²)
AMC	Added mass coefficient of cable; AMC = 1.0 for round cable
AFAC	Cross-sectional area of cable = AFAC * $\pi d^2 / 4$; AFAC = 1.0 for round cable
TMIN	Minimum algebraic tension which can be supported by cable in pounds (newtons)
TINV1	Initial time interval in seconds for dynamic calculations
DT1	Time step in seconds for which printout is desired for $0 \leq t \leq TINV1$
TOTT	Total time in seconds for which dynamic calculations are desired
DT2	Time step in seconds for which printout is desired for $TINV1 < t \leq TOTT$
DIR	DIR < 0, if initial conditions are prescribed at the bottom (towing cable case); otherwise DIR ≥ 0
TBH	Applied force in pounds (newtons) on lower weight, body NCAB-i, in x-direction
TBYMX	Maximum absolute value in pounds (newtons) of tension in cable just below buoy; for buoy-cable system, set TBYMX equal to a large number, say, 99999
FLC(K)	Length of Kth cable segment in feet (meters)
DCI(K)	Diameter of Kth cable segment in inches (centimeters)
CDN(K)	Normal drag coefficient of Kth cable segment
CDT(K)	Tangential drag coefficient of Kth cable segment
WC(K)	Weight in fluid in pounds/foot (newtons/meter) of Kth cable segment at the reference cable tension
CM(K)	Mass of Kth cable segment in slugs/foot (kilograms/meter) at the reference cable tension
TREF(K)	Reference tension in pounds (newtons) of Kth cable segment
C1(K) ⁵ , C2(K)	Tension = TREF(K) + C1(K) * $\epsilon^{C2(K)}$ + CINT(K) * $\dot{\epsilon}$; for linearly elastic material, C1(K) = AE and C2(K) = 1
CINT(K)	
WBD(K)	Weight in fluid of Kth body in pounds (newtons)
CDABX(K) ⁶ , CDABY(K) ⁶	Drag area of Kth body in feet ² (meters ²) for flow in (x, y) directions
XMBV(K) ⁶ , YMBV(K) ⁶	Virtual mass (mass + added mass) in slugs (kilograms) of Kth body in (x, y) directions

YY(I) ⁷	Value of y in feet (meters)
CCK(I)	Value of current in knots (meters/second) at y = YY(I)
PHID(I) ⁸	Initial value of ϕ of Ith cable segment in degrees
TENI(I) ⁸	Initial value of tension of Ith cable segment in pounds (newtons)
XPI(I)	Initial value of $\dot{x}$ of Ith node in feet/second (meters/second)
YPI(I)	Initial value of $\dot{y}$ of Ith node in feet/second (meters/second)

DEFINITION OF INPUT VARIABLES FOR SURFACE BUOY

CDASY	Drag area for y-direction in feet ² (meters ²)
WAS	Weight in air in pounds (newtons)
RWY	Vertical distance of wind loading center of pressure from buoy center of gravity YCG in feet (meters)
RTX, RTY	(x, y) distance of cable attachment point from YCG in feet (meters)
YCG	Submergence of center of gravity below the free surface under the action of its own weight in air WAS and the vertical component of the steady-state tension (-TIY) in feet (meters)
BIN	Moment of inertia in air about YCG in slug feet ² (kilogram meters ²)
XSI, ZETI, SYDI ⁹	Initial values of (x, ζ , ψ) in (feet, feet, degrees)(meters, meters, degrees), where ζ is the vertical displacement of the center of gravity from its equilibrium value YCG
XPSI, ZTPI, SYPD1	Initial values of ($\dot{x}$, $\dot{\zeta}$, $\dot{\psi}$) in (feet/second, feet/second, degrees/second) (meters/second, meters/second, degrees/second)

EXPLANATORY NOTES

1. ITER = 0, no iteration (prescribed initial steady-state conditions)
 1. free-floating cable system
 2. moored cable with given length in given depth
 3. iteration scheme to be programmed by user
2. For $1000. \leq \text{FSM}(1) < 2000.$, the program makes the prescribed surface motion components equal to the surface wave components by setting $\text{AXSM}(K) = \text{AYSM}(K) = \text{ASW}(K)$, $\text{FSM}(K) = \text{FRSW}(K)$, and $\text{FIDSM}(K) = \text{FIDSW}(K)$ for $K = 1$ to $K = \text{NSM}$; the program automatically sets $\text{NSM} = \text{NSW}$.

For $2000. \leq \text{FSM}(1) < 3000.$, the program accepts input data for a spar buoy and considers $\text{AXSM}(K)$ to be the cross-sectional area of the buoy in feet² (meters²) at depth $\text{AYSM}(K)$ feet (meters) below the free surface. $\text{AYSM}(1) = 0$, and $\text{AYSM}(\text{NSM}) = \text{total draft}$ under the combined action of buoy weight in air and the vertical component of the

steady-state tension. NSM should be an odd number. The input values for FIDSM(K) may take on any values such as, say, 0.

For FSM(1) > 3000., the program accepts input data for a spheroidal buoy and considers AXSM(1) to be the radius of the buoy cross section at the free surface and AYSM(1) to be the total draft. The rest of the input values of AXSM(K) and AYSM(K) as well as all of the FIDSM(K) may take on any values, e.g., 0.

3. For ASW(1) > 1000., the program computes the amplitude of the ASW surface wave components by using the Pierson-Moskowitz sea spectrum. In these cases, the program considers the significant wave height in feet (meters) to be (ASW(1) - 1000.) and FRSW(1) and FRSW(2) to respectively be the lower and upper frequencies of the spectrum in cycles per second. The program internally generates the phases of the wave components by considering them to be uniformly separated by 360/NSW degrees. The phase of the lowest frequency component, in degrees, is taken to be the input value of FIDSW(1).

4. For the case of a surface buoy (FSM(1) ≥ 2000.), the program calculates the drag acting on the surface buoy due to the ocean current by taking the value of the ocean current SUBM feet (meters) below the free surface. Thus, 0 ≤ SUBM ≤ total draft.

The total horizontal force at the top point of the cable $TIX = TWX + (1/2)\rho * CDASX * CCF(SUBM) * ABS(CCF(SUBM))$. In cases where there is no surface buoy (i.e., prescribed surface motion), TWX and/or CDASX may be set equal to zero. For cases of a surface buoy, TWX represents the wind loading on the buoy in pounds (newtons).

5. For free-floating and towing cables where the last (K = NCAB) cable connecting the lower weight to the ocean bottom is fictitious, read in a value for C1(NCAB) less than 0.0001 pounds (0.0004 newtons). In these cases, the program sets DCI(NCAB) = CDN(NCAB) = CDT(NCAB) = WC(NCAB) = CM(NCAB) = CINT(NCAB) = 0, FLC(NCAB) = 2 * FLC(NCAB - 1), and C2(NCAB) = 1.

6. If CDABX(K) is negative, the program considers the body to be a circular disk with plane perpendicular to the x-axis and calculates drag and added mass forces by using the formulation given in Equation (55). In these cases, CDABX(K) is the negative of the actual drag area and XMBV(K) is the mass (not the virtual mass) of the disk. In these cases, CDABY(K) and YMBV(K) should be positive and retain the definitions given previously. Similar remarks apply if CDABY(K) is read in as a negative number except that the plane of the disk is now perpendicular to the y-axis.

7. When ITER = 2, the program takes YY(NCUR) to be the ocean depth.

8. For |PHID(1)| ≥ 360., the program takes the initial values of the angle and tension of each cable segment to correspond to their respective steady-state values at the midpoint of

each segment. These steady-state values have been previously calculated by the program. This approach will minimize transient dynamic effects. In these cases, input values for the remaining PHID(K) as well as all of the TENI(K) may be arbitrary, e.g. 0.

9. For SYDI $\geq 360.$, the program sets the initial value for buoy inclination ψ equal to the steady-state value of ψ , which has previously been calculated by the program. This will tend to minimize transient dynamic motions of the surface body.

PROGRAM STORAGE AND TIME REQUIREMENTS

On the CDC 6700 currently in use at the Center, the program requires a memory of approximately 47,200 octal words to load and 33,700 octal words to execute. Compilation time is approximately 23 seconds. Execution time for a particular case depends on a large number of factors, the most important of which include the tension-strain relation of the cable, the number of cable nodes, the frequencies of the exciting surface waves and the prescribed surface motion (if any), and the amount of time over which the dynamic motions are desired. Table 2 shows the computer execution time ET and cost for all of the sample problems presented in the following chapter. A computer priority (CP) of P2 indicates over-night priority whereas P3 is the standard daytime priority at the DTNSRDC Computer Center.

**TABLE 2 – COMPUTER EXECUTION TIMES AND COST
FOR ALL THE SAMPLE PROBLEMS**

<u>Prob.</u>	<u>NCAB-1</u>	<u>C1</u> <u>lb</u> <u>(4.45N)</u>	<u>C2</u>	<u>ET</u> <u>sec</u>	<u>CP</u>	<u>Total</u> <u>Cost</u> <u>\$</u>
1A	4	2.4×10^1	1.0	61.7	P2	9.93
1B	4	2.4×10^2	1.0	57.8	P2	9.56
1C	4	2.4×10^3	1.0	62.4	P2	9.99
1D	4	2.4×10^4	1.0	85.0	P2	12.00
1E	4	2.4×10^5	1.0	250.0*	P2	28.00*
1F	4	2.4×10^3	0.5	1000.0*	P2	100.00*
1G	4	2.4×10^3	2.0	55.2	P2	8.93
2A	1	2.4×10^3	1.0	9.3	P2	5.15
2B	2	2.4×10^3	1.0	25.1	P2	6.60
2C	4	2.4×10^3	1.0	62.4	P2	9.99
2D	8	2.4×10^3	1.0	180.0*	P2	20.00*
2E	15	2.4×10^3	1.0	600.0*	P2	60.00*
3A	4	2.0×10^1	1.0	90.0**	P3	15.00**
3B	4	2.0×10^1	1.0	100.0**	P3	16.00**
3C	4	2.0×10^1	1.0	100.0**	P3	16.00**
4A	4	****	****	82.6	P3	14.27
4B	4	****	****	74.2	P2	11.10
4C***	4	****	****	100.0*	P3	16.00*

- * Extrapolated to 50 sec of dynamic motion
- ** Extrapolated to 20 sec of deployment time
- *** Six surface wave components
- **** See Figure 11

SAMPLE PROBLEMS

Input cards are listed for the four sample problems presented to illustrate use of the program. Representative portions of the program output are listed for one of the cases of Problem 1, but only some final results are shown for the other three problems.

PROBLEM 1 – UNIFORM CABLE WITH VARIOUS TENSION-STRAIN RELATIONS

Problem: Compute the dynamic behavior of a cable suspended from an ocean platform in the presence of a uniform current of 1 knot in the +x-direction for different values of the elastic constants C_1 and C_2 appearing in Equation (47)

Case	C1 lb (4.45 N)	C2
A	2.4×10	1.0
B	2.4×10^2	1.0
C	2.4×10^3	1.0
D	2.4×10^4	1.0
E	2.4×10^5	1.0
F	2.4×10^3	0.5
G	2.4×10^3	2.0

The fixed surface motion, surface wave, cable, and lower body parameters are as follows:

Surface motion = surface wave:

number of components	1
frequency	0.1 cps
amplitude in x- and y-directions	10 ft (3.05 m)
phase angle	0 deg

Cable:

length	1000 ft (305 m)
diameter	0.2 in. (0.508 cm)
normal drag coefficient	1.4
tangential drag coefficient	0.02
weight in fluid	0.01 lb ft (0.146 N m)
mass	0.001 slugs ft (0.0478 kg/m)
reference tension	25 lb (111.2 N)
internal damping coefficient	0

Lower weight:

weight in fluid	20 lb (89 N)
drag area in x-direction	0.3 ft^2 (0.0279 m ²)
drag area in y-direction	0.3 ft^2 (0.0279 m ²)
virtual mass in x-direction	1.0 slugs (14.6 kg)
virtual mass in y-direction	1.0 slugs (14.6 kg)

Fluid density:

1.94 slugs/ft³ (1000.6 kg/m³)

Represent the cable by four equal segments, not including the fictitious cable segment below the lower weight. Dynamic motions are desired for a total of five cycles of the surface motions, i.e. 50 sec. For the initial interval of 10 sec. print out the transient motions every

0.25 sec. For the final 40 sec, increase the printout interval to 1.0 sec. Let the cable start from rest with the initial angle and tension of each segment equal to the steady-state values.

Solution: The data cards for this problem are listed in Table 3. The cards which are the same for all the cases are listed at the top of the table. The cards for the title and the elastic constants C1 and C2, which differ for each case, are listed at the bottom of the table. The symbol b denotes a blank in this and subsequent tables which list data cards for the sample problems. Also, Column 1, 11, 21, 31, 41, 51, 61, and 71 have been indicated since most of the data start in these columns.

TABLE 3 – INPUT DATA FOR SAMPLE PROBLEM 1

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 3	bb1bb1bb5bb2bb0							
Card 4	0.1							
Card 5	10.0							
Card 6	10.0							
Card 7	0.							
Card 8	10.0							
Card 9	0.1							
Card 10	0.							
Card 11	1.94	0.	0.	-50.	0.	1.0	1.0	0.
Card 12	10.	0.25	50.	1.0	-1.0	0.	99999.	
Card 13	250.	250.	250.	250.				
Card 14	0.2	0.2	0.2	0.2				
Card 15	1.4	1.4	1.4	1.4				
Card 16	0.02	0.02	0.02	0.02				
Card 17	0.01	0.01	0.01	0.01				
Card 18	0.001	0.001	0.001	0.001				
Card 19	25.	25.	25.	25.				
Card 22	0.	0.	0.	0.				
Card 23	0.	0.	0.	20.				
Card 24	0.	0.	0.	0.3				
Card 25	0.	0.	0.	0.3				
Card 26	0.	0.	0.	1.0				
Card 27	0.	0.	0.	1.0				
Card 28	0.	10000.						
Card 29	1.	1.						

TABLE 3 – (continued)

	1	11	21	31	41	51	61	71
Card 30	999.	0.	0.	0.				
Card 31	0.	0.	0.	0.				
Card 32	0.	0	0.	0.				
Card 33	0.	0.	0.	0.				
Card 2	bbb PROBLEM 1A, C1 = 24, C2 = 1							
Card 20	24.	24.	24.	24.				
Card 21	1	1.	1.	1.				
Card 2	bbb PROBLEM 1B, C1 = 240, C2 = 1							
Card 20	240.	240.	240.	240.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1C, C1 = 2400, C2 = 1							
Card 20	2400.	2400.	2400.	2400.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1D, C1 = 24000, C2 = 1							
Card 20	24000.	24000.	24000.	24000.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1E, C1 = 240000, C2 = 1							
Card 20	240000.	240000.	240000.	240000.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1F, C1 = 2400, C2 = 0.5							
Card 20	2400.	2400.	2400.	2400.				
Card 21	0.5	0.5	0.5	0.5				
Card 2	bbb PROBLEM 1G, C1 = 2400, C2 = 2							
Card 20	2400.	2400.	2400.	2400.				
Card 21	2.0	2.0	2.0	2.0				

Table 4 shows the first six and the last two pages of the computer output for Problem 1D. The pages which have been left out simply contain output for the dynamic motions for intermediate time intervals. Table 4 shows that the first page of the output lists a table of conversion from English to metric units. The second page lists the input data. For the present case of a suspended cable, where the initial conditions are known at the lower body, two integrations are performed for the steady-state configuration (see section on Initial Value Cases). The results of these two integrations are given in the next two pages. The remainder of the output is a listing of the dynamic displacements, velocities, and accelerations of the surface waves, upper cable point, and each node at the prescribed time intervals. The output also lists the angle, angular velocity, tension, strain, and strain rate of each cable segment.

TABLE 4 - PROGRAM OUTPUT FOR PROBLEM 1D

CONVERSION FROM ENGLISH UNITS TO METRIC UNITS

ENGLISH	METRIC
1 INCH=	2.540 CM
1 FOOT=	0.3048 METERS
1 SQ FT=	0.09290 SQ M
1 CU FT=	0.02831 CU M
1 POUND=	4.452 NEWTONS
1 SLUG=	14.607 KGM
1 SECOND=	1 SECOND
1 KNOT=	0.5144M/SEC

TABLE 4 -- (continued)

PROBLEM 1D.C1=24000.C2=1

LISTING OF ENVIRONMENTAL AND CABLE-BUOY CHARACTERISTICS

OCEAN CONDITIONS

SURFACE WAVE- FREQ(CPS) AMPL(FT) PHASE(D) WL(FT) WK(1/FT)
 .10 10.00 0.00 512.40 .0123

CURRENT PROFILE DEPTH(FT) CURR(FT)
 0.00 1.00
 10000.00 1.00

FLUID DENSITY= 1.9400 SL/GUFT

SURFACE MOTION-FREQ(CPS) X-A(FT) Y-A(FT) PHASE(DEG)
 .1000 10.0000 10.0000 0.0000

GENERAL CABLE CHARACTERISTICS

AM COEFF AREA FAC T MIN(LB)
 1.0000 1.0000 0.00

CABLE PROPERTIES				BODY PROPERTIES											
NUM	LEN(FT)	DIAM(IN)	CDM	GOI	W(LB/FT)	M(SL/FT)	T REF(LB)	C1(LB)	EXP C2	CINT(LB)	COAX(F2)	COAT(F2)	WT(LB)	XVM(SL)	YVM(SL)
1	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
2	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
3	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
4	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	20.000	1.0000	1.0000
5	500.00	0.0000	0.0000	0.0000	0.0000	.000000	0.00	0.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000

K-LOAD ON GOI WT= 0.0000 LB

SURFACE BUOY CHARACTERISTICS

SUBM(FT) WIND LO(LB) COAX(FISQ) MAX TEN(LB)
 0.0000 0.0000 0.0000 99999.0000

INITIAL VALUES AT TOP OF CABLE
 XA= 10.0000 YA= 0.0000 XVA= 0.0000 YVA= 6.2032

TABLE 4 - (continued)

RUN NUMBER 1		STEADY-STATE CONFIGURATION						
PIX=	.03	TIY=	20.00	DIRECTION=	-1.00			
MODE	S	REF(FT)	S	STR(FT)	X(FT)	Y(FT)	TEN(LB)	PHIS(DEC)
0	3.03	125.00	124.98	0.03	10.00	0.00	23.02	177.63
4	250.00	249.96	249.96	124.98	-17.97	-121.13	21.24	157.34
3	250.00	249.96	249.96	249.96	-83.72	-228.86	22.34	143.28
3	375.00	374.95	374.95	374.95	-163.02	-322.84	23.33	143.28
3	500.00	499.94	499.94	499.94	-258.39	-483.68	24.21	134.02
2	523.03	522.94	522.94	522.94	-359.72	-633.68	24.21	127.99
2	625.03	624.94	624.94	624.94	-465.24	-768.83	25.02	123.92
1	750.00	749.94	749.94	749.94	-573.50	-883.82	25.77	121.07
1	875.03	874.95	874.95	874.95	-683.63	-999.96	26.48	119.82
1	1000.03	999.96	999.96	999.96	-683.63	-665.45	27.16	117.52
0	1000.00	999.96	999.96	999.96	-683.63	-665.45	27.16	117.52
X-COMPONENT OF TENSION= -24.09 LB								
Y-COMPONENT OF TENSION= -12.55 LB								
REVISED VALUE OF WIND LO= -24.0654 LB								
INITIAL VALUES AT TOP OF CABLE								
XA=	10.3703	YA=	0.3003	XVA=	0.3303	YVA=	6.2832	

TABLE 4 -- (continued)

RUN NUMBER 1

STEADY-STATE CONFIGURATION

YIX=	-24.09	TIV=	-12.55	DIRECTION=	1.00
MODE S REF(FT)	S STRIFT)	X(FT)	Y(FT)	TEN(LB)	PHIS(DEC)
0	0.00	0.00	0.00	27.16	-62.10
1	125.00	125.01	120.13	59.14	-68.98
1	250.00	250.02	228.39	121.63	-58.93
1	250.00	250.02	228.39	121.63	-58.93
2	375.00	375.02	333.91	188.62	-56.98
2	500.00	500.02	435.24	261.77	-52.81
2	500.00	500.02	435.24	261.77	-52.81
3	625.00	625.01	529.81	343.41	-45.98
3	750.00	750.03	612.91	436.60	-36.80
3	750.00	750.03	612.91	436.60	-36.80
4	875.00	874.98	675.66	544.32	-22.66
4	1000.00	999.96	703.63	665.45	-2.37
4	1000.00	999.96	703.63	665.45	-2.37
5	1250.00	1279.45	424.63	648.81	93.41
5	1500.00	1558.95	145.63	632.17	93.41
5	1500.00	1558.95	145.63	632.17	93.41

X-COMPONENT OF TENSION= -.00 LB
Y-COMPONENT OF TENSION= -.00 LB

CABLE INITIAL CONDITIONS

MODE	PHI(DEC)	TEN(LB)	X(FT)	Y(FT)	XV(FT/S)	YV(FT/S)
1	-63.9757	26.48	228.62	121.30	0.0000	0.0000
2	-56.0834	25.02	436.88	260.80	0.0000	0.0000
3	-45.9844	23.33	615.85	434.50	0.0000	0.0000
4	-22.6616	21.24	712.16	665.16	0.0000	0.0000
5	93.4133	.00	154.16	631.88	0.0000	0.0000

TIME INFORMATION

INITIAL TIME INTERVAL= 10.000 SEC TIME STEP= .2500 SEC
TOTAL TIME= 50.000 SEC TIME STEP= 1.0000 SEC

TABLE 4 - (continued)

COMPUTED CABLE SYSTEM MOTIONS AND TENSIONS

NUM	T (SEC)	DT (SEC)	X (FT)	Y (FT)	XPI (FT/S)	VP (FT/S)	KPP (F/SS)	VPP (F/SS)	TEN (LB)	FI (DEG)	FIP (O/S)	STRAIN STP (1/1)
WAVE	.2500	.003006	9.00	1.56	-1.9029	6.2050	-3.0992	-6.176	17.93	-61.38	-1.70	.000315 .000950
0	.2500	.003006	9.00	1.56	-1.9029	6.2050	-3.0992	-6.176	17.93	-61.38	-1.70	.000315 .000950
1	.2500	.003006	229.26	121.28	2.7690	1.6805	-11.1273	-8.4333	10.05	-55.99	.43	.000506 .001506
2	.2500	.003006	436.36	261.06	2.0676	1.6805	-11.0352	-10.2809	5.58	-45.90	.07	.000809 .002274
3	.2500	.003006	615.59	434.04	1.7831	1.7836	4.7333	-1.1113	6.75	-22.64	.23	.000864 .000929
4	.2500	.003006	712.16	665.16	-1.0653	.5736	5.0006	12.2671	.00	93.61	.06	.117973 .000436
WAVE	.5000	.001953	9.51	3.09	-1.9616	5.9757	-3.7566	-1.2280	11.24	-61.01	-1.76	.000573 .000117
0	.5000	.001953	9.51	3.09	-1.9616	5.9757	-3.7566	-1.2280	11.24	-61.01	-1.76	.000573 .000117
1	.5000	.001953	229.72	121.12	1.7157	1.7065	9.1461	5.7000	13.95	-55.09	.42	.000401 .004300
2	.5000	.001953	436.62	261.26	1.6859	1.3270	17.0053	15.9003	10.02	-45.90	.12	.000291 .003242
3	.5000	.001953	616.34	434.93	1.0106	2.2826	2.7311	7.1357	19.21	-22.59	.19	.000241 .000321
4	.5000	.001953	712.36	665.69	1.0099	2.0691	-6.365	-1.3366	.00	93.67	.27	.110643 .002499
WAVE	.7500	.015625	0.91	4.54	-2.0525	5.5904	-3.5176	-1.7923	40.71	-62.25	-1.74	.000655 .000260
0	.7500	.015625	0.91	4.54	-2.0525	5.5904	-3.5176	-1.7923	40.71	-62.25	-1.74	.000655 .000260
1	.7500	.015625	230.30	121.03	.6373	-1.1672	-16.5216	-7.2067	32.31	-55.70	.37	.000305 .005235
2	.7500	.015625	437.00	261.67	.0005	.9802	-19.9169	-16.6330	24.32	-45.95	.07	.000020 .003793
3	.7500	.015625	616.76	435.99	1.2762	1.7085	-6.7719	-6.9015	20.64	-22.55	.12	.000173 .001001
4	.7500	.015625	712.62	666.33	.9916	2.4159	-.9024	-2.2004	.00	93.53	.26	.119063 .002276
WAVE	1.0000	.003006	0.09	5.00	-3.0932	5.0032	-3.1939	-2.3205	46.04	-62.60	-1.69	.000077 .003160
0	1.0000	.003006	0.09	5.00	-3.0932	5.0032	-3.1939	-2.3205	46.04	-62.60	-1.69	.000077 .003160
1	1.0000	.003006	230.40	120.73	.1920	-1.1130	-1.7409	.0075	42.00	-55.69	.35	.000749 .002296
2	1.0000	.003006	437.05	261.25	.0077	.6679	-2.1330	-2.2960	40.03	-45.94	.04	.000651 .000999
3	1.0000	.003006	616.83	435.78	.0507	.7026	-4.3969	-7.2701	36.07	-22.55	.05	.000661 .003075
4	1.0000	.003006	712.77	666.69	-.1256	-.1931	-5.4790	-13.0703	.00	93.57	.02	.119371 .000275
WAVE	1.2500	.007013	7.07	7.07	-4.4629	4.4629	-2.7915	-2.7915	50.20	-63.09	-1.63	.001050 .003600
0	1.2500	.007013	7.07	7.07	-4.4629	4.4629	-2.7915	-2.7915	50.20	-63.09	-1.63	.001050 .003600
1	1.2500	.007013	230.24	120.33	-2.0316	-2.2301	-2.9597	-1.3702	43.65	-55.62	.19	.000777 .000541
2	1.2500	.007013	436.74	261.68	-2.3060	-1.5741	-1.0034	-1.6221	39.03	-45.97	.21	.000610 .000610
3	1.2500	.007013	616.59	435.46	-1.6580	-2.1142	-3.7315	-5.0021	32.24	-22.50	.16	.000302 .000626
4	1.2500	.007013	712.62	666.36	-.9355	-2.2422	-2.0039	-7.0023	.00	93.53	.22	.119063 .002164
WAVE	1.5000	.015625	5.00	0.09	-5.0032	3.0932	-2.3205	-3.1939	47.34	-63.49	-1.52	.000931 .000070
0	1.5000	.015625	5.00	0.09	-5.0032	3.0932	-2.3205	-3.1939	47.34	-63.49	-1.52	.000931 .000070
1	1.5000	.015625	229.79	119.08	-2.1106	-2.2264	-6.1964	-2.7707	39.17	-55.50	.13	.000590 .000000
2	1.5000	.015625	436.14	261.19	-2.4467	-1.7535	-6.7735	-2.3253	33.57	-46.03	.26	.000357 .000917
3	1.5000	.015625	616.13	434.83	-1.0297	-2.7232	-.5994	-3.2663	26.58	-22.63	.16	.000066 .002231
4	1.5000	.015625	712.32	665.61	-1.3350	-3.5067	.0909	-.1930	.00	93.46	.35	.110341 .003200
WAVE	1.7500	.031250	4.54	6.91	-5.5904	2.0525	-1.7923	-3.5176	43.66	-63.05	-1.37	.000777 .000032
0	1.7500	.031250	4.54	6.91	-5.5904	2.0525	-1.7923	-3.5176	43.66	-63.05	-1.37	.000777 .000032
1	1.7500	.031250	229.12	114.10	-2.9610	-2.2355	.4640	1.1000	36.77	-55.56	.05	.000490 .000470
2	1.7500	.031250	435.41	260.61	-2.9759	-2.3037	2.9253	2.4303	33.47	-46.10	.29	.000369 .000942
3	1.7500	.031250	615.62	434.83	-1.0972	-3.1255	-.0642	1.0020	27.52	-22.67	.16	.000105 .000315
4	1.7500	.031250	711.90	664.75	-1.3609	-3.4732	-.0662	-.00106	.00	93.37	.35	.117563 .003162
WAVE	2.0000	.031250	3.09	9.51	-5.9757	1.9616	-1.2280	-3.7566	50.53	-64.17	-1.17	.001064 .000577
0	2.0000	.031250	3.09	9.51	-5.9757	1.9616	-1.2280	-3.7566	50.53	-64.17	-1.17	.001064 .000577
1	2.0000	.031250	22	35	-3.6107	-2.6125	-6.2274	-1.2244	40.33	-55.56	.01	.000639 .001160
2	2.0000	.031250	431	5	-3.2855	-2.5020	-3.2843	-2.4069	35.12	-46.10	.32	.000422 .000002
3	2.0000	.031250	615.11	433.22	-2.1016	-3.4292	-1.4336	-1.0211	27.50	-22.71	.18	.000104 .004651
4	2.0000	.031250	711.03	663.06	-1.4097	-3.5750	-.7370	-.7355	.00	93.20	.36	.110766 .003220

TABLE 4 - (continued)

WAVE	2.2500	.031250	1.56	9.04	-6.2850	-.9029	-.6176	-3.0992	50.10	-4.43	-.96	.001206	.001329
0	2.2500	.031250	1.56	7.02	-6.2850	-.9029	-.6176	-3.0992	49.66	-55.53	-.12	.000661	.000990
1	2.2500	.031250	227.36	117.92	-6.1318	-2.5023	-2.3069	.0657	40.38	-66.26	-.23	.000661	.000644
2	2.2500	.031250	632.77	239.26	-3.6626	-2.6994	-2.0911	-1.6997	31.94	-22.76	-.22	.000209	.000097
3	2.2500	.031250	616.52	432.31	-2.5096	-3.7910	-1.3693	-1.0097	.00	93.19	-.61	.115909	-.003721
4	2.2500	.031250	711.25	662.91	-1.6329	-6.1337	-1.1049	-2.0428	.00				
WAVE	2.5000	.031250	.00	16.00	-6.2832	-.0000	-.0000	-3.9678	61.99	-.66	-.69	.001561	.000495
0	2.5000	.031250	.00	10.00	-6.2832	-.0000	-.0000	-3.9678	49.97	-55.62	-.21	.001060	.000630
1	2.5000	.031250	226.25	117.26	-6.0426	-2.6659	-2.2602	.0337	46.85	-66.35	-.19	.000796	.000639
2	2.5000	.031250	632.79	250.50	-3.3497	-3.3497	-1.2950	-1.0998	36.48	-22.82	-.25	.000395	.000465
3	2.5000	.031250	613.63	411.27	-2.1097	-6.4952	-1.2693	-2.1791	.00	91.08	-.68	.115909	-.002800
4	2.5000	.031250	710.41	661.00	-1.0006	-6.7979	-1.0966	-2.0271	.00				
WAVE	2.7500	.031252	-1.56	9.04	-6.2050	-.9029	-.6176	-3.0992	65.32	-66.77	-.62	.001600	.000391
0	2.7500	.031250	-1.56	7.02	-6.2050	-.9029	-.6176	-3.0992	52.51	-55.66	-.38	.001166	.000326
1	2.7500	.031250	226.96	116.69	-5.3687	-2.5982	-2.0700	.1366	46.03	-66.46	-.63	.000876	.000100
2	2.7500	.031250	631.69	237.71	-4.5360	-3.6275	-1.6296	-1.6923	35.84	-27.00	-.27	.000652	.000069
3	2.7500	.031250	613.06	430.08	-3.1096	-6.9664	-.9090	-1.6923	.00	92.95	-.56	.113769	-.000795
4	2.7500	.031250	710.31	660.52	-2.1223	-5.6622	-.6662	-1.7000	.00				
WAVE	3.0000	.031250	-3.09	9.51	-5.9757	-1.9616	1.2200	-3.7566	66.37	-66.04	-.16	.001726	.000056
0	3.0000	.031250	-3.09	7.02	-5.9757	-1.9616	1.2200	-3.7566	53.65	-55.77	-.38	.001166	.000003
1	3.0000	.031250	223.30	115.96	-5.7077	-2.4795	-.9657	-.6904	46.94	-66.57	-.65	.000916	.000077
2	3.0000	.031250	630.52	256.77	-4.7537	-3.6847	-.3222	-.6030	36.52	-22.95	-.20	.000400	.000017
3	3.0000	.031250	610.24	428.48	-3.3746	-5.2736	-.3950	-.6030	.00	92.61	-.50	.112933	-.000060
4	3.0000	.031250	709.76	659.12	-2.2597	-5.7426	-.6104	-1.0164	.00				
WAVE	3.2500	.062500	-.66	8.91	-5.5906	-2.0525	1.7923	-3.5176	66.25	-66.04	-.15	.001719	.000166
0	3.2500	.062500	-.66	8.91	-5.5906	-2.0525	1.7923	-3.5176	53.65	-55.87	-.65	.001166	.000067
1	3.2500	.062500	222.14	115.17	-5.0078	-2.2400	-.8650	-.0178	46.07	-66.66	-.66	.000916	.000060
2	3.2500	.062500	629.31	255.88	-4.0156	-3.5316	-.8040	-.1066	36.36	-22.82	-.26	.000473	.000041
3	3.2500	.062500	611.30	427.86	-3.4942	-5.4621	-.3225	-.2100	.00	92.66	-.60	.112768	-.000179
4	3.2500	.062500	709.13	657.66	-2.3100	-5.6912	-.3363	-.2793	.00				
WAVE	3.5000	.062500	-5.46	8.09	-5.0032	-3.6937	1.3205	-3.1939	66.66	-66.77	-.63	.001652	.000356
0	3.5000	.062500	-5.46	8.09	-5.0032	-3.6937	1.3205	-3.1939	53.60	-55.99	-.51	.001190	.000107
1	3.5000	.062500	220.65	114.02	-4.9505	-2.0643	.0647	1.0753	46.20	-66.80	-.65	.000803	.000107
2	3.5000	.062500	628.13	254.81	-4.7952	-3.9178	.6225	.2130	35.00	-22.95	-.78	.000454	.000163
3	3.5000	.062500	610.52	426.11	-3.6301	-5.3919	.1910	.2715	.00	92.51	-.60	.109992	-.000176
4	3.5000	.062500	700.61	656.19	-2.3310	-5.9924	.3365	.2715	.00				
WAVE	3.7500	.062500	-7.07	7.07	-4.6629	-4.6629	2.7915	-2.7915	61.00	-66.63	-.69	.001533	.000601
0	3.7500	.062500	-7.07	7.07	-4.6629	-4.6629	2.7915	-2.7915	50.01	-56.13	-.55	.001075	.000377
1	3.7500	.062500	219.17	114.35	-5.0769	-1.7450	.6425	1.2207	46.71	-66.91	-.64	.000801	.000246
2	3.7500	.062500	626.95	253.46	-4.0876	-3.0201	.0026	.5229	36.74	-23.16	-.27	.000600	.000226
3	3.7500	.062500	609.57	424.77	-3.1505	-5.2736	.6761	.6096	.00	92.36	-.59	.100669	.000072
4	3.7500	.062500	700.03	654.72	-2.2991	-5.7933	.2101	.6662	.00				
WAVE	4.0000	.031250	-6.09	5.00	-3.6932	-5.0032	3.1939	-2.3295	57.61	-66.63	-.96	.001359	.000002
0	4.0000	.031250	-6.09	5.00	-3.6932	-5.0032	3.1939	-2.3295	46.80	-56.27	-.50	.000956	.000550
1	4.0000	.031250	217.72	113.95	-3.6526	-1.6931	1.1720	1.2039	42.37	-67.02	-.61	.000726	.000557
2	4.0000	.031250	625.03	252.91	-4.3695	-3.0624	.7770	1.1073	33.00	-23.22	-.25	.000337	.000330
3	4.0000	.031250	600.85	423.46	-3.2800	-5.0825	.2220	1.1795	.00	92.22	-.57	.107626	.000669
4	4.0000	.031250	707.66	653.30	-2.2206	-5.5652	.6100	1.1795	.00				
WAVE	4.2500	.031250	-8.01	6.56	-2.0525	-5.5906	3.5176	-1.7923	52.24	-66.16	1.17	.001135	.000976
0	4.2500	.031250	-8.01	6.56	-2.0525	-5.5906	3.5176	-1.7923	46.25	-56.42	-.60	.000802	.000692
1	4.2500	.031250	216.35	113.62	-3.2095	-1.1235	1.7361	1.3593	39.23	-67.12	-.30	.000593	.000535
2	4.2500	.031250	624.79	252.02	-3.9091	-3.3061	.16530	1.5076	30.62	-23.20	-.23	.000262	.000426
3	4.2500	.031250	606.00	422.26	-2.9646	-5.7160	.1036	1.5076	.00	92.60	-.53	.102646	.000455
4	4.2500	.031250	706.92	651.95	-2.0090	-5.2059	.6200	1.7066	.00				
WAVE	4.5000	.031250	-9.51	3.09	-1.9616	-5.9757	3.7566	-1.2200	66.04	-62.05	1.36	.000877	.001003
0	4.5000	.031250	-9.51	3.09	-1.9616	-5.9757	3.7566	-1.2200	36.76	-56.57	-.60	.000635	.000796
1	4.5000	.031250	215.09	113.3	-4.7970	-.7796	2.3306	1.6093	35.43	-67.21	-.36	.000439	.000672
2	4.5000	.031250	623.65	251.21	-3.5270	-.6032	2.9312	2.0693	20.00	-23.36	-.20	.000127	.000400
3	4.5000	.031250	607.37	421.33	-2.6695	-6.2562	1.0671	2.0693	.00	91.95	-.60	.105196	.000430
4	4.5000	.031250	700.62	658.71	-1.0955	-6.7110	.0671	2.2552	.00				

TABLE 4 - (continued)

MAVE 36.0000 .015625	-0.09	-5.00	3.6932	-9.0032	3.1939	2.3295	16.01	-60.89	1.60--000341--000202
0 36.0000 .015625	-0.09	-5.00	3.6932	-5.0032	3.1939	2.3295	16.01	-60.89	-20--000357--000216
1 36.0000 .015625	218.25	115.72	-0.006	1.2855	3.7552	1.4006	16.52	-50.15	00--000381--000105
2 36.0000 .015625	422.56	267.50	0.9552	-2.066	3.3660	2.4950	15.06	-49.17	06--000431--000326
3 36.0000 .015625	611.64	410.97	-4.297	-6.631	2.6273	3.6580	16.05	-22.20	06--000431--000326
4 36.0000 .015625	786.09	642.36	-1.020	-5.346	1.6389	6.1922	.00	91.89	06--000431--000326
MAVE 37.0000 .015625	-3.09	-9.51	5.9757	-1.9416	1.2200	3.7546	11.02	-59.43	1.15--000509--000479
0 37.0000 .015625	-3.09	-9.51	5.9757	-1.9416	1.2200	3.7546	11.02	-59.43	-08--000509--000364
1 37.0000 .015625	212.04	117.57	3.3276	2.3059	2.0386	-7.946	12.00	-50.29	23--000513--000312
2 37.0000 .015625	424.62	240.90	3.2612	2.6408	2.2367	1.6620	12.00	-60.99	20--000570--000234
3 37.0000 .015625	613.19	412.04	2.5463	2.9432	2.0966	1.7072	13.73	-22.03	34--000570--000234
4 37.0000 .015625	786.91	644.40	1.3957	3.3455	-9.776	2.1791	.00	91.31	34--000570--000234
MAVE 38.0000 .031250	3.39	-9.51	5.9757	1.9416	-1.2199	3.7546	4.06	-50.73	-20--000600--000130
0 38.0000 .031250	3.39	-9.51	5.9757	1.9416	-1.2199	3.7546	4.06	-50.73	-22--000729--000110
1 38.0000 .031250	216.59	120.14	5.4890	2.0755	1.2605	-1.102	7.50	-50.18	26--000704--000100
2 38.0000 .031250	426.07	251.06	4.9536	3.0030	-7.966	-6.102	8.10	-60.75	69--000612--000005
3 38.0000 .031250	616.70	416.57	6.1739	4.3319	-7.919	-7.774	10.30	-21.62	52--000707--000469
4 38.0000 .031250	789.74	646.06	2.1793	5.1040	-3.017	-9.143	.00	91.75	-08--000670--000540
MAVE 39.0000 .042500	8.09	-5.00	3.6932	5.0032	-3.1939	2.3295	8.91	-59.06	-48--000626--000306
0 39.0000 .042500	8.09	-5.00	3.6932	5.0032	-3.1939	2.3295	8.91	-59.06	-48--000626--000306
1 39.0000 .042500	222.37	122.50	5.4094	3.5594	-1.0550	-1.2597	9.99	-57.07	-19--000177--000460
2 39.0000 .042500	433.94	255.47	4.8362	3.5594	-1.1050	-5.377	10.50	-60.60	-48--000626--000306
3 39.0000 .042500	621.01	421.04	6.1614	4.4672	-0.9353	-6.925	11.95	-21.12	-48--000626--000306
4 39.0000 .042500	711.03	646.17	2.2300	5.2593	-3.3767	-0.932	.00	92.79	-53--000617--000477
MAVE 40.0000 .081250	10.00	-1.00	-0.000	6.2032	-3.9070	-0.000	25.44	-60.31	-1.50--000010--000069
0 40.0000 .081250	10.00	-1.00	-0.000	6.2032	-3.9070	-0.000	25.44	-60.31	-47--000096--000543
1 40.0000 .081250	227.10	123.44	3.5610	-3.759	-3.1215	-1.9196	22.69	-57.41	-19--000177--000460
2 40.0000 .081250	437.79	258.40	2.5602	2.1936	-2.9943	-2.0461	20.76	-60.26	-19--000177--000460
3 40.0000 .081250	624.30	424.49	2.0959	3.2953	-2.6390	-2.4320	20.42	-20.76	-33--000191--000332
4 40.0000 .081250	712.90	646.62	1.5652	3.2953	-1.2020	-3.0151	.00	92.74	-33--000191--000332
MAVE 41.0000 .007013	8.09	5.00	-3.6932	5.0032	-3.1939	-2.3295	30.13	-62.01	-1.72--000507--000367
0 41.0000 .007013	8.09	5.00	-3.6932	5.0032	-3.1939	-2.3295	30.13	-62.01	-32--000362--000254
1 41.0000 .007013	220.97	123.26	-0.955	-1.4902	-3.0290	-1.6231	33.69	-57.00	-05--000236--000217
2 41.0000 .007013	430.71	259.49	-7.963	-2.2902	-3.2426	-2.6202	30.06	-60.17	-26--000225--000355
3 41.0000 .007013	625.04	426.25	-5.979	-6.565	-2.2310	-3.7052	25.45	-20.73	-10--000019--000020
4 41.0000 .007013	713.52	646.07	-1.033	-5.000	-1.4406	-4.0326	.00	92.09	-06--000139--000425
MAVE 42.0000 .015625	3.09	9.51	-5.9757	1.9416	-1.2200	-3.7546	53.04	-62.51	-1.17--000122--000441
0 42.0000 .015625	3.09	9.51	-5.9757	1.9416	-1.2200	-3.7546	53.04	-62.51	-00--000020--000014
1 42.0000 .015625	227.11	121.16	-3.5140	-2.5250	-3.0219	-5.500	44.67	-50.83	-32--000362--000254
2 42.0000 .015625	436.54	258.00	-3.3943	-2.6202	-2.2160	-1.0996	39.04	-60.37	-26--000225--000355
3 42.0000 .015625	623.51	424.26	-2.3567	-3.6005	-1.5061	-2.9600	30.40	-20.91	-30--000422--000263
4 42.0000 .015625	712.77	657.04	-1.2000	-3.7267	-1.0017	-2.9046	.00	92.66	-30--000422--000263
MAVE 43.0000 .031250	-3.09	9.51	-5.9757	-1.9416	1.2199	-3.7546	67.20	-60.10	-14--000170--000100
0 43.0000 .031250	-3.09	9.51	-5.9757	-1.9416	1.2199	-3.7546	67.20	-60.10	-33--000139--000174
1 43.0000 .031250	222.36	118.57	-5.6677	-2.6702	-1.5925	-5.996	54.73	-57.00	-49--000974--000157
2 43.0000 .031250	432.20	254.01	-6.0622	-3.6016	-0.9549	-0.500	40.37	-60.79	-35--000044--000096
3 43.0000 .031250	620.54	419.77	-3.4199	-5.2365	-0.3310	-0.174	36.13	-21.23	-50--000422--000263
4 43.0000 .031250	711.09	652.02	-1.9032	-5.7654	-0.3759	-0.9709	.00	92.16	-50--000422--000263
MAVE 44.0000 .031250	-0.09	5.00	-3.6932	-5.0032	3.1939	-2.3295	59.06	-62.77	-93--000163--000794
0 44.0000 .031250	-0.09	5.00	-3.6932	-5.0032	3.1939	-2.3295	59.06	-62.77	-53--000163--000794
1 44.0000 .031250	216.50	116.52	-5.6600	-3.5507	1.5925	1.2006	50.46	-57.45	-46--000020--000053
2 44.0000 .031250	427.44	251.19	-6.5370	-3.5507	1.5925	1.2006	46.06	-60.20	-46--000020--000053
3 44.0000 .031250	617.07	414.43	-3.3770	-5.1326	-7.009	1.0330	33.01	-21.50	-33--000359--000320
4 44.0000 .031250	709.03	646.09	-2.0105	-5.7370	-3.369	1.0050	.00	91.56	-59--000151--000460

TABLE 4 - (continued)

WAVE	55.0000	.031250	-10.00	--.0000	-6.2032	3.9070	--.0000	34.00	-02.00	1.01	.000000	-.001115
1	55.0000	.031250	-10.00	--.0000	-6.2032	3.9070	--.0000	34.00	-02.00	.00	.000000	-.000000
2	55.0000	.031250	211.76	-3.0000	-6.1909	3.0029	1.0232	31.07	-07.00	.00	.000000	-.000000
3	55.0000	.031250	623.10	-2.9206	-2.1019	2.7042	1.9556	20.00	-00.00	.00	.000000	-.000000
4	55.0000	.031250	616.32	-1.9100	-3.1166	1.0001	3.0199	22.02	-21.00	.00	.000000	-.000000
5	55.0000	.031250	707.32	-1.2710	-3.5160	1.1004	3.2102	.00	91.07	.00	.000000	-.000000
WAVE	56.0000	.015625	-0.00	3.0032	-9.0032	3.1039	2.3209	10.00	-00.00	1.07	.000000	-.000000
1	56.0000	.015625	-0.00	3.0032	-9.0032	3.1039	2.3209	10.00	-00.00	.00	.000000	-.000000
2	56.0000	.015625	209.99	-0.020	1.2011	3.7010	1.0070	10.00	-00.00	.00	.000000	-.000000
3	56.0000	.015625	622.01	-0.7951	-1.0001	3.3007	2.9001	10.00	-00.00	.00	.000000	-.000000
4	56.0000	.015625	610.70	.3000	.0000	2.0000	3.0000	10.00	-00.00	.00	.000000	-.000000
5	56.0000	.015625	700.70	.1000	.0000	1.0000	2.0000	10.00	-00.00	.00	.000000	-.000000
WAVE	57.0000	.015625	-3.00	3.9797	-1.9016	1.2000	3.7906	11.70	-00.00	1.10	.000000	-.000000
1	57.0000	.015625	-3.00	3.9797	-1.9016	1.2000	3.7906	11.70	-00.00	.00	.000000	-.000000
2	57.0000	.015625	211.70	3.2000	2.2000	2.0000	2.0000	12.00	-00.00	.00	.000000	-.000000
3	57.0000	.015625	620.00	2.2000	2.2000	2.2000	2.2000	12.00	-00.00	.00	.000000	-.000000
4	57.0000	.015625	619.01	2.2000	2.2000	2.2000	2.2000	12.00	-00.00	.00	.000000	-.000000
5	57.0000	.015625	707.00	2.2000	2.2000	2.2000	2.2000	12.00	-00.00	.00	.000000	-.000000
WAVE	58.0000	.012500	3.00	3.9797	1.0016	-1.2000	3.7906	11.70	-00.00	1.10	.000000	-.000000
1	58.0000	.012500	3.00	3.9797	1.0016	-1.2000	3.7906	11.70	-00.00	.00	.000000	-.000000
2	58.0000	.012500	210.00	3.0000	2.0000	2.0000	2.0000	12.00	-00.00	.00	.000000	-.000000
3	58.0000	.012500	620.00	3.0000	2.0000	2.0000	2.0000	12.00	-00.00	.00	.000000	-.000000
4	58.0000	.012500	610.00	3.0000	2.0000	2.0000	2.0000	12.00	-00.00	.00	.000000	-.000000
5	58.0000	.012500	700.00	3.0000	2.0000	2.0000	2.0000	12.00	-00.00	.00	.000000	-.000000
WAVE	59.0000	.006250	0.00	3.0032	9.0032	-3.1039	2.3209	0.70	-00.00	.00	.000000	-.000000
1	59.0000	.006250	0.00	3.0032	9.0032	-3.1039	2.3209	0.70	-00.00	.00	.000000	-.000000
2	59.0000	.006250	222.11	3.0000	3.0000	-1.0000	-1.0000	0.70	-00.00	.00	.000000	-.000000
3	59.0000	.006250	620.00	3.0000	3.0000	-1.0000	-1.0000	0.70	-00.00	.00	.000000	-.000000
4	59.0000	.006250	622.00	3.0000	3.0000	-1.0000	-1.0000	0.70	-00.00	.00	.000000	-.000000
5	59.0000	.006250	711.00	3.0000	3.0000	-1.0000	-1.0000	0.70	-00.00	.00	.000000	-.000000
WAVE	60.0000	.031250	10.00	--.0000	0.2032	-3.9070	--.0000	20.00	-00.00	1.00	.000000	-.000000
1	60.0000	.031250	10.00	--.0000	0.2032	-3.9070	--.0000	20.00	-00.00	.00	.000000	-.000000
2	60.0000	.031250	220.00	3.0000	3.0000	-1.0000	-1.0000	20.00	-00.00	.00	.000000	-.000000
3	60.0000	.031250	620.00	3.0000	3.0000	-1.0000	-1.0000	20.00	-00.00	.00	.000000	-.000000
4	60.0000	.031250	620.00	3.0000	3.0000	-1.0000	-1.0000	20.00	-00.00	.00	.000000	-.000000
5	60.0000	.031250	713.00	3.0000	3.0000	-1.0000	-1.0000	20.00	-00.00	.00	.000000	-.000000

Figure 5 shows the tension in the upper cable segment for $0 \leq t \leq 20$ for Cases 1A to 1E, where $C1$ increases from 2.4×10 lb (1.07×10^2 N) to 2.4×10^5 lb (1.07×10^6 N). As would be expected, the figure shows that tension fluctuations increase with increasing values of $C1$. At the highest value of $C1 = 2.4 \times 10^5$ lb (1.07×10^6 N), Figure 5 shows that the tension is zero at $t = 0.25$ sec (i.e., the cable in slack) and then jumps to a value of 89.47 lb (398.1 N) at $t = 0.5$ sec. This sudden jump in tension after a slack condition is often referred to as "snap loading." At the other extreme, the tension shows a peak-to-trough fluctuation of less than 2.5 lb (11.1 N) at the lowest value of $C1 = 2.4 \times 10$ lb (1.07×10^2 N).

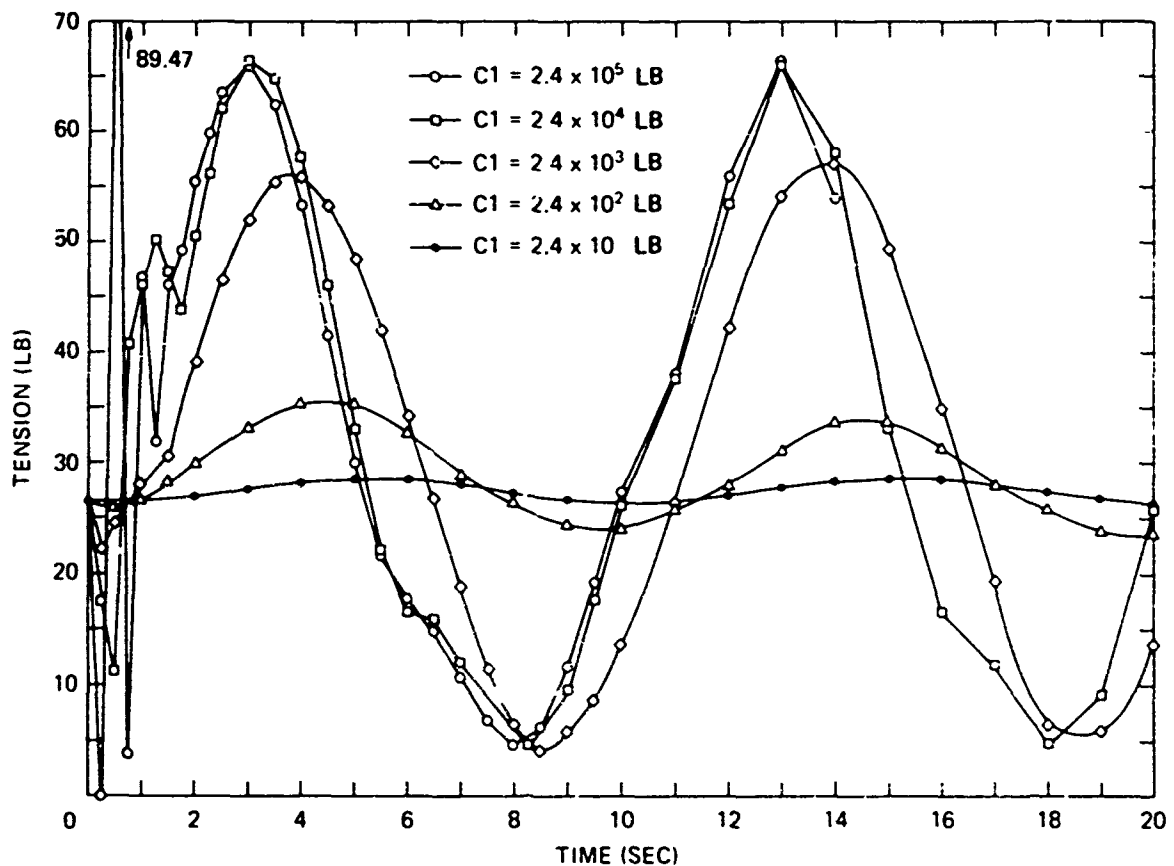


Figure 5 – Tension in Upper Cable Segment
for Various Values of $C1$

Table 2 indicates that the computer execution time remains at approximately 60 sec for Cases 1A, 1B, and 1C for which $C1 \leq 2.4 \times 10^3$ lb (1.07×10^4 N). At higher values of $C1$, Cases 1D and 1E, execution time increases with increasing $C1$. Execution time also increases with decreasing values of $C2$, Case 1F. The reasons for these increases may be most conveniently explained by considering Equation (9) which shows that for a given value of

($T - T_0$), ϵ decreases with increasing values of $C1$ and decreasing values of $C2$. Small values of ϵ , in turn, mean that the x - and y -displacements must be calculated with greater precision, leading to smaller integration time steps.

PROBLEM 2 – UNIFORM CABLE REPRESENTED BY VARIOUS NUMBERS OF SEGMENTS

Problem: Solve Problem 1D with the single exception of representing the cable by the following number of nodes, NCAB-1: 1, 2, 4, 8, and 15. Consider the nodes to be equally spaced.

Solution: The data cards for this problem are listed in Table 5. Cards 1 and 4 to 12, which are identical to those for Problem 1D, are omitted. Also omitted are Cards 14 to 33 which are similar to those for Problem 1D with the exception that the number of entries depends on NCAB.

TABLE 5 – INPUT DATA FOR SAMPLE PROBLEM 2

	1	11	21	31	41	51	61	71
Card 2	bbb PROBLEM 2A, NCAB-1 = 1							
Card 3	bb1bb1bb2bb2							
Card 13	1000.							
Card 2	bbb PROBLEM 2B, NCAB-1 = 2							
Card 3	bb1bb1bb3bb2							
Card 13	500.	500.						
Card 2	bbb PROBLEM 2C, NCAB-1 = 4							
Card 3	bb1bb1bb5bb2							
Card 13	250.	250.	250.	250.				
Card 2	bbb PROBLEM 2D, NCAB-1 = 8							
Card 3	bb1bb1bb9bb2							
Card 13	125.	125.	125.	125.	125.	125.	125.	125.
Card 13	bbb							
Card 2	bbb PROBLEM 2E, NCAB-1 = 15							
Card 3	bb1bb1b16bb2							
Card 13	66.667	66.667	66.667	66.667	66.667	66.667	66.667	66.667
Card 13	66.667	66.667	66.667	66.667	66.667	66.667	66.667	

Figure 6 shows how the steady-state location of the lower weight varies with NCAB-1. The results are poor for $NCAB-1 \leq 2$, good for $NCAB-1 = 4$, and converged for $NCAB-1 \geq 8$.

Figure 7 shows the velocities $\dot{x}$ and $\dot{y}$ of the lower unit at $t = 4$ and 10 for various values of NCAB-1. The results suggest that a minimum of four nodes is required to obtain maximum

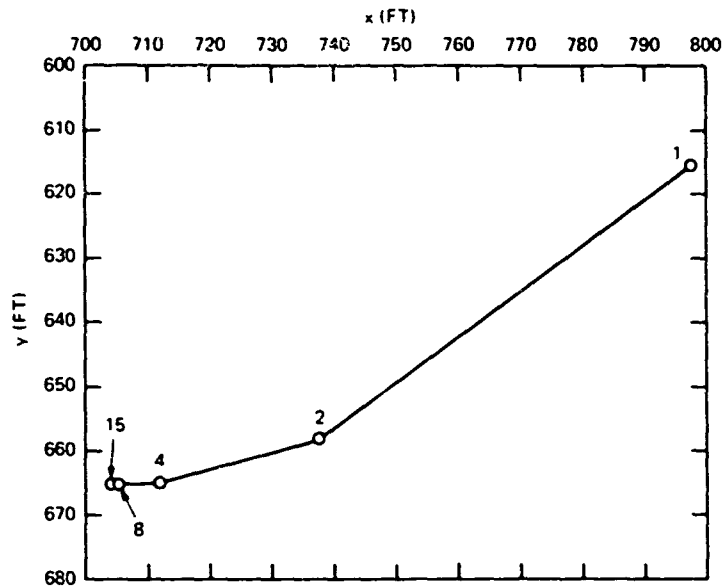


Figure 6 - Steady-State Location of Lower Weight for Various Numbers of Nodes

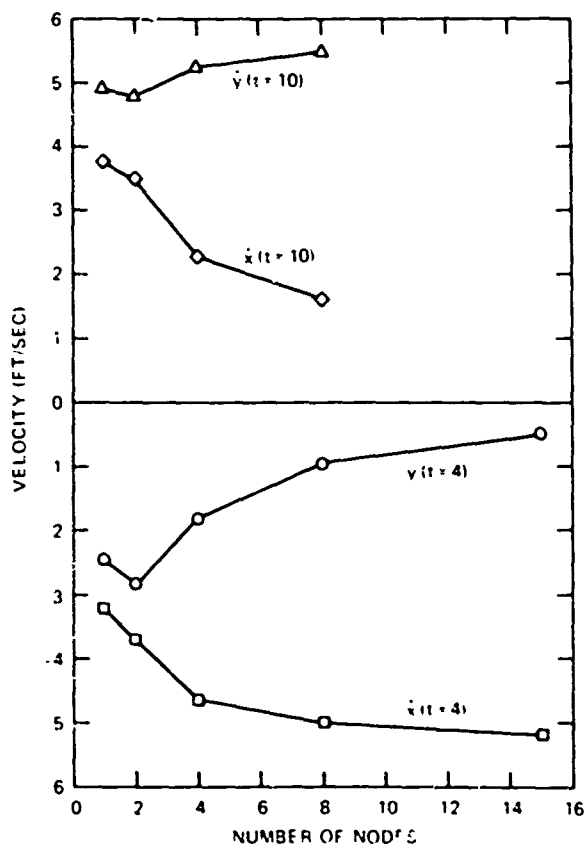


Figure 7 - Velocity of Lower Weight for Various Numbers of Nodes

velocities with accuracies to within 10-20 percent. The magnitudes of the computed velocities generally increase with increasing number of nodes.

Table 2 shows the manner in which the computer execution time ET increases with the number of nodes. The execution times are approximately proportional to NCAB squared

$$ET \propto (NCAB)^2 \quad (56)$$

PROBLEM 3 – DEPLOYMENT OF SUSPENDED CABLE IN CIRCULATING WATER CHANNEL

Problem: Compute the deployment of an initially vertical cable, suspended in the DTNSRDC Circulating Water Channel, to its final steady-state configuration in the presence of channel flow speeds of 1, 2, and 4 knots (0.515, 1.03, 2.06 m/s). The fixed cable and lower body parameters are as follows:

Cable:

length	12 ft (3.66 m)
diameter	0.12 in. (0.305 cm)
normal drag coefficient	1.4
tangential drag coefficient	0.02
weight in fluid	0
mass	0.0002 slugs/ft (0.00957 kg/m)
reference tension	2 lb (8.9 N)
C_1	20 lb (89. N)
C_2	1.
internal damping coefficient	0.

Lower weight:

weight in fluid	2 lb (8.9 N)
drag area in x-direction	0.05 ft ² (0.00465 m ²)
drag area in y-direction	0.05 ft ² (0.00465 m ²)
virtual mass in x-direction	0.1 slugs (1.46 kg)
virtual mass in y-direction	0.1 slugs (1.46 kg)

Fluid density: 1.94 slugs/ft³ (1000.6 kg/m³)

Represent the cable by four equal segments, not including the fictitious cable segment below the lower weight. Take the total time interval to be 20 sec. For the initial interval of 1 sec, printout of the transient cable configuration is desired every 0.1 sec. For the final 19 sec, increase the printout interval to 0.2 sec. Let the system start from rest with the initial tension in each cable segment equal to 2 lb (8.9 N).

Solution: The data cards for this problem are listed in Table 6. The cards which are the same for all the cases are listed at the top of the table. The cards for the title and the current magnitude which differ for each case are listed at the bottom of the table.

TABLE 6 – INPUT DATA FOR SAMPLE PROBLEM 3

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 3	bb1bb1bb5bb2							
Card 4	0.1							
Card 5	0.							
Card 6	0.							
Card 7	0.							
Card 8	0.							
Card 9	0.1							
Card 10	0.							
Card 11	1.94	0.	0.	-15.	0.	1.0	1.0	0.
Card 12	1.	0.1	20.	0.2	-1.	0.	99999.	
Card 13	3.	3.	3.	3.				
Card 14	0.12	0.12	0.12	0.12				
Card 15	1.4	1.4	1.4	1.4				
Card 16	0.02	0.02	0.02	0.02				
Card 17	0.	0.	0.	0.				
Card 18	0.0002	0.0002	0.0002	0.0002				
Card 19	2.	2.	2.	2.				
Card 20	20.	20.	20.	20.				
Card 21	1.0	1.0	1.0	1.0				
Card 22	0.	0.	0.	0.				
Card 23	0.	0.	0.	2.				
Card 24	0.	0.	0.	0.05				
Card 25	0.	0.	0.	0.05				
Card 26	0.	0.	0.	0.1				
Card 27	0.	0	0.	0.1				
Card 28	0.	100.						
Card 30	0.	0.	0.	0.				
Card 31	2.	2.	2.	2.				
Card 32	0.	0.	0.	0.				
Card 33	0.	0.	0.	0.				

TABLE 6 - (continued)

	1	11	21	31	41	51	61	71
Card 2	bbb PROBLEM 3A, V = 1 KNOT							
Card 29	1.0	1.0						
Card 2	bbb PROBLEM 3B, V = 2 KNOTS							
Card 29	2.0	2.0						
Card 2	bbb PROBLEM 3C, V = 4 KNOTS							
Card 29	4.0	4.0						

Figures 8, 9, and 10 show the configuration of the cable nodes at various times during deployment for currents of 1, 2, and 4 knots (0.515, 1.03, 2.06 m/s), respectively. These figures show that approximately 8 sec are required to reach the steady-state configuration.

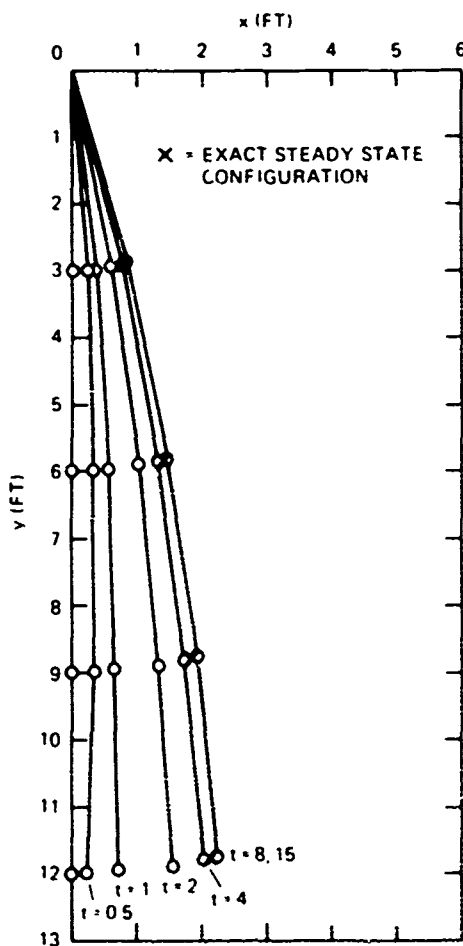


Figure 8 - Configuration of Nodes at Various Times during Deployment.
C = 1 Knot

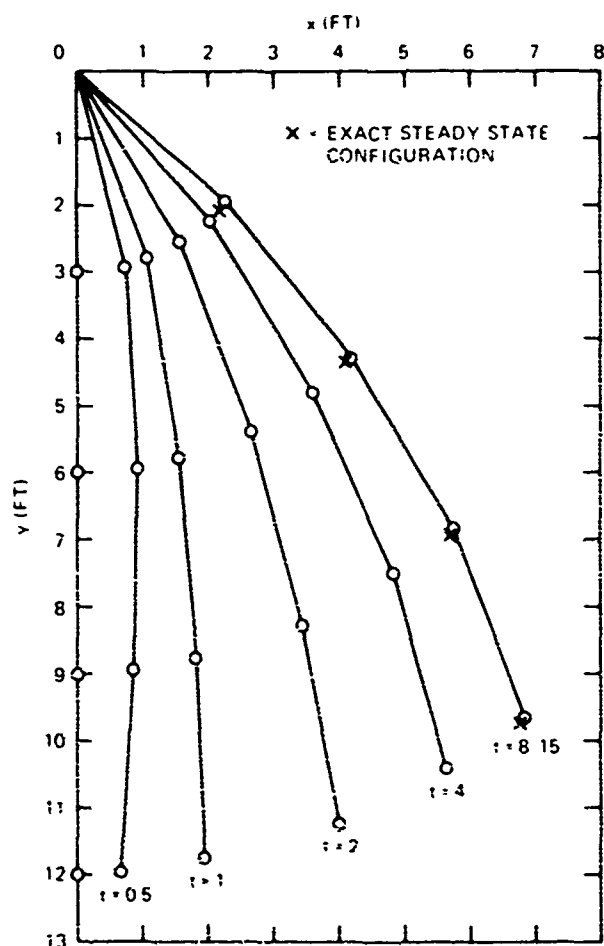


Figure 9 - Configuration of Nodes at Various Times during Deployment.
C = 2 Knots

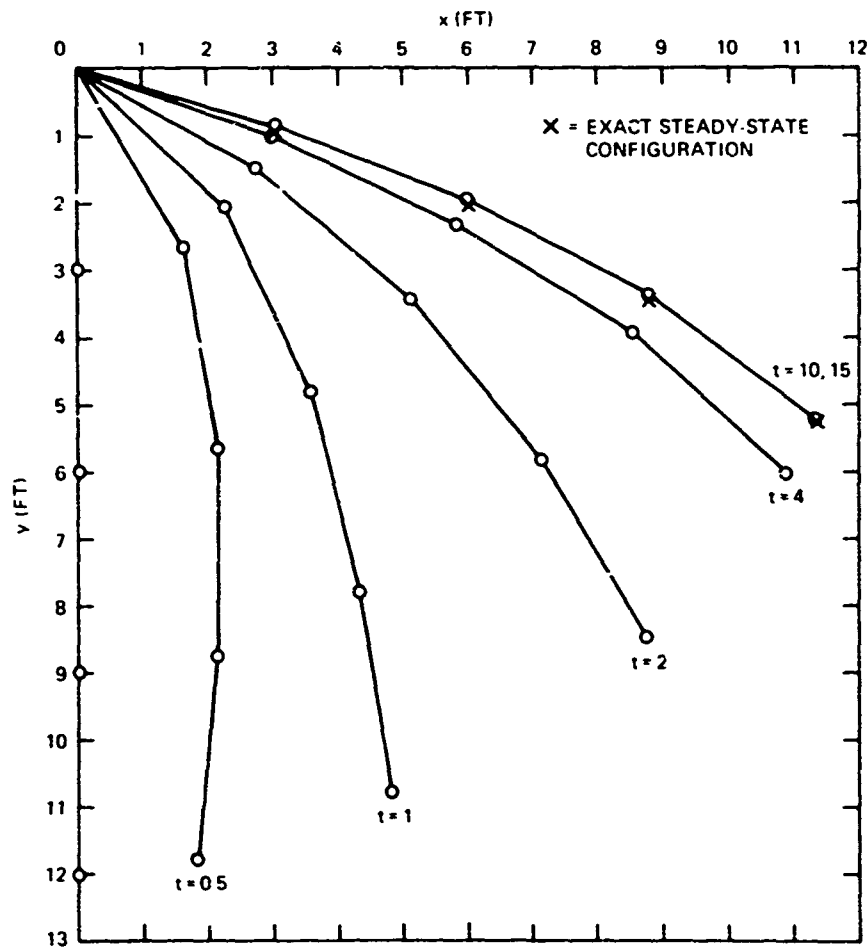


Figure 10 – Configuration of Nodes at Various Times during Deployment, $C = 4$ Knots

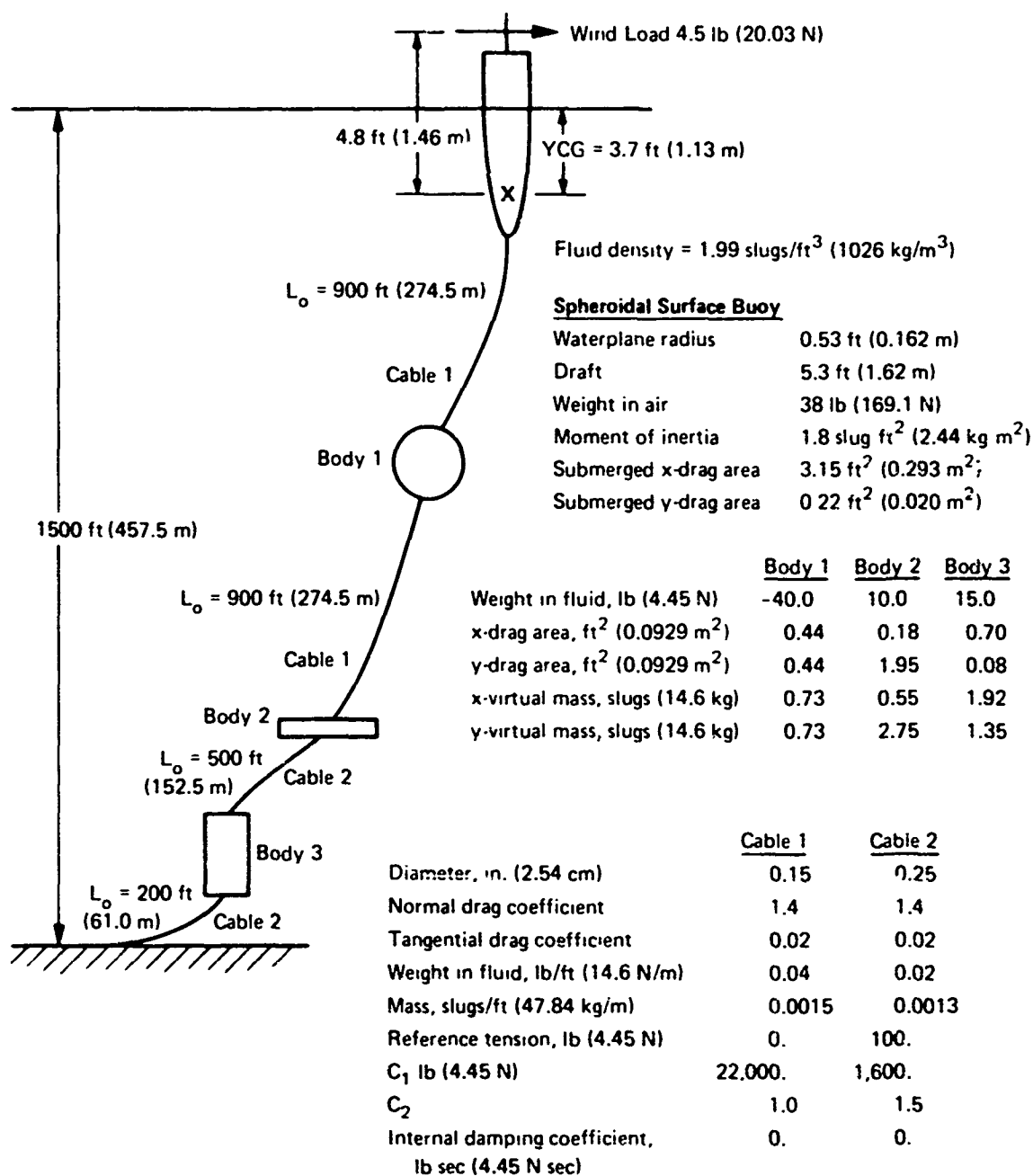
In all three cases, the final deployed configuration modeled by the four nodes was in close agreement with the exact configuration calculated by using the differential equations (1) to (5). It is of interest to note that because of its large inertia, the lower weight characteristically lags during the initial instants of deployment.

Table 2 shows that the computer execution time for a total of 20 sec of deployment time, which is well in excess of the 8 sec required to reach the steady-state configuration, is approximately 100 sec.

PROBLEM 4 – COMPLETE MOORED BUOY-CABLE-BODY SYSTEM

Problem: Compute the dynamic motions for the moored buoy-cable-body system, with parameters as shown in Table 7.

TABLE 7 – PARAMETERS FOR MOORED BUOY-CABLE-BODY SYSTEM



Current Profile:	Depth	Current
	(ft)	(knots)
	(0.305 m)	(0.515 m/s)
	0.	2.50
	500.	1.30
	1000.	0.50
	1500.	0.50

The upper body is a buoyancy bag, the middle body is a damping disk, and the lower body is an acoustic unit. Consider the following three cases:

Case A. Use the formulation contained in the program for a spheroidal buoy. Let the surface wave be composed of a single component with frequency = 0.1 cps, amplitude = 7.5 ft (2.29 m), and phase = 0 degrees.

Case B. Same as Case A except that the buoy is read in as a spar buoy, modeled by 11 cross-sectional areas as a function of depth from 0 to 5.3 ft (1.62 m).

Case C. Same as Case A except that the surface wave amplitudes are to be calculated by using the Pierson-Moskowitz sea spectrum for six components. Take the significant wave height as 15 ft (4.58 m), the range of frequencies from 0.04 to 0.28 cps, and the phase of the lowest frequency component equal to -60 deg.

For all three cases, model the cable by 4 nodes, with three of them corresponding to the three intermediate bodies and the extra node 200 ft of cable below the surface buoy. Compute the dynamic motions for 50 sec. For the initial 10 sec, print out the dynamic motions every 0.1 sec. For the final 40 sec, increase the printout interval to 0.5 sec. Let the system start from rest with the initial angle and tension of each segment equal to the steady-state values. Let the initial x-displacement of the buoy center of gravity be 7.5 ft (2.29 m).

Solution: The data cards for this problem are listed in Table 8. Again, cards which are the same for all the cases are listed at the top of the table. The cards for the title, surface buoy, and surface waves, which differ for each case, are listed at the bottom of the table.

Figure 11 shows the pitch angle ψ of the surface buoy for all three cases for $20 \leq t \leq 40$. Perhaps the principal feature is the comparison of the results for the same surface buoy treated as a spheroidal buoy and as a spar buoy. The figure shows that when the spheroidal buoy formulation was used, pitch results were about 1 to 2 deg higher than those obtained from the spar buoy formulation. This discrepancy is due to the difference in the added inertia terms for the two formulations (compare Equations (27), (28), (32) and Table 1).

The figure also shows that results for the single frequency cases 4A and 4B exhibit a periodic behavior with a period of 10 sec; the results for the multifrequency case 4C show a more random behavior.

Table 2 shows that the execution times for the single-frequency cases 4A and 4B were approximately 80 sec. This time was increased to 100 sec for Case 4C, where the program must calculate six components to obtain the surface wave.

TABLE 8 – INPUT DATA FOR SAMPLE PROBLEM 4

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 11	1.99	0.	4.5	-100.	3.15	1.0	1.0	0
Card 12	10.	0.1	50.	0.5	1.0	0.	99999.	
Card 13	200.	700.	900.	500.	200.			
Card 14	0.15	0.15	0.15	0.25	0.25			
Card 15	1.4	1.4	1.4	1.4	1.4			
Card 16	0.02	0.02	0.02	0.02	0.02			
Card 17	0.04	0.04	0.04	0.02	0.02			
Card 18	0.0015	0.0015	0.0015	0.0013	0.0013			
Card 19	0.	0.	0.	100.	100.			
Card 20	22000.	22000.	22000.	1600.	1600.			
Card 21	1.0	1.0	1.0	1.5	1.5			
Card 22	0.	0.	0.	0.	0.			
Card 23	0.	-40.	10.	15.	0.			
Card 24	0.	0.44	0.18	0.70	0.			
Card 25	0.	0.44	1.95	0.08	0.			
Card 26	0.	0.73	0.55	1.92	0.			
Card 27	0.	0.73	2.75	1.35	0.			
Card 28	0.	500.	1000.	1500.				
Card 29	2.50	1.30	0.50	0.50				
Card 30	9999.	0.	0.	0.	0.			
Card 31	0.	0.	0.	0.	0.			
Card 32	0.	0.	0.	0.	0.			
Card 33	0.	0.	0.	0.	0.			
Card 34	0.22	38.	-4.8	0.	1.6	3.7	1.8	
Card 35	7.5	0.	999.	0.	0.	0.		
Card 2	bbb PROBLEM 4A, SPHEROIDAL BUOY, SINGLE WAVE FREQUENCY							
Card 3	bb1bb1bb5bb4bb2							
Card 4	3500.							
Card 5	0.53							
Card 6	5.3							
Card 7	0.							
Card 8	7.5							
Card 9	0.1							
Card 10	0.							

TABLE 8 - (continued)

	1	11	21	31	41	51	71
Card 2	bbb PROBLEM 4B, SPAR BUOY, SINGLE WAVE FREQUENCY						
Card 3	b11bb1bb5bb4bb2						
Card 4	2700.						
Card 4							
Card 5	0.883	0.852	0.812	0.757	0.687	0.600	0.498
Card 5	0.247	0.097	0.				0.380
Card 6	0.	1.0	1.5	2.0	2.5	3.0	4.0
Card 6	4.5	5.0	5.3				
Card 7	0.						
Card 7	0.						
Card 8	7.5						
Card 9	0.1						
Card 10	0.						
Card 2	bbb PROBLEM 4C, SPHEROIDAL BUOY, SIX WAVE FREQUENCIES						
Card 3	bb1bb6bb5bb4bb2						
Card 4	3500.						
Card 5	0.53						
Card 6	5.3						
Card 7	0.						
Card 8	1015.						
Card 9	0.04	0.28					
Card 10	-60.						

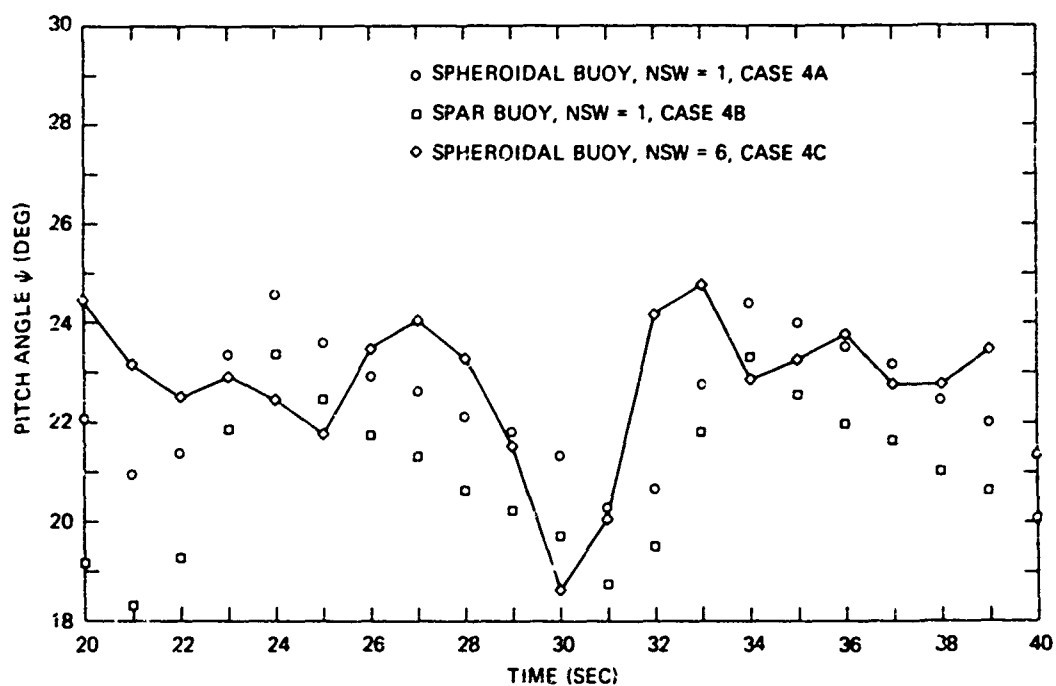


Figure 11 – Pitch of Surface Buoy

ACKNOWLEDGMENT

The author thanks Dr. K.J. Bai who performed the calculations for the added inertia coefficients of the spheroidal buoys.

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APPENDIX
LISTING OF COMPUTER PROGRAM

```

1      PROGRAM CABUOY (INPUT, OUTPUT, TAPE=INPUT, TAPE=>OUTPUT)
COMMON/MS1/DRAGN, DRAGT, MPUL, TRF, ICI, IEX1
COMMON/H01/AXSM(20), ATSM(20), FISM(20), WSM(20), SIG(20), WSM(20),
1FISM(20), NSH
COMMON/H03/THIN, NCAB, MGEZ, NDE1, OKUL, OKLL, TBYNK
COMMON/H04/CI(50), C2(50), C1MT(50), ORN(50), ORT(50), ANH(50), GH(50),
1MTL(50), TREF(50), FLC(50)
COMMON/H05/ASH(20), FMSH(20), NSH, MTRC
COMMON/H06/WH0, PI, G, CFI, FSHL, TMS, TFS, SUBM, RTX, RMY, YCG,
10IN, BG, WAS, COASX, COAST, XA, YA, XPA, YPA
COMMON/H07/XPSI, ZETPP, STYP, XSI, ZETI, SYI, XPSI, ZTPI, STYPI
COMMON/H08/NBO(50), COABX(50), COABY(50), XMBV(50), YMBV(50)
COMMON/H09/XMB(50), YMB(50), TBM
COMMON/H10/VCUR, FIRST, VCK
COMMON/H11/XS, YS, XSP, YSP, XSP, YSP, X(51), Y(51), XP(51),
1YP(51), YPP(51), YPP(51)
COMMON/H12/PHISL, XSL, YSL, TFL, VNR, VNM, BCYL, ITER, ICS, MBOF, ORGBTM, TRV
1->Y150
DIMENSION FNM(20), FIOSM(20), WLSM(20), DCI(50), COM(50), MC(50),
1COT(50), CM(50), CCK(10), FIOSM(20), API(51), YPI(51)
DIMENSION PHIO(51), YPO(106), PHIOS(102), TENIS(102), TENI(51), PHIV(51)
DIMENSION TITLE(20)
EXTERNAL STAT, DYNA
25      PRINT TABLE OF CONVERSION FROM ENGLISH UNITS TO METRIC UNITS
      WRITE(6,241)
241      FORMAT(141,//////,12X,
1*CONVERSION FROM ENGLISH UNITS TO METRIC UNITS//
225X,"ENGLISH", 3X,"METRIC"/25X,"1 INCH=2.54 CM",
325X,"1 FOOT=30.48 CM", 3048 METERS/25X,"1 MILE=1.60934 KM",
425X,"1 GJ FT=2.20462E+07 N", 9.80665E+01 CU M/25X,"1 POUND=4.53592E+01 NEWTONS",
525X,"1 SLUG=14.5939 KG", 14.5939 KG/25X,"1 SECOND=1.0E+01 SECOND",
625X,"1 ANGLE=360 DEGREES", 360 DEGREES/25X,"1 RADIANS=57.2958 DEGREES")
      READ(5,1) NVALUES
      1 FORMAT(2413)
C      READ IN DATA
      READ(5,301) TITLE
301      FORMAT(20A1)
      READ(5,1) NSH, MSM, NCAB, NCUR, ITER, MTRC
      NDU=NCAB-1
      2 FORMAT(1F10.4)
      3 FORMAT(1F10.2)
      4 FORMAT(1F10.6)
      5 FORMAT(1F10.8)
45      READ(5,2) (AXSM(K), K=1, NSH)
      READ(5,2) (ATSM(K), K=1, NSH)
      READ(5,2) (FISM(K), K=1, NSH)
      READ(5,2) (ASHM(K), K=1, NSH)
      READ(5,2) (FRSM(K), K=1, NSH)
      READ(5,2) (FIUSM(K), K=1, NSH)
      READ(5,2) (WH0, SUBM, TMS, TFS, COASX, ANH, AFAC, THIN)
      READ(5,2) (XMB1, OT1, TOT1, OT2, D1M, TBM, TBYNK)
      READ(5,3) (FLC(K), K=1, NCAB)
      READ(5,2) (CCK(K), K=1, NCAB)
      READ(5,2) (JDM(K), K=1, NCAB)
      READ(5,2) (JDT(K), K=1, NCAB)
      READ(5,2) (MC(K), K=1, NCAB)

```

```

60 READ(5,4) (CM(K),K=1,NCAB)
   READ(5,3) (TREF(K),K=1,NCAB)
   READ(5,5) (LJ(K),K=1,NCAB)
   READ(5,2) (CINT(K),K=1,NCAB)
   READ(5,2) (MBD(K),K=1,NCAB)
   READ(5,2) (DABX(K),K=1,NCAB)
   READ(5,2) (CABY(K),K=1,NCAB)
   READ(5,2) (TMBV(K),K=1,NCAB)
   READ(5,3) (TY(I),I=1,NCUR)
   READ(5,2) (PHIO(I),I=1,NCAB)
   READ(5,3) (TEM(I),I=1,NCAB)
   READ(5,2) (TPI(I),I=1,NCAB)
   READ(5,2) (TPI(I),I=1,NCAB)
   DIMP=JAN
   JO 1000 NC=1,NCASES
   OIR=OIRP
   READ(5,3) (LCA(I),I=1,NCUR)
   IF (MIRCLC=0) GO TO 221
   C CONVERT METRIC INPUT TO ENGLISH UNITS
   JO 222 I=1,NSM
   AXSM(I)=3.281*AXSM(I)
   IF (FSM(I)-5E-2000-.AND.FSM(I)-LT.3000.) AXSM(I)=3.201*AXSM(I)
   222 AYSM(I)=3.201*AYSM(I)
   IF (ASM(I)-LE.1000.) GO TO 224
   ASM(I)=1000+.3.201*(ASM(I)-1000.)
   GO TO 226
   224 CONTINUE
   JO 225 I=1,NSM
   225 ASM(I)=3.201*ASM(I)
   226 RHO=0.0013308*HMO
   SUBM=3.201*SUBMTMX=TMX/4.452STLY=TY/4.452
   GOASX=3.201*3.201*GOASXTMIN=TMIN/4.452STB=TBH/4.452
   TBMH=TBVH/4.452
   JO 227 K=1,NCAB
   FLC(K)=3.201*FLC(K)SGCI(K)=0.3937*OGI(K)SMC(K)=0.00046*MC(K)
   CM(K)=0.02047*CM(K)STREF(K)=TREF(K)/4.452SGCI(K)=C1(K)/4.452
   CINT(K)=CINT(K)/4.452SMBD(K)=W3D(K)/4.452
   COABX(K)=3.28+.3.201*COABX(K)SGOABY(K)=3.201*3.201*GOABY(K)
   TMBV(K)=0.000467*TMBV(K)STMBV(K)=0.000467*TMBV(K)
   TEM(K)=TEM(K)/4.452STPI(K)=3.201*PI(K)
   227 TPI(K)=3.201*TPI(K)
   TY(I)=3.201*TY(I)
   JO 228 I=1,NCUR
   228 CLK(I)=3.201*CLK(I)/1.6074
   221 CONTINUE
   IF (C1(NCAB)-GT.0.0001) GO TO 115
   FLC(NCAB)=2.*FLC(NCAB-1)SULI(NCAB)=0.5CON(NCAB)=0.
   DT(NCAB)=0.5MC(NCAB)=0.5CM(NCAB)=0.5C1(NCAB)=0.001
   C2(NCAB)=1.5CINT(NCAB)=0.
   115 CONTINUE
   FDISW=FDISW(1)
   FSW1=FSW(1)
   PI=3.141592656=32.2
   XSL=0.
   OKUL=2.2/1.12

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04/19/77 11.49.22

FTN 4.60428

PROGRAM CABUOY 74/74 OPT=0 ROUNDO=0/ TRACE

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115      UKLL=1./3.0
      JO 151 I=1,NZAB
      RMB(I)=RMB(I)+YMBV(I)
151 CONTINUE
      IF (ASH(I).LE.1000.) GO TO 88
      DO 89 I=1,NSM
      FISM=NSM
      F1=I-1
      89 FIOSM(I)=FISM*(360.*PI)/FISM
      CALL SPECT
      88 CONTINUE
      DO 91 I=1,NSM
      SIG(I)=2.*PI*FISM(I)
      MLSM(I)=2.*PI*G/(SIG(I)*SIG(I))
      MNSM(I)=2.*PI/MLSM(I)
130 51 FISM(I)=FIOSM(I)*PI/180.
      IF (FISM(I).LE.1000.) OR (FISM(I).GE.2000.) GO TO 91
      NSM=NSM
      DO 90 I=1,NSM
      FSM(I)=FSM(I)+FIOSM(I)
      AMSM(I)=ASM(I)+FSM(I)
135 90 CONTINUE
      91 CONTINUE
      C PRINT DATA
      WRITE(6,302) TITLE
      JO2 FORMAT(141,10X,20A4)
      WRITE(6,30)
      6 FORMAT(104,
      15)MLSTING OF ENVIRONMENTAL AND CABLE-BUOY CHARACTERISTICS)
      WRITE(6,7)
      7 FORMAT(5X,16HOCEN CONDITIONS)
      WRITE(6,8)
      8 FORMAT(1X,15H$URFACE WAVE-5X,9HFREQ(CPS),1X,8HAMPL(FT),2X,
      10)PHASE(10),3X,6HML(FT),2X,8HMK(1/FT))
      JO 31 I=1,NSM
      31 WRITE(6,9) FISM(I),ASM(I),FIOSM(I),MLSM(I),MNSM(I)
      9 FORMAT(17X,4F10.2,F10.4)
      WRITE(6,10)
      10 FORMAT(1X,15HCURRENT PROFILE,5X,9HDEPTH(FT),2X,8HCURR(KT))
      JO 32 I=1,400K
      32 WRITE(6,11) Y(I),LCK(I)
      11 FORMAT(20X,2F10.2)
      WRITE(6,12) K10
      12 FORMAT(1X,14HFLUID DENSITY,F10.4,1X,7HSL/10UFT)
      WRITE(6,13)
      13 FORMAT(75X,15H$URFACE MOTION-9HFREQ(CPS),3X,7H-A(FT),3X,
      17)W-A(FT),1X,10H$ASE(10))
      JO 33 I=1,NSM
      33 WRITE(6,14) FSM(I),ASM(I),AYSM(I),FIOSM(I)
      14 FORMAT(20X,4F10.4)
      WRITE(6,15)
      15 FORMAT(77X,29HGENERAL CABLE CHARACTERISTICS)
      WRITE(6,16)
      16 FORMAT(2X,9HAM COEFF-2X,84HAREA FAL-2X,9HT MIN(LB))
      WRITE(6,17) AMC,AFAC,FMN
      17 FORMAT(2F10.4,F10.2)
      WRITE(6,18)

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04/19/77 11.49.22

FTM 4.6+20

TRACE

PROGRAM CABUOY

74/74

OPT=0 ROUND=0

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10 FORMAT(/5X,16MCABLE PROPERTIES,72X,15MBOY PROPERTIES)
WRITE(6,19)
19 FORMAT(1X,3HNUM,1X,7HLEN(F),2X,4MDIAM(IN),2X,3HCON,5X,3HLOT,3X,
17H(LB/F),1X,7H(SL/F),1X,9H REF(LB),3X,6HCL(LB),1X,
21X,6HEXP C2,2X,6HINT(LB),1X,6HCOA,72X,1X,6HCOA(F2),1X,
36HMT(LB),1X,7HVM(SL),1X,7HVM(SL))
DO 34 I=1,NCAB
WRITE(6,20) I,FLC(I),DCI(I),CDM(I),CDT(I),WC(I),CM(I),TREF(I),
161(I),C2(I),C1(I),C0(I),COAB(I),COABY(I),WBO(I),XMBV(I),YMBV(I))
34 CONTINUE
20 FORMAT(1X,13,F10.2,4F8.4,6F8.6,F10.2,F10.0,F8.4,
168.4,2X,3F8.3,2F8.4)
WRITE(6,25) TBM
55 FORMAT(1X,17HX-LOAD ON BOT MT-,F12.4,1X,2HMB)
WRITE(6,59)
59 FORMAT(1X,20H SURFACE BUOY CHARACTERISTICS)
WRITE(6,52)
52 FORMAT(4X,4H SUBM(F),2X,11H WIND LO(LB),2X,10H COA(FTSO),2X,
11H MAX TEN(LB))
WRITE(6,53) SUMM,TMX,COASX,TBYMX
53 FORMAT(F12.4)
C SET CONSTANTS AND CONVERT DATA
EPSI=0.00018EPM=8.00016EPR=0.00016
RAO=100./PI
DELTA=0.00000001
DO 61 I=1,NSM
MSM(I)=2.*PI*FSM(I)
FI(M(I))-FI(SM(I))*PI/100.
61 CONTINUE
DO 42 I=1,NCUR
DO 42 CCF(I)=CCK(I)*1.6678
WBOI=WBOI(MBOI)
VCX=0.
ICSA=1
SYISO=0.
IF(ITER.LE.0) GO TO 93
C PERFORM INITIAL CALCULATIONS FOR ITERATION CASES
VIR=1.0
DO 55 I=1,NCAB
DO 96 I=1,NCAD
96 SCYL=WCYI+FLC(I)*WC(I)+WBO(I)
TOT=0.
DO 198 I=1,NCAB
198 TOTL=TOTL+1.*FLC(I)
VHX=1000.*VHM=1000.
DO 94 I=1,NCUR
IF(CCF(I)-I.*VHX)VHX=CCF(I)
IF(CCF(I)-I.*VHM)VHM=CCF(I)
IF(VY(I)-GT.TOTL) GO TO 102
94 CONTINUE
102 IF(VHX.LT.0.) GO TO 103
VHX=1.05*VHX
VHM=0.95*VHM
GO TO 93
103 VHX=0.95*VHX
VHM=1.05*VHM
93 CALL ITCKA

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238      C CALCULATE STEADY-STATE VARIABLES
      FIRST=1.
      CALL CURISUBM,CUI
      CCF1=CU
      TDX=0.5*RH0*COASX*CCF1*ABS(CCF1)
      TZX=TDXTMA
      IF (DIR.LT.0.) TIX=0.5*RH0*ABS(COABX(MB0))*CCF1*ABS(CCF1)*TBM
      IF (DIR.LT.0.) TIY=MB0(MCAB-1)
      TIZ=DIRTIIIX*TIY*TIY
      63 PHIS=ATAN2(TIX,-TIY)
      T6N=TZ
      PHISU=PHIS*HAD
      IYS=-TIYATIX*-TIX
      IF (FISMLE-2000.) GO TO 46
      IF (DIR.LT.0.) GO TO 96
      CALL BUOY
      GO TO 99
      98 CONTINUE
      XA=0.5YA-SJ0M5XPA=0.6YPA=0.
      DO 44 I=1,M,N
      44 XA=AXSH(I)*COS(FISH(I))
      YA=YA-AXSH(I)*SIN(FISH(I))
      XPA=XPA+XSH(I)*AXSH(I)*SIN(FISH(I))
      YPA=YPA+XSH(I)*ATSM(I)*COS(FISH(I))
      44 CONTINUE
      43 CONTINUE
      AL=XASTU-YASR=0.4SE=0.
      IF (ITER-6E.1) GO TO 264
      KJIE(6,116)
      116 FORMAT(/IX,30INITIAL VALUES AT TOP OF CABLE)
      WRITE(6,117) XA,YA,XPA,YPA
      117 FORMAT(/IX,3XKA=F10.4,5X,3YKA=F10.4,5X,4XPYA=F10.4,5X,4MPVA=,
      1F10.4)
      45 WRITE(6,65) MC
      65 FORMAT(1M1,5X,10HRUN NUMBER,13)
      WRITE(6,66)
      66 FORMAT(/10X,26STEADY-STATE CONFIGURATION)
      66 WRITE(6,66) TIX,TIY,DIR
      66 FORMAT(/IX,4MTIX=F10.2,5X,4MTIY=F10.2,5X,10NOIRECTION=F10.2)
      67 FORMAT(/IX,4MNODE,IX,9MS REF(FT),
      11X,9MS STR(FT),3X,5HX(FT),5X,5HY(FT),3X,7MTEN(LB),3X,9MPHIS(DEG))
      JS=0
      WRITE(6,69) JS,SR,SE,XC,YC,TEM,PHISD
      69 FORMAT(/IX,1X,6F10.2)
      264 JM=1
      ILST=MCAB
      IF (DIR.LT.0.) ILST=MB0
      C COMPUTE STEADY-STATE CONFIGURATION
      DO 71 I=1M,ILST
      IC=1
      IF (DIR.LT.0.) IC=MCAB-1
      START=0.
      JRA0=0.5*RH0*(OC1IC)/12.1*COM(1C)
      JRA1=0.5*RH0*(OC1IC)/12.1*COY(1C)
      MPUL=WC(1C)
      TWF=TRF(1C)

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290      TC1=C1(I)
      TEXT=1.7C2(I)
      PA=FLC(I)/2.
      DO 81 I=1,2
      Y8(I)=TEN
      Y8(2)=PHIS
      Y8(3)=XC
      Y8(4)=YC
      Y8(5)=SE
      CALL KUTHER(S,SH,Y8,EPSTA,SPA,SPART,MCH,EPB,STAT)
      FIMST=1.
      TEM=Y8(1)*PHIS=Y8(2)*XC=Y8(3)*YC=Y8(4)*SE=Y8(5)
      PHIS=Y8(2)*RAD
      IF (ITEM-GE-1) GO TO 205
      WRITE(6,69) I,SH,SE,XC,YC,TEM,PAISO
205  IF (I-1) 81,72,81
      72  IC=IC
      TEMS(I)=TEN
      PHIS(I)=PHIS
      81  CONTINUE
      C  COMPUTE TENSION AND ANGLE AT BODY
      CALL COMTC(CB)
      IB=1C
      IF (I-LE-8) GO TO 144
      F8X=0.5*PHIS*ABS(CDABX(I))*C0*ABS(CB)
      IF (I-GE-8) F8X=F8X*TEM
      IF (I-LE-4) NGU) UNGRM=F8X
      143  F8Y=MBU(I)
      T81=SIM(PHIS)*TEN*F8X
      T82=CO2(PHIS)*TEN*F8Y
      IF (85(I-2) .LI. DELTA) T82=DELTA
      TEM=URIT(T81,T81+T82+T82)
      PHIS=ATAN2(T81,-T82)
      PHIS=PHIS*RAD
      IF (IC-EO-M3) KXLT=XG
      1. (IC-EO-M3) YLB=YC
      IF (ITE-GE-1) GO TO 71
      144  WRITE(6,69) I,SH,SE,XC,YC,TEM,PAISO
      71  CONTINUE
      THNKA=TEM*SIM(PHIS)
      TVERT=TEM*CO2(PHIS)
      IF (ITE-GE-1) GO TO 267
      WRITE(6,73)
      73  FORMAT(1)
      WRITE(6,75) THNKA
      WRITE(6,76) TVERT
      75  FORMAT(1X,2M4,COMPONENT OF TENSION=F10.2,1X,2MLB)
      76  FORMAT(1X,2M4,COMPONENT OF TENSION=F10.2,1X,2MLB)
      IF (ITE-LE-8) GO TO 211
      C  DEFINE END CONDITIONS FOR TRANSMITTAL TO SUBROUT AE ITENA
      267  PHIS=PHIS
      XLT=XG
      YLB=YC
      TLT=TEN
      IF (IC-EO-1) WRITE(6,262)
      262  FORMAT(1M1,2X,3M1M,5X,4M3JXK,8X,4M12X)

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CORR 92
CORR 93


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400      TT=0.
        WRITE(6,21)
21      FORMAT(1M0,5X,24MCABLE INITIAL CONDITIONS)
405      WRITE(6,22)
22      FORMAT(1X,4MNODE,2X,8MPT(DEC),3X,7MTEN(LB),4X,5HX(FT),5X,
        15HY(FT),4X,8MVP(FT/S),2X,8MVP(FT/S))
        DO 36 I=1,NLAB
          II=I
36      WRITE(6,23) I,PHI(II),TEN(II),X(II),Y(II),XPI(II),YPI(II)
23      FORMAT(1X,13,4X,F10.4,F10.2,2F10.2,2F10.4)
        WRITE(6,24)
24      FORMAT(1/5X,16MTIME INFORMATION)
        WRITE(6,86) TINV1,OT1
86      FORMAT(1X,22MINITIAL TIME INTERVAL=F10.4,1X,3HSEC,1X,
        18H1ME STEP=F10.4,1X,3HSEC)
415      WRITE(6,25) TOT1,OT2
25      FORMAT(12X,11MTOTAL TIME=F10.4,1X,3HSEC,3X,18H1ME STEP=F10.4,
        11X,3HSEC)
        WRITE(6,27)
27      FORMAT(1M1,10X,42MCOMPUTED CABLE SYSTEM MOTIONS AND TENSIONS)
420      WRITE(6,28)
28      FORMAT(1/2X,3MNUM,3X,6MT(SEC),2X,7MOT(SEC),3X,5HX(FT),5X,
        15HY(FT),3X,8MVP(FT/S),2X,8MVP(FT/S),1X,9HXPP(FT/S),1X,
        2MVP(FT/S),3X,7MTEN(LB),1X,7MFI(DEC),1X,8MFE(FT/S),1X,6MSTRAIN,
        11X,8MSTP(1/5))
        ITOP=0
        TIM1=TINV1-DELTA
        TIM2=TINV1+DELTA
        OT=OT1
        FIRST=-1.5*START=0.
430      DO 241 K=1,7500
        DO 161 I=1,NBO
          YB(6-I-1)=X(11)*YB(6-I-2)+XP(11)
          YB(6-I-1)=((11)*YB(6-I)+YPI(11))
101      CONTINUE
          IF(MDE2-EQ,MDE1) GO TO 114
          YB(MDE-5)=YB(MDE-4)+MPS18YB(MDE-3)-ZET1
          YB(MDE-2)=ZTPI8YB(MDE-1)+SY18YB(MDE)+SYPI
114      IF(ITT-GE,TIM1).AND.(ITT-LE,TIM2) START=0.
          CALL ROTMER(MDE,ITT,YO,EPDYM OT,START,MCA,EPD,DYNA)
          COMPUTE SURFACE WAVE MOTIONS
          ASM=0.5YSM=0.
          XSNP=0.5XSNP=0.
          XSNPP=0.5XSNPP=0.
          DO 161 IM=1,NSW
            MKSF=MKSM(IM)*XSI-SIG(IM)*TAFISM(IM)
            CMASF=COS(MASF)*SMXSF+SIN(MASF)
            XSM=XSM+ASM(IM)*CMASF
            YSM=YSM+ASM(IM)*SMXSF
            XSNP=XSNP+SIG(IM)*ASM(IM)*CMASF
            YSNP=YSNP+SIG(IM)*ASM(IM)*CMASF
            XSNPP=XSNPP+SIG(IM)*2*ASM(IM)*CMASF
            YSNPP=YSNPP+SIG(IM)*2*ASM(IM)*SMXSF
161      CONTINUE
          WRITE(6,162) TT,MCA,XSM,YSM,XSNP,YSNP,XSNPP,YSNPP
162      FORMAT(1X,4M,1AVE,F0.4,F4.6,2F10.2,2F10.4)

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IF (INUER.EQ.MDE1) GO TO 121
SVQ=C*V1*100./PI*SYPO-SYPI*100./PI*SYPO-SYPI*100./PI
MR11(6,123) IT-MCK-XSI-ZET1-XPS1-ZIPI-XPS1-ZETPP-SYO-SYPO-SYPP0
123 FORMAT(1X,4HBUOY,F8.4,F8.6,2F10.2,4F10.4,10F10.2,2F8.2,
11X,5MSYPP,F8.2,2X,4HND/SS)
121 DELX=X(11)-X50DELX*Y(11)-YS
DXP=X(11)-X50DELX*Y(11)-YS
FLS=SQRT(DELX*DELX+OELX*OELX)
FIOS=ATAN2(-DELX,OELX)*180./PI
EPS=(FLS-FLC(1))/FLC(1)
EPSP=(DELX*DXP+OELX*OYP)/(FLS*FLC(1))
TENS5=C1(11)*(ABS(EPSP))**2*(11)-1.)*EPS*TRF(11)*CIMI(11)*EPSP
IF (TENS5.LE.1MIN) TENS5=1MIN
FIPO5=((OXP/FLX)+OELX*(DELX*DXP+OELX*OYP)/FLS**3)/
ICD5(FIOS*PI/180.)
FIPO5=FIPO5*180./PI
MR1,2(6,123) (OP,TT,MCK,XS,YS,XSP,YSP,TENS5,FIOS,FIPO5,EPSP
125 FORMAT(2X,F8.4,F8.6,2F10.2,2F10.4,2F10.4,10F10.2,2F8.6)
DO 107 I=2,NCAN
OELX=X(11)-X(11-1)*DELX*Y(11)-Y(11-1)
DXP=X(11)-X(11-1)*DXP*Y(11)-Y(11-1)
FLS=SQRT(DELX*DELX+OELX*OELX)
FIOS=ATAN2(-DELX,OELX)*180./PI
EPS=(FLS-FLC(1))/FLC(1)
EPSP=(DELX*DXP+OELX*OYP)/(FLS*FLC(1))
TENS5=C1(11)*(ABS(EPSP))**2*(11)-1.)*EPS*TRF(11)*CIMI(11)*EPSP
IF (TENS5.LE.1MIN) TENS5=1MIN
FIPO5=((OXP/FLX)+OELX*(DELX*DXP+OELX*OYP)/FLS**3)/
ICD5(FIOS*PI/180.)
FIPO5=FIPO5*180./PI
11=1-1
WRITE(6,24) 11,TT,MCK,X(11),Y(11),XPI(11),YPI(11),XPP(11),
1TENS5,FIOS,FIPO5,EPSP
24 FORMAT(2X,13,F8.4,F8.6,2F10.2,4F10.4,10F10.2,2F8.6)
107 CONTINUE
IF (TT.GE.TOTT) GO TO 1000
FIRST=1000
201 CONTINUE
1000 CONTINUE
STOP
END

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84/10/77 11.48.22

CTN 4.00028

74/74 OPT=0 SOUND=0 TRACE

SUBROUTINE STAT

```

1  SUBROUTINE STAT(STAT,IN,DER)
   COMMON/MS2/DRACH,UNACT,MPUL,TAF,TC1,TEX1
   DIMENSION FIM(5),DER(5)
   IF(FIM(1).LE.8.00000001) FIM(1)=8.80000002
   CALL CURFIM(5),CX
   CMORH=COS(FIN(2))*CX
   CTANH=SINH(FIN(2))*CX
   SINX=(ABS(FIM(1))-TRF(TC1))*((TEX1-L.)*(FIM(1)-TRF)/TC1)
   JER(5)=SINX
10  G=ORAG/(TAN*ASSIGTAN)
   FIDKACH=CHURH*ABS(CHORN)
   DER(1)=G-CDS(FIM(2))*MPUL
   DER(2)=G-FI-SIMPIM(2))*MPUL)/(-FIN(1))
   DER(3)=SIN(FIM(2))*DER(5)
   JER(4)=CDS(FIM(2))*DER(5)
   RETURN
   END

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04/13/77 11.49.22

FTW 6.64420

TRACE

SUBROUTINE DYNA

74/74

OZI=9

POUNU=7

TRAC

```

1  SUBROUTINE DYNA(IT,FI,OF)
   DIMENSION J(106),FI(106)
   COMMON/ND1/AXSM(20),AYSM(20),FZSM(20),WKS(20),SIG(20),WSM(20),
   1 FISM(20),NSM
   COMMON/ND2/AS(20),FNSM(20),MSM(20),HRC
   COMMON/ND3/THIN,MCAB,MOE2,MOE1,OKUL,CALL,TBYMX
   COMMON/ND4/CL(50),C2(30),CIN(150),JRM(50),JRM(50),JRM(50),GM(50),
   1 JTC(50),JTRF(50),PLC(50)
   COMMON/ND5/RS,PI,G,CGFI,F5H1,IMX,TKS,ITY,SUAM,RTY,RTX,RHT,YCG,
   1 ABIN,BG,MAS,CDAX,CNAST,XA,YA,XPA,YPA
   COMMON/ND6/XPST,ZETPP,SYPP,XSI,ZETI,SYI,XPSI,ZYPI,SYPI
   COMMON/ND7/MD(50),CUADK(50),CDAB(50),XMBV(50),CMBV(50),CMBV(50)
   COMMON/ND8/XM(50),YMB(50),ZMB(50),XMBV(50),YMBV(50),ZMBV(50)
   COMMON/ND9/XS,YS,XSP,YSP,XSPP,YSPP,Z(51),Y(51),XP(51),
   1 YP(51),XPP(51),YPP(51)
   COMMON/TPAR/PS0,PS1,PS2,QS0(20),QS1(20),RGS0,BVMX,BVMZ
   COMMON/SPHE/ZBVP,SPF,RCVCG,MVLP,OYM,MVMX,MVMZ,DB
   MOE2=MOE2*MOE2/NCAB-1
   DO 5 I=1,MOE2
   5 OL(2*I-1)=PI(2*I)
   DO 6 I=1,CS0
   6 FI=FI(4*I-3)*XP(1)+FI(4*I-2)
   7 FI=FI(4*I-1)*YP(1)+FI(4*I)
   , CONTINUE
   IF(F5H1.LE.200.) GO TO 45
   XSI=FI(MOE-5)*PSI*DE(MOE-5)
   ZETI=FI(MOE-3)*ZETPP*DE(MOE-3)
   SYI=FI(MOE-1)*SYPI*DE(MOE-1)
   XS=XSI*ATA-RTY*SYI
   YS=YSP*PSI-RTY*SYPI
   ZB=ZCG+ZETI*RTX*SYI*RTY
   YSP=ZETPP*RTX*SYPI
   GO TO 12
45 XS=0.,YS=SUM(XSP)+0.,YSP=0.
   DO 11 I=1,NSM
   11 XSI=XS+NSM(I)*FISM(I)
   YS=XSI+ARSM(I)*COS(NSIF)
   YS=YS-AYSM(I)*SIN(NSIF)
   XSP=XSP+XSM(I)*ZC(I)
   YSP=YSP+YSM(I)*COS(NSIF)
   11 YSP=YSP+XSM(I)*AYSM(I)*COS(NSIF)
   12 XA=XSYA+YCGXAP=XSP*YAP=YS
   IC=1
   FLN=FLG(IG)
   UEL=X(13)-XA
   DEL=Y(13)-YA
   FIV=ATAN2(-DEL,X*DELY)
   OXP=XP(11)-XAP*OYP=YP(11)-YAP
   CSF=COS(FIV)/SIN(SIM(FIV))
   EPSB=DELY/USF-FLN/FLN
   EPPB=DELX*OXP*DELY*OYP/(SQRT(DELX**2+DELY**2)*FLN)
   TB=CL(11)*ABS(EPSB)*C2(11)-1.*EPSB*TRCF(11)*CINT(1)*EPPB
   IF(TB.LE.TBIM) TB=TBIM
   TENB=TB*SFV*FIV
   IF(ABS(TENB).GE.TBYMX) TENB=TB*YMX*YMB/ABS(TENB)
   DO 41 IC=1,MCAB
   41 GMM=AMN(IG)*GM(12)
   C  CALCULATE EQUATIONS FOR GUNNER ELEMENTS

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CABUOY 433
 CABUOY 434
 CABUOY 435
 CABUOY 436
 CORR 114
 CORR 115
 CABUOY 439
 CABUOY 440
 CABUOY 441
 CABUOY 442
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 CABUOY 444
 CABUOY 445
 CABUOY 446
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 CORR 116
 CORR 117
 CORR 118
 CORR 119
 CABUOY 463
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 CABUOY 465
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 CABUOY 481
 CABUOY 482
 CABUOY 483
 CABUOY 484
 CABUOY 485
 CORR 124
 CABUOY 486
 CABUOY 487
 CABUOY 488

06/19/77 11.49.22

FTN 4.6+020

TRACE

74/76

SUBROUTINE UTM/

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60      IF (IC.EQ.NCAB) GO TO 43
        GSFA=GSFASMA-SMFA-TB
        FCA=1.08FCB-1.0
        IF (IC.EQ.1) FCA=2.0
        IF (IC.EQ.(NCAB-1)) FCB=2.0
        IC1=IC+1
        DELX=X(IC1)-X(IC)
        DELY=Y(IC1)-Y(IC)
        FIV=ATAN2(-DELY,DELX)
        UXP=XP(IC1)-XP(IC)
        UYP=Y(IC1)-Y(IC)
        GSP=COS(FIV)
        FLN=FLC(IC)
        EPSB=(DELY/UXP-FLN)/FLN
        EPB=(DELY/UXP+DELY/YP)/(ISQR(DELY**2+DELY**2)*FLN)
        TBCA(IC1)=ABS(EPB)*IC2(IC1)-1.)*EPSB+TREF(IC1)+
        ICINT(IC1)*EPB
        IF (TB.LE.TMIN) TB=TMIN
        TX=TA+SMFA-TB*SMF
        TY=TA+CSFA-TB*CSF
        XMP=0.
        YMP=0.
        DO 37 IS=1,NSH
            URY=UKSM(IS)*Y(IC)
            IF (ABS(UY).GE.5.) GO TO 38
            UKSF=UKSM(IS)*X(IC)-SIG(IS)*T*FISM(IS)
            XMP=XMP+ASH(15)*SIG(IS)*EXP(-UKY)*SIN(UKSF)
            YMP=YMP+ASH(15)*SIG(IS)*EXP(-UKY)*COS(UKSF)
37      CALL CUR(Y(IC),ZU)
38      CALL CUR(Y(IC),ZU)
        VRY=XMP*CU-XP(IC)
        VRY=YMP*Y(IC)
        VRSQRT(VRY*VRY+VRY*VRY)
        VRNA=VRX*GSFA+VRY*SMFA
        VRNB=VRX*CSF+VRY*SMF
        VRTA=VRX*SMF+VRY*GSFA
        VRTB=VRX*SMF+VRY*CSF
        ONA=0.
        ODRN(IC)=VRNA*ABS(VRNA)
        ONB=0.
        ODRN(IC)=VRNB*ABS(VRNB)
        OTA=0.
        ODRT(IC)=VRTA*ABS(VRTA)
        OTB=0.
        ODRT(IC)=VRTB*ABS(VRTB)
        ONA=PCA*ONA+CSFA*PCA*ONB*CSF
        ONY=PCA*ONA+SMFA*PCA*ONB*SMF
        OTX=PCA*OTA+SMFA*PCA*OTB*SMF
        OTY=PCA*OTA+CSFA*PCA*OTB*CSF
        IF (ICDARK(IC).LT.0.) OR (ICDABY(IC).LT.0.) GO TO 61
        COAR=COARX(IC)/ICDABY(IC)+0.0000001
        IF (ICDAR.LE.0.5) OR (ICDAR.GE.2.) GO TO 71
        JBR=0.
        COARX(IC)=VR*VRX
        JBY=0.
        COABY(IC)=VR*VRY
        GO TO 72
105      C COMPUTE DRAG AND ADDED MASS COEFFICIENTS FOR CIRCULAR DISK
        C ACCORDING TO REPORT NADC-AE-7120
        C1 IF (ICUABY(IC).LT.0.) GO TO 85
        UJAN=SQRT(-4.*COABX(IC)/11.*PI)
        IF (ABS(XP(IC1))-LE.0.0000001) XP1(IC)=0.0000001
        VZAD=ABS(XP(IC)*XP(IC1))/(XP1(IC)*QJAM)
        SVZ=SQRT(VZAD)
        IF (SVZ.GE.0.001) SVZ=0.001
        COARX(IC)=(PI*DIAM**2/4.)*2.2/SVZ
        XMBV(IC)=XMB(IJ)+1.2*SVZ*R*O*DIAM**3

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115      60 TO 71
120      85 QIAN=SQRT(1+COABY(IC)/(1.12*PI))
      IF IAS=YPPI(IC).LE.0.000001 YPI(IC)=0.0000001
      V240=ANS(1YPI(IC)*YPI(IC))/(YPI(IC)*OIAM))
      SV2=SQRT(V240)
      IF (SV2-GE.3KUL) SV2=DKULSIF(SV2,LE.0KLL) SV2=OKLL
      COABY(IC)=(PI*OIAM*2/4)*2.2/SV2
      YMBW(IC)=YMBW(IC)+1.2*SV2*HMO*OIAM**3
125      71 DBA=0.5*HMO*COABY(IC)*VRY*ABS(VRY)
      DBY=0.5*HMO*COABY(IC)*VRY*ABS(VRY)
      FX=IX*OKX+JTX*DBI
      IF ILC=EQ.NBU) FX=XI*Y+IBH
      FY=TY*OKY+JTY*DBY+0.5*FCG*WIC(IC)+0.5*FCG*WIC(IC)*HMO(IC)
      FIZ=0.5*(F+0.5*CHM(IC)+FCG*CHM(IC))+FCG*AMNIC)*CSFA*CSFA+
      1*FCG*AMNIC)*CSF)*XMBV(IC)
      FYI=0.5*(FY+0.5*FJA*CHM(IC)+FCG*CHM(IC))+FCG*AMNIC)*SNFA*SNFA+
      1*FCG*AMNIC)*SNF)*YMBV(IC)
      FKA=0.5*(FKA+0.5*IFCA*AMNIC)*SNFA*CSFA+FCG*AMNIC)*SNF*CSF)
      XPP(IC)=(FYI*FX-FKX*FY)/(FIZ*FY-FKX*FKX)
      YPP(IC)=(FIZ*FY-FKX*FX)/(FYI*FY-FKX*FKX)
      DE(4,IC-2)=XPP(IC)*DE(4,IC)=YPP(IC)
130      41 CONTINUE
      43 CONTINUE
      IF (FSH1-GE.2000.) GO TO 51
      RETURN
135      C CALCULATE COMMON TERMS FOR SURFACE BUOY
      51 XMP=0.3YMP*0.
      DO 52 IS=1,NSH
      UYV=MSH(IS)*SUBM
      IF IABS(UYV)-GE.5.) GO TO 52
      UKXS=MSH(IS)*XSI-SIG(IS)*TOFISH(IS)
      AMP=XMP*ASH(IS)*SIG(IS)*EXP(-UKY)*SIN(UKXS)
      YMP=YMP+ASH(IS)*SIG(IS)*EXP(-UKY)*COS(UKXS)
140      52 CONTINUE
      53 VSR=XMP*CGFI-(XPSI-0G*SYPI)
      VSY=YMP-2IP1
      INR=-TEN*PSIN(FYBI)ATN=TCMB*COS(FYB)
      DBR=0.5*HMO*COASH*VSR*ABS(VSR)
      FX=UBR*INR+INX
      DBY=0.5*HMO*COASH*VSY*ABS(VSY)
      FY=UBY*ATN-FYS-RGSB*RETI
      FSY=UBR*(1-0G)*(-RTY*SYI+RTX)*TMY-(RTX*SYI+RTY)
      1*TKR-RMY*THA
      IF (FSH1-GE.3000.) GO TO 41
145      C CALCULATE DIFFERENTIAL EQUATIONS FOR SPAR BUOY
      PSIC=PSI
      FRKRX=0.4FRKRY=0.4FRKRS=0*PSI*SYI
      DO 55 I=1,NSH
      SGFI=MSH(I)*XSI-SIG(I)*TOFISH(I)
      FRKRX=FRKRX-2.0*SIG(I)*2*ASH(I)*COS(SGFI)*QS0(I)
      FRKRY=FRKRY-2.0*SIG(I)*2*ASH(I)*COS(SGFI)*QS1(I)
      FRKRS=FRKRS-2.0*SIG(I)*2*ASH(I)*COS(SGFI)*QS1(I)
      DE(INDI-4)=(BIM*PS2)*SIN(SGFI)*(-SIG(I)*2*HUNZ*QS0(I)+RGSB)
      1*(BVMK*(BIM*PS2)-PSIC*02)
      1*PSIC*02)
      DE(INDI)=(BVMK*(FSY+FRKRS)*PSIC*(FX+FRKRX))/(BVMK*(BIM*PS2)-
      1*PSIC*02)
      DE(INDI-2)=(FI+FRKRY)/BVMZ

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06/19/77 11.49.22

FTM 4.6428

SUBROUTINE DYNA 74/71 OPT=^ ROUND=^ / TRACE

```

      GO TO 64
      61 CONTINUE
      C CALCULATE DIFFERENTIAL EQUATIONS FOR SPHEROIDAL BUOY
      PCN=SPF
      FRKX=0.5FRKY=0.5FRKS=RGVEU*SYI
      UYS=0.
      UC 65 I=1,M2M
      SSFI=KSM(I)*X(I-SIG(I))*T+ISM(I)
      FRKX=FRKX+VMX*SIG(I)+2*ASM(I)+COS(SGF1)
      FRKS=FRKS+SPC*SYI+SIG(I)+2*ASM(I)+COS(SGF1)
      65 FRKY=FRKY+ASX(I)*SIN(SGF1)+(-SIG(I)+2*VMZ+RGS0)
      DE(MUF-4)=(BVIP*(FX+FRKX)+SPC*(FSY+FRKS-UYS))/
      1 (BVX*BVIP-SPC*2)
      DE(MDE-2)=(FY+FRKY)/VMZ
      U(MDE)=(BVX*(FSY+FRKY-UYS)+SPC*(FX+FRKX))/(BVX*BVIP-SPC*2)
      64 RPPSI=DE(MJ(-4))$ZETP=DE(MDE-2)$YPP=DE(MDE)
      RETURN
      END

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CABUOY 549
 CABUOY 609
 CABUOY 601
 CORR 135
 CORR 136
 CORR 137
 CORR 605
 CABUOY 606
 CABUOY 607
 CORR 138
 CABUOY 609
 CORR 139
 CORR 140
 CABUOY 612
 CORR 141
 CABUOY 613
 CORR 142
 CABUOY 616

04/19/77 11.49.22

PTN 4.6420

TRACE

OPT=8 ROUND=0

14/14

SUBROUTINE CUR

```

1      SUBROUTINE CUR(V,CUR
COMMON/MCU/VV(10),CCF(10),MCMR,FIRST,VCR
IF (FIRST.LT.8) I=1
IF (V.LI.8) GO TO 88
IF (V.GT.VV(MCMR)) GO TO 98
IF (V.EQ.VV(I)) .AND. (V.LE.VV(I+1)) GO TO 38
IF (V.GE.VV(I-1)) .AND. (V.LE.VV(I)) GO TO 48
IF (V.GE.VV(I+1)) .AND. (V.LE.VV(I+2)) GO TO 58
68 I=1
78 IF (V.LE.VV(I+1)) GO TO 38
I=I+1
GO TO 70
38 CU=CCF(I)+(CCF(I+1)-CCF(I))/(VV(I+1)-VV(I))* (V-VV(I))
1-VCR
RETURN
48 I=I+1
GO TO 38
58 I=I+1
GO TO 38
88 CU=CCF(1)-V.X
RETURN
98 CU=CCF(MCMR)-VCR
RETURN
END

```

CABUOY 617
 CABUOY 618
 CABUOY 619
 CABUOY 620
 CABUOY 621
 CABUOY 622
 CABUOY 623
 CABUOY 624
 CABUOY 625
 CABUOY 626
 CABUOY 627
 CABUOY 628
 CABUOY 629
 CABUOY 630
 CABUOY 631
 CABUOY 632
 CABUOY 633
 CABUOY 634
 CABUOY 635
 CABUOY 636
 CABUOY 637
 CABUOY 638
 CABUOY 639
 CABUOY 640

11-19-77

FTN 4-6-428

TRACE

SUBROUTINE SPECT

1/4/74

OPT=0

ROUND=0

```

1      SUBROUTINE SPECT
COMMON/MSDP/ASH(20),FRSM(20),NSM,MTRC
G=32.28PI=3.1415926
FLL=FRSM(1)
FUL=FRSM(2)
FRSM=NSM
DELTAN=2.0PI*(FUL-FLL)/FRSM
MP=2.0PI*FLL
IF (ASH(1).GE.2000.) GO TO 20
*PIERSOM-MOSKONTZ FREQUENCY SPECTRUM
10  MSG=ASH(1)-1000.
A=0.001*0.658=33.56/(MSG*MSG)
DO 11 I=1,NSM
F1=I
M1=MP+DELTAN
M2=0.5*(M1+M2)
MP=M1
FRSM(I)=M1/(2.0PI)
SSM=A*EXP(-M1/M2)/M2*5
ASH(I)=SORT(SSM*DELTAN)
11 CONTINUE
RETURN
C  COMPUTE HERE OTHER FREQUENCY SPECTRA
20 CONTINUE
END

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CABUOY 641
CORR 143
CABUOY 643
CABUOY 644
CABUOY 645
CABUOY 646
CABUOY 647
CABUOY 648
CABUOY 649
CABUOY 650
CABUOY 651
CABUOY 652
CABUOY 653
CABUOY 654
CABUOY 655
CABUOY 656
CABUOY 657
CABUOY 658
CABUOY 659
CABUOY 660
CABUOY 661
CABUOY 662
CABUOY 663
CABUOY 664
CABUOY 665

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1 SUBROUTINE BUOY
COMMON/MBD/MD,PI,G,CCF1,FSH1,TMX,TKS,TYS,SUBH,RTY,RTX,RMY,YCG,
18M,96,MAS,QUASX,COASY,KA,TA,XPA,YPA
COMMON/MSB/HPPS1,ZETPP,SYPP,XS1,ZETI1,SYI,XPS1,ZTPI,SYPI
COMMON/SPAR/PS0,PS1,PS2,OS0(20),OS1(20),RGS0,BVMX,BVMZ
COMMON/MDI/ARSM(20),AYSH(20),FISH(20),MKSH(20),MSH(20),
1FSM(20),NSM
COMMON/MDSP/ASM(20),FRSM(20),NSM,MISC
COMMON/SPHER/BNIP,SPF,RCVBS,MVIP,DYN,MVMX,MVMZ,MVB
1DIRECTION PH0(20),QH1(20)
COMMON/MT/PHISL,XAL,YTL,TIL,VHX,VHM,3CYI,ITER,ICS,NDOT,ORCBTH,TIV
1,SYISU
1DIRECTION MH(20),FS(20),FM(20),FP(20),FPS(20)
IF(ICS.GE.2) GO TO 31
READ(5,1) COASY,MAS,MNY,RTX,RTY,YCG,BIN
READ(5,1) XS1,ZETI1,SYI,XPS1,ZTPI,SYPI
IF(MTAC.LE.0) GO TO 211
1 CONVERT METRIC INPUT TO ENGLISH UNITS
COASY=3.281*3.281*COASY,MAS=MAS/4.452,BMY=1.281*MNY
RTX=3.281*RTX,RTY=3.281*RTY,YCG=3.281*YCG,BIN=0.7370*BIN
XS1=3.281*XS1,ZETI1=3.281*ZETI,XPS1=3.281*XPS1,ZTPI=3.281*ZTPI
211 CONTINUE
1 FORMAT(4F10.4)
SYI=SYI*PI/180.
SYPI=SYPI*PI/180.
WRITE(6,2)
3 FORMAT(7X,2HSURFACE BUOY PARAMETERS)
WRITE(6,3)
4 FORMAT(1/1X,10HCOAST(FTS),2X,6HMT(LB),4X,7HMY(FT),3X,7HRTX(FT),
1X,7HRTY(FT),2X,7HYSU(FT),2X,10HINISLFTSD,2X,6HMT(FT),2X,
2HMETAI(FT),2X,6HMYI(NEG),1X,8HMTI(FT/S),1X,9HMTVI(FT/S),
1X,9HMYVI(J/2))
WRITE(6,5) COASY,MAS,MNY,RTX,RTY,YCG,BIN,XS1,ZETI1,SYI,XPS1,
1ZTPI,SYPI
5 FORMAT(11F10.4)
MAS=MAS/G
11 FYI=1-TYS/MAS
IF(FSM1.GE.3000.) GO TO 101
1 COMPUTE COEFFICIENTS FOR SPAR BUOY
BVMZ=BMS*(1.0+RND/3.0)*((BMS+TYS/G)/(RMG*PI*AYSH(NSM)))**1.5
JD 11 I=1,NM
QM0(I)=0.
11 JM(I)=0.
PH0=0.0,PM1=0.0,PN2=0.
NSM2=NSM-2
H=AYSH(1S+1)-AYSH(1S)
ALFA=(AYSH(1S+2)-AYSH(1S+1))/H
ALCM=(ALFA+1.0)/(6.0*ALFA)
ALP2=2.0*ALFA-1.0,ALP1=(ALFA+1.0)**2,ALP=ALFA*(2.0-ALFA)
32=ARSM(1S+2)/AS1=ARSM(1S+1)SS=ARSM(1S)
Y2=AYSH(1S+2)*Y1=AYSH(1S+1)SY=AYSH(1S)
Y2=Y2-YC, Y1=Y1-YC, Y1-YC=Y1-YC
PH0=PH0+FA*(ALP2+2*ALP1+3*ALP+S)
PH1=PH1+FA*(ALP2+YCG+S2+4.0*Y1S+31*ALP+YCG+S)
PH2=PH2+FA*(ALP2+YCG+S2+ALP+Y1G+20*51*ALP+YCG+S2+S)

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60      DO 14 IM=1,NSM
          YK=YKSM(IM)
          YK1=YKSM(IM)
          YK2=YKSM(IM)
          EXP=EXP(YK)
          QM8(IM)=QM8(IM)*FAC*(ALP2*EKY2*52*ALP1*EKY1*51*ALP*EKY*51)
          QM1(IM)=QM1(IM)*FAC*(ALP2*EKY2*52*ALP1*EKY1*51*ALP*EKY*51)
          1ALP=YK6*EKY*51
14      CONTINUE
2      CONTINUE
          FAC=1/YS1/(RHO*G*PN9)
          PS9=FAC*PN9*RHOPSI=FAC*PN1*RHOPSI2*FAC*PN2*RHOPSI
          DO 6 I=1,NSM
              QM8(I)=FAC*QM8(I)*RHO
              QM1(I)=FAC*QM1(I)*RHO
              RGS8=AND*G*AKSM(I)
              YCB=PS1/PS9
              BC=YLB
              MNWZ=1.0/(MYR2-QRS)/PS9
              IF (1/ITER-GE.1)-AMD-(ICS-GE.2)) GO TO 481
              21 WRITE(6,23)
              22 FORMAT(7X,23HCONSTANTS FOR SPAR BUOY)
              WRITE(6,26) FAC
              26 FORMAT(1X,26HINITIAL RATIO Y / P9=.F10.5)
              23 FORMAT(1X,3HP9=.F10.5,X,3HP1=.F10.5,X,3HP2=.F10.5)
              WRITE(6,24) (QSM(I),I=1,NSM)
              24 FORMAT(1X,3HQ8=.12F10.5/X,12F10.5)
              25 FORMAT(1X,3HQ1=.12F10.5/X,12F10.5)
              27 WRITE(6,29) MNWZ,RGS8
              29 FORMAT(1X,5HWNWZ=.F10.5,X,5HRCG8=.F10.5)
              GO TO 481
101      CONTINUE
C      COMPUTE COEFFICIENTS FOR PROLATE OR OBLATE SPHEROID
          QFT=AYS(M1)88*AKSM(I)
          A=88MA=DT/TA
          IF (MA.GT.0.1) GO TO 141
          PK5=0.0748*MA/0.1
          FAP=1.27*0.1/MA
          FKPS=0.3
          GO TO 121
141      IF (MA.GT.10.) GO TO 161
          MH(1)=0.18MH(2)=0.28MH(3)=0.38MH(4)=0.5
          MH(5)=0.78MH(6)=0.98MH(7)=1.18MH(8)=1.5
          MH(9)=2.0MH(10)=3.0MH(11)=5.0MH(12)=7.0
          MH(13)=10.
          FS(1)=0.0748FS(2)=0.1438FS(3)=0.2048FS(4)=0.31
          FS(5)=0.3978FS(6)=0.4688FS(7)=0.5088FS(8)=0.622
          FS(9)=0.7848FS(10)=0.8668FS(11)=0.8968FS(12)=0.933
          FS(13)=0.96
          FM(1)=12.064FM(2)=5.044FM(3)=3.5726FM(4)=2.005
          FM(5)=1.325FM(6)=0.906FM(7)=0.636FM(8)=0.404
          FM(9)=0.323FM(10)=0.186FM(11)=0.0826FM(12)=0.049
          FM(13)=0.028
          FP(1)=1.276FP(2)=0.558FP(3)=0.3128FP(4)=0.117

```

SUBROUTINE BUOY 74/74 OPT=0 ROUNO=0/ TRACC

```

115      FP(5)=0.03508FP(6)=0.00308FP(7)=0.8FP(8)=0.0731
      FP(9)=0.272FP(10)=0.9938FP(11)=3.058FP(12)=0.20
      FP(13)=20.0
      FPS(1)=0.30FPS(2)=0.2046FPS(3)=0.2378FPS(4)=0.177
      FPS(5)=0.116FPS(6)=0.00398FPS(7)=0.5FPS(8)=0.191
      FPS(9)=0.3318FPS(10)=0.7803FPS(11)=1.568FPS(12)=-2.30
      FPS(13)=-3.75
      I=1
147      IF(MA.LE.MM(1)) GO TO 143
      I=I+1
      GO TO 147
143      CONTINUE
      FKSPS(1)=(FPS(1)-FM(1))/(MM(1)-MM(1))*(MA-MM(1))
      FKSPS(2)=(FPS(2)-FM(2))/(MM(2)-MM(2))*(MA-MM(1))
      FKSPS(3)=(FPS(3)-FM(3))/(MM(3)-MM(3))*(MA-MM(1))
      FKSPS(4)=(FPS(4)-FM(4))/(MM(4)-MM(4))*(MA-MM(1))
      FKSPS(5)=(FPS(5)-FM(5))/(MM(5)-MM(5))*(MA-MM(1))
      GO TO 121
      C USE SPAR BUOY STRIP THEORY FOR W/A.GT.10
141      CONTINUE
      FKSPS(1)=0.84*EXP(-0.09944*(MA-10.))
      FM=0.020
      FKSP=NA*2/5.
      FKPS=-3.*MA/8.
      GO TO 121
121      VOL=2.*PI*DT*0.0000/3.
      VMI=PI*0.0000*(DT*DT/4.-7.*YCG*DT/3.)
      FACG=TVST/(RHO*G*VOL)
      VOL=FACG*VOLSVMI*FACG*VMI
      BG=VMI/VOL
      LOUPL=FKPS*A*YCG*FKS
      API=FKP*A*2.*YCG*FKPS*A*YCG*2*FKS
      BVMI=BMS*FKS*RHO*VOL
      BVNZ=BMS*FKS*RHO*VOL
      BVIP=BIM*API*RHO*VOL
      VMI=(1.-FKS)*RHO*VOL
      VNZ=(1.-FKM)*RHO*VOL
      SPI=COUPL*RHO*VOL
      RCBG=RHO*G*VOL*86
      RGS0=RHO*G*PI*0.0000
      PSI=RHO*VMI
      IF(ITER.GE.1).AND.(IGS.GE.2) GO TO 401
      WRITE(6,131)
131      FORMAT(15X,29HCONSTANTS FOR SPHEROIDAL BUOY)
      WRITE(6,132)
      WRITE(6,132)
132      FORMAT(11X,9HORAFT(FT),3X,5H0(FT),4X,7HORAFT/B*2X,
      19HVOL(CUFT),1X,10HVOL*(FT^3),4X,3HFKS,7X,3HFKM,7X,3HFKP,6X,
      14HFKPS,6X,4HRCG0)
      WRITE(6,133) DT,0.0,MA,VOL,VMI,FKS,FKM,FKP,FKPS,RGS0
133      FORMAT(10F10.4)
141      CONTINUE
      VSI=YCG*ZETI
      C CALCULATE STATIC VALUE OF SY
      OBM=(-TMR-TXS)*(-BG)
      SYM=-OBM-RIS*TS*RTYS*RTXS*RTY*RTXS*RTYS*RTX*RTS
      SYIO=CPSP1-RTY*TS-RTX*TS
      SYIS=SYIM/SYIO)

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CORR 181
 CORR 182
 CORR 183
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 CORR 189
 CORR 190
 CORR 191
 CORR 192
 CORR 193
 CORR 194
 CORR 195
 CORR 196
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 CORR 201
 CORR 202
 CORR 203
 CORR 204
 CABUOY 764
 CABUOY 765
 CABUOY 766
 CABUOY 767
 CABUOY 768
 CORR 285
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 CABUOY 785
 CABUOY 786
 CABUOY 787
 CABUOY 788
 CABUOY 789
 CABUOY 790
 CABUOY 791
 CABUOY 792
 CABUOY 793
 CABUOY 794
 CABUOY 795
 CABUOY 796
 CABUOY 797
 CABUOY 798
 CABUOY 799
 CABUOY 800
 CORR 221
 CORR 222

	SUBROUTINE BUOY	74/74	OPT=0	ROUND=0/	TRACE	FTN 4.6+420	04/19/77	11.49.22	PAGE 4
175	<pre> SYISO=SYIS*100./PI ZF(ITER-64.1).AND.(IC>GE.2)) GO TO 404 WRITE(6,20) BU 20 FOR AT(5X,8MYCB-YCG=F10.4,1X,2HFT) MRI E(6.27) SYISO 27 FOR MAT(5X,11HSTEADY SYI=F10.4,1X,3HDEI) 404 77 (STUL-66.368.) SYI=SYIS C COMPUTE YAX,XAP,YPA XAX=XSL*MTX-KTY*SYI YAX=YSL*MTX-KTY*SYI XPA=XPSL-RTY*SYPI YPA=YPSL-RTY*SYPI RETURN END </pre>						CABUOY 888 CORR 223 CABUOY 801 CABUOY 802 CABUOY 803 CABUOY 804 CORR 224 CABUOY 806 CORR 229 CORR 226 CORR 227 CORR 228 CABUOY 811 CABUOY 812		
180									
185									

```

1  SUBROUTINE ITERA
   COMMON/MCU/VY(10),GCF(10),MCUR,FIRST,VCK
   COMMON/MT/PMISL,XL,VYL,TTL,VNX,VNM,BCYI,ITER,ICS,MOUT,ORGBTH,TY
   1,5YISD
   5  IF(ITER.LE.0) RETURN
      GO TO (101,201,301) ITER
   C  PERFORM ITERATIONS FOR FREE FLOATING CASE
   101 IF(ICS.EQ.2) GO TO 111
   102 VCK=0.5*(VNX+VNM)
   110 TTY=BCYI
      TTYNM=BCYI
      TTYX=0.
      DMFAC=0.7
      TMAX=1-DETHIN=1-0
      PMERY=1000.
      RETURN
   211 ERR=-(TTL-SIN(P*ISL))
      ERR=TL*JOS(P*ISL)
      ERR=SQRT(ERR*ERR*ERY*ERY)
      RATIO2=ABS(ERR/MOUT)
      MOUT=0.1*ABS(MOUT)
      IF(ABS(ORGBTH)-LE.MBT1) ORGBTH=MOUT1
      IF(ABS(ORGBTH)-LE.ABS(MOUT1)) ORGBTH=ABS(MOUT)
      RATIO3=ABS(TTX/ORGBTH)
      VTEMP=VCK
      TYTEMP=TY
      IF((RATIO2.LE.0.01).AND.(RATIO3.LE.0.01)) GO TO 501
      IF(RATIO3.LE.0.01) GO TO 121
      IF(ERR.LT.0.) GO TO 115
   112 VCK=0.5*(VCK+VNM)
      VNM=VTEMP
      RETURN
   115 VCK=0.5*(VCK+VNM)
      VNM=VTEMP
      RETURN
   121 IF(1-ERY/PMERY).GT.0.5) DMFAC=0.5*DMFAC
      IF(ERY/PMERY).GT.0.7) DMFAC=1.5*DMFAC
      PMERY=ERY
      TTY=TYTEMP+DMFAC*ERY
      IF(ERY.LT.0.) GO TO 125
   122 IF(115-5E-11VNX) TTY=0.5*(TYTEMP+TYNM)
      TMIN=TTY/TYTEMP
      TMAX=TYTEMP/TTY
      TYNM=TYTEMP
      GO TO 127
   125 IF(115-LE-11VNM) TTY=0.5*(TYTEMP+TYNM)
      TMAX=TTY/TYTEMP
      TMIN=TYTEMP/TTY
      TYNX=TYTEMP
      TTYX=TYTEMP
   127 VNX=(TMAX+0.05)*VCK
      VNM=(TMIN-0.05)*VCK
      WRITE(6,191)
   191 FORMAT(//)
      RETURN
   201 CONTINUE
   C  PERFORM ITERATIONS FOR MOORED CASE
      IF(ICS.EQ.2) GO TO 211

```

04/19/77 11-09-22

FTN 4.64420

SUBROUTINE ITERA 74/74 OPT=0 RCUMD=0/ TRACE

```

        TIV=-2.0BCYI
        TIVM=-100.0BCYI
        TIVM=0.
        RETURN
211 ERY=YVL-YV(MCUR)
        ABSERY=ABS(ERY)
        IF(ABSERY-LT.0.81) GO TO 501
        TTEMP=TIV
        IF(ERY) 212+212+214
212 TIV=0.5*(TTEMP+TIVM)
        TIVM=TTEMP
        RETURN
214 TIV=0.5*(TTEMP+TIVM)
        TIVM=TTEMP
        RETURN
301 CONTINUE
501 ITER=0
        RETURN
        END
CORR      249
CORR      250
CORR      251
CORR      252
CORR      253
CORR      254
CORR      255
CORR      256
CORR      257
CORR      258
CORR      259
CORR      260
CORR      261
CORR      262
CORR      263
CASUDY    860
CASUDY    861
CASUDY    862
CASUDY    863

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04/19/77 11.49.22

FTN 4.6+428

SUBROUTINE KUTHER 74/74 OPT=8 ROUND=0/ TRACE

```

1      SUBROUTINE KUTHER(M,T,Y0,EPS,M,FIRST,MCX,A,DAUX)
      KUTHER ROUTINE REVISED FOR IVOOE JAN 30,1964
      DIMENSION Y0(106),Y1(106),Y2(106),F0(106),F1(106),F2(106)
      IF(FIRST)20,10,20
      MC=M
      IPLOC=1
      FIRST=1.
      20 LOC=0
      MCX=MC
      30 CALL DAUX (T,Y0,F0)
      35 DO 40 I=1,N
      40 Y1(I)=Y0(I)+(MC/3.)*F0(I)
      CALL DAUX (T+MC/3.,Y1,F1)
      DO 50 I=1,M
      50 Y1(I)=Y0(I)+(MC/6.)*F0(I)+(MC/6.)*F1(I)
      DO 60 I=1,M
      60 Y1(I)=Y0(I)+(MC/9.)*F0(I)+.375*MC*F1(I)
      CALL DAUX (T+MC/2.,Y1,F2)
      DO 70 I=1,M
      70 Y1(I)=Y0(I)+(MC/2.)*F0(I)-1.5*MC*F1(I)+2.*MC*F2(I)
      CALL DAUX (T+MC,Y1,F1)
      DO 80 I=1,M
      80 Y2(I)=Y0(I)+(MC/6.)*F0(I)+.66666667*MC*F2(I)+(MC/6.)*F1(I)
      INC=0
      DO 110 I=1,M
      110 I=1,M
      222=ABS (Y1(I))-A
      IF(122) 85,67,67
      85 ERROR = ABS(.2*(Y1(I)-Y2(I)))
      IF(ERROR-A)100,100,90
      87 ERROR=ABS (.2-.2*Y2(I)/Y1(I))
      IF(ERROR-EPS)100,100,90
      90 CONTINUE
      KYSGIE=24
      CZATR=2.*KYSGIE
      XX= CZATR*ABS(MC)-ABS(M)
      IF (XX) 91,95,95
      91 WRITE(9,92) I,ERROR,I
      92 FORMAT(21M RELATIVE ERROR AT X= 1PIE12.33M 1SF10.6/ 6M I= .14)
      FIRST = 2.
      RETURN
      95 MC=MC/2.
      IPLOC=2.*IPLOC
      LOC=2.*LOC
      MCX=MC
      GO TO 30
      100 IF(ERROR*6.-EPS)110,110,101
      101 INC=1
      110 CONTINUE
      111 T=T+MC
      112 Y0(I)=Y2(I)
      LOC=LOC+1
      IF(LOC-IPLOC)120,210,210
      120 IF(LOC)210,130,210
      130 IF(LOC-(LOC/2.)*2)210,140,210
      140 IF(IPLOC-1)210,210,200

```

04/19/77 11.49.22

FTN 4.6+420

74/74 OPT=0 20.00-0/ T/AGE

SUBROUTINE KUTNER

CABU0Y 921
CABU0Y 922
CABU0Y 923
CABU0Y 924
CABU0Y 925
CABU0Y 926

311 MC=2*MC
100 LOC/2
101 ILOC=ILOC/2
210 IF (ILOC-LOC) 30,220,30
220 RETURN
END

60

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