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A Fortran Program for Computing the Power Response of a Hydrophone Array to a Plane Wave and Plotting it as an Isometric Surface

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FOREWORD

The documentation of computer programs requires a careful explanation of the various aspects of each program. The Research Computation Center of NRL has a desirable and recommended format for reporting computer programs. This report follows that format.

The author thanks his coworkers in the Signal Processing Branch, Acoustics Division, and the members of the Research Computation Center for their encouragement, cooperation, suggestions, and advice.

ABSTRACT

BEAMPLOT is a Fortran program designed to simulate the power response of an arbitrary, focused hydrophone array to an incoming plane wave with or without pattern multiplication as desired. It is used with a three-dimensional plot routine to display output values as a response surface. The program is useful in the study of response dependence on such factors as focal direction, delays due to hydrophone positioning, signal frequency, and hydrophone weighting.

PROBLEM STATUS

This is a final report on one phase of the NRL Problem.

AUTHORIZATION

NRL Problem S01-39
Project RF 05-552-403, Task 4069

Manuscript submitted January 21, 1972

A FORTRAN PROGRAM FOR COMPUTING THE POWER RESPONSE OF A HYDROPHONE ARRAY TO A PLANE WAVE AND PLOTTING IT AS AN ISOMETRIC SURFACE

1. IDENTIFICATION

1.1 Title

Hydrophone Array Power Response to a Plane Wave

1.2 Identification Name

T3-NRL-BEAMPLØT

1.3 Classification Code

T3 - Applications and Application-Oriented Programs, Other Physical Sciences

1.4 NRL-Research-Computation-Center Identification Number

T3001Ø00

1.5 Entry Points

BEAMPLØT

1.6 Programming Language

Language: 3600/3800 Fortran

Routine Type: Main program

Operating System: DRUM SCOPE 2.0

1.7 Computer and Configuration

CDC 3800

1.8 Contributor or Programmer

Leon P. LaLumiere, Jr., Code 8144, Signal Processing Branch, Acoustics Division (the program is based on the original of J. W. Jenkins, Code 8144, cited as Ref. 1 in Section 3.15)

1.9 Contributing Organization

Naval Research Laboratory (NRL), Washington, D.C. 20390

1.10 Program Availability

1.10.1 Submittal: Program write-up, Fortran source deck, and the source listing

1.10.2 On File: Program library of the NRL Research Computation Center

1.11 Verification

This program has been used and tested as discussed in Section 7.

1.12 Date

1 September 1970

2. PURPOSE

2.1 Description of the Routine

BEAMPLOT calculates the power response of an arbitrary, focused hydrophone array to an incoming plane wave with or without pattern multiplication as desired. These calculations are then used to produce plotting commands for use by the subroutine cited as Ref. 2 in Section 3.15 in making an isometric response surface.

2.2 Problem Background

Many sonar systems use a beamformed array of receptors as their primary sensor. An array of receptors is the most convenient means of sampling a large-scale, long-wavelength, extended field. Since the individual receptors of a large array cannot be moved, control of the array directional sensitivity must be introduced through processing of their output signals. The beamformer performs this task by altering the relative delays and amplitude of individual receptor outputs before summing them to form an array output.

The computer program described herein was developed to provide visual aid in acquiring insight into the response of a beamformed array of hydrophones to a plane wave. In particular the effect of a parameter such as hydrophone position, beamformer angle, frequency, or hydrophone weighing on array response can be easily seen.

The basic geometric variables involved in array response to an incoming plane wave are shown in Fig. 1. This computer program can handle three cases of hydrophone array geometry: linear, planar, and volumetric. A brief discussion of the mathematics of array processing is presented in Section 4.

References are listed in Section 3.15. Extended discussions of array processing are presented in Refs. 3 and 4. The analysis and conclusions based on the results of this program are given in Ref. 5. This report has a companion in Ref. 6.

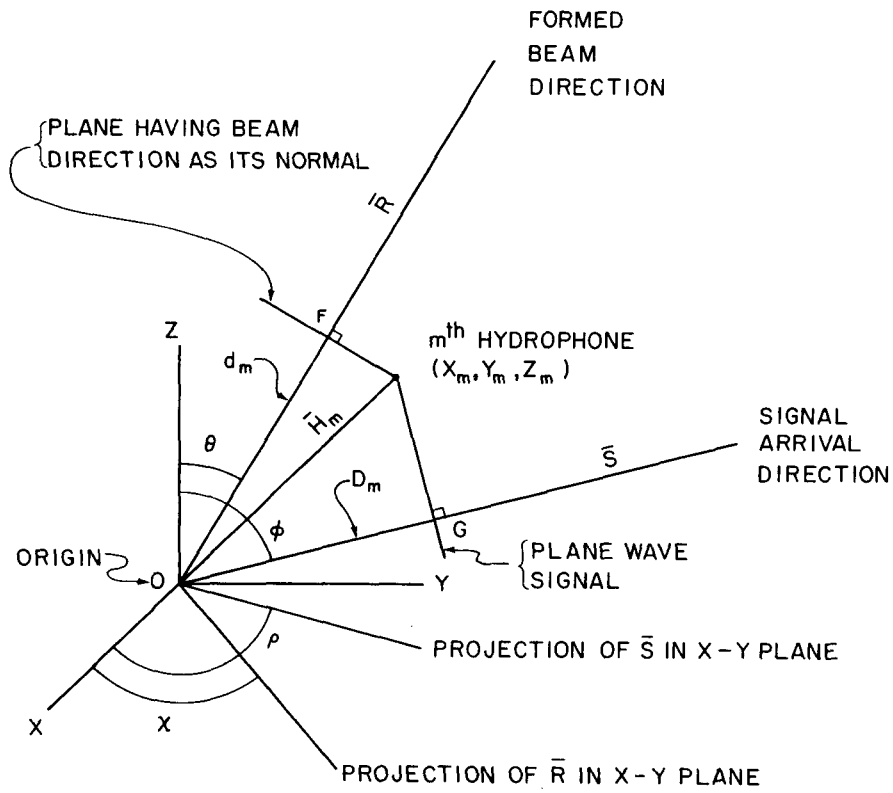

Fig. 1—Basic geometric variables

3. USAGE

3.1 Calling Sequence of Operational Procedure

Since BEAMPLOT is a complete program, the insertion of data cards along with the necessary control cards is the only requirement. The data cards control the program.

3.2 Arguments, Parameters, and Initial Conditions

The following parameters must be punched on data cards (Section 3.9 gives the formats):

LUN1 = storage unit for the plotting commands. (This may be the drum or magnetic tape as desired.)

LUN2 = storage unit for the array response calculations

LUN3 = storage unit for the array response calculations in the first direction with or without pattern multiplication

LUN4 = storage unit for the array response calculations in the second direction for pattern multiplication

LUN5 = storage unit for the array response calculations in the third direction for pattern multiplication. (LUN1 through LUN5 must be integer numbers in the range 1-49.)

C = speed of sound in water

NHYDRØ = number of hydrophones in the first direction with or without pattern multiplication

KHT = number of hydrophones in the second direction for use in pattern multiplication

LDF = number of hydrophones in the third direction for use in pattern multiplication

R(1,1) = minimum theta

R(1,2) = maximum theta (may be left blank)

N(1) = number of increments in theta (leave blank if R(1,2) is blank)

R(2,1) = minimum chi

R(2,2) = maximum chi (may be left blank)

N(2) = number of increments in chi (leave blank if R(2,2) is blank)

R(3,1) = minimum phi

R(3,2) = maximum phi (may be left blank)

N(3) = number of increments in phi (leave blank if R(3,2) is blank)

R(4,1) = minimum rho

R(4,2) = maximum rho (may be left blank)

N(4) = number of increments in rho (leave blank if R(4,2) is blank)

X, Y, Z = coordinates of each hydrophone

W = weighting of each hydrophone (if blank, it is assumed to be 1)

XZERØ = horizontal distance in inches to the lower left-hand corner of plot from the plot origin

YZERØ = vertical distance in inches to the lower left-hand corner of the plot from the plot origin

DELTAX = horizontal separation of data points in inches

DELTAY = vertical separation of horizontal cuts in inches

SLANT = horizontal offset in inches of adjacent horizontal cuts

HIDDEN = instruction concerning hidden points (if > 0, hidden points are to be plotted; if $\leqslant 0$, hidden points are not to be plotted)

SCALE = multiplying factor giving the desired height of the plots, since $0 \leqslant$ response $\leqslant 1$.

3.3 Space Required (Decimal and Octal)

3.3.1 Unique Storage: 33470 octal or 14143 decimal locations

3.3.2 Common Blocks:

CØMMØN/BLK/NHYDRØ, WAVE, N SCALE, W(402), X(400), Y(400), Z(400), P(400), SP(650), CP(650), SR(650), CR(650), LUN1, NH, KHT, ZAMP(650), LUN2, LUN3, NI, NJ, DATATAB(650), SCALE, NUMX, LUN4, LUN5, LUN6, LDP, NK, DAMP(650)

3.3.3 Temporary Storage: Results of the calculations are stored on the drum or magnetic tape as desired. Plotting commands are stored on the drum or magnetic tape as desired.

3.4 Messages and Instructions to the Operator

None

3.5 Error Returns, Messages, and Codes

A message is printed if neither phi nor rho is incremented.

3.6 Informative Messages to the User

The following are listed:

- All input data along with computed increments
- The largest computation multiplied by 1 million in decimal and octal
- The number of records for plotting purposes in decimal and octal
- The plotting parameters used in subroutine PLOTISOM
- The identifying number of each storage unit

3.7 Input

The input consists of data cards containing the parameters listed in Section 3.2 and illustrated in Section 3.9

3.8 Output

The output is given in Section 3.6. All plotting commands can be placed on a magnetic tape for off-line plotting (and is recommended). All computations can be placed on magnetic tape if desired (and is recommended, since different plots can be made from the tapes).

3.9 Formats

Example of an Input Data Deck

Card*	Data in Various Columns on the Cards							
	1-6	10	14-20	24-30	36-40	46-50	55-58	66-68
1		1	2	3	4	5		
2	4900.							
3		4	4	4				
4	490.0							
5	90.0							
6	90.0							
7	0.0				181			
8	0.0		180.0		629			
NHYDRØ	45.0		0.0	0.0				
	30.0		0.0	15.0				
	15.0		0.0	30.0				
	0.0		0.0	45.0				
KHT	45.0		0.0	0.0				
	30.0		0.0	−15.0				
	15.0		0.0	−30.0				
	0.0		0.0	−45.0				
LDP	45.0		0.0	0.0				
	45.0		15.0	0.0				
	45.0		30.0	0.0				
	45.0		45.0	0.0				
LAST	0.0		0.250	0.020	0.040	0.040	−1.0	2.0
	0.0		0.250	0.020	0.040	0.040	−1.0	2.0
	0.0		0.250	0.020	0.040	0.040	−1.0	2.0
	0.0		0.020	0.020	0.040	0.040	−1.0	2.0

*The cards contain data as follows (defined in Section 3.2):

Card 1 = LUN1, LUN2, LUN3, LUN4, LUN5 (in 5I10)
Card 2 = C (in F10.3)
Card 3 = NHYDRO, KHT, LDP (in 3I10)
Card 4 = FREQMN (in 3F10.3)
Card 5 = R(1,1) (in 3F10.3,I10)
Card 6 = R(2,1) (in 3F10.3,I10)
Card 7 = R(3,1), R(3,2), R3,37), N(3) (in 3F10.3,I10)
Card 8 = R(4,1), R(4,2), R(4,3), N(4) (in 3F10.3,I10)
NHYDRO CARDS = X, Y, Z, W (in 4F10.3)
KHT CARDS = X, Y, Z, W (in 4F10.3)
LDP CARDS = X, Y, Z, W (in 4F10.3)
LAST CARDS = XZERO, YZERO, DELTAX, DELTAY, SLANT, HIDDEN, SCALE (in 7F10.3)

3.10 External Routines and Symbols

DATAGETR
WEIGHT
ZWEIGHT
DWEIGHT
PHASE
ØUTPUT
ØUTTWØ
ØUTTHREE
ØUTFØUR
CALC
ØRTHØRAY
THRIDIR
PLØTS
PLØTISØM
STØPPLØT
SINF
CØSF
SQRTF
PLØT

3.11 Timing

The compile time is 90 seconds; the running time is approximately 0.3 second per hydrophone per line of plot using 629 angular increments.

3.12 Accuracy

The accuracy is variable, depending on the input data; it is also limited by the accuracy of the plotter: 0.01 inch.

3.13 Cautions of Users

The control of this program depends on the optional use of incremental parameters at the discretion of the user. The maximum number of angular increments is 629. The maximum number of hydrophones is 400. At least one of the angles must be incremented (usually phi or rho or both). For off-line plotting at the RCC, plotting tape(s) must be recorded at low density (200 bits/in.).

3.14 Program Deck Structure

7/9 JØB card

7/9 EQUIP cards
,,
,,
,,
,,
7/9 EQUIP cards

} for magnetic tapes (optional)

7
9 FTN card

program BEAMPLOT
subroutine WEIGHT
subroutine ZWEIGHT
subroutine DWEIGHT
function PHASE
subroutine CALC
subroutine ØRTHØRAY
subroutine THIRDIR
subroutine ØUTPUT
subroutine ØUTTWØ
subroutine ØUTTHREE
subroutine ØUTFØUR
subroutine DATAGETR
subroutine PLØTISØM (JS-NRL-PLØTISØM)
SCØPE card

7
9 LØAD card

7
9 RUN card

data cards

77
88 EØF card

3.15 References—Literature

(1) James Jenkins, "Program to Compute Array Response Surfaces," NRL Memorandum Report 2077, Sept. 1969

(2) Henry A. Brown, "A CDC 3800 Computer Subroutine For Producing Isometric Plots on the 565 CalComp Plotter," NRL Computer Note 31, 1 Aug. 1969

(3) Edward C. Jordan and K.G. Balmain, "Electromagnetic Waves and Radiating Systems," 2nd edition, Prentice-Hall, Englewood Cliffs, N.J., 1968

(4) John D. Kraus, "Antennas," McGraw-Hill, New York, 1950

(5) George W. Byram, G.V. Olds, and L.P. LaLumiere, Jr., "Array Beamforming Response Studies," NRL Report No. 7331, Oct. 1971.

(6) Leon P. LaLumiere, Jr., "A Fortran Program for Computing the Power Response of an Hydrophone Array to a Spherical Wave and Plotting It as an Isometric Surface," NRL Report 7393, 17 April 1972

4. METHOD OR ALGORITHM

In Fig. 1 the geometry is as follows:

R = vector from the origin in the beam direction,

S = vector from the origin in the signal direction,

$\mathbf{H}_m$ = vector from the origin to the mth hydrophone,

d_m = distance from the origin to point F on **R**,

D_m = distance from the origin to point G on S.

For an array of n hydrophones the power response is $P = A^2$, where the amplitude A is defined by

$$A = \left(\sqrt{(R_E)^2 + (I_M)^2}\right) \Big/ \sum_{m=1}^{n} W_m$$

in which

$$R_E = \sum_{m=1}^{n} W_m \cos\left[2\pi \frac{f}{c}(D_m - d_m)\right]$$

and

$$I_M = \sum_{m=1}^{n} W_m \cos\left[2\pi \frac{f}{c}(D_m - d_m)\right]$$

Here W_m is the weighting of the mth hydrophone, f is the frequency, and c is the speed of sound in water. D_m determines the delay due to the signal, and d_m determines the delay due to the beam.

The unit vector in the signal direction is defined by

$$s = \frac{S}{|S|} = \mathbf{i} \sin\phi \cos\rho + \mathbf{j} \sin\phi \sin\rho + \mathbf{k} \cos\phi.$$

For the mth hydrophone,

$$\mathbf{H}_m = \mathbf{i}X_m + \mathbf{j}Y_m + \mathbf{k}Z_m.$$

Then $D_m = s \cdot H_m$ and

$$D_m = (\mathbf{i} \sin\phi \cos\rho + \mathbf{k} \cos\phi) \cdot (\mathbf{i}X_m + \mathbf{j}Y_m = \mathbf{k}Z_m)$$

$$= X_m \sin\phi \cos\rho + Y_m \sin\phi \sin\rho + Z_m \cos\phi.$$

Similarly

$$\mathbf{r} = \frac{\mathbf{R}}{|\mathbf{R}|} = \mathbf{i} \sin\theta \cos\chi + \mathbf{j} \sin\theta \sin\chi + \mathbf{k} \cos\theta$$

and

$$d_m = \mathbf{r} \cdot \mathbf{H}_m,$$

whence

$$d_m = X_m \sin\theta \cos\chi + Y_m \sin\theta \sin\chi + Z_m \cos\theta.$$

The variables are calculated in subroutines as follows with pattern multipliers shown in parentheses: P in DATAGETR, A in ØUTPUT and ØUTTWØ (and ØUTTHREE and ØUTFØUR), R_E and I_M and D_m in CALC (and ØRTHØRAY and THIRDIR), and d_m in PHASE; WEIGHT (and ZWEIGHT and DWEIGHT) sums the hydrophone weighings, and this result is used to normalize A in ØUTPUT and ØUTTWØ (and ØUTTHREE and ØUTFØUR).

5. SOURCE LANGUAGE LISTING

A listing of the program in the Fortran language is reproduced on the following 16 pages.

```
PRØGRAM BEAMPLØT                                                        A   1
IDENT NUMBER - T3001000                                                 A   2
TITLE - HYDRØPHØNE ARRAY PØWER RESPØNSE TØ A PLANE WAVE.                A   3
IDENT NAME - T3-NRL-BEAMPLØT                                            A   4
LANGUAGE - FØRTRAN                                                      A   5
CØMPUTER - CDC-3800                                                     A   6
CØNTRIBUTER - LEØN P. LA LUMIERE JR., CØDE 8144                         A   7
(PRØGRAM BASED ØN THE ØRIGINAL ØF J. W. JENKINS, CØDE 8144)             A   8
                  SIGNAL PRØCESSING BRANCH, ACØUSTICS DIVISIØN          A   9
ØRGANIZATIØN - NRL - NAVAL RESEARCH LABØRATØRY                          A  10
                     WASHINGTØN, D.C. 20390                             A  11
DATE - 1 SEPT 1970                                                      A  12
PURPØSE - TØ CALCULATE THE PØWER RESPØNSE ØF AN HYDRØPHØNE ARRAY        A  13
          TØ A PLANE WAVE TØ BE USED FØR PLØTTING AN ISØMETRIC          A  14
          SURFACE. THIS PRØGRAM MAY BE USED FØR A LINEAR ARRAY ØR       A  15
          FØR A PLANAR ØR A VØLUME ARRAY USING PATTERN                  A  16
          MULTIPLICATIØN AS DESIRED.                                    A  17
                                                                        A  18
.....INPUT DATA DECK. DATA CARDS CAN BE LEFT BLANK AS DESIRED.          A  19
..CARD 1 - LØGICAL UNIT NUMBER (LUN1), (LUN2), (LUN3), (LUN4),          A  20
(LUN5), IN (5I10).                                                      A  21
LUN1 IS THE STØRAGE UNIT FØR THE PLØTTING CØMMANDS. PLØTTING            A  22
CØMMANDS STØRED ØN MAGNETIC TAPE MUST BE IN LØ DENSITY.                 A  23
LUN2 IS THE STØRAGE UNIT FØR THE ARRAY RESPØNSE CALCULATIØNS.           A  24
LUN3 IS THE STØRAGE UNIT FØR THE ARRAY RESPØNSE CALCULATIØNS IN         A  25
THE FIRST DIRECTIØN FØR PATTERN MULTIPLICATIØN. IF PATTERN              A  26
MULTIPLICATIØN IN THE FIRST DIRECTIØN IS NØT USED THEN LUN3 MUST        A  27
BE BLANK ØR ZERØ.                                                       A  28
LUN4 IS THE STØRAGE UNIT FØR THE ARRAY RESPØNSE CALCULATIØNS IN         A  29
THE SECØND DIRECTIØN FØR PATTERN MULTIPLICATIØN. IF PATTERN             A  30
```

```
C     MULTIPLICATION IN THE SECOND DIRECTION IS NOT USED THEN LUN4 MUST
C     BE BLANK OR ZERO,
C     LUN5 IS THE STORAGE UNIT FOR THE ARRAY RESPONSE CALCULATIONS IN
C     THE THIRD DIRECTION FOR PATTERN MULTIPLICATION, IF PATTERN
C     MULTIPLICATION IN THE THIRD DIRECTION IS NOT USED THEN LUN5 MUST
C     BE BLANK OR ZERO,
C     ..CARD 2 = SPEED OF SOUND, IN (F10.3).
C     ..CARD 3 = NUMBER OF HYDROPHONES .LE. 400, IN (3I10). THE FIRST
C     NUMBER IS THE NUMBER OF HYDROPHONES IN THE FIRST DIRECTION, THE
C     SECOND IS THE NUMBER IN THE SECOND DIRECTION, AND THE THIRD IS THE
C     NUMBER IN THE THIRD DIRECTION.
C     ..CARD 4 = MINIMUM FREQUENCY, MAXIMUM FREQUENCY, INCREMENT, IN
C     (3F10.3). IF INCREMENTS ARE NOT DESIRED USE MINIMUM ONLY.
C     ..4 CARDS GIVING ANGULAR PARAMETERS IN DEGREES, IN (3F10.3,I10).
C     IF INCREMENTS ARE NOT DESIRED N(I) SHOULD BE BLANK OR ZERO. AT
C     LEAST ONE OF THE SET (N(3), N(4)) SHOULD BE .GE. 2 AND NONE SHOULD
C     EXCEED 629. THEN THE ANGULAR R(I,3) ARE COMPUTED INTERNALLY. IF
C     R(3,3) OR R(4,3) ARE INCLUDED AS DATA THE CORRESPONDING N(I)
C     MUST BE BLANK OR ZERO.
C     R(1,1) = MINIMUM THTA, R(1,2) = MAXIMUM THTA, R(1,3) = INCREMENT.
C     N(1) = NUMBER OF INCREMENTS.
C     R(2,1) = MINIMUM CHI, R(2,2) = MAXIMUM CHI, R(2,3) = INCREMENT,
C     N(2) = NUMBER OF INCREMENTS.
C     R(3,1) = MINIMUM PHI, R(3,1) = MAXIMUM PHI, R(3,3) = INCREMENT,
C     N(3) = NUMBER OF INCREMENTS.
C     R(4,1) = MINIMUM RHO, R(4,1) = MAXIMUM RHO, R(4,3) = INCREMENT,
C     N(4) = NUMBER OF INCREMENTS.
C     THTA = ANGLE OF PREFERRED BEAM FOCUS DIRECTION FROM THE Z-AXIS.
C     CHI  = ANGLE OF PREFERRED BEAM FOCUS DIRECTION FROM THE X-AXIS.
C     PHI  = ANGLE OF INCIDENT BEAM FOCUS DIRECTION FROM THE Z-AXIS.
C     RHO  = ANGLE OF INCIDENT BEAM FOCUS DIRECTION FROM THE X-AXIS.
C     ..NHYDRO CARDS, EACH GIVING THE X,Y,Z COORDINATES OF THE
C     HYDROPHONES AND W, THE WEIGHTING OF EACH HYDROPHONE IF DESIRED,
C     IN (4F10.3). OTHERWISE W IS ASSUMED TO BE ONE.
C     IF PATTERN MULTIPLICATION IN THE SECOND DIRECTION IS NOT USED,
C     THEN KHT IS BLANK OR ZERO, AND THE FOLLOWING DATA CARDS MUST NOT
C     BE PRESENT.
C     ..KHT CARDS, EACH GIVING THE X,Y,Z COORDINATES OF THE HYDROPHONES
C     AND W, THE WEIGHTING OF EACH HYDROPHONE IF DESIRED, IN (4F10.3).
C     OTHERWISE W IS ASSUMED TO BE ONE.
C     IF PATTERN MULTIPLICATION IN THE THIRD DIRECTION IS NOT USED, THEN
C     LDP IS BLANK OR ZERO, AND THE FOLLOWING DATA CARDS MUST BE ABSENT.
C     ..LDP CARDS, EACH GIVING THE X,Y,Z COORDINATES OF THE HYDROPHONES
C     AND W, THE WEIGHTING OF EACH HYDROPHONE IF DESIRED, IN (4F10.3).
C     OTHERWISE W IS ASSUMED TO BE ONE.
C     THE FOLLOWING DATA CARDS ARE REQUIRED FOR SUBROUTINE PLOTISOM AND
C     EQUALS FOUR MINUS THE NUMBER OF LUNS LEFT BLANK OR ZERO.
C     ..LAST CARDS = XZERO, YZERO, DELTAX, DELTAY, SLANT, HIDDEN, SCALE
C     IN (7F10.3) FOR PLOTTING COMMANDS TO LUN1. IF PATTERN
C     MULTIPLICATION IS NOT USED ONLY ONE CARD IS REQUIRED.
C     SCALE IS A MULTIPLIER GIVING THE DESIRED HEIGHT OF THE PLOTS.
C     NUMX, NUMY, AND INTERP ARE COMPUTED INTERNALLY BY THE MAIN PROGRAM
C     SUBROUTINE PLOTISOM IS THE RCC LIBRARY IDENT, NAME J5-NRL-PLOTISOM
C
      DIMENSION AMP(650), R(4,3), N(4), PLTARRAY(254), PEAK(6909)
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400)
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)
      EXTERNAL DATAGETR
    1 FORMAT (2X,48HHYDROPHONE ARRAY RESPONSE TO A PLANE WAVE SIGNAL/)
    2 FORMAT (19H  SPEED OF SOUND = ,F10.3/)
    3 FORMAT (2X,24HNUMBER OF HYDROPHONES = ,I3,//,7X,1HX,9X,1HY,9X,1HZ,
```

```
 17X,6HWEIGHT/)                                                          A  93
 4 FORMAT (14H  FREQUENCY = ,3F10.3,//,1X,18H ANGULAR VARIABLES/)        A  94
 5 FORMAT (2X,16HHYDROPHONE ARRAY/)                                      A  95
 6 FORMAT (2X,58HHYDROPHONE PATTERN MULTIPLIER ARRAY IN THE FIRST DIR    A  96
  1ECTION/)                                                              A  97
 7 FORMAT (2X,59HHYDROPHONE PATTERN MULTIPLIER ARRAY IN THE SECOND DI    A  98
  1RECTION/)                                                             A  99
 8 FORMAT (2X,58HHYDROPHONE PATTERN MULTIPLIER ARRAY IN THE THIRD DIR    A 100

  1ECTION/)                                                              A 101
 9 FORMAT (/,2X,17HLARGEST NUMBER = ,I7,10H OR OCTAL ,O7)                A 102
10 FORMAT (/,2X,17HNO. OF RECORDS = ,I3,10H OR OCTAL ,O3,11H FOR LUN     A 103
  1= ,I2)                                                                A 104
11 FORMAT (37H ERROR NEITHER PHI NOR RHO INCREMENT )                     A 105
12 FORMAT (5I10)                                                         A 106
13 FORMAT (2X,2HR(,I1,6H,J) = ,3F10.3,I10)                               A 107
14 FORMAT (1H 10F10.3)                                                   A 108
15 FORMAT (3F10.3,I10)                                                   A 109
16 FORMAT (4F10.3)                                                       A 110
17 FORMAT (7F10.3)                                                       A 111
18 FORMAT (2X,19HPLOTTING PARAMETERS/)                                   A 112
19 FORMAT (2X,9HNUMX   = ,I3/,2X,9HNUMY   = ,I3/,2X,9HINTERP = ,I3)      A 113
20 FORMAT (2X,9HXZERO  = ,F6.3/,2X,9HYZERO  = ,F6.3/,2X,9HDELTAX = ,F    A 114
  16.3/,2X,9HDELTAY = ,F6.3/,2X,9HSLANT  = ,F6.3/,2X,9HHIDDEN = ,F6.3    A 115
  2/,2X,9HSCALE  = ,F6.3/2X,9HLUN    = ,I2/)                             A 116
21 FORMAT (//,2X,7HLUN1 = ,I2,/,2X,7HLUN2 = ,I2,/,2X,7HLUN3 = ,I2,/,2    A 117
  1X,7HLUN4 = ,I2,/2X,7HLUN5 = ,I2)                                      A 118
22 FORMAT (1H1)                                                          A 119
   READ 12, LUN1,LUN2,LUN3,LUN4,LUN5                                     A 120
   READ 15, C                                                            A 121
   READ 12, NHYDRO,KHT,LDP                                               A 122
   READ 15, FREQMN,FREQMX,DFREQ                                          A 123
   PRINT 1                                                               A 124
   PRINT 2, C                                                            A 125
   PRINT 4, FREQMN,FREQMX,DFREQ                                          A 126
   DO 30 I=1,4                                                           A 127
   READ 15, (R(I,J),J=1,3),N(I)                                          A 128
   IF (N(I)) 23,24,23                                                    A 129
23 T=N(I)-1                                                              A 130
   R(I,3)=(R(I,2)-R(I,1))/T                                              A 131
   GO TO 27                                                              A 132
24 IF (R(I,3)) 26,25,26                                                  A 133
25 N(I)=1.0                                                              A 134
   GO TO 27                                                              A 135
26 N(I)=ABS((R(I,2)-R(I,1))/R(I,3))+1.9                                  A 136
27 PRINT 13, I,(R(I,J),J=1,3),N(I)                                       A 137
   DO 28 J=1,3                                                           A 138
   R(I,J)=R(I,J)/57.295778                                               A 139
28 CONTINUE                                                              A 140
   IF (N(I)) 29,30,30                                                    A 141
29 N(I)=-N(I)                                                            A 142
30 CONTINUE                                                              A 143
   DO 31 J=1,NHYDRO                                                      A 144
31 READ 16, X(J),Y(J),Z(J),W(J)                                          A 145
   CALL WEIGHT                                                           A 146
   PRINT 22                                                              A 147
   IF (KHT) 32,32,33                                                     A 148
32 PRINT 5                                                               A 149
   GO TO 34                                                              A 150
```

```
33 PRINT 6
34 PRINT 3, NHYDRO
   DO 42 J=1,NHYDRO
   IF (J-51) 42,41,35
35 IF (J-101) 42,41,36
36 IF (J-151) 42,41,37
37 IF (J-201) 42,41,38
38 IF (J-251) 42,41,39
39 IF (J-301) 42,41,40
40 IF (J-351) 42,41,42
41 PRINT 22
   PRINT 3, NHYDRO
42 PRINT 14, X(J),Y(J),Z(J),W(J)
   IF (KHT) 43,54,44
43 KHT=-KHT
44 K1=NHYDRO+1
   K2=NHYDRO+KHT
   DO 45 K=K1,K2
45 READ 16, X(K),Y(K),Z(K),W(K)
   CALL ZWEIGHT (K1,K2)
   PRINT 22
   PRINT 7
   PRINT 3, KHT
   DO 53 J=K1,K2
   IF (J-51) 53,52,46
46 IF (J-101) 53,52,47
47 IF (J-151) 53,52,48
48 IF (J-201) 53,52,49
49 IF (J-251) 53,52,50
50 IF (J-301) 53,52,51
51 IF (J-351) 53,52,53
52 PRINT 22
   PRINT 3, KHT
53 PRINT 14, X(J),Y(J),Z(J),W(J)
   GO TO 56
54 NY=N(4)
   DO 55 I=1,NY
55 ZAMP(I)=1.0
   W(402)=1.0
56 IF (LDP) 57,68,58
57 LDP=-LDP
58 K3=K2+1
   K4=K2+LDP
   DO 59 K=K3,K4
59 READ 16, X(K),Y(K),Z(K),W(K)
   CALL DWEIGHT (K3,K4)
   PRINT 22
   PRINT 8
   PRINT 3, LDP
   DO 67 J=K3,K4
```

```
33 PRINT 6                                                          A 151
34 PRINT 3, NHYDR0                                                  A 152
   D0 42 J=1,NHYDR0                                                 A 153
   IF (J-51) 42,41,35                                               A 154
35 IF (J-101) 42,41,36                                              A 155
36 IF (J-151) 42,41,37                                              A 156
37 IF (J-201) 42,41,38                                              A 157
38 IF (J-251) 42,41,39                                              A 158
39 IF (J-301) 42,41,40                                              A 159
40 IF (J-351) 42,41,42                                              A 160
41 PRINT 22                                                         A 161
   PRINT 3, NHYDR0                                                  A 162
42 PRINT 14, X(J),Y(J),Z(J),W(J)                                    A 163
   IF (KHT) 43,54,44                                                A 164
43 KHT=-KHT                                                         A 165
44 K1=NHYDR0+1                                                      A 166
   K2=NHYDR0+KHT                                                    A 167
   D0 45 K=K1,K2                                                    A 168
45 READ 16, X(K),Y(K),Z(K),W(K)                                     A 169
   CALL ZWEIGHT (K1,K2)                                             A 170
   PRINT 22                                                         A 171
   PRINT 7                                                          A 172
   PRINT 3, KHT                                                     A 173
   D0 53 J=K1,K2                                                    A 174
   IF (J-51) 53,52,46                                               A 175
46 IF (J-101) 53,52,47                                              A 176
47 IF (J-151) 53,52,48                                              A 177
48 IF (J-201) 53,52,49                                              A 178
49 IF (J-251) 53,52,50                                              A 179
50 IF (J-301) 53,52,51                                              A 180
51 IF (J-351) 53,52,53                                              A 181
52 PRINT 22                                                         A 182
   PRINT 3, KHT                                                     A 183
53 PRINT 14, X(J),Y(J),Z(J),W(J)                                    A 184
   G0 T0 56                                                         A 185
54 NY=N(4)                                                          A 186
   D0 55 I=1,NY                                                     A 187
55 ZAMP(I)=1.0                                                      A 188
   W(402)=1.0                                                       A 189
56 IF (LDP) 57,68,58                                                A 190
57 LDP=-LDP                                                         A 191
58 K3=K2+1                                                          A 192
   K4=K2+LDP                                                        A 193
   D0 59 K=K3,K4                                                    A 194
59 READ 16, X(K),Y(K),Z(K),W(K)                                     A 195
   CALL DWEIGHT (K3,K4)                                             A 196
   PRINT 22                                                         A 197
   PRINT 8                                                          A 198
   PRINT 3, LDP                                                     A 199
   D0 67 J=K3,K4                                                    A 200
```

```
      IF (J-51) 67,66,60                                          A 201
   60 IF (J-101) 67,66,61                                         A 202
   61 IF (J-151) 67,66,62                                         A 203
   62 IF (J-201) 67,66,63                                         A 204
   63 IF (J-251) 67,66,64                                         A 205
   64 IF (J-301) 67,66,65                                         A 206
   65 IF (J-351) 67,66,67                                         A 207
   66 PRINT 22                                                    A 208
      PRINT 3, LDP                                                A 209
   67 PRINT 14, X(J),Y(J),Z(J),W(J)                               A 210
      GO TO 70                                                    A 211
   68 ND=N(4)                                                     A 212
      DO 69 I=1,ND                                                A 213
   69 DAMP(I)=1.0                                                 A 214
      W(403)=1.0                                                  A 215
   70 NSCALE=0                                                    A 216
      WAVE=FREQMN/C                                               A 217
      THTA=R(1,1)                                                 A 218
      CHI=R(2,1)                                                  A 219
      I=0                                                         A 220
      INDEX=4                                                     A 221
      AA=R(3,1)                                                   A 222
      BB=R(4,1)                                                   A 223
      NX=N(3)                                                     A 224
      DO 71 K=1,NX                                                A 225
      SP(K)=SIN(AA)                                               A 226
      CP(K)=COS(AA)                                               A 227
   71 AA=AA+R(3,3)                                                A 228
      NX=N(4)                                                     A 229
      DO 72 K=1,NX                                                A 230
      SR(K)=SIN(BB)                                               A 231
      CR(K)=COS(BB)                                               A 232
   72 BB=BB+R(4,3)                                                A 233
      IF (DFREQ) 73,77,74                                         A 234
   73 DFREQ=-DFREQ                                                A 235
   74 FREQ=FREQMN-DFREQ                                           A 236
      INDEX=1                                                     A 237
   75 IF (FREQMX-FREQ) 129,129,76                                 A 238
   76 FREQ=FREQ+DFREQ                                             A 239
      WAVE=FREQ/C                                                 A 240
      GO TO 85                                                    A 241
   77 IF (N(1)-1) 78,81,78                                        A 242
   78 INDEX=2                                                     A 243
      THTA=R(1,1)-R(1,3)                                          A 244
   79 IF (N(1)-I) 129,129,80                                      A 245
   80 THTA=THTA+R(1,3)                                            A 246
      I=I+1                                                       A 247
      GO TO 85                                                    A 248
   81 IF (N(2)-1) 82,85,82                                        A 249
   82 INDEX=3                                                     A 250
```

```
      CHI=R(2,1)-R(2,3)                                                 A 251
   83 IF (N(2)=I) 129,129,84                                            A 252
   84 CHI=CHI+R(2,3)                                                    A 253
      I=I+1                                                             A 254
   85 DO 86 J=1,NHYDRO                                                  A 255
      P(J)=PHASE(THTA,CHI,X(J),Y(J),Z(J))                               A 256
   86 CONTINUE                                                          A 257
      IF (KHT) 91,91,87                                                 A 258
   87 DO 88 K=K1,K2                                                     A 259
   88 P(K)=PHASE(THTA,CHI,X(K),Y(K),Z(K))                               A 260
      IF (LDP) 91,91,89                                                 A 261
   89 DO 90 K=K3,K4                                                     A 262
   90 P(K)=PHASE(THTA,CHI,X(K),Y(K),Z(K))                               A 263
   91 RHO=R(4,1)                                                        A 264
      PHI=R(3,1)                                                        A 265
      IF (N(3)=1) 94,92,108                                             A 266
   92 IF (N(4)=1) 94,93,95                                              A 267
   93 PRINT 11                                                          A 268
   94 STOP 4                                                            A 269
   95 RHO=R(4,1)-R(4,3)                                                 A 270
      M=0                                                               A 271
      MN=1                                                              A 272
   96 IF (N(4)=M) 97,97,104                                             A 273
   97 CALL OUTPUT (N(4),AMP)                                            A 274
      IF (LUN3) 99,99,98                                                A 275
   98 CALL OUTTWO (N(4),AMP)                                            A 276
   99 IF (LUN4) 101,101,100                                             A 277
  100 CALL OUTTHREE (N(4),ZAMP)                                         A 278
  101 IF (LUN5) 103,103,102                                             A 279
  102 CALL OUTFOUR (N(4),DAMP)                                          A 280
  103 GO TO (75,79,83,129), INDEX                                       A 281
  104 RHO=RHO+R(4,3)                                                    A 282
      M=M+1                                                             A 283
      CALL CALC (MN,M,AMP(M))                                           A 284
      IF (KHT) 107,107,105                                              A 285
  105 CALL ORTHORAY (MN,M,ZAMP(M),K1,K2)                                A 286
      IF (LDP) 107,107,106                                              A 287
  106 CALL THIRDIR (MN,M,DAMP(M),K3,K4)                                 A 288
  107 GO TO 96                                                          A 289
  108 PHI=R(3,1)-R(3,3)                                                 A 290
      MN=0                                                              A 291
      M=1                                                               A 292
  109 IF (N(3)=MN) 110,110,112                                          A 293
  110 IF (5-INDEX) 111,129,111                                          A 294
  111 CALL OUTPUT (N(3),AMP)                                            A 295
      GO TO (75,79,83,129,129), INDEX                                   A 296
  112 MN=MN+1                                                           A 297
      PHI=PHI+R(3,3)                                                    A 298
      IF (N(4)=1) 117,113,117                                           A 299
  113 CALL CALC (MN,M,AMP(MN))                                          A 300
```

```
      IF (KHT) 116,116,114
  114 CALL ORTHORAY (MN,M,ZAMP(MN),K1,K2)
      IF (LDP) 116,116,115
  115 CALL THIRDIR (MN,M,DAMP(M),K3,K4)
  116 GO TO 109
  117 RHO=R(4,1)-R(4,3)
      INDEX=5
      M=0
  118 IF (N(4)=M) 119,119,125
  119 CALL OUTPUT (N(4),AMP)
      IF (LUN3) 121,121,120
  120 CALL OUTTWO (N(4),AMP)
  121 IF (LUN4) 124,124,122
  122 CALL OUTTHREE (N(4),ZAMP)
      IF (LUN5) 124,124,123
  123 CALL OUTFOUR (N(4),DAMP)
  124 GO TO 109
  125 M=M+1
      RHO=RHO+R(4,3)
      CALL CALC (MN,M,AMP(M))
      IF (KHT) 128,128,126
  126 CALL ORTHORAY (MN,M,ZAMP(M),K1,K2)
      IF (LDP) 128,128,127
  127 CALL THIRDIR (MN,M,DAMP(M),K3,K4)
  128 GO TO 118
  129 PRINT 22
      PRINT 9, NSCALE,NSCALE
      IF (LUN2) 131,131,130
  130 END FILE LUN2
      REWIND LUN2
      PRINT 10, NH,NH,LUN2
  131 IF (LUN3) 133,133,132
  132 END FILE LUN3
      REWIND LUN3
      PRINT 10, NI,NI,LUN3
  133 IF (LUN4) 135,135,134
  134 END FILE LUN4
      REWIND LUN4
      PRINT 10, NJ,NJ,LUN4
  135 IF (LUN5) 137,137,136
  136 END FILE LUN5
      REWIND LUN5
      PRINT 10, NK,NK,LUN5
  137 IF (LUN2) 141,141,138
  138 LUN6=LUN2
      NUMY=NH
      READ 17, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE
      INTERP=DELTAX/0.01-1.
      IF (SCALE) 140,139,140
  139 SCALE=1.0
```

```
140 CALL PLOTS (PLTARRAY,254,LUN1)                                      A 351
    CALL PLOTISOM (XZERO,YZERO,NUMX,NUMY,DELTAX,DELTAY,SLANT,INTERP,HI  A 352
   1DDEN,DATAGETR,DATATAB,PEAK)                                         A 353
    XNEW = SLANT*(NUMY-1) + DELTAX*(NUMX-1)                             A 354
    CALL PLOT (XNEW, YZERO, -3)                                         A 355
    CALL PLOTS (0,0)                                                    A 356
    REWIND LUN6                                                         A 357
    PRINT 22                                                            A 358
    PRINT 18                                                            A 359
    PRINT 19, NUMX,NUMY,INTERP                                          A 360
    PRINT 20, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE,LUN6         A 361
141 IF (LUN3) 145,145,142                                               A 362
142 LUN6=LUN3                                                           A 363
    NUMY=NI                                                             A 364
    READ 17, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE               A 365
    INTERP=DELTAX/0.01+1.                                               A 366
    IF (SCALE) 144,143,144                                              A 367
143 SCALE=1.0                                                           A 368
144 CALL PLOTS (PLTARRAY,254,LUN1)                                      A 369
    CALL PLOTISOM (XZERO,YZERO,NUMX,NUMY,DELTAX,DELTAY,SLANT,INTERP,HI  A 370
   1DDEN,DATAGETR,DATATAB,PEAK)                                         A 371
    XNEW = SLANT*(NUMY-1) + DELTAX*(NUMX-1)                             A 372
    CALL PLOT (XNEW, YZERO, -3)                                         A 373
    CALL PLOTS (0,0)                                                    A 374
    REWIND LUN6                                                         A 375
    PRINT 19, NUMX,NUMY,INTERP                                          A 376
    PRINT 20, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE,LUN6         A 377
145 IF (LUN4) 149,149,146                                               A 378
146 LUN6=LUN4                                                           A 379
    NUMY=NJ                                                             A 380
    READ 17, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE               A 381
    INTERP=DELTAX/0.01+1.                                               A 382
    IF (SCALE) 148,147,148                                              A 383
147 SCALE=1.0                                                           A 384
148 CALL PLOTS (PLTARRAY,254,LUN1)                                      A 385
    CALL PLOTISOM (XZERO,YZERO,NUMX,NUMY,DELTAX,DELTAY,SLANT,INTERP,HI  A 386
   1DDEN,DATAGETR,DATATAB,PEAK)                                         A 387
    XNEW = SLANT*(NUMY-1) + DELTAX*(NUMX-1)                             A 388
    CALL PLOT (XNEW, YZERO, -3)                                         A 389
    CALL PLOTS (0,0)                                                    A 390
    REWIND LUN6                                                         A 391
    PRINT 19, NUMX,NUMY,INTERP                                          A 392
    PRINT 20, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE,LUN6         A 393
149 IF (LUN5) 153,153,150                                               A 394
150 LUN6=LUN5                                                           A 395
    NUMY=NK                                                             A 396
    READ 17, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE               A 397
    INTERP=DELTAX/0.01+1.                                               A 398
    IF (SCALE) 152,151,152                                              A 399
151 SCALE=1.0                                                           A 400
```

```
  152 CALL PLOTS (PLTARRAY,254,LUN1)                                    A 401
      CALL PLOTISOM (XZERO,YZERO,NUMX,NUMY,DELTAX,DELTAY,SLANT,INTERP,HI  A 402
     1DDEN,DATAGETR,DATATAB,PEAK)                                        A 403
      REWIND LUN6                                                       A 404
      PRINT 19, NUMX,NUMY,INTERP                                        A 405
      PRINT 20, XZERO,YZERO,DELTAX,DELTAY,SLANT,HIDDEN,SCALE,LUN6       A 406
  153 XNEW = SLANT*(NUMY-1) + DELTAX*(NUMX-1)                           A 407
      CALL PLOT (XNEW, YZERO, -3)                                       A 408
      CALL PLOTS (0,0)                                                  A 409
      END FILE LUN1                                                     A 410
      REWIND LUN1                                                       A 411
      CALL STOPPLOT                                                     A 412
      PRINT 21, LUN1,LUN2,LUN3,LUN4,LUN5                                A 413
      STOP                                                              A 414
      END                                                               A 415-

      SUBROUTINE WEIGHT                                                 B   1
C     COMPUTES THE SUMMATION OF HYDROPHONE WEIGHTINGS IN THE FIRST      B   2
C     DIRECTION WITH OR WITHOUT PATTERN MULTIPLICATION.                 B   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) B   4
     1,SP(65O),CP(65O),SR(65O),CR(65O),LUN1,NH,KHT,ZAMP(65O),LUN2,LUN3,N B   5
     2I,NJ,DATATAB(65O),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65O)      B   6
      DO 2 I=1,NHYDRO                                                   B   7
      IF (W(I)) 2,1,2                                                   B   8
    1 W(I)=1.0                                                          B   9
    2 W(401)=W(401)+ABS(W(I))                                           B  10
      RETURN                                                            B  11
      END                                                               B  12-

      SUBROUTINE ZWEIGHT (K1,K2)                                        C   1
C     COMPUTES THE SUMMATION OF HYDROPHONE WEIGHTINGS IN THE SECOND     C   2
C     DIRECTION WHEN USING PATTERN MULTIPLICATION.                      C   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) C   4
     1,SP(65O),CP(65O),SR(65O),CR(65O),LUN1,NH,KHT,ZAMP(65O),LUN2,LUN3,N C   5
     2I,NJ,DATATAB(65O),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65O)      C   6
      DO 2 K=K1,K2                                                      C   7
      IF (W(K)) 2,1,2                                                   C   8
    1 W(K)=1.0                                                          C   9
    2 W(402)=W(402)+ABS(W(K))                                           C  10
      RETURN                                                            C  11
      END                                                               C  12-

      SUBROUTINE DWEIGHT (K3,K4)                                        D   1
C     COMPUTES THE SUMMATION OF HYDROPHONE WEIGHTINGS IN THE THIRD      D   2
C     DIRECTION WHEN USING PATTERN MULTIPLICATION.                      D   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) D   4
     1,SP(65O),CP(65O),SR(65O),CR(65O),LUN1,NH,KHT,ZAMP(65O),LUN2,LUN3,N D   5
     2I,NJ,DATATAB(65O),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65O)      D   6
      DO 2 K=K3,K4                                                      D   7
      IF (W(K)) 2,1,2                                                   D   8
```

```
    1 W(K)=1.0                                                          D   9
    2 W(403)=W(403)+ABS(W(K))                                           D  10
      RETURN                                                            D  11
      END                                                               D  12-

      FUNCTION PHASE (A,B,R,S,T)                                        E   1
      COMPUTES THE HYDROPHONE DELAYS DUE TO THE BEAM FOCUS.             E   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) E   3
     1,SP(65_0),CP(65_0),SR(65_0),CR(65_0),LUN1,NH,KHT,ZAMP(65_0),LUN2,LUN3,N E   4
     2I,NJ,DATATAB(65_0),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65_0)    E   5
      DATA (AA=99.),(BB=99.0)                                           E   6
      IF (A-AA) 1,2,1                                                   E   7
    1 SA=SIN(A)                                                         E   8
      CA=COS(A)                                                         E   9
      AA=A                                                              E  10
    2 IF (B-BB) 3,4,3                                                   E  11
    3 SB=SIN(B)                                                         E  12
      CB=COS(B)                                                         E  13
      BB=B                                                              E  14
    4 PHASE=6.28319*WAVE*(SA*(R*CB+S*SB)+T*CA)                          E  15
      RETURN                                                            E  16
      END                                                               E  17-

      SUBROUTINE CALC (MN,M,AP)                                         F   1
C     COMPUTES THE AMPLITUDE DUE TO THE SUMMATION OF ALL DELAYS IN THE  F   2
C     FIRST DIRECTION WITH OR WITHOUT PATTERN MULTIPLICATION.           F   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) F   4
     1,SP(65_0),CP(65_0),SR(65_0),CR(65_0),LUN1,NH,KHT,ZAMP(65_0),LUN2,LUN3,N F   5
     2I,NJ,DATATAB(65_0),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65_0)    F   6
      A=0.0                                                             F   7
      B=0.0                                                             F   8
      DO 1 I=1,NHYDRO                                                   F   9
      ARG=6.28318*WAVE*(SP(MN)*(X(I)*CR(M)+Y(I)*SR(M))+Z(I)*CP(MN))-P(I) F  10
      A=A+W(I)*SIN(ARG)                                                 F  11
      B=B+W(I)*COS(ARG)                                                 F  12
    1 CONTINUE                                                          F  13
      AP=SQRT(A*A+B*B)                                                  F  14
      RETURN                                                            F  15
      END                                                               F  16-

      SUBROUTINE ORTHORAY (MN,M,ZAP,K1,K2)                              G   1
C     COMPUTES THE AMPLITUDE DUE TO THE SUMMATION OF ALL DELAYS IN THE  G   2
C     SECOND DIRECTION WHEN USING PATTERN MULTIPLICATION.               G   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) G   4
     1,SP(65_0),CP(65_0),SR(65_0),CR(65_0),LUN1,NH,KHT,ZAMP(65_0),LUN2,LUN3,N G   5
     2I,NJ,DATATAB(65_0),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(65_0)    G   6
      A=0.0                                                             G   7
      B=0.0                                                             G   8
      DO 1 K=K1,K2                                                      G   9
      ARG=6.28318*WAVE*(SP(MN)*(X(K)*CR(M)+Y(K)*SR(M))+Z(K)*CP(MN))-P(K) G  10
```

```
      A=A+W(K)*SIN(ARG)                                                 G  11
      B=B+W(K)*COS(ARG)                                                 G  12
    1 CONTINUE                                                          G  13
      ZAP=SQRT(A*A+B*B)                                                 G  14
      RETURN                                                            G  15
      END                                                               G  16-

      SUBROUTINE THIRDIR (MN,M,DAP,K3,K4)                               H   1
C     COMPUTES THE AMPLITUDE DUE TO THE SUMMATION OF ALL DELAYS IN THE  H   2
C     THIRD DIRECTION WHEN USING PATTERN MULTIPLICATION,                H   3
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) H   4
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N H   5
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      H   6
      A=0.0                                                             H   7
      B=0.0                                                             H   8
      DO 1 K=K3,K4                                                      H   9
      ARG=6.28318*WAVE*(SP(MN)*(X(K)*CR(M)+Y(K)*SR(M))+Z(K)*CP(MN))*P(K) H  10
      A=A+W(K)*SIN(ARG)                                                 H  11
      B=B+W(K)*COS(ARG)                                                 H  12
    1 CONTINUE                                                          H  13
      DAP=SQRT(A*A+B*B)                                                 H  14
      RETURN                                                            H  15
      END                                                               H  16-

      SUBROUTINE OUTPUT (K,A)                                           I   1
C     STORES THE RESPONSE CALCULATIONS IN LUN2,                         I   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) I   3
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N I   4
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      I   5
      DATA (NA=629(0)),(BA=629(0))                                      I   6
      DIMENSION A(650), NA(650), BA(650)                                I   7
      NUMX=K                                                            I   8
      DO 2 J=1,K                                                        I   9
      BA(J)=A(J)/W(401)*ZAMP(J)/W(402)*DAMP(J)/W(403)                   I  10
      NA(J)=BA(J)*1000000.                                              I  11
      IF (NA(J)-NSCALE) 2,2,1                                           I  12
    1 NSCALE=NA(J)                                                      I  13
    2 CONTINUE                                                          I  14
    3 IF (UNIT,LUN2) 3,4                                                I  15
    4 BUFFER OUT (LUN2,1) (BA(1),BA(NUMX))                              I  16
      NH=NH+1                                                           I  17
      RETURN                                                            I  18
      END                                                               I  19-

      SUBROUTINE OUTTWO (K,A)                                           J   1
C     STORES THE RESPONSE CALCULATIONS IN THE FIRST DIRECTION IN LUN3.  J   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) J   3
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N J   4
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      J   5
      DATA (XA=629(0))                                                  J   6
```

```
      DIMENSION A(650), XA(650)                                         J   7
      NUMX=K                                                            J   8
      DO 1 J=1,K                                                        J   9
    1 XA(J)=A(J)/W(401)                                                 J  10
    2 IF (UNIT,LUN3) 2,3                                                J  11
    3 BUFFER OUT (LUN3,1) (XA(1),XA(NUMX))                              J  12
      NI=NI+1                                                           J  13
      RETURN                                                            J  14
      END                                                               J  15-

      SUBROUTINE OUTTHREE (K,A)                                         K   1
;     STORES THE RESPONSE CALCULATIONS IN THE SECOND DIRECTION IN LUN4, K   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) K   3
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N K   4
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      K   5
      DATA (YA=629(0))                                                  K   6
      DIMENSION A(650), YA(650)                                         K   7
      NUMX=K                                                            K   8
      DO 1 J=1,K                                                        K   9
    1 YA(J)=A(J)/W(402)                                                 K  10
    2 IF (UNIT,LUN4) 2,3                                                K  11
    3 BUFFER OUT (LUN4,1) (YA(1),YA(NUMX))                              K  12
      NJ=NJ+1                                                           K  13
      RETURN                                                            K  14
      END                                                               K  15-

      SUBROUTINE OUTFOUR (K,A)                                          L   1
C     STORES THE RESPONSE CALCULATIONS IN THE THIRD DIRECTION IN LUN5,  L   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) L   3
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N L   4
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      L   5
      DATA (DA=629(0))                                                  L   6
      DIMENSION A(650), DA(650)                                         L   7
      NUMX=K                                                            L   8
      DO 1 J=1,K                                                        L   9
    1 DA(J)=A(J)/W(403)                                                 L  10
    2 IF (UNIT,LUN5) 2,3                                                L  11
    3 BUFFER OUT (LUN5,1) (DA(1),DA(NUMX))                              L  12
      NK=NK+1                                                           L  13
      RETURN                                                            L  14
      END                                                               L  15-

      SUBROUTINE DATAGETR                                               M   1
C     INPUTS THE RESPONSE CALCULATIONS FOR USE BY SUBROUTINE PLOTISOM,  M   2
      COMMON /BLK/ NHYDRO,WAVE,NSCALE,W(403),X(400),Y(400),Z(400),P(400) M   3
     1,SP(650),CP(650),SR(650),CR(650),LUN1,NH,KHT,ZAMP(650),LUN2,LUN3,N M   4
     2I,NJ,DATATAB(650),SCALE,NUMX,LUN4,LUN5,LUN6,LDP,NK,DAMP(650)      M   5
      BUFFER IN (LUN6,1) (DATATAB(1),DATATAB(NUMX))                     M   6
    1 IF (UNIT,LUN6) 1,2                                                M   7
    2 DO 3 I=1,NUMX                                                     M   8
```

```
    3 DATA TAB(I)=DATATAB(I)*DATATAB(I)*SCALE                          M   9
      RETURN                                                           M  10
      END                                                              M  11-

      SUBROUTINE PLOTISOM( XZERO, YZERO, NUMX, NUMY, DELTA X, DELTA Y,  00000100
     1 SLANT, INTERP, HIDDEN, DATA GETR, DATA TAB, PEAK )               00000200
C     IDENT NUMBER - J5003R00                                           00000300
C     TITLE - ISOMETRIC PLOTTING                                        00000400
C     IDENT NAME - J5-NRL-PLOTISOM                                      00000500
C     LANGUAGE - FORTRAN                                                00000600
C     COMPUTER - CDC-3800                                               00000700
C     CONTRIBUTOR - HENRY A. BROWN, CODE 5344                           00000800
C                   TARGET CHARACTERISTICS BRANCH, RADAR DIVISION       00000900
C     ORGANIZATION - NRL - NAVAL RESEARCH LABORATORY                    00001000
C                          WASHINGTON, D.C.  20390                      00001100
C     DATE - 1 AUGUST 1969                                              00001200
C     PURPOSE - TO PLOT THE HORIZONTAL CUTS OF A FUNCTION               00001300
C               OF TWO VARIABLES ONE CUT AT A TIME.                     00001400
C *** THE FOLLOWING PARAMETERS MUST BE SET IN THE CALLING PROGRAM ---   00001500
C                                                                       00001600
C --- XZERO   = HORIZONTAL DISTANCE IN INCHES TO LOWER LEFT HAND CORNER 00001700
C               OF PLOT FROM PLOT ORIGIN                                00001800
C                                                                       00001900
C --- YZERO   = VERTICAL DISTANCE IN INCHES TO LOWER LEFT HAND CORNER   00002000
C               OF PLOT FROM PLOT ORIGIN                                00002100
C                                                                       00002200
C --- NUMX    = NUMBER OF DATA POINTS IN X DIRECTION                    00002300
C                                                                       00002400
C --- NUMY    = NUMBER OF HORIZONTAL CUTS TO BE PLOTTED                 00002500
C                                                                       00002600
C --- DELTA X = HORIZONTAL SEPARATION OF DATA POINTS IN INCHES          00002700
C                                                                       00002800
C --- DELTA Y = VERTICAL SEPARATION OF HORIZONTAL CUTS IN INCHES        00002900
C                                                                       00003000
C --- SLANT   = HORIZONTAL OFFSET IN INCHES OF ADJACENT HORIZONTAL CUTS 00003100
C                                                                       00003200
C --- INTERP  = NUMBER OF LINEARLY INTERPOLATED POINTS TO BE INSERTED   00003300
C               BETWEEN DATA POINTS                                     00003400
C                                                                       00003500
C --- HIDDEN .GT. 0.IF HIDDEN POINTS ARE TO BE PLOTTED                  00003600
C            .LT. 0.IF HIDDEN POINTS ARE NOT TO BE PLOTTED              00003700
C                                                                       00003800
C --- *DATA GETR* IS A SUBROUTINE WRITTEN BY THE USER AND DECLARED      00003900
C                 EXTERNAL IN THE CALLING PROGRAM WHICH TRANSFERS INTO  00004000
C                 DATA TAB THE DATA REPRESENTING ONE HORIZONTAL CUT FOR 00004100
C                 EACH CALL TO DATA GETR IN SEQUENCE FROM THE FRONT OF  00004200
C                 THE PLOT TO THE REAR OF THE PLOT.                     00004300
C                                                                       00004400
C --- *DATA TAB* IS THE ARRAY INTO WHICH DATA GETR TRANSFERS ONE        00004500
C                HORIZONTAL CUT OF DATA. THIS ARRAY MUST BE DIMENSIONED 00004600
```

```
C                 IN THE CALLING PROGRAM FOR NUMX LOCATIONS,
C
C --- *PEAK* IS A WORK ARRAY USED BY PLOTISOM AND MUST BE DIMENSIONED
C             IN THE CALLING PROGRAM FOR ( NUMX -1) *INTERP + NUMX
C             LOCATIONS
C
      DIMENSION DATA TAB(1), PEAK(1)
      EXTERNAL DATA GETR
      ASSIGN 220 TO IJP
      ASSIGN 32 TO IJK
      IF( HIDDEN .GT. 0. ) ASSIGN 210 TO IJP
      LMCK = 2 * INTERP
      DIX = DELTAX /( INTERP + 1.)
      NSLANT = INTF( SLANT / DIX )
      DZX = DIX * NSLANT
      NUBX = ( NUMX -1 )* INTERP + NUMX
      LM5 = NUBX - NSLANT
      LM6 = LM5 +1
      LM7 = NUMX / 2
      LM8 = NUBX / 2
      XZ = XZERO - DZX    $    YZ = YZERO - DELTAY
      DO 1 I = 1, NUBX
    1 PEAK(I) = -.52
      IFLAGD = -1
COMMENCE HORIZONTAL CUT LOOP
      DO 22 IY = 1, NUMY
      IFLAGD = -1 * IFLAGD
      YZ = YZ + DELTAY
      X2 = XZ = XZ + DZX
      CALL DATA GETR
      GO TO IJK,( 30, 32 )
C *** PREPARE FOR NEG X DIRECTION PLOTTING
   30 X2 = ( NUMX -1 )* DELTAX + XZ
      DELTAX = -1.* DELTAX
      DIX = -1.* DIX
      LL = NUMX +1
      DO 31 I = 1, LM7
      LL = LL -1
      TT = DATA TAB(I)
      DATA TAB(I) = DATA TAB(LL)
      DATA TAB(LL) = TT
   31 CONTINUE
      ASSIGN 32 TO IJK
      ASSIGN 19 TO JP1
      ASSIGN 21 TO JP2
      ASSIGN 16 TO JP3
      GO TO 33
   32 ASSIGN 30 TO IJK
      ASSIGN 16 TO JP1
      ASSIGN 19 TO JP2
```

```
      ASSIGN 21 TO JP3
   33 Y2 = DATA TAB(1) + YZ
      YPK = PEAK(1)
      IF( Y2 .GT. PEAK(1) ) GO TO 2
      IFLAG2 = -1
      GO TO 200
   2  IFLAG2 = 1
      PEAK(1) = Y2
  200 IF( IFLAGD .LT. 0 ) GO TO 201
      IF( Y2 .LE. YZ ) GO TO 203
      IF( Y2 .LE. YPK ) GO TO 203
      Y3 = YZ
      IF( YPK .GT. YZ ) Y3 = YPK
      GO TO 202
  201 IF( Y2 .LE. YZ ) GO TO 203
      Y3 = YZ
  202 CALL PLOT( X2, Y3, 3 )
      CALL PLOT( X2, Y2, 2 )
  203 CALL PLOT( X2, Y2, 3 )
COMMENCE PLOTTING OF SINGLE HORIZONTAL CUT
      DO 15 IX = 2, NUMX
      YP = Y1 = Y2   $   XL = 0.
      XA = XP = X1 = X2
      X2 = X2 + DELTAX
      Y2 = DATA TAB(IX) + YZ
      GO TO IJP,( 210, 220)
C *** PLOT ALL POINTS ( HIDDEN .GT. 0 )
  210 CALL PLOT( X2, Y2, 2 )
      GO TO 15
C *** DO NOT PLOT HIDDEN POINTS ( HIDDEN .LT. 0 )
  220 LM1 = IX *( INTERP +1 ) - LMCK
      LM2 = LM1 + INTERP -1
      LM3 = LM2 +1
      SS = ( Y2 -Y1 )/ DELTAX
   3  DO 7 I = LM1, LM2
      IFLAG1 = IFLAG2
      XL = XL + DIX   $   XA = XA + DIX
      YL = SS * XL + Y1
      IFLAG2 = -1
      IF( YL .LT. PEAK(I) ) GO TO 34
      PEAK(I) = YL
      IFLAG2 = 1
   34 IFLAGM =IFLAG1 + IFLAG2
      IF( IFLAGM .GT. 0 ) GO TO 6
      IF( IFLAG2 .LT. 0 ) GO TO 5
      CALL PLOT( XA, YL, 3 )
      GO TO 6
   5  CALL PLOT( XP, YP, 2 )
   6  XP = XP + DIX
      YP = YL
```

```
  7   CONTINUE                                                          00014700
      IFLAG1 = IFLAG2    $    IFLAG2 = -1                                00014800
      YPK = PEAK(LM3)                                                   00014900
      IF( Y2 .LT. YPK ) GO TO 70                                        00015000
      PEAK(LM3) = Y2                                                    00015100
      IFLAG2 = 1                                                        00015200
      IPEN = 2                                                          00015300
      IF( IFLAG1 .LT. 0 ) IPEN = 3                                      00015400
      CALL PLOT( X2, Y2, IPEN )                                         00015500
      GO TO 15                                                          00015600
  70  IF( IFLAG1 .LT. 0 ) GO TO 15                                      00015700
      CALL PLOT( XP, YP, 2 )                                            00015800
  15  CONTINUE                                                          00015900
      Y3 = YZ                                                           00016000
      IF( IFLAGD .LT. 0 ) GO TO 150                                     00016100
      IF( Y2 .GE. YZ ) 152, 153                                         00016200
  150 IF( Y2 .LE. YPK ) GO TO 153                                       00016300
      IF( Y2 .GE. YZ ) 151, 153                                         00016400
  151 IF( YPK .GT. YZ ) Y3 = YPK                                        00016500
  152 CALL PLOT( X2, Y2, 3 )                                            00016600
      CALL PLOT( X2, Y3, 2 )                                            00016700
  153 CONTINUE                                                          00016800
      GO TO JP1, ( 16, 19 )                                             00016900
C *** SLIP PEAK TABLE                                                   00017000
  16  DO 17 I = 1, LM5                                                  00017100
      LM1 = I + NSLANT                                                  00017200
  17  PEAK(I) = PEAK(LM1)                                               00017300
      DO 18 I = LM6, NUBX                                               00017400
      PEAK(I) = -.52                                                    00017500
  18  CONTINUE                                                          00017600
      GO TO JP2,( 19, 21 )                                              00017700
C *** FLIP PEAK TABLE                                                   00017800
  19  LL = NUBX +1                                                      00017900
      DO 20 I = 1, LM8                                                  00018000
      LL = LL -1                                                        00018100
      TT = PEAK(I)                                                      00018200
      PEAK(I) = PEAK(LL)                                                00018300
      PEAK(LL) = TT                                                     00018400
  20  CONTINUE                                                          00018500
      GO TO JP3,( 16, 21 )                                              00018600
  21  IF( DELTAX .LT. 0. ) DELTAX = -1.* DELTAX                         00018700
      IF( DIX .LT. 0. ) DIX = -1.* DIX                                  00018800
  22  CONTINUE                                                          00018900
      END                                                               00019000
```

6. COMPARISON

Except for the companion program of Ref. 6 (Section 3.15), no similar program is available.

7. TEST METHOD AND RESULTS

The input data deck illustrated in Section 3.9 was used in the program producing the plots shown in Figs. 2a through 2d and the printout on the following 3 pages. The plots are the computed responses of an array occupying a cube and are an example of pattern multiplication. In plots such as Figs. 2a through 2d the vertical axis defines the power response. The horizontal axes define the direction of the incoming wave; the generality of the program makes any specific labeling arbitrary.

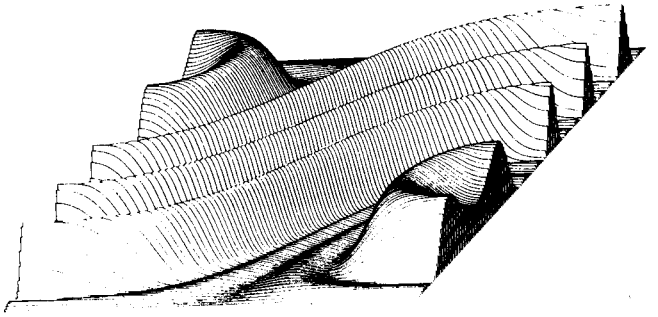

Fig. 2a — Response of four hydrophones along one edge of a cube

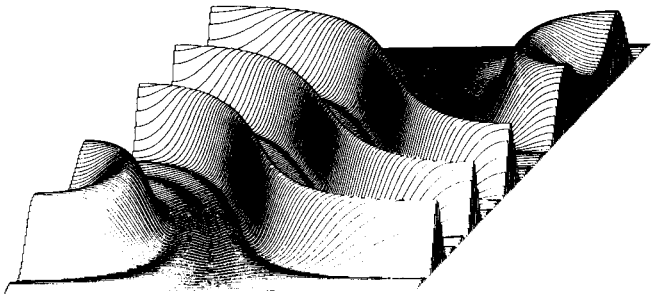

Fig. 2b — Response of four hydrophones along an edge of the cube perpendicular to the first line of hydrophones (Fig. 2a)

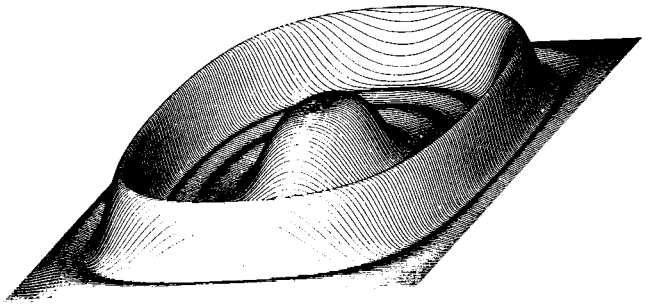

Fig. 2c — Response of four hydrophones along an edge of the cube perpendicular to the plane defined by the first two lines of hydrophones (Figs. 2a and 2b)

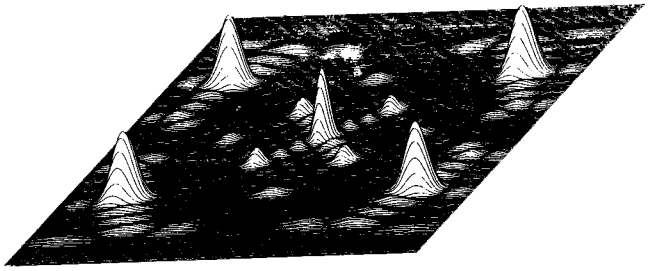

Fig. 2d — Pattern-multiplication product of the responses of the three linear arrays of hydrophones (Figs. 2a through 2c)

HYDROPHONE ARRAY RESPONSE TO A PLANE WAVE SIGNAL

SPEED OF SOUND = 4900.000

FREQUENCY = 490.000 -0.000 -0.000

ANGULAR VARIABLES

R(1,J) =	90.000	-0.000	-0.000	1
R(2,J) =	90.000	-0.000	-0.000	1
R(3,J) =	0.000	180.000	1.000	181
R(4,J) =	0.000	180.000	0.287	629

HYDROPHONE PATTERN MULTIPLIER ARRAY IN THE FIRST DIRECTION

NUMBER OF HYDROPHONES = 4

X	Y	Z	WEIGHT
45.000	0.000	0.000	1.000
30.000	0.000	15.000	1.000
15.000	0.000	30.000	1.000
0.000	0.000	45.000	1.000

HYDROPHONE PATTERN MULTIPLIER ARRAY IN THE SECOND DIRECTION

NUMBER OF HYDROPHONES = 4

X	Y	Z	WEIGHT
45.000	0.000	0.000	1.000
30.000	0.000	-15.000	1.000
15.000	0.000	-30.000	1.000
0.000	0.000	-45.000	1.000

HYDROPHONE PATTERN MULTIPLIER ARRAY IN THE THIRD DIRECTION

NUMBER OF HYDROPHONES = 4

X	Y	Z	WEIGHT
45.000	0.000	0.000	1.000
45.000	15.000	0.000	1.000
45.000	30.000	0.000	1.000
45.000	45.000	0.000	1.000

LARGEST NUMBER = 999999 OR OCTAL 3641077

NO. OF RECORDS = 181 OR OCTAL 265 FOR LUN = 2

NO. OF RECORDS = 181 OR OCTAL 265 FOR LUN = 3

NO. OF RECORDS = 181 OR OCTAL 265 FOR LUN = 4

NO. OF RECORDS = 181 OR OCTAL 265 FOR LUN = 5

PLOTTING PARAMETERS

```
NUMX   = 629
NUMY   = 181
INTERP =   1
XZERO  =  0.000
YZERO  =  0.250
DELTAX =  0.020
DELTAY =  0.040
SLANT  =  0.040
HIDDEN = -1.000
SCALE  =  2.000
LUN    =  2
```

```
NUMX   = 629
NUMY   = 181
INTERP =   1
XZERO  =  0.000
YZERO  =  0.250
DELTAX =  0.020
DELTAY =  0.040
SLANT  =  0.040
HIDDEN = -1.000
SCALE  =  2.000
LUN    =  3
```

```
NUMX   = 629
NUMY   = 181
INTERP =   1
XZERO  =  0.000
YZERO  =  0.250
DELTAX =  0.020
DELTAY =  0.040
SLANT  =  0.040
HIDDEN = -1.000
SCALE  =  2.000
LUN    =  4
```

```
NUMX   = 629
NUMY   = 181
INTERP =   1
XZERO  =  0.000
YZERO  =  0.250
DELTAX =  0.020
DELTAY =  0.040
SLANT  =  0.040
HIDDEN = -1.000
SCALE  =  2.000
LUN    =  5
```

```
LUN1 =  1
LUN2 =  2
LUN3 =  3
LUN4 =  4
LUN5 =  5
```

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater acoustics						
Hydrophones						
Plane waves						
Computer programs						
Array beamforming						
Linear array						
Planar array						
Volume array						
Array focusing						
Array shading						
Array pattern extrapolation						
Pattern multiplication						
Computer isometric displays						

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