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An Investigation Conducted by
Leon E. Borgman, Inc., Laramie, WY

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Brief Instructions for Subroutine SIMBAT, A Computer Package for Unconditional and Conditional Simulation of Ocean Wave Kinematics

ABSTRACT SIMBAT is a FORTRAN subroutine for computer simulation of ocean wave kinematics. Given an estimate of directional wave spectrum, the program calculates kinematics in the irregular wave field. These calculations can be conditioned on a particular kinematic or surface elevation time series. Brief instructions for use of SIMBAT are given.

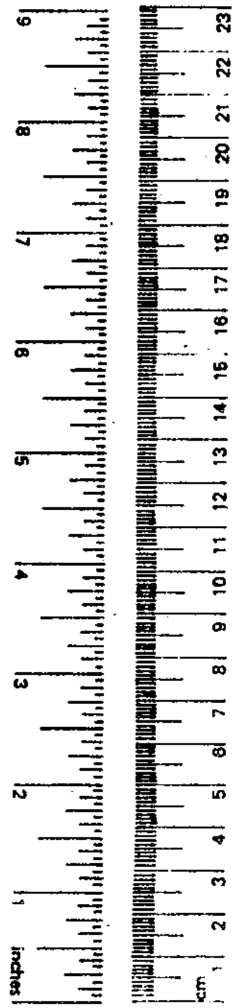
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

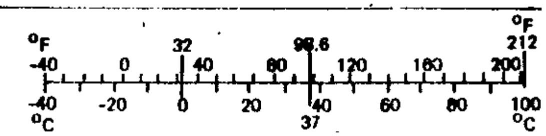
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SIMBAT is a FORTRAN subroutine for computer simulation of ocean wave kinematics. Given an estimate of directional wave spectrum, the program calculates kinematics in the irregular wave field. These calculations can be conditioned on a particular kinematic or surface elevation time series. Brief instructions for use of SIMBAT are given.

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EXECUTIVE SUMMARY

As the title suggests this document provides brief instructions for a set of computer subroutines called SIMBAT. SIMBAT can unconditionally and conditionally simulate random directional ocean wave properties. Given an estimate of the directional wave spectrum, the program calculates elevations, kinematics, and pressures in the random wave field. These calculations can be conditioned on particular kinematic or surface elevation time series.

Conditional simulation of wave property time series statistically consistent with a specified measurement set, provides a very powerful approach to certain ocean engineering problems. The usual computer simulation of waves satisfying a specified model for the directional spectral density suffers from a serious practical defect if one is primarily interested in producing very large waves. Most simulations produce only average waves unless the simulation is run for a very, very long time. SIMBAT allows for the inclusion of a large wave profile or wave group to be embedded into the wave train, resulting in very short computer simulations.

The report describes basic wave properties in their complex form, describes the program SIMBAT, and explains in detail the development of the Legendre polynomials for storage of the large volume of wave kinematic data generated.

This contract report was prepared by Dr. Leon Borgman, professor of Statistics and Geology at the University of Wyoming, working for the Naval Civil Engineering Laboratory through his statistical consulting firm, Leon E. Borgman, Inc. The work was principally funded by the Mineral Management Service through Charles Smith of the Technology Assessment & Research Branch. Additional work in fiscal year 1990 is planned under Naval Facilities Engineering Command funding for testing, modifying, and annotating SIMBAT.

TABLE OF CONTENTS

1.0 GENERAL COORDINATE SYSTEM

The ocean wave kinematics will be referenced to a general horizontal coordinate system. All horizontal coordinate axes are established within navigation headings measured clockwise from true north.

$$\theta_x = \text{direction of positive x-axis}$$

$$\theta_y = \text{direction of positive y-axis} \qquad (1)$$

$$|\theta_x - \theta_y| = 90^\circ$$

Let the vertical axis z be zero at mean water level and positive downward.

The direction of travel of a wave is θ in navigation heading. The wave is traveling toward direction θ if $\beta_o = 1$ and is coming from direction θ if $\beta_o = -1$.

2.0 BASIC WAVE PROPERTIES

Eight wave properties are of interest. In terms of real functions, there are

(1) The water level elevation:

$$\eta(x,y,t) = a \cos \{\beta_o k [x \cos(\theta - \theta_x) + y \cos(\theta - \theta_y)] - 2\pi ft - \phi\} \qquad (2)$$

(2) The components of water perticle velocity:

$$\begin{bmatrix} V_x(x,y,z,t) \\ V_y(x,y,z,t) \end{bmatrix} = a(2\pi f) \frac{\cosh[k(d-z)]}{\sinh(kd)} \begin{bmatrix} \beta_o \cos(\theta-\theta_x) \\ \beta_o \cos(\theta-\theta_y) \end{bmatrix} \cdot \cos [\beta_o k\{x \cos(\theta-\theta_x) + y \cos(\theta-\theta_y)\} - 2\pi ft - \phi] \qquad (3)$$

$$V_z(x,y,z,t) = a(2\pi f)\,\frac{\sinh[k(d-z)]}{\sinh(kd)}\,\sin[\beta_o k\{x\cos(\theta-\theta_x)$$

$$+\, y\cos(\theta-\theta\ )\} - 2\pi ft - \phi] \qquad (4)$$

(3) The components of water particle acceleration:

$$\begin{bmatrix} a_x(x,y,z,t) \\ a_y(x,y,z,t) \end{bmatrix} = a(2\pi f)^2\,\frac{\cosh[k(d-z)]}{\sinh(kd)} \begin{bmatrix} \beta_o \cos(\theta-\theta_x) \\ \beta_o \cos(\theta-\theta_y) \end{bmatrix}$$

$$\cdot\ \sin[\beta_o k\{x\cos(\theta-\theta_x) + y\cos(\theta-\theta_y)\}$$

$$-\, 2\pi ft - \phi] \qquad (5)$$

$$a_z(x,y,z,t) = -\,a(2\pi f)^2\,\frac{\sinh[k(d-z)]}{\sin(kd)}\,\cos[\beta_o k\{x\cos(\theta-\theta_x)$$

$$+\, y\cos(\theta-\theta_y)\} - 2\pi ft - \phi] \qquad (6)$$

(4) The water pressure anomaly (plus and minus about hydrostatic pressure):

$$p(x,y,z,t) = a\rho g\,\frac{\cosh[k(d-z)]}{\cosh(kd)}\,\cos[\beta_o k\{x\cos(\theta-\theta_x)$$

$$+\, y\cos(\theta-\theta_y)\} - 2\pi ft + \phi] \qquad (7)$$

In these formulas

a = wave amplitude

f = wave frequency

d = water depth

k = wave number = 2π/wavelength

ϕ = wave phase

ρ = water density

g = acceleration due to gravity

3.0 WAVE PROPERTIES IN COMPLEX FORM

Through the use of the complex form of cos α and sin α where

$$\cos\alpha = \frac{\exp(i\alpha) + \exp(-i\alpha)}{2} \tag{8}$$

$$\sin\alpha = \frac{\exp(i\alpha) - \exp(-i\alpha)}{2i} \tag{9}$$

All of the wave properties listed above can be expressed in the form:

$$B(f) = \frac{ae^{i\phi}}{2} G(z)\; T(f)\; H(\theta)\; \exp[-i\beta_o k\{x \cos(\theta-\theta_x) + y \cos(\theta-\theta_y)\}]\; \exp(i2\pi ft) \tag{10}$$

for positive f. The original real-valued wave time property equals $B(f) + B(f)^*$ where

$$B^*(f) = \text{complex conjugate of } B(f) \tag{11}$$

The functions G, T, and H for each wave property are:

(1) Water level elevation:

$$G(z) = T(f) = H(\theta) \equiv 1.0 \tag{12}$$

(2) Velocity:

$$G(z) = \begin{cases} \dfrac{\cosh[k(d-z)]}{\sinh(kd)} = \dfrac{\{e^{-kz} + e^{-k(2d-z)}\}}{\{1 - e^{-2kd}\}}, & \text{for } V_x \text{ and } V_y \\[2ex] \dfrac{\sinh[k(d-z)]}{\sinh(kd)} = \dfrac{\{e^{-kz} - e^{-k(2d-z)}\}}{\{1 - e^{-2kd}\}}, & \text{for } V_z \end{cases} \tag{13}$$

$$T(f) = \begin{cases} 2\pi f, & \text{for } V_x \text{ and } V_y \\ 2\pi f i, & \text{for } V_z \end{cases} \tag{14}$$

$$H(\theta) = \begin{cases} \beta \cos(\theta-\theta_x), & \text{for } V_x \\ \beta \cos(\theta-\theta_y), & \text{for } V_y \\ 1.0, & \text{for } V_z \end{cases} \tag{15}$$

(3) Acceleration:

$$G(z) = \begin{cases} \dfrac{\cosh[k(d-z)]}{\sinh(kd)} = \dfrac{\{e^{-kz} + e^{-k(2d-z)}\}}{\{1 - e^{-2kd}\}} , & \text{for } a_x \text{ and } a_y \\ \dfrac{\sinh[k(d-z)]}{\sinh(kd)} = \dfrac{\{e^{-kz} - e^{-k(2d-z)}\}}{\{1 - e^{-2kd}\}} , & \text{for } a_z \end{cases} \tag{16}$$

$$T(f) = \begin{cases} (2\pi f)^2 i , & \text{for } a_x \text{ and } a_y \\ -(2\pi f)^2 , & \text{for } a_z \end{cases} \tag{17}$$

$$H(\theta) = \begin{cases} \beta \cos(\theta-\theta_x) , & \text{for } a_x \\ \beta \cos(\theta-\theta_y) , & \text{for } a_y \\ 1.0 , & \text{for } a_z \end{cases} \tag{18}$$

(4) Pressure anomaly:

$$G(z) = \frac{\cosh[k(d-z)]}{\cosh(kd)} = \frac{\{e^{-kz} + e^{-k(2d-z)}\}}{\{1 + e^{-2kd}\}} \tag{19}$$

$$T(f) = \rho g \tag{20}$$

$$H(\theta) = 1.0 \tag{21}$$

4.0 WAVE PROPERTIES AS A DISCRETE FOURIER TRANSFORM

Let $ae^{i\phi}$ be replaced by the complex-valued wave amplitude A_{mj} for frequencies, f_m:

$\left\{m\ \Delta f; \quad 1 \le m \le \frac{N}{2} - 1\right\}$ and directions, θ_j,

$\{j\ \Delta\theta; \quad 1 \le j \le J\}$

where $\Delta\theta = 2\pi/J$

$\Delta f = 1/(N\ \Delta t)$

Δt = time increment

$N\ \Delta t$ = length of time series

Also let k be replaced by k_m where

$$(2\pi f_m^2) = g\, k_m \tanh(k_m d) \tag{22}$$

The sequence, defined above for $1 \le m < N/2$, can be extended to $N/2 < m \le N-1$ by requiring that (in analogy to Eq 10)

$$B[(N-m)\Delta f] = B(m\, \Delta f)^* \tag{23}$$

where B(f) is the general complex-valued wave property defined previously. The sum of these wave forms over $0 \le m \le N-1$ gives a discrete Fourier transform version of the wave properties. Here, it is assumed that $A_{mj} = 0$ for $m = 0$ and $m = N/2$. The $m = 0$ value is the mean or DC component. Taking it as zero guarantees that the wave property oscillates about zero. The value at $m = N/2$ is a very high frequency component at the Nyquest frequency. The length of the time series, N, and the time increment, Δt, can always be selected so that there is no energy at $f_{N/2} = (N/2)\, \Delta f$.

Then,

$$\begin{Bmatrix}\text{wave property}\\ \text{at } t = n\,\Delta t\end{Bmatrix} = \sum_{m=0}^{N-1}\left[\sum_{j=1}^{J} A_{mj}\, G_m\, T_m\, H_j \cdot e^{-i\beta_o k_m\{x \cos(\theta_j - \theta_x) + y \cos(\theta_j - \theta_y)\}}\right] e^{i2\pi \frac{mn}{N}} \quad \ldots\ldots\ (24)$$

This represents a summing of many waves, each with their own frequency, phase, and direction.

The last equation provides the general procedure for frequency-domain wave simulation. The quantity in the bracket is computed for $1 \le m < N/2$. Usually this is only necessary for a relatively small subset of the interval, say

$$0 < m_B \le m \le m_L < N/2 \tag{25}$$

or

$$NUM = m_L - m_B + 1 \tag{26}$$

frequency increments. Then the rest of the coefficients for $0 \leq m \leq N/2$ are set to zero. The values for $N/2 < m \leq N-1$ are the complex conjugate of those in the left half of the sequence. That is,

$$\{\text{coefficient at } N-m\} = \{\text{coefficient at } m\}^* \tag{27}$$

5.0 PROGRAM LAYOUT

The program has seven options in addition to exit and help options. These are:

(1) Option No. 1.

A complex-valued matrix of wave amplitudes in the form:

$$A(m,j) = \rho(m,j)\, e^{i\phi(m,j)}$$

is simulated by frequency-domain computations. Here, ρ is the wave amplitude, ϕ is the phase. The m-index ranges over a regular grid of frequencies, and the j-index ranges over direction of wave travel. This option gives an unconditional simulation.

(2) Option No. 2.

A conditional simulation is a time series simulation which is forced to agree with a specified initial data time series segment, while maintaining appropriate correlated randomness. The program SIMBAT develops conditional simulation by several methods, all based on first producing a conditional simulation of the A(m,j) described under the first option. These A(m,j) however are conditionally simulated, rather than unconditionally simulated. The production of such a set of conditional simulation requires a number of pre-computed arrays. Option

No. 2 develops these input arrays. Thus, it is a pre-processor to the various options which subsequently compute the actual conditional simulations.

(3) Option No. 3.

This option uses the output from the previous option, for the case where the conditioning interval is shorter than the full time series, to compute a conditional simulation of the A(m,j) complex matrix of wave amplitudes.

(4) Option No. 4.

This option is the same as Option No. 3 above, except that the conditioning interval is a full time series. That is, a measured time series of length, N, is used to develop the A(m,j) complex-valued wave amplitude, which in turn may be used to simulate in a later option, time series of length, N.

(5) Option No. 5.

This option uses the complex amplitude table of A(m,j) values to generate full time series (of length N) for various wave properties as specified. It basically is designed to be useful for the case where only a few time series (say 20 or less) are needed.

(6) Option No. 6.

This option is the fastest way to develop velocities and accelerations at many load points throughout a complex structure. It provides orthogonal polynomial coefficients for a Legendre expansion of each of eight wave properties (η, V_x, V_y, V_z, a_x, a_y, a_z, pressure) within a region ($x_o-D_1 < x < x_o+D_1$), ($y_o-D_2 < y < y_o+D_2$), and $0 < z < d$. A different, (optional) set of coefficients are provided at time step, as stored on a file. Option No. 6 computes these coefficients and stores them on a master file. The user then reads the master file, time-step by time-step, and uses coefficients at that time step to generate all the wave kinematics at the various (x,y,z) locations throughout the structure. Then the user reads the next coefficient set at that time step, and so forth.

(7) Option No. 7.

This option provides a short list of wave amplitudes, phases, frequencies, wave numbers, and travel directions which give a wave train that approximates the full wave field represented by the A(m,j) matrix. It will not exactly agree with the condition set, but will be somewhat near. It is probably slower also, in use, than Option No. 6 above.

An overall flow chart is shown in Figure 1. The delta stretching is applied by the user as based on having the sea surface elevation and the wave kinematics at the same (x,y) location. Other spectral models and spreading functions will also be coded into the package. Currently, the Ochi-Hubble and Gaussian spreading function are implemented. However, it is easy to insert other choices as subroutines into the structure.

It is anticipated that many further enhancements and modifictions will be introduced during July and August 1988 as a natural outgrowth of experience and further needs as the program is used in applications.

6.0 SIMBAT SEPARATE-MODULE PACKAGE

The SIMBAT simulation package is also provided in separate modules of relatively small size for computation on larger microcomputers. The modules are:

1. SIM125 -- options 1, 2, and 5
2. SIM3 -- option 3
3. SIM4 -- option 4
4. SIM6 -- option 6
5. SIM7 -- option 7

Before running program: Set parameters and compile, either for unconditional simulation (option no. 1) or conditional simulations (option no. 2)

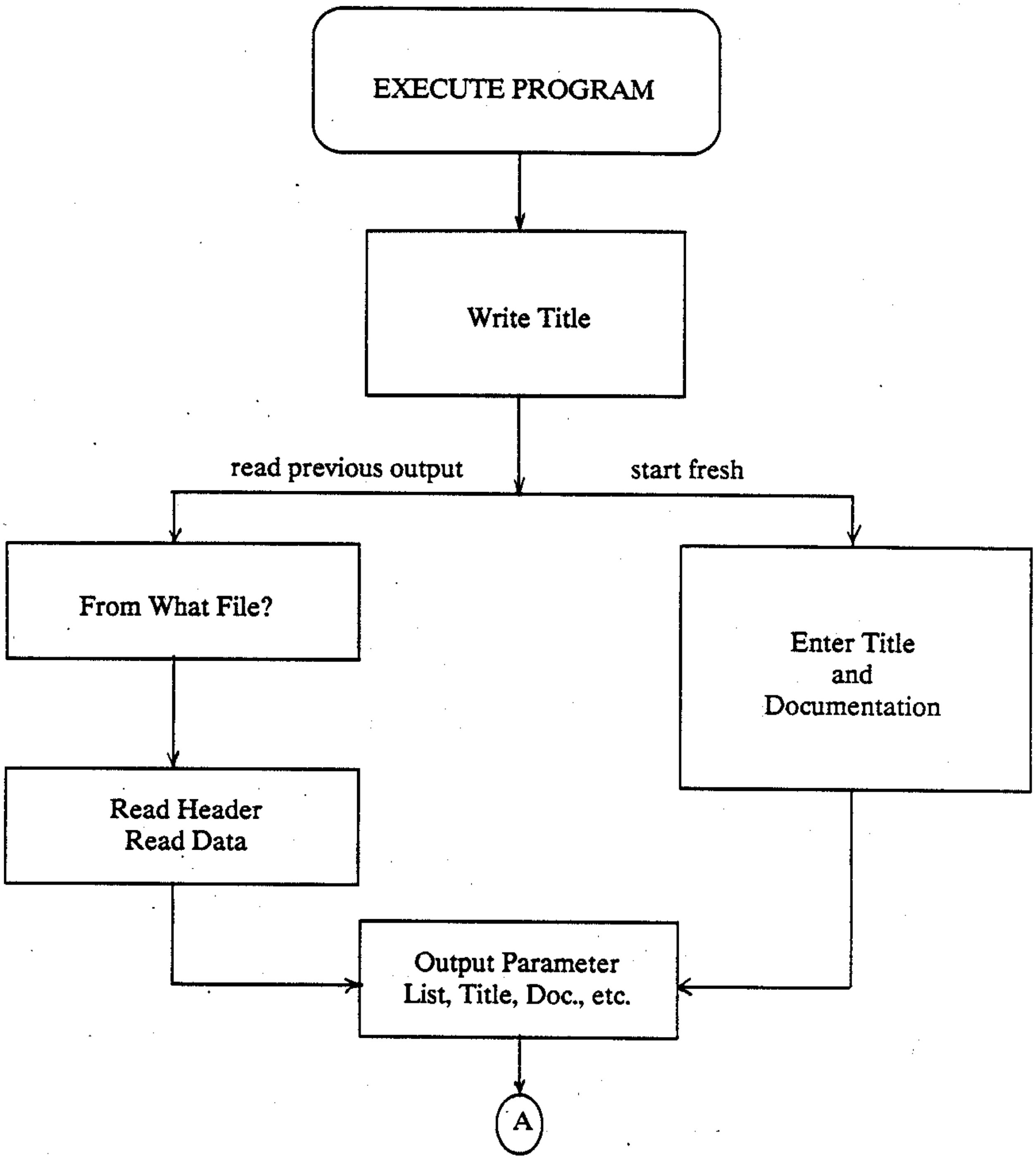


Figure 1. Overall flow chart for SIMBAT.FOR.

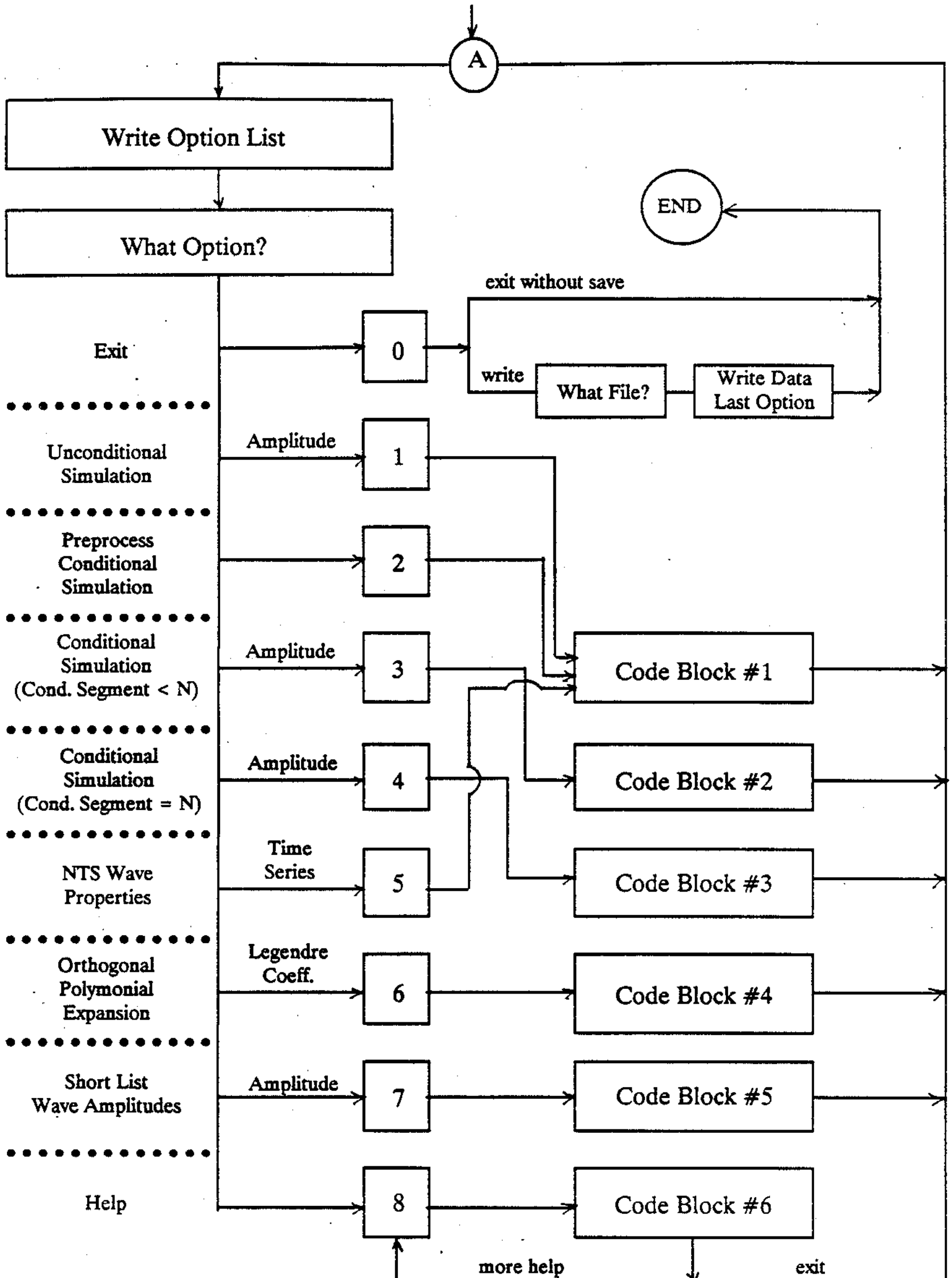
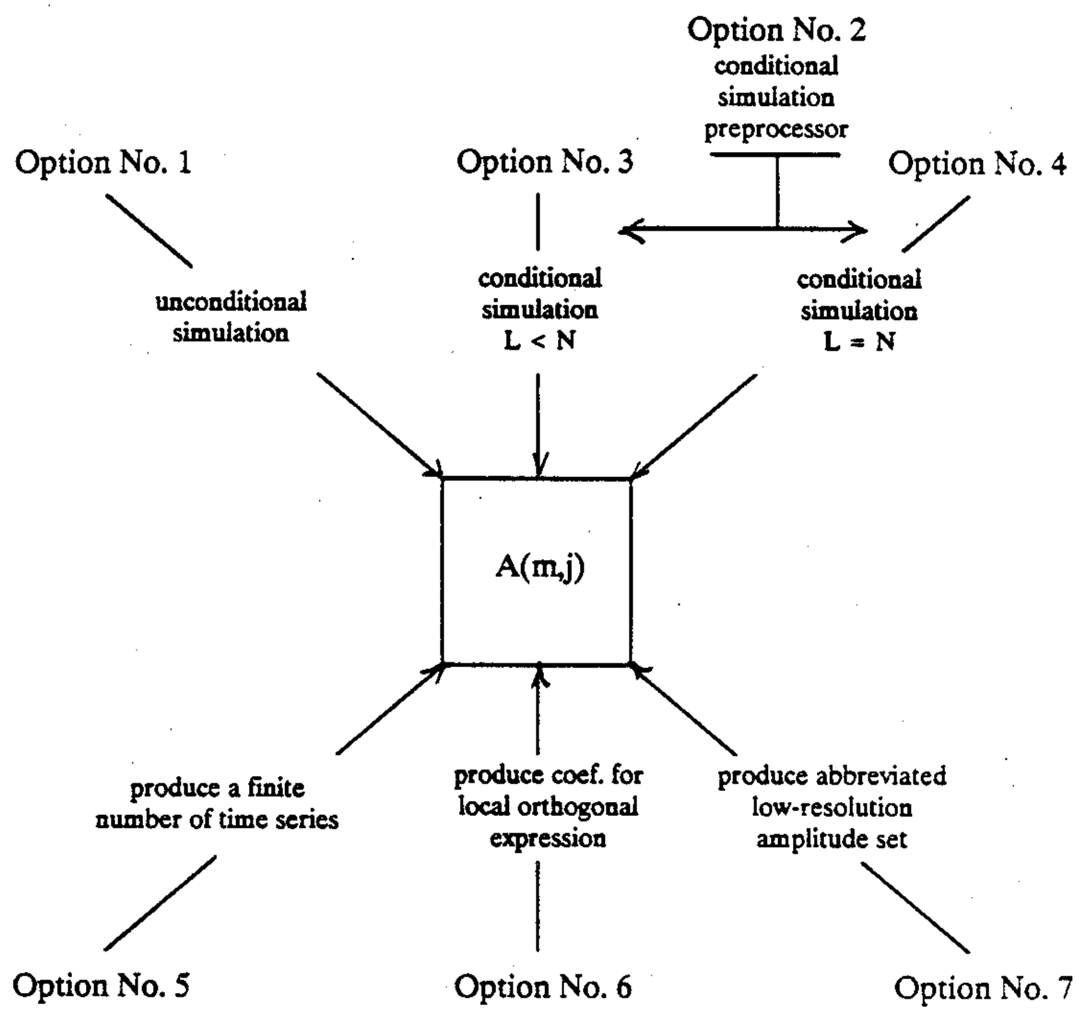


Figure 1. Overall flow chart for SIMBAT.FOR (continued).

Each module is used by executing the module and exiting with storage of the results on a user-selected file. The set of complex wave amplitudes

$$\{A(m,j) \; ; \quad 0 \le m \le N-1, \quad 0 \le j \le J-1\}$$

Each option can be classified relative to its relation to A(m,j) as shown in Figure 2.



Option Nos. 1, 3, and 4 produce a set of A(m,j). Option Nos. 5, 6, and 7 use an amplitude matrix as input and produce time series or algorithms to lead to time series. Option 2 is a special preprocessor which must precede the execution of Option Nos. 3 or 4.

Figure 2. SIMBAT module relationship.

Any of the basic inputs (1), (2,3), or (2,4) can be combined with any of the basic outputs (5), (6), or (7). Typical example runs are shown in Appendix A and as files on the accompanying diskettes. The fundamental output for Option No. 6 is given on the diskette as file MAST6.DAT. Option No. 6 requires further theoretical discussion. Similarly, the concepts of conditional probability deserve an expanded exposition.

7.0 ORTHOGONAL EXPANSION (OPTION 6)

The shear mass of computations required to compute forces at many load points in a moving structure subject to wave actions is a major problem in operating with either conditional or unconditional simulations of wave kinematics. One approach is to try to reduce the number of waves required to produce (approximately) the same wave train. This is provided by Option No. 7. Another approach is to summarize the local variations of the wave kinematics in some sort of additive function system. Option No. 6 is based on Legendre and shifted Legendre orthogonal polynomials. Let

$$p_n(x) = a_o + a_1 x + \dots + a_n x^n \tag{28}$$

$$p_n^*(x) = a_o^* + a_1^* x + \dots + a_n^* x^n \tag{29}$$

be the Legendre and shifted Legendre othogonal polynomials of order n. The coefficients are selected so that

$$\int_{-1}^{1} p_m(x)\, p_n(x)\, dx = \begin{cases} 0 & , \text{ if } m \neq n \\ \dfrac{2}{2n+1} & , \text{ if } m = n \end{cases} \tag{30}$$

$$\int_{0}^{1} p_m^*(x)\, p_n^*(x)\, dx = \begin{cases} 0 & , \text{ if } m \neq n \\ \dfrac{1}{2n+1} & , \text{ if } m = n \end{cases} \tag{31}$$

The first several Legendre polynomials are

$p_o(x) = 1$

$p_1(x) = x$

$p_2(x) = (3x^2-1)/2$

$p_3(x) = (5x^3-3x)/2$

$p_4(x) = (35x^4-30x^2+3)/8$

$p_5(x) = (63x^5-70x^3+15x)/8$

The SIMBAT programs incorporate Legendre polynomials up to order 12. Most approximations to wave kinematics will not require orders greater than 5.

The use of orthogonal polynomials to approximate an arbitrary function, g(x), defined on (-1,1) can be illustrated as follows. Suppose the approximation to be used is

$$g(x) \simeq \sum_{n=0}^{N} a_n \, p_n(x) \tag{33}$$

The coefficients a_n are chosen from a "least-squares" criterion. Let a_n be those values which minimize

$$Q = \int_{-1}^{1} \left[g(x) - \sum_{n=0}^{N} a_n \, p_n(x) \right]^2 dx \tag{34}$$

Then

$$\frac{\partial Q}{\partial a_k} = - \int_{-1}^{1} 2 \left[g(x) - \sum_{n=0}^{N} a_n \, p_n(x) \right] p_k(x) \, dx \tag{35}$$

$$\frac{1}{2} \left(\frac{\partial Q}{a_k} \right) = - \int_{-1}^{1} g(x) \, p_k(x) \, dx + \sum_{n=0}^{N} a_n \int_{-1}^{1} p_n(x) \, p_k(x) \, dx \tag{36}$$

Q is at an extreme if $\partial Q/\partial a_k = 0$ for all $k=0,1,2,\ldots,N$. This reduces to

$$\sum_{n=0}^{N} a_n \int_{-1}^{1} p_n(x)\ p_k(x)\ dx = \int_{-1}^{1} g(x)\ p_k(x)\ dx \tag{37}$$

But by the orthogonality relation, this further reduces to

$$a_k\left(\frac{2}{2k+1}\right) = \int_{-1}^{1} g(x)\ p_k(x)\ dx \tag{38}$$

$$a_k = \left(\frac{2k+1}{2}\right) \int_{-1}^{1} g(x)\ p_k(x)\ dx \tag{39}$$

The similar development for shifted Legendre polynomials gives

$$a_k^* = (2k+1) \int_{0}^{1} g(x)\ p_k^*(x)\ dx \tag{40}$$

How can these relations be applied to ocean wave kinematics? The essential cannonical form for a linear wave property is given in Equation 24. It should be noted that in every case, $G_m(z)$ is either 1.0 (water level elevation) or is of the form

$$\frac{e^{-k_m z} + s_1\ e^{-k_m(2d-z)}}{1 + s_2\ e^{-2k_m d}} \tag{41}$$

where k_m is the wave number. Thus, the general wave property, $p(n\ \Delta t)$ can be expressed from Equation 10 as

$$p(n\ \Delta t) = \sum_{m=0}^{N-1} C_m\ e^{i2\pi mn/N} \tag{42}$$

where C_m is the FFT coefficient given by

$$C_m = \sum_{j=1}^{J} A_{mj}\ e^{-i\beta_o k_m\{x \cos(\theta-\theta_x) + y \cos(\theta-\theta_y)\}} \tag{43}$$

for sea surface elevations, and

$$C_m = \sum_{j=1}^{J} A_{mj} T_m H_j \frac{\left\{e^{-k_m z} + s_1 e^{-k_m(2d-z)}\right\}}{\left\{1 + s_2 e^{-k_m d}\right\}}$$

$$\cdot e^{-i\beta_o k_m\{x \cos(\theta-\theta_x) + y \cos(\theta-\theta_y)\}} \tag{44}$$

for the other wave properties. These can be expressed as a sum of products of separate functions of x, y, and z as

<u>Sea Surface</u>

$$C_m = \sum_{j=1}^{J} A_{mj} e^{i\beta_o k_m x \cos(\theta-\theta_x)} e^{i\beta_o k_m y \cos(\theta-\theta_y)} \tag{45}$$

<u>Other Wave Properties</u>

$$C_m = \sum_{j=1}^{J} \frac{A_{mj} T_m H_j}{1 + s_2 e^{-k_m d}} \left\{e^{-k_m z} + s_1 e^{-k_m(2d-z)}\right\}$$

$$\cdot e^{-i\beta_o k_m x \cos(\theta-\theta_x)} e^{-i\beta_o k_m y \cos(\theta-\theta_y)} \tag{46}$$

Suppose it is desired to obtain a good representation locally in the vicinity of the structure. Consider the volume

$$x_o-D_1 \le x \le x_o+D_1$$

$$y_o-D_2 \le y \le y_o+D_2 \tag{47}$$

$$0 \le z \le d$$

(Here z has been taken as positive downwards and zero at mean water level.)

It is natural to scale the function as

Sea Surface

$$C_m = \sum_{j=1}^{J} A_{mj}\, e^{-i\beta_o k_m x_o \cos(\theta-\theta_x)}\, e^{-i\beta_o k_m D_1\left(\frac{x-x_o}{D_1}\right)\cos(\theta-\theta_x)}$$

$$\cdot\, e^{-i\beta_o k_m y_o \cos(\theta-\theta_y)}\, e^{-i\beta_o k_m D_2\left(\frac{y-y_o}{D_2}\right)\cos(\theta-\theta_y)} \qquad (48)$$

Other Wave Properties

$$C_m = \sum_{j=1}^{J} \frac{A_{mj}\, T_m\, H_j}{1 + s_2\, e^{-2k_m d}} \left\{e^{-k_m z} + s_1\, e^{-k_m(2d-z)}\right\}$$

$$\cdot\, e^{-i\beta_o k_m x_o \cos(\theta-\theta_x)}\, e^{-i\beta_o k_m D_1\left(\frac{x-x_o}{D_1}\right)\cos(\theta-\theta_x)}$$

$$\cdot\, e^{-i\beta_o k_m y_o \cos(\theta-\theta_y)}\, e^{-i\beta_o k_m D_2\left(\frac{y-y_o}{D_2}\right)\cos(\theta-\theta_y)} \qquad (49)$$

Let

$$e^{-i\beta_o k_m D_1\left(\frac{x-x_o}{D_1}\right)\cos(\theta-\theta_x)} = \sum_{\alpha=0}^{N} a_\alpha\, p_\alpha\left(\frac{x-x_o}{D_1}\right) \qquad (50)$$

$$e^{-i\beta_o k_m D_2\left(\frac{y-y_o}{D_2}\right)\cos(\theta-\theta_y)} = \sum_{\beta=0}^{N} a_\beta\, p_\beta\left(\frac{y-y_o}{D_2}\right) \qquad (51)$$

$$e^{-k_m z} = \sum_{\gamma=0}^{N} C_\gamma\, p_\gamma^*\left(e^{-k_o z}\right) \qquad (52)$$

where k_o is a selected single reference wave number. For many applications, the second term

$$e^{-k_m(2d-z)}$$

is negligible because depth is large. For the moment suppose that this second term can be ignored. It will be reintroduced later. Then if

$$u = (x-x_o)/D_1$$

$$v = (y-y_o)/D_2 \qquad (53)$$

$$w_1 = e^{-k_o z}$$

<u>Sea Surface</u>

$$C_m = \sum_{j=1}^{J} A_{mj}\, e^{-i\beta_o k_m[x_o \cos(\theta-\theta_x) + y_o \cos(\theta-\theta_y)]}$$

$$\cdot \sum_{\alpha=0}^{N} a_\alpha\, p_\alpha(u) \cdot \sum_{\beta=0}^{N} b_\beta\, p_\beta(v) \qquad (54)$$

<u>Other Wave Properties</u>

$$C_m = \sum_{j=1}^{J} \frac{A_{mj}\, T_m\, H_j\, e^{-i\beta_o k_m[x_o \cos(\theta-\theta_x) + y_o \cos(\theta-\theta_y)]}}{1 + s_2\, e^{-2k_m d}}$$

$$\cdot \sum_{\alpha=0}^{N} a_\alpha\, p_\alpha(u) \cdot \sum_{\beta=0}^{N} b_\beta\, p_\beta(v) \cdot \sum_{\gamma=0}^{N} c_\gamma\, p_\gamma^*(e^{-k_o z}) \qquad (54)$$

If this is substituted into Equation 42

$$p(n\,\Delta t) = \sum_{\alpha=0}^{N} \sum_{\beta=0}^{N} \sum_{\gamma=0}^{N} B_{\alpha,\beta,\gamma}(n\,\Delta t)\, p_\alpha(u)\, p_\beta(v)\, p_\gamma^*(e^{-k_o z}) \qquad (55)$$

where (sea surface case)

$$B_{\alpha,\beta,\gamma}(n\ \Delta t) = \sum_{m=0}^{N-1} \left[\sum_{j=1}^{J} a_\alpha\ b_\beta\ A_{mj}\ e^{-i\beta_o k_m x_o \cos(\theta-\theta_x)} \cdot e^{-i\beta_o k_m y_o \cos(\theta-\theta_y)} \right] e^{i2\pi mn/N} \qquad (56)$$

This is an FFT of the quantity within { } for each α, β, and γ combination.

The other wave properties have a similar expression with

$$B_{\alpha,\beta,\gamma}(n\ \Delta t) = \sum_{m=0}^{N-1} \left[\sum_{j=1}^{J} a_\alpha\ b_\beta\ c_\gamma\ A_{mj}\ T_m\ H_j \cdot \frac{e^{-i\beta_o k_m [x_o \cos(\theta-\theta_x) + y_o \cos(\theta-\theta_y)]}}{1 + s_2\ e^{-2k_m d}} \right] e^{i2\pi mn/N}$$

.... (57)

At a given time, n Δt, many of the $B_{\alpha,\beta,\gamma}$, for a given wave property, are negligible. After all the region $x_o \pm D_1$ and $y_o \pm D_2$ is relatively small relative to the wave lengths. Hence low order polynomials are all that are required in order to represent the variation over the horizontal region. The variation vertically is more or less exponentially attenuated with depth, so a polynomial in

$$e^{-k_o z}$$

should only need relatively low order.

Hence, at a given time, only a few $B_{\alpha,\beta,\gamma}$ will be needed to represent the wave property. The particular coefficient needed may, however, be different from one time step to another.

Up to here the actual computation of a_α, b_β, and c_γ has been not explicitly stated. From the definition of orthogonal polynomials

$$a_\alpha = \frac{2\alpha+1}{2} \int_{-1}^{1} e^{-ik_m \beta_o D_1 \cos(\theta-\theta_x)u} \; p_\alpha(u) \, du \tag{58}$$

$$b_\beta = \frac{2\beta+1}{2} \int_{-1}^{1} e^{-ik_m \beta_o D_2 \cos(\theta-\theta_y)v} \; p_b(v) \, dv \tag{59}$$

$$c_\gamma = (2\gamma+1) \int_{0}^{1} w_1^{k_m/k_o} \; p^*_\gamma(w_1) \, dw \tag{60}$$

8.0 IMPLEMENTATION IN CODE

The a_α, b_β, and c_γ, which are functions of m and j, are computed and combined as given in Equation 56 and 57 and then Fourier transform with the fast Fourier transform to develop $B_{\alpha,\beta,\gamma}(n\ \Delta t)$ for each wave property. These are sorted in order of absolute value at each time step and listed in a sequential file.

The coefficients are listed in the file in integer form with the last 3 digits giving an index which may be used to determine the orders α, β, and γ for that coefficient. Thus, the coefficient with value xxx.xxx is listed as the integer xxxxxxyyy where yyy is the order designator. A matrix

LSTXYZ (yyy,1) = α

LSTXYZ (yyy,2) = β

LSTXYZ (yyy,3) = γ

gives the order associated with each yyy value. The integers are ranked in order of decreasing absolute value. Thus the user can compute with the much abbreviated list of coefficients needed at that time step to represent the wave property within the local region.

9.0 OTHER DEPTH TERM

Let

$$w_2 = e^{-k_o(2d-z)}$$

Then an exactly similar expansion with the same coefficients can be developed. The resulting representation of the wave property is

$$p(n\,\Delta t) = \sum_{\alpha=0}^{N} \sum_{\beta=0}^{N} \sum_{\gamma=0}^{N} B_{\alpha,\beta,\gamma}(n\,\Delta t)\; p_\alpha(u)\; p_\beta(v)$$

$$\cdot \left\{ p_\alpha^*(e^{-k_o z}) + s_1\, p_\alpha^*(e^{-k_o(2d-z)}) \right\}$$

Note: The Module SIM6 is still under testing and may be changed further as the study continues.

Appendix A

EXAMPLE RUNS

OPTION NO. 1 CONSOLE LISTING
TO BE FOLLOWED BY OPTION NO. 5

```
 **************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE. WYOMING)

PLEASE KEY RETURN TO CONTINUE
 *******************************************************
```

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES. N = NO
N
**********************************************
ENTER A 50-CHARACTER TITLE FOR THE TIME SERIES DATA.
-----------------------------------------------
5/30/88  5:07 AM CONSOLE LIST EXAMPLE
**********************************************
ENTER A 50-CHARACTER SUMMARY OF THE TIME SERIES
   DOCUMENTATION FOR FUTURE REFERENCE.
--------------------------------------------------
THE OUTPUT IS STORED ON L:LIST1.DAT
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
```

1 **OPTION NO.**

```
ENTER SPECTRAL-LINE CUTOFF FRACTION. (NOTE: A SMALL
VALUE IS GOOD.  ONLY THOSE LINES GIVING VARIANCE CONTRIBUTION
GREATER THAN OR EQUAL TO (CUTOFF*LARGEST SPECTRAL LINE) ARE
KEPT
0.00001
***********************************************
ENTER SEED INTEGER FOR RANDOM NUMBER GENERATOR. I10
-----------------------------------------------
123456
************************************************
ENTER IOPT:
     IOPT=1 INDICATES DSPEC MATRIX IS COMPUTED AND THEN
        STORED FOR FUTURE USE IN A USER-SPECIFIED FILE.
     IOPT=2 INDICATES DSPEC MATRIX IS READ FROM A
```

```
WHAT IS YOUR CHOICE?
*****************************************************
1
ENTER FILE NAME TO WHICH THE DATA IS TO BE STORED.
J:DSPEC1.DAT
*************************************************
ENTER A 50-CHARACTER TITLE FOR DRSPEC. MATRIX
--------------------------------------------------
EXAMPLE DIR. SPECTRA NO. 1

MODE NUMBER AT THIS STEP =    1
DO YOU WANT TO ENTER ANOTHER MODE?
    ENTER N=NO IF NO MORE MODES ARE TO BE ENTERED.
    OTHERWISE. ENTER Y=YES
WHAT IS YOUR CHOICE?
Y
ENTER LAMDA FOR O-H SPECTRA.  NOTE: LAMDA=1.0 FOR
P-M SPECTRA OR JONSWAP SPECTRA
1.0
ENTER MODAL FREQUENCY FOR MODE.
0.1
ENTER TOTAL VARIANCE OF MODE.
VARIANCE DIMENSIONS DETERMINE SPECTRA DIMENSIONS
DR.SPECT.DENSITY WILL BE IN UNITS OF
LENGTH**2 PER (HERTZ-RADIAN)
100.0

PRINC.DIR.=PRINC.DIR.CONST.+
           PRINC.DIR.SLOPE*(FREQ.-MODAL FREQ.)
DIMENSIONS: PRINC.DIR.CONST. IN NAV. DEGREES
            PRINC.DIR.SLOPE IN DEGREES-SEC.
ENTER PRINCIPAL DIRECTION CONSTANT FOR MODE.
0.0
ENTER PRINCIPAL DIRECTION SLOPE FOR MODE.
0.0

SPRD.STD.DEV.=SPRD.STD.DEV.CONST.+
              SPRD.STD.DEV.SLOPE*(FREQ.-MODAL FREQ.)
DIMENSIONS: SPRD.STD.DEV.CONST. IN NAV. DEGREES
            SPRD.STD.DEV.SLOPE IN DEGREES-SEC.
ENTER SPREADING STD. DEV. CONSTANT FOR MODE.
30.0
ENTER SPREADING STD. DEV. SLOPE FOR MODE.
0.0
SPECTRA PARAMETERS: LAMDA, F0, VAR=        1.00000            .10000        100.:
SPREAD PARAMETERS: THET0.THET1.SIG0.SIG1=         .00000            .00000
ARE THESE THE VALUES YOU WANTED? IF NOT, ENTER N=NO
    AND RE-ENTER PARAMETERS FOR THIS MODE.
    OTHERWISE ENTER Y=YES
WHAT IS YOUR CHOICE?
Y

MODE NUMBER AT THIS STEP =    2
DO YOU WANT TO ENTER ANOTHER MODE?
    ENTER N=NO IF NO MORE MODES ARE TO BE ENTERED.
    OTHERWISE. ENTER Y=YES
WHAT IS YOUR CHOICE?
N
*************************************************
AMPLITUDE RANDOMNESS MENU
1.    RANDOM PHASE. BUT WAVE AMPLITUDE DETERMINISTIC AND
         CONSTRAINED TO BE EQUAL TO  2.0*SQRT(S(F.THETA))
2.    RANDOM PHASE AND RANDOM AMPLITUDE
PLEASE ENTER YOUR CHOICE
*****************************************************
```

```
POINT A REACHED
 POINT B REACHED
 POINT C REACHED
 POINT D REACHED
 NUMBER OF DEGREES OF FREEDOM = 1707
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
**************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)

0
DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
Y
PLEASE ENTER THE FILE NAME FOR STORAGE
J:OUT1.DAT
```

OUTPUT FILE

```
Programmed STOP
```

The printer listing is in file LIST1.DAT.
The output to be used as input to Option no. 5 is stored in OUT2.DAT.

CONSOLE LIST FOR OPTION NO. 5 FOLLOWING OPTION NO. 1

```
 ****************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 **********************************************************
```

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES, N = NO
Y
 WHAT IS THE FILE NAME FOR PREVIOUS OUTPUT?
J:OUT1.DAT
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
**************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
```

5 OPTION NO.

```
ENTER NOISE TO SIGNAL RATIO, AS RATIO OF NOISE
    STANDARD DEVIATION TO SIGNAL STANDARD DEVIATION
0.0
CHANNEL NUMBER:      1
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:      2
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:      3
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
ENTER TIME STEP FOR START OF LIST AND RETURN
1
ENTER TIME STEP AT TERMINATION OF LIST AND RETURN
200
ENTER 0 IF GRAPHICAL OUTPUT IS DESIRED
KEY 1 IF NUMERICAL LIST OF TIME SERIES IS WANTED
0
 NUMBER OF DEGREES OF FREEDOM = 0
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
```

```
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
*************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)

5
ENTER NOISE TO SIGNAL RATIO, AS RATIO OF NOISE
    STANDARD DEVIATION TO SIGNAL STANDARD DEVIATION
0.0
CHANNEL NUMBER:      1
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:      2
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:      3
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
ENTER TIME STEP FOR START OF LIST AND RETURN
1
ENTER TIME STEP AT TERMINATION OF LIST AND RETURN
200
ENTER 0 IF GRAPHICAL OUTPUT IS DESIRED
KEY 1 IF NUMERICAL LIST OF TIME SERIES IS WANTED
1
 NUMBER OF DEGREES OF FREEDOM = 0
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
*************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)


DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
N
```

NO OUTPUT

```
Programmed STOP

F>
```

CONSOLE LIST FOR PREPROCESSOR
OPTION NO. 2

```
*****************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 ***********************************************************
```

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES, N = NO
N
*************************************************
ENTER A 50-CHARACTER TITLE FOR THE TIME SERIES DATA.
-------------------------------------------------
5/30/88  5:26 PM CONSOLE LIST FOR OPTION 2
*************************************************
ENTER A 50-CHARACTER SUMMARY OF THE TIME SERIES
   DOCUMENTATION FOR FUTURE REFERENCE.
----------------------------------------------------
LIST OUTPUT STORED ON JL J:LIST2.DAT
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
***************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
```

OPTION NO.

```
2
ENTER SPECTRAL-LINE CUTOFF FRACTION. (NOTE: A SMALL
VALUE IS GOOD.  ONLY THOSE LINES GIVING VARIANCE CONTRIBUTION
GREATER THAN OR EQUAL TO (CUTOFF*LARGEST SPECTRAL LINE) ARE
KEPT
0.000001
**************************************************
ENTER SEED INTEGER FOR RANDOM NUMBER GENERATOR. I10
--------------------------------------------------
1357934
***************************************************
ENTER IOPT:
     IOPT=1 INDICATES DSPEC MATRIX IS COMPUTED AND THEN
        STORED FOR FUTURE USE IN A USER-SPECIFIED FILE.
     IOPT=2 INDICATES DSPEC MATRIX IS READ FROM A
```

```
[illegible]
*****************************************************
2
 POINT V REACHED
ENTER FILE NAME FROM WHERE THE DATA IS TO BE READ.
J:DSPEC1.DAT
 POINT W REACHED
 POINT X REACHED
 POINT Y REACHED
 POINT Z REACHED
*****************************************************
AMPLITUDE RANDOMNESS MENU
1.     RANDOM PHASE, BUT WAVE AMPLITUDE DETERMINISTIC AND
          CONSTRAINED TO BE EQUAL TO  2.0*SQRT(S(F,THETA))
2.     RANDOM PHASE AND RANDOM AMPLITUDE
PLEASE ENTER YOUR CHOICE
*****************************************************
2
 POINT B REACHED
 POINT C REACHED
 POINT D REACHED
 NUMBER OF DEGREES OF FREEDOM = 1729
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
*****************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)


DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
J:OUT2.DAT

Programmed STOP

F>
```

Store output on OUT2.DAT.
Printer output is shown on LIST2.DAT.

CONSOLE LIST
OPTION NO. 3

```
 ***************************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 ***************************************************************
```

INPUT

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES. N = NO
Y
 WHAT IS THE FILE NAME FOR PREVIOUS OUTPUT?
J:OUT2.DAT
 TITLE: 5/23/88
 DOCUMENTATION: 6:20 Pm
 ISEED=  12345677  ICHUZ=    2  N=        512  NTS=          1
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 3. DEVELOP COMPLEX-VALUED AMPLITUDES. CONDITIONED ON GIVEN
      INPUT. WHERE CONDITIONING INPUT IS LESS THAN N.
      (USES OUTPUT FROM STEP #2.)
 8. HELP
*************************************************
     (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
```

OPTION NO.

```
3
MENU FOR OPTION #3 CONDITIONING INPUT:
  1. READ THE CONDITIONING TIME SERIES INTERVAL FROM A FILE.
  2. INPUT FROM CONSOLE A SINGLE POINT CHECK COMPUTATION.
1
THE GIVEN TIME SERIES IS TO BE READ FROM WHAT FILE?
J:GTS3.DAT
 AT A. XC(1,1,1)=+1.387074E+02
 AT B. XC(1,1,1)=+1.387074E+02
 ITER=1      ERROR=+2.87978591006331E-001
 ITER=2      ERROR=+1.49614657785246E-001
 ITER=3      ERROR=+8.33678097563081E-002
 ITER=4      ERROR=+6.25658778317937E-002
 ITER=5      ERROR=+4.79428186885693E-002
 ITER=6      ERROR=+3.98655722717029E-002
 ITER=7      ERROR=+4.07938739941164E-002
 ITER=8      ERROR=+4.82520036410251E-002
 ITER=9      ERROR=+4.01262099826422E-002
 ITER=10      ERROR=+3.70754879940331E-002
 ITER=11      ERROR=+3.61288061379002E-002
 ITER=12      ERROR=+3.7309347341977E-002
```

```
ITER=14      ERROR=+4.35425570387[illegible]E-002
ITER=15      ERROR=+4.31572720665299E-002
ITER=16      ERROR=+3.65276807834511E-002
ITER=17      ERROR=+4.05862967637825E-002
ITER=18      ERROR=+4.50411327745454E-002
ITER=19      ERROR=+4.23025648241650E-002
ITER=20      ERROR=+3.22563850185996E-002
ITER=21      ERROR=+4.52897460582820E-002
ITER=22      ERROR=+5.80676454774573E-002
ITER=23      ERROR=+6.82274676210544E-002
ITER=24      ERROR=+8.50967519543853E-002
ITER=25      ERROR=+1.81185624147220E-001
ITER=26      ERROR=+1.77650397112268E-001
ITER=27      ERROR=+3.41351864835669E-002
ITER=28      ERROR=+4.44516861145773E-002
ITER=29      ERROR=+7.15560563985889E-002
ITER=30      ERROR=+4.29835306096395E-002
ITER=31      ERROR=+4.51449594922817E-002
ITER=32      ERROR=+4.19182391619607E-002
ITER=33      ERROR=+3.42003073397959E-002
ITER=34      ERROR=+4.77779413038873E-002
ITER=35      ERROR=+2.83636885692342E-002
ITER=36      ERROR=+4.15758046336139E-002
ITER=37      ERROR=+5.14872682905144E-002
ITER=38      ERROR=+5.46444103222024E-002
ITER=39      ERROR=+6.33359288827841E-002
ITER=40      ERROR=+6.23405431514012E-002
ITER=41      ERROR=+8.06736839722208E-002
ITER=42      ERROR=+4.99087506993048E-002
ITER=43      ERROR=+5.66191924849098E-002
ITER=44      ERROR=+1.49716651227054E-001
ITER=45      ERROR=+1.83133175338544E-001
ITER=46      ERROR=+[illegible].94330193305322
ITER=47      ERROR=+1.02469503219081E-001
ITER=48      ERROR=+8.90559085664480E-002
ITER=49      ERROR=+1.14525902226387E-001
ITER=50      ERROR=+2.04505272049408E-002
ITER=51      ERROR=+2.60558536876116E-002
ITER=52      ERROR=+7.11497611871963E-002
ITER=53      ERROR=+4.80361928804419E-002
ITER=54      ERROR=+2.25687866839736E-002
ITER=55      ERROR=+2.18535948253765E-002
ITER=56      ERROR=+8.37377339729528E-002
ITER=57      ERROR=+3.62731923206972E-002
ITER=58      ERROR=+2.85838936056325E-002
ITER=59      ERROR=+2.34223279212249E-002
ITER=60      ERROR=+1.54923490182749E-002
ITER=61      ERROR=+1.65379395479899E-002
ITER=62      ERROR=+5.66233677253651E-002
ITER=63      ERROR=+8.69765590127990E-002
ITER=64      ERROR=+1.57571994050783
ITER=65      ERROR=+2.18276951114641E-001
ITER=66      ERROR=+6.61002517974959E-002
ITER=67      ERROR=+4.34095887431083E-002
ITER=68      ERROR=+4.07719354531788E-002
ITER=69      ERROR=+3.66710794604408E-002
ITER=70      ERROR=+3.58025320207473E-002
ITER=71      ERROR=+4.99229799444528E-002
ITER=72      ERROR=+4.29717808093476E-002
ITER=73      ERROR=+3.08658578035917E-002
ITER=74      ERROR=+2.14248542172881E-002
ITER=75      ERROR=+1.09470819602268E-002
ITER=76      ERROR=+1.01245272460577E-002
ITER=77      ERROR=+1.60491731739915E-002
ITER=78      ERROR=[illegible]
```

```
ITER=80      ERROR=+3.27576537226734E-002
ITER=81      ERROR=+3.01063520751197E-002
ITER=82      ERROR=+7.85060658680657E-002
ITER=83      ERROR=+4.84016653152273E-002
ITER=84      ERROR=+8.00292309830918E-002
ITER=85      ERROR=+6.49071228082659E-002
ITER=86      ERROR=+2.79351874097461E-001
ITER=87      ERROR=+7.21765644381938E-001
ITER=88      ERROR=+1.73025615699822E-001
ITER=89      ERROR=+1.14763319543632E-001
ITER=90      ERROR=+5.58919685444346E-002
ITER=91      ERROR=+4.70702618209135E-002
ITER=92      ERROR=+3.21496447601316E-002
ITER=93      ERROR=+3.09370687939432E-002
ITER=94      ERROR=+2.31559111334062E-002
ITER=95      ERROR=+1.79544365212953E-002
ITER=96      ERROR=+1.36371453823398E-002
ITER=97      ERROR=+7.37858935380434E-003
SUBR CG EXITED
OPTIONS ACTIVE IN THIS SUBPROGRAM:
0. EXIT PROGRAM
3. DEVELOP COMPLEX-VALUED AMPLITUDES. CONDITIONED ON GIVEN
     INPUT, WHERE CONDITIONING INPUT IS LESS THAN N.
     (USES OUTPUT FROM STEP #2.)
9. HELP
************************************************
     (PLEASE ENTER YOUR CHOICE AND KEY RETURN)


DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
Y
PLEASE ENTER THE FILE NAME FOR STORAGE
J:OUT3.DAT
```

OUTPUT FILE

```
Programmed STOP

F>
```

L:SIM125

CONSOLE LIST FOR OPTION NO. 5
WITH
OUT3.DAT AS INPUT

```
***************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 ******************************************************
```

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES, N = NO
Y
 WHAT IS THE FILE NAME FOR PREVIOUS OUTPUT?
C:OUT3.DAT
```

INPUT

```
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
***************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)

5
```

OPTION NO.

```
ENTER NOISE TO SIGNAL RATIO, AS RATIO OF NOISE
   STANDARD DEVIATION TO SIGNAL STANDARD DEVIATION
0.0
CHANNEL NUMBER:        1
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:        2
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:        3
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
ENTER TIME STEP FOR START OF LIST AND RETURN
1
ENTER TIME STEP AT TERMINATION OF LIST AND RETURN
300
ENTER 0 IF GRAPHICAL OUTPUT IS DESIRED
KEY 1 IF NUMERICAL LIST OF TIME SERIES IS WANTED
1
 NUMBER OF DEGREES OF FREEDOM = 0
```

```
[illegible] FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3. OR #4.)
 8. HELP
*******************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)

0
DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
N

Programmed STOP

F>
```

L:SIM4

CONSOLE LIST
OPTION NO. 4

```
 *****************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 ***********************************************************




 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES, N = NO
Y
 WHAT IS THE FILE NAME FOR PREVIOUS OUTPUT?
J:OUT2.DAT    <----- INPUT
 TITLE: 5/23/88
 DOCUMENTATION: 6:20 PM
 ISEED=  12345677  ICHUZ=    2  N=        512  NTS=          1
 OPTIONS ACTIVE IN THIS SUBPROGRAM:/' 0. EXIT PROGRAM
 4. DEVELOP COMPLEX-VALUED AMPLITUDES, CONDITIONED ON GIVEN
      INPUT, WHERE CONDITIONING INTERVAL EQUALS N.
      (USES OUTPUT FROM STEP #2.)
 8. HELP
*****************************************************
      (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
4   <----- OPTION NO.
THE GIVEN TIME SERIES IS TO BE READ FROM WHAT FILE?
J:GTS4.DAT
 OPTION 4: JM=1
 OPTION 4: JM=2
 OPTION 4: JM=3
 OPTION 4: JM=4
 OPTION 4: JM=5
 OPTION 4: JM=6
 OPTION 4: JM=7
 OPTION 4: JM=8
 OPTION 4: JM=9
 OPTION 4: JM=10
 OPTION 4: JM=11
 OPTION 4: JM=12
 OPTION 4: JM=13
 OPTION 4: JM=14
 OPTION 4: JM=15
 OPTION 4: JM=16
 OPTION 4: JM=17
 OPTION 4: JM=18
 OPTION 4: JM=19
 OPTION 4: JM=20
```

These can easily be removed from FORTRAN code. However, it is pleasant to see on the console that the computer is moving along in the calculations.

```
OPTION 4: JM=22
OPTION 4: JM=23
OPTION 4: JM=24
OPTION 4: JM=25
OPTION 4: JM=26
OPTION 4: JM=27
OPTION 4: JM=28
OPTION 4: JM=29
OPTION 4: JM=30
OPTION 4: JM=31
OPTION 4: JM=32
OPTION 4: JM=33
OPTION 4: JM=34
OPTION 4: JM=35
OPTION 4: JM=36
OPTION 4: JM=37
OPTION 4: JM=38
OPTION 4: JM=39
OPTION 4: JM=40
OPTION 4: JM=41
OPTION 4: JM=42
OPTION 4: JM=43
OPTION 4: JM=44
OPTION 4: JM=45
OPTION 4: JM=46
OPTION 4: JM=47
OPTION 4: JM=48
OPTION 4: JM=49
OPTION 4: JM=50
OPTION 4: JM=51
OPTION 4: JM=52
OPTION 4: JM=53
OPTION 4: JM=54
OPTION 4: JM=55
OPTION 4: JM=56
OPTION 4: JM=57
OPTION 4: JM=58
OPTION 4: JM=59
OPTION 4: JM=60
OPTION 4: JM=61
OPTION 4: JM=62
OPTION 4: JM=63
OPTION 4: JM=64
OPTION 4: JM=65
OPTION 4: JM=66
OPTION 4: JM=67
OPTION 4: JM=68
OPTION 4: JM=69
OPTION 4: JM=70
OPTION 4: JM=71
OPTION 4: JM=72
OPTION 4: JM=73
OPTION 4: JM=74
OPTION 4: JM=75
OPTION 4: JM=76
OPTION 4: JM=77
OPTION 4: JM=78
OPTION 4: JM=79
OPTION 4: JM=80
OPTION 4: JM=81
OPTION 4: JM=82
OPTION 4: JM=83
OPTION 4: JM=84
OPTION 4: JM=85
OPTION 4: JM=86
```

```
OPTION 4: JM=88
OPTION 4: JM=89
OPTION 4: JM=90
OPTION 4: JM=91
OPTION 4: JM=92
OPTION 4: JM=93
OPTION 4: JM=94
OPTION 4: JM=95
OPTION 4: JM=96
OPTION 4: JM=97
OPTION 4: JM=98
OPTION 4: JM=99
OPTION 4: JM=100
OPTION 4: JM=101
OPTION 4: JM=102
OPTION 4: JM=103
OPTION 4: JM=104
OPTION 4: JM=105
OPTION 4: JM=106
OPTION 4: JM=107
OPTION 4: JM=108
OPTION 4: JM=109
OPTION 4: JM=110
OPTION 4: JM=111
OPTION 4: JM=112
OPTION 4: JM=113
OPTION 4: JM=114
OPTION 4: JM=115
OPTION 4: JM=116
OPTION 4: JM=117
OPTION 4: JM=118
OPTION 4: JM=119
OPTION 4: JM=120
OPTION 4: JM=121
OPTION 4: JM=122
OPTION 4: JM=123
OPTION 4: JM=124
OPTION 4: JM=125
OPTION 4: JM=126
OPTION 4: JM=127
OPTIONS ACTIVE IN THIS SUBPROGRAM:/' 0. EXIT PROGRAM
4. DEVELOP COMPLEX-VALUED AMPLITUDES, CONDITIONED ON GIVEN
      INPUT, WHERE CONDITIONING INTERVAL EQUALS N.
      (USES OUTPUT FROM STEP #2.)
8. HELP
**************************************************
      (PLEASE ENTER YOUR CHOICE AND KEY RETURN)
0
DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
Y
PLEASE ENTER THE FILE NAME FOR STORAGE
J:OUT4.DAT
```

OUTPUT FILE

```
Programmed STOP

F>
```

L:SIM125

CONSOLE LIST FOR OPTION NO. 5
USING OUT4.DAT AS INPUT

```
 ***************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 **********************************************************
```

```
 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
OF OPTIONS #1 OR #2? (Y = YES, N = NO
Y
 WHAT IS THE FILE NAME FOR PREVIOUS OUTPUT?
J:OUT4.DAT
```

INPUT

```
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)

5
```

OPTION NO.

```
ENTER NOISE TO SIGNAL RATIO. AS RATIO OF NOISE
    STANDARD DEVIATION TO SIGNAL STANDARD DEVIATION
0.0
CHANNEL NUMBER:       1
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:       2
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
CHANNEL NUMBER:       3
PLEASE ENTER MEAN VALUE DESIRED FOR THIS CHANNEL
0.0
ENTER TIME STEP FOR START OF LIST AND RETURN
1
ENTER TIME STEP AT TERMINATION OF LIST AND RETURN
200
ENTER 0 IF GRAPHICAL OUTPUT IS DESIRED
KEY 1 IF NUMERICAL LIST OF TIME SERIES IS WANTED
1
 NUMBER OF DEGREES OF FREEDOM = 0
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
```

```
 1. PRODUCE COMPLEX AMPLITUDES FOR UNCONDITIONAL SIMULATIONS
 2. PRE-PROCESS DATA TO PRODUCE NECESSARY INPUT FOR A
      CONDITIONAL SIMULATION
 5. SIMULATE TIME SERIES FROM AMPLITUDES (USES OUTPUT FROM
      STEP #1, #3, OR #4.)
 8. HELP
*************************************************
    (PLEASE ENTER YOUR CHOICE AND KEY RETURN)


DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
 STEP ON A SEPARATE USER SPECIFIED FILE ? Y OR N
N

Programmed STOP

F>
```

Time series are stored in printer listing LIST45.DAT

_:SIM7

CONSOLE LIST
OPTION NO. 7

```
 ****************************************************

PROGRAM SIMULATES WAVE PROPERTIES BY FREQUENCY DOMAIN METHODS
 FOR EITHER UNCONDITIONAL OR CONDITIONAL SIMULATIONS.
   (WRITTEN BY LEON BORGMAN, LARAMIE, WYOMING)

PLEASE KEY RETURN TO CONTINUE
 **********************************************************

 DO YOU WISH TO READ OUTPUT FROM PREVIOUS RUNS
AS INPUT FOR THIS RUN? (Y = YES.  N = NO
Y
 WHAT IS THE FILE NAME FOR THIS INPUT?
J:OUT4.DAT  <------ INPUT
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 7. PRODUCE A REDUCED SET OF AMPLITUDES FOR A LOW RESOLUTION
      REPRESENTION THE SEA SURFACE AND KINEMATICS.
      (USES OUTPUT FROM STEPS #1 OR STEP #3.)
 8. HELP
*************************************************
        (PLEASE KEY YOUR CHOICE AND RETURN)
7 <------ OPTION NO.
PLEASE ENTER THE LOWEST AMPLITUDE OF INTEREST
0.1
QWKSRT
DO YOU WANT TO SEE A COMPARISON OF THE FULL
RESOLUTION AND THE LOW RESOLUTION WAVE TIME HISTORIES
AT X=0. Y=0 ?  (Y OR N)
Y
ENTER TIME STEP FOR START OF LIST AND RETURN
1
ENTER TIME STEP AT TERMINATION OF LIST AND RETURN
200
ENTER 0 IF GRAPHICAL OUTPUT IS DESIRED
KEY 1 IF NUMERICAL LIST OF TIME SERIES IS WANTED
0
 OPTIONS ACTIVE IN THIS SUBPROGRAM:
 0. EXIT PROGRAM
 7. PRODUCE A REDUCED SET OF AMPLITUDES FOR A LOW RESOLUTION
      REPRESENTION THE SEA SURFACE AND KINEMATICS.
      (USES OUTPUT FROM STEPS #1 OR STEP #3.)
 8. HELP
*************************************************
        (PLEASE KEY YOUR CHOICE AND RETURN)

DO YOU WANT TO SAVE THE OUTPUT FROM LAST OPTION
```

```
Programmed STOP

F>
```

List of low resolution amplitudes is printed on line printer as shown in LIST7.DAT.

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