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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

GRASS (Germinating Ray-Acoustics Simulation System) is a set of linked digital computer programs (Fortran), or modules. These modules: (1) convert salinity, temperature, and depth (STD) data to sound-speed profiles; (2) interpolate and extrapolate the sound-speed field; (3) generate Calcomp or Gerber plots of the sound-speed profiles; (4) generate contour and three-dimensional isometric plots of the sound-speed field; (5) trace rays and calculate intensities; (6) generate ray diagrams; and (7) construct plots of the calculated transmission loss versus range.

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19.

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Ray acoustics
Underwater sound
Wave equation
Sound speed
Geometrical acoustics
Intensity
Long range
Deep ocean
Propagation
Spreading loss
Inhomogeneous media
Geometrical optics
Multiple velocity profiles
Linear segmented bottom
Calcomp plotting
Isometric plotting
Contour plotting

20.

The system can handle multiple profiles and a linear-segmented bottom profile. It is presently running on a CDC 3800. This report, the second of a two-volume set, is intended as a user's manual. In addition to describing input and output for each module, it contains a sample test case based upon actual experimental measurements.

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PREFACE

This is the second of a two-volume set of reports describing a modular underwater acoustics ray-tracing and transmission-loss prediction system called GRASS (Germinating Ray-Acoustics Simulation System). This system is called "germinating" because, although it is presently operational, it could grow into a more powerful system.

The first volume (cited on the inside front cover) is intended for the reader who is interested in gaining an overview of the system. It includes the theory behind each of the seven system modules, some of the guiding philosophy and techniques used in their implementation, qualitative comparisons with other ray-tracing and normal-mode approaches, the results of some sample test cases, and some recommendations for improvement.

This, the second, volume is intended for those who wish to use the system, or to compare it quantitatively with other ray acoustic systems. It describes in detail how to use the programs, and it contains a sample test case. The input data for this test case were obtained from experimental measurement. In addition, experimental transmission loss measurements were obtained and are given so that direct comparison can be made between computed and measured values.

ACKNOWLEDGMENT

I thank the many individuals both within and without NRL who provided assistance and encouragement during the evolution of GRASS and the writing of this report. In particular, I thank Dr. Homer P. Bucker, former head of the Propagation Branch of the Acoustics Division of NRL, and Burton G. Hurdle, current head of the Propagation Branch, for their guidance and support, and John Cybulski for reviewing the manuscript and offering many helpful suggestions. Further, I thank Cdr. Peter Tatro and Dr. Ray Cavanaugh of the Maury Center for Ocean Science for providing the environmental data and experimental transmission-loss measurements.

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GRASS: A DIGITAL-COMPUTER RAY-TRACING AND TRANSMISSION-LOSS-PREDICTION SYSTEM, VOLUME 2 -- USER'S MANUAL

1. INTRODUCTION

GRASS (Germinating Ray-Acoustics Simulation System) is a set of digital-computer programs for underwater acoustics ray-tracing and transmission-loss prediction. The logical relationship between these programs is shown in Fig. 1. GRASS is documented in two volumes, or reports. This, the second, volume is a user's manual. It describes in detail the input and output of each program. A sample test case is included. The input data for this test case is based upon actual experimental measurements. This particular test case was chosen because it is small and because, in addition to the environmental input, transmission-loss measurements are available. Hence a comparison between calculated and experimental transmission-loss values is possible. This test case does not however demonstrate the full power of GRASS. For example it does not illustrate how the system can extrapolate and interpolate between shallow and deep sound-speed profiles. Representative output from each of the programs for this test case is included. Appendix A of this report contains a set of conversion factors which are useful in preparing input data.

2. CONVERSION OF SALINITY, TEMPERATURE, AND DEPTH (STD) DATA TO SOUND-SPEED PROFILES

2.1 Program Summary

Title of program: DTSTOV

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63

High-speed store required: 7679 (decimal) words, exclusive of system routines.

Number of bits in a word: 48

Is program overlaid? No

Number of magnetic tapes required: none

Other peripherals used: disk for storage of DTSTOV, card reader, printer, and card punch

Number of cards in program deck: 338

Card punching code: BCD

Manuscript submitted August 7, 1973.

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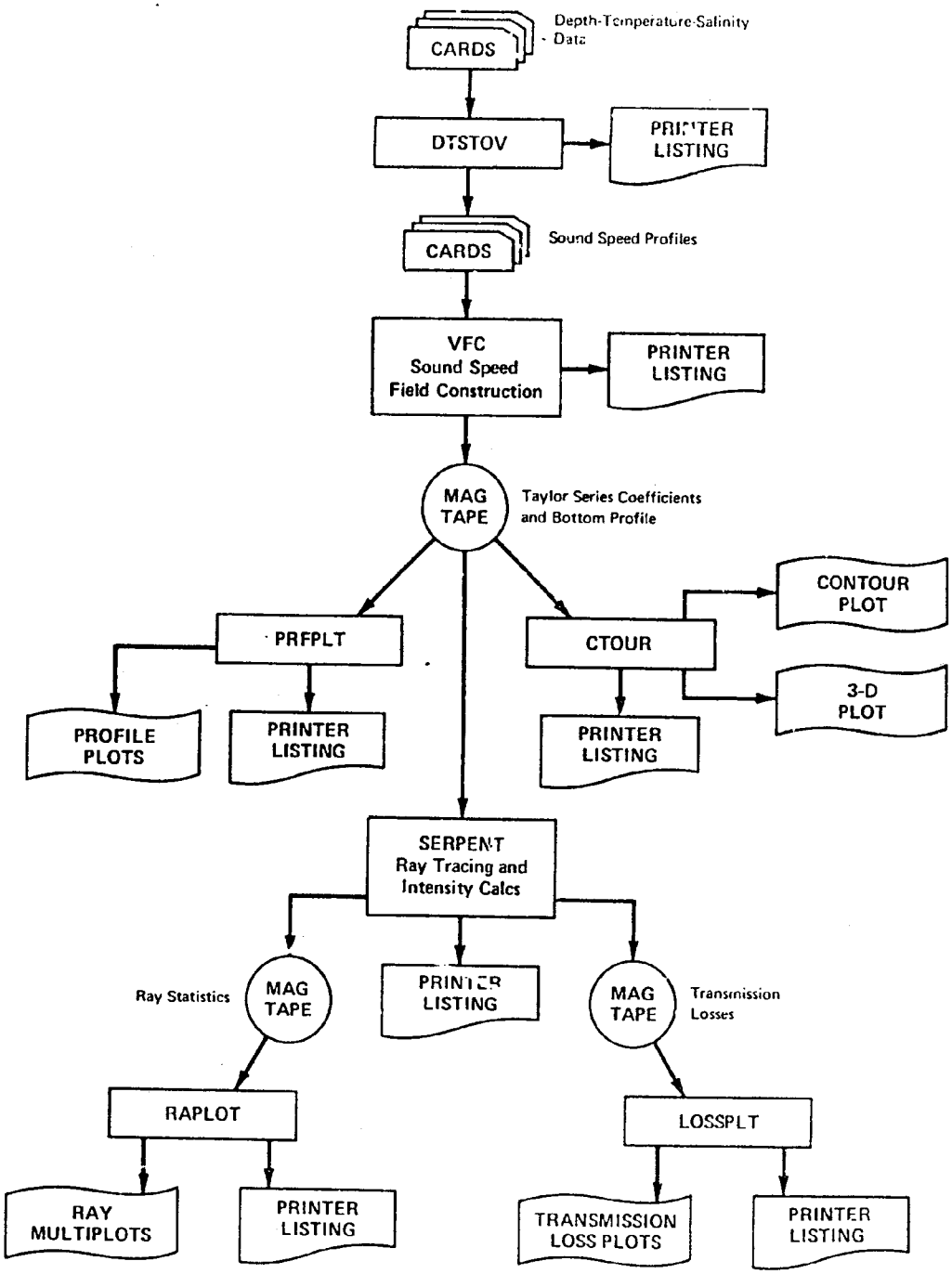

Fig. 1 — GRASS (Germinating Ray-Acoustics Simulation System)

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Nature of Physical Problem

Converting STD data to sound-speed profiles.

Method of Solution

Leroy's equation (See Section 2.1.1 of Volume 1.)

Restrictions on Complexity of Problem

The salinity is limited to 20 to 42‰, the temperature is limited to −2 to 34°C, and the depth is limited to 0 to 10,000 m. The maximum number of profiles has no limit. The maximum number of points per sound-speed profile is 1000. The first depth of each profile must be 0 meters. All input profile points must be arranged in increasing order of depth.

Typical Running Time

It took approximately 25 seconds to load the DTSTOV object deck from the disk and execute the sample problem of Section 2.3.

2.2 Input

2.2.1 Control Cards and Job-Request Forms

The control cards used by the Drum Scope operating system are shown in Fig. 2. A typical job-request form is shown in Fig. 3.

Line 2 of Fig. 2 is the job card. It provides the system user identification and estimated-running-time information.

Line 3 is the EQUIP card telling the system logical unit 20 will be used to refer to the disk.

Line 4 tells the system to load the DISKLOAD program [1] into core and start executing it.

Lines 5 and 6 contain the data used by the DISKLOAD program. They tell DISKLOAD where to find the program DTSTOV on the disk and command it to write DTSTOV onto logical unit 25 (a section of the drum). These cards are described in detail in Ref. 1.

Lines 7 and 8 are two end-of-file cards required by DISKLOAD.

Line 9 is a system command to load logical unit 25 (DTSTOV) into core.

Line 10 tells the system to run DTSTOV for a maximum of 2 minutes and 3500 printer lines.

The data cards for DTSTOV follow the run card.

FORTRAN CODING FORM

PROGRAM

ROUTINE

FORTRAN STATEMENT

0 = ZERO
Ø = ALPHA O

1 = ONE
I = ALPHA I

	TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT
1		Job		request form
2	79	JØB,	X	XXXXXX, XXXXX, 2
3	79	EQUIP		,20=DF
4	79	DISK		LØAD
5		20		11
6	D	TSTØ	V	4 R9J2 25 1
7				end-of-file card
8				end-of-file card
9	79	LØAD,		25
10	79	RUN,	2	,3500
11				
12				Data cards
13				
14				end-of-file card
15				
16				

Fig. 2 — CDC 3800 control cards for the DTSTOV program

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JOB REQUEST FORM

Computer #1

(NAME)

(EXT)

FOR WCC USE ONLY

PRIORITY

SEQ NO.

(CHARGE NUMBER)

(IDENTIFICATION)

MAXIMUM TIME THIS JOB 2 MIN

TOTAL # OF PRINT LINES ON RUN CARDS 3500 LINES

PUNCHED CARD OUTPUT [X]

PAPER TAPE OUTPUT: APPROX. length ____ ft.

PLOTTER OUTPUT: CHART PAPER # ____

NUMBER OF PLOTS ____ APPROX. LENGTH ____

PAPER TAPE INPUT

TAPE LABELS ____

MAGNETIC TAPES

LOGICAL UNIT#	INPUT	OUTPUT	SAVE	TAPE SERIAL NO.
DF	[ ]	[ ]	[ ]	
	[ ]	[ ]	[ ]	
	[ ]	[ ]	[ ]	
	[ ]	[ ]	[ ]	
	[ ]	[ ]	[ ]	

SEE REVERSE SIDE FOR ADDITIONAL INSTRUCTIONS

NDW-NRL-10462/6006 (5-66)

IBM 845077

Fig. 3 — Sample job request form for the DTSTOV program

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2.2.2 Data Cards

The input consists of salinity, temperature, and depth (STD) profiles and their respective titles, ranges, latitudes, and longitudes. All input data are read off cards. All data, with the exception of the title cards, are read with a general-purpose input routine [2]. Hence the particular card columns in which the numbers are placed are of no importance.

The data for DTSTOV must be arranged in the following order:

```
TITLE
NPUNCH
NAREA
RANGE LATD LATM LONGD LONGM  )
PROFTITLE                    |  repeated for each
D(1) T(1) S(1)               |  STD profile
D(2) T(2) S(2)               |
    . . .                    |
D(LAST) T(LAST) S(LAST) -1   )
-7
```

The meaning of the above parameters is as follows:

TITLE	an 80-column title card identifying the data with up to 80 arbitrary characters.
NPUNCH	a parameter which is set to 1 to punch sound-speed cards for VFC; it is set to 0 if no sound-speed cards are desired.
NAREA	a parameter which is set to 0 if no pressure calculations desired; it is set to 1 for areas other than the Black or Baltic seas,* set to 2 for the Black Sea, and set to 3 for the Baltic Sea.
RANGE	the range of the STD profile in nautical miles.
LATD	the degrees part of the profile latitude.
LATM	the minutes part of the profile latitude.
LONGD	the degrees part of the profile longitude.
LONGM	the minutes part of the profile longitude.
PROFTITLE	an 80-column title card identifying the profile.
D(i)	depth of the ith point in meters.
T(i)	temperature of the ith point in degrees centigrade.
S(i)	salinity of the ith point in parts per thousand.
-1	an indicator signaling the end of the STD profile.
-7	an indicator signaling the end of the data set.

*Owing to the low density of these two bodies of water, the pressure is characterized by special algorithms [3].

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2.3 Sample Input and Output

Figure 4 shows the data cards for three STD profiles lying along a great-circle track. These profiles resulted from actual experimental measurements. We specified pressure calculations for an area other than the Baltic or Black Sea. The latitudes and longitudes were chosen randomly.* Figure 5 shows the printed output, which should be self-explanatory. DMIN and DMAX are the maximum and minimum depths for the profile, TMIN and TMAX refer to the maximum and minimum temperatures, and SMIN and SMAX refer to salinities. In addition to the printout a deck of cards is punched by DTSTOV for input into the VFC program.

```
SAMPLE TEST CASE
1 1 0 30 0 30 0
FIRST PROFILE
       0 23.80 35.29      31 23.80 35.29      40 23.80 35.29      50 23.80 35.29
      55 23.80 35.29      61 23.80 35.29      70 23.80 35.29      75 23.80 35.29
      80 23.50 35.29      85 23.00 35.29      91 22.30 35.29     122 19.40 35.25
     182 16.60 34.92     243 14.50 34.63     365 11.10 34.33     400 10.23 34.20
     600  6.38 34.08     800  4.59 34.20    1000  3.80 34.35    1500  2.73 34.57
    2000  1.99 34.60    2500  1.73 34.64    3000  1.76 34.67    3500  1.60 34.69
    4000  1.57 34.68    5000  1.54 34.71    8000  1.50 34.70
-1
61.051836 30. 0. 30 0
SECOND PROFILE
       0 23.40 35.17      31 23.40 35.17      40 23.40 35.17      50 23.40 35.17
      55 23.40 35.17      61 23.40 35.17      70 23.40 35.17      75 23.40 35.17
      80 23.40 35.17      85 23.10 35.16      91 22.60 35.15     122 19.60 35.01
     182 16.10 34.69     243 13.80 34.48     365 10.30 34.22     400  9.36 34.10
     600  5.94 34.04     800  4.48 34.22    1000  3.77 34.40    1500  2.74 34.56
    2000  2.00 34.60    2500  1.86 34.65    3000  1.76 34.67    3500  1.63 34.69
    4000  1.60 34.68    5000  1.53 34.73    8000  1.50 34.70
-1
178.15388 30 0 30 0
THIRD PROFILE
       0 22.30 34.85      31 22.30 34.85      40 22.30 34.85      50 22.30 34.85
      55 22.30 34.85      61 22.30 34.85      70 22.30 34.85      75 21.80 34.82
      80 21.10 34.80      85 20.50 34.77      91 19.90 34.75     122 17.40 34.68
     182 14.60 34.54     243 13.00 34.41     365 10.80 34.23     400 10.09 34.15
     600  6.07 34.01     800  4.36 34.16    1000  3.67 34.32    1500  2.68 34.54
    2000  2.00 34.59    2500  1.79 34.65    3000  1.75 34.67    3500  1.60 34.69
    4000  1.57 34.69    5000  1.55 34.71    8000  1.50 34.70
-1 -7
```

Fig. 4 — Sample-test-case input data cards for the DTSTOV program

3. INTERPOLATION AND EXTRAPOLATION OF THE SOUND-SPEED FIELD

3.1 Program Summary

Title of program: VFC

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63

*They do not correspond to the actual measurement locations.

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```
THIS IS A RUN OF PROGRAM DTSTOV
DTSTOV CALCULATES SOUND SPEED FROM DEPTH-TEMPERATURE-SALINITY PROFILES
USING LEKHYS EQUATION, REF. JASA 44,P235,1969
SAMPLE TEST CASE
SEAWC SPEED CARDS WILL BE PUNCHED
PRESSURES WILL BE CALCULATED USING LEKHYS EQUATION, JASA 44, P951,1968
*****************************************************************************
FIRST PROFILE
RANGE (KM) =      0.0000      LATITUDE =  30 DEG   0.0 MIN     LONGITUDE =  30 DEG   0.0 MIN
RANGE (KM) =      0.0000
    DEPTH(M)      TEMP(C)      SALN(PPT)   PRES(KG/SQCM)   VEL(M/S)      VEL(FT/S)
      0.0000      23.4000      35.2970        1.0400      1537.1053     5024.4311
     31.0000      23.4000      35.2970        4.2271      1537.4176     5025.5071
     40.0000      23.4000      35.2970        5.1440      1537.5445     5026.0873
     50.0000      23.4000      35.2970        6.1727      1537.6249     5029.5265
     55.0000      23.4000      35.2970        6.6840      1533.0070     5029.7961
     61.0000      23.4000      35.2970        7.3070      1537.1057     5030.1196
     70.0000      23.4000      35.2970        8.2241      1537.2536     5030.6070
     75.0000      23.4000      35.2970        8.7385      1537.3356     5030.8747
     80.0000      23.5000      35.2970        9.2529      1537.4176     5026.7021
     85.0000      23.4000      35.2970        9.7643      1537.5016     5024.4544
     91.0000      22.3000      35.2970       10.3874      1527.1328     5019.1156
    127.0000      18.4000      35.2970       13.5640      1522.4443     4995.2775
    167.0000      16.0000      34.9250       16.7200      1514.9346     4970.5004
    245.0000      14.9000      34.8370       25.0967      1507.5515     4951.1981
    305.0000      11.1000      34.3350       38.5376      1499.1081     4919.2035
    400.0000      10.2300      34.2070       42.1368      1494.5314     4910.4477
    600.0000       6.9000      34.3600       62.7155      1485.7996     4873.2644
    800.0000       4.9000      34.2000       83.3144      1481.5577     4860.9907
   1000.0000       3.8000      34.3970      103.9335      1481.4077     4861.7947
   1500.0000       2.7300      34.5770      155.5696      1485.5337     4875.3485
   2000.0000       1.9000      34.6070      207.3318      1491.7346     4897.7498
   2500.0000       1.7300      34.6400      259.2203      1495.7040     4917.2545
   3000.0000       1.7000      34.6700      311.2350      1507.5190     4946.1667
   3500.0000       1.6000      34.5970      363.3756      1515.5796     4972.4134
   4000.0000       1.5700      34.5800      415.6429      1524.2516     5001.0748
   5000.0000       1.5400      34.7100      520.5556      1542.0382     5059.4274
   6000.0000       1.5000      34.7000      630.3226      1597.0881     5240.0788
       D=IN          D=AX         T=IN         T=AX         S=IN          S=AX
      0.0000    4000.0000       1.5000       23.0000      34.0970       35.2900

*****************************************************************************
SECOND PROFILE
RANGE (KM) =     63.6954      LATITUDE =  30 DEG   0.0 MIN     LONGITUDE =  30 DEG   0.0 MIN
RANGE (KM) =    111.2134
    DEPTH(M)      TEMP(C)      SALN(PPT)   PRES(KG/SQCM)   VEL(M/S)      VEL(FT/S)
      0.0000      23.4000      35.1700        1.0400      1537.0719     5023.1190
     31.0000      23.4000      35.1700        4.2271      1531.4412     5024.7900
     40.0000      23.4000      35.1700        5.1440      1531.5291     5025.2752
     50.0000      23.4000      35.1700        6.1727      1531.7935     5025.8144
     55.0000      23.4000      35.1700        6.6840      1531.8756     5026.0840
     61.0000      23.4000      35.1700        7.3070      1531.9743     5026.4075
     70.0000      23.4000      35.1700        8.2241      1532.1272     5026.9926
     75.0000      23.4000      35.1700        8.7385      1532.2044     5027.3626
     80.0000      23.4000      35.1700        9.2529      1532.2866     5027.6322
     85.0000      23.3000      35.1600        9.7643      1531.4040     5025.1979
     91.0000      22.6000      35.1500       10.3874      1527.4214     5021.3126
    127.0000      19.4000      35.1130       13.5640      1522.7598     4984.1750
    167.0000      16.1000      34.6900       16.7200      1517.1329     4964.5802
    245.0000      13.8000      34.4800       25.0967      1504.6044     4943.1690
    305.0000      10.3000      34.2200       38.5376      1488.3301     4909.4592
    400.0000       9.1600      34.1070       42.1368      1493.3576     4899.6899
    600.0000       5.9400      34.1400       62.7155      1483.9014     4867.3881
    800.0000       4.4000      34.2230       83.3144      1481.1306     4859.5895
   1000.0000       3.7700      34.4000      103.9335      1481.7439     4861.6017
   1500.0000       2.7400      34.5600      155.5696      1485.8631     4875.4451
   2000.0000       2.0000      34.6090      207.3318      1491.2742     4892.8839
   2500.0000       1.8400      34.6500      259.2203      1498.2871     4919.1610
   3000.0000       1.7600      34.6700      311.2350      1507.5190     4946.1667
   3500.0000       1.6300      34.6970      363.3756      1515.7048     4973.0469
   4000.0000       1.5400      34.5800      415.6429      1524.3026     5001.4904
   5000.0000       1.5300      34.7370      520.5556      1542.0382     5059.4274
   6000.0000       1.5000      34.7005      630.3226      1597.0881     5240.0788
       D=IN          D=AX         T=IN         T=AX         S=IN          S=AX
      0.0000    4000.0000       1.5000       23.4000      34.0970       35.1700

*****************************************************************************
THIRD PROFILE
RANGE (KM) =    178.1538      LATITUDE =  30 DEG   0.0 MIN     LONGITUDE =  30 DEG   0.0 MIN
RANGE (KM) =    289.0303
    DEPTH(M)      TEMP(C)      SALN(PPT)   PRES(KG/SQCM)   VEL(M/S)      VEL(FT/S)
      0.0000      22.7000      34.4970        1.0400      1527.8083     5012.7390
     31.0000      22.7000      34.4970        4.2271      1528.3176     5014.4190
     40.0000      22.7000      34.4970        5.1440      1528.4655     5014.8952
     50.0000      22.7000      34.4970        6.1727      1528.6298     5015.4344
     55.0000      22.7000      34.4970        6.6840      1529.7170     5015.7040
     61.0000      22.9000      34.4970        7.3070      1528.8176     5016.0275
     70.0000      22.3000      34.4970        8.2241      1526.9545     5016.5179
     75.0000      21.9000      34.4970        8.7385      1527.7055     5017.4017
     80.0000      21.1000      34.4970        9.2529      1525.912.     5006.5195
     85.0000      20.5000      34.7770        9.7643      1524.3453     5001.1703
     91.0000      19.8000      34.7550       10.3874      1522.7745     4996.2232
    127.0000      17.4000      34.8000       13.5640      1516.9499     4974.1597
    167.0000      14.4000      34.9400       16.7200      1509.2561     4948.5882
    245.0000      13.0000      34.4140       25.0967      1503.3802     4934.2310
    305.0000      10.8000      34.2370       38.5376      1494.1186     4915.1272
    400.0000      10.4000      34.1700       42.1368      1494.5352     4908.4900
    600.0000       6.0700      34.5170       62.7155      1483.9795     4868.9308
    800.0000       4.9600      34.1800       83.3144      1481.5540     4857.4978
   1000.0000       3.8700      34.3270      103.9335      1481.7161     4859.0700
   1500.0000       2.4400      34.5470      155.5696      1485.6782     4874.5103
   2000.0000       2.0000      34.5970      207.3318      1491.2846     4892.9303
   2500.0000       1.7900      34.6500      259.2203      1494.8818     4906.1592
   3000.0000       1.7500      34.6700      311.2350      1507.4745     4944.0234
   3500.0000       1.6000      34.6970      363.3756      1515.5796     4972.4134
   4000.0000       1.5700      34.6900      415.6429      1524.2666     5001.1186
   5000.0000       1.5500      34.7100      520.5556      1542.0383     5059.4179
   6000.0000       1.5000      34.7000      630.3226      1597.0881     5240.0788
       D=IN          D=AX         T=IN         T=AX         S=IN          S=AX
      0.0000    4000.0000       1.5000       22.3000      34.4150       34.8500
```

Fig. 5 — Printer output from the DTSTOV program for the sample test case of Fig. 4

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High-speed store required: 20,832 (decimal) words, exclusive of system routines

Number of bits per word: 48

Is program overlaid? No

Number of magnetic tapes required: one

Other peripherals used: disk (for program storage), card reader, printer, and drum for intermediate scratch storage

Number of cards in program deck: 1237

Card punching code: BCD

Nature of physical problem

Interpolation and extrapolation of the sound-speed field.

Method of Solution

Cubic-spline interpolation in depth; linear interpolation in range. (See Section 2.1.2 of Volume 1.)

Restrictions on Complexity of Problem

There is no limit to the number of sound-speed profiles. A sound-speed profile has a maximum of 1000 points (which could be increased by changing a DIMENSION statement). The bottom has a maximum of 1000 points (which could also be changed).

Typical Running Time

It took approximately 34 seconds to load the VFC object deck from the disk and execute the sample problem of Section 3.3. Execution alone took 12 seconds.

3.2 Input

3.2.1 Control Cards and Job-Request Forms

The *job-request form* for the VFC program should be filled out as shown in Fig. 3, with the exception that the punched-card-output box should not be marked. In addition "Computer 1" should be written under the title "job-request form." (Computer 1 is the only one of the two CDC 3800 computers at NRL that can access the disk file.) Also under the words "magnetic tapes," logical unit 1 should be specified as an output tape to saved, and the user's tape number should be included, such as 2594. This tape will be referred to as the "coefficient tape." The time limit and number of lines of output required will depend on the particular problem. For most small problems 2 minutes and 3500 lines are sufficient.

The *control cards* for the VFC program are shown in Fig. 6. Line 4 of that figure is the EQUIP card for logical unit 1, the coefficient tape. This output tape contains the Taylor series coefficients (derivatives) for the sound-speed profiles and the bottom profile. The other lines in Fig. 6 are explained in Section 2.2.1.

	TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
1		Jo	b	request form
2	79	JQB,	X	XXXXXXXXXXXX,2
3	79	EQUI	P	,20=DF
4	79	EQUI	P	,1=(CQEFTAPE,1,1,999),LQ,DA
5	79	DISK	L	QAD 1
6		20		1
7	V	FC		4 R9J2 25 1
8				end-of-file card
9				end-of-file card
10	79	LQAD,	2	5
11	79	RUN,	2	,3500
12				
13				Data cards for VFC program
14				
15				end-of-file card
16				
17				

Fig. 6 — CDC 3800 control cards for the VFC program

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3.2.2 Data Cards

The following numbers are read by the general-purpose input routine. The columns in which the numbers are placed are not important, but the numbers need be entered in the following order:

```
TITLE
NMONTH
NDAY
NYEAR
DPTHMX
VMIN
VMAX
ZMINFL
ZMAXFL
DMINFL
DMAXFL
NPRINT1
NPRINT2
NPLOT
NECUR
BRCON
BDCON
BTRANG(1)   ⎫
BTDPTH(1)   ⎪
BTRANG(2)   ⎬ bottom profile
   . . .    ⎪
BTRANG(last)⎪
BTDPTH(last)⎪
-1          ⎭
TEMPDP
DPINC
RCON
DPCON
VELCON
RANGE       ⎫
LATD        ⎪
LATM        ⎪
LONGD       ⎪
LONGM       ⎪
TMDO        ⎪
SAL         ⎬ repeat this section for each
PRFTIT      ⎬ sound-speed profile
DPTH(1)     ⎪
VEL(1)      ⎪
DPTH(2)     ⎪
VEL(2)      ⎪
   . . .    ⎪
DPTH(last)  ⎪
VEL(last)   ⎪
-1          ⎭
-7
```

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The above variables are defined as follows:

TITLE	a data title. This title uses an entire 80-column card. The rest of the numbers must appear after the first card.
NMONTH	an arbitrary month number for identifying the data ($1 \leqslant$ NMONTH $\leqslant 12$).
NDAY	an arbitrary day for identifying the data ($1 \leqslant$ NDAY $\leqslant 31$).
NYEAR	an arbitrary year number for identifying the data ($60 \leqslant$ NYEAR $\leqslant 80$).
DPTHMX	the maximum depth allowed in the data, including bottom depths and profile depths. DPTHMX must be inputted in meters.
VMIN	the minimum allowed value of sound-speed in the input profiles. This value must be inputted in meters per second. It is used for checking the correctness of profiles. If it is exceeded, the program will print an error message and stop. A typical value is 1400.
VMAX	the maximum allowed value of sound speed, similar to VMAX. A typical value is 1600.
ZMINFL	a flag for signaling large negative vertical gradients. If a gradient is less than this value, a warning message will be printed. Normally it is set to −0.1.
ZMAXFL	a flag for signaling large positive vertical gradients. A warning message will be printed if it is exceeded. Normally it is set to +0.1.
DMINFL	a flag for signaling large negative curvatures. If a curvature is less than this value, a warning message will be printed. Normally it is set to −0.01.
DMAXFL	a flag similar to DMINFL. Normally it is set to +0.01.
NPRINT1	an output option controller. If it is set to 1, the input profile points will be printed and printer plotted. If it is set to 0, they will not. Typically it is set to 0 to save printer lines and time.
NPRINT2	an output option controller. If it is set to 1, the final sound speeds, gradients, and curvatures will be printed for each corrected profile. If it is set to 0, they will not. Typically it is set to 0.
NPLOT	an output option controller. If it is set to 1, the final sound-speed profiles will be printer plotted. The corresponding depths and sound speeds are printed next to each plotted point. If it is set to 0, no plots will be generated. Typically it is set to 1.
NECUR	a number which should be set to 1 if the user wishes to correct the input profiles and bottom depths for earth curvature. If not, it should be set to 0.
BRCON	a factor for converting input bottom ranges to nautical miles (1 n.mi. = 1852 meters). If bottom ranges are inputted in nautical miles, then BRCON is set to 1. (A conversion factor table is given by Appendix A.)
BDCON	a factor for converting input bottom depths to meters. For example, if bottom depths are inputted in feet, then BRCON is set to 0.3048 (Appendix A).

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BTRANG(1)	the range of the first bottom point (must be 0).
BTDPTH(1)	the depth of the first bottom point.*
BTRANG(2)	the range of the second bottom point.
. . .	
BTRANG(last)	the range of the last bottom point.†
BTDPTH(last)	the depth of the last bottom point.*
−1	an indicator to signal the end of the bottom range-and-depth pairs.
TEMPDP	the depth (in meters) at which the temperature of the ocean remains constant for increasing depths. TEMPDP is used to distinguish between deep and shallow profiles. Those profiles whose maximum depth of observation is less than TEMPDP are considered shallow.
DPINC	the depth increment (in meters) for extrapolation of deep profiles. All deep profiles will be extrapolated to depth DPTHMX using Leroy's equation. Additional points will be added at intervals of size DPINC from the maximum depth of the original profile to depth DPTHMX. If DPINC is 0, the deep profiles will not be extrapolated.
RCON	a multiplicative conversion factor for converting input profile ranges to nautical miles (1 n.mi. = 1852 meters). For example, if the input ranges are in meters, then RCON = 0.00053996 (Appendix A).
DPCON	a multiplicative conversion factor (Appendix A) for converting input profile depths to meters.
VELCON	a multiplicative conversion factor (Appendix A) for converting input profile velocities to meters per second.
RANGE	the range of the profile. The range of the first profile must be 0. The range of the last profile must be identical to the range of the last bottom point. The user must enter at least two profiles, but these may be identical.
LATD	the degrees part of the profile latitude.
LATM	the minutes part of the profile latitude.
LONGD	the degrees part of the profile longitude.
LONGM	the minutes part of the profile longitude.
TMDO	the temperature at the maximum depth of observation of the profile in degrees centigrade.
SAL	the salinity at the maximum depth of observation of the profile in parts per thousand.
PRFTIT	an 80-column title card identifying the profile.
DPTH(1)	the depth of the first profile point. It must be 0.

*All bottom depths must be less than or equal to DPTHMX. As many as 1000 bottom range-and-depth pairs are allowed.

†The range of the last bottom point must be identical to the range of the last profile.

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VEL(1)	the velocity of the first profile point.
. . .	
DPTH(last)	the depth of the last profile point.
VEL(last)	the velocity of the last profile point.
−1	an indicator that signals the end of the profile.
−7	an indicator that signals the end of all the profile data.

Each profile may have up to 1000 points. Profile depths are arbitrary and may vary from profile to profile. Profile depths must lie between 0 and DPTHMX. Profile sound speeds (velocities) must lie between VMIN and VMAX.

3.3 Sample Input and Output

Figure 7 shows the data cards for the three-profile test case of Section 2.3.

The input sound-speed-profile deck was generated by DTSTOV. The bottom-profile data were obtained by experimental measurement from range 0 to approximately 241 km. The bottom was assumed to be flat from 241 to approximately 330 km, for lack of available measurements.

Figures 8a through 8f show the resulting VFC printer output. Although the calculated gradients and curvatures were not printed in this example, the maximum and minimum values are displayed. To be specific, Fig. 8a shows TSTART (the number of seconds available for computation before the VFC program will have exceeded its time limit), the title card for the test case, and the values of certain input parameters. Next the bottom profile is printed out as shown in Fig. 8b. Figure 8c shows a partial printer plot of the bottom profile and also shows the values of some additional input parameters. Figure 8d shows the printed information for the first profile. The warning messages were triggered by the input parameters ZMINFL, ZMAXFL, DMINFL, and DMAXFL. Figures 8e and 8f show similar output for the second and third profiles respectively. TEND at the bottom of Fig. 8f is the number of seconds available for computation at the completion of the VFC run. TDELTA (= TSTART − TEND) is the amount of time in seconds required to execute the VFC program once it had been loaded from the disk.

4. PROFILE PLOTTING

4.1 Program Summary

Title of program: PRFPLT

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63

High-speed store required: 11,662 (decimal) words, exclusive of system routines

Number of bits per word: 48

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```
SAMPLE TEST CASE
5 25 73 8000 1400 1600 -.1 .1 -.01 .01 0 0 1 1 .53996 1
   0.000 5340.10   3.706 5310.84   7.413 5448.00  11.119 5554.07  14.826 5471.77
  18.532 5579.67  22.238 5554.07  25.945 5680.25  29.651 5665.62  31.504 5725.97
  33.358 5702.20  37.064 5600.95  40.770 5665.62  42.624 5632.70  44.477 5570.52
  46.330 5583.33  48.183 5546.75  50.036 5625.39  51.890 5407.76  53.743 5566.87
  55.596 5590.64  59.302 5592.47  63.009 5535.78  68.568 5568.70  72.275 5576.01
  74.128 5640.02  75.981 5627.22  79.688 5632.70  83.394 5623.58  87.100 5559.55
  90.807 5488.40  94.513 5318.15  96.366 5287.06  98.220 5332.78 100.073 5310.84
 103.779 5660.14 105.632 5777.18 107.486 5731.46 109.339 5596.13 111.192 5698.54
 113.045 5682.08 114.898 5696.71 116.605 5702.20 120.458 5671.11 122.311 5742.43
 124.164 5672.94 126.018 5438.85 127.871 5594.30 129.724 5682.08 131.577 5652.82
 133.430 5696.71 135.284 5656.46 138.990 5771.69 140.843 5600.95 142.696 5702.20
 146.403 6267.30 148.256 6329.48 150.109 5681.42 153.816 5543.09 157.522 5305.35
 161.228 5248.66 163.082 5438.85 164.935 5429.71 166.788 5619.90 172.348 5179.16
 176.054 5746.09 179.760 5786.32 183.467 5799.12 187.173 5764.38 192.733 5468.11
 194.586 5394.96 198.292 5908.85 200.146 6148.43 201.999 6102.71 207.558 5841.19
 209.412 5539.44 211.265 5978.35 214.971 6058.81 216.824 6091.73 218.678 5936.28
 220.531 6024.07 222.384 5865.06 226.090 5806.44 229.797 5665.74 233.503 5643.68
237.210 5606.93 240.916 5438.85 329.93903 5428.85 -1
2000 200 1 1 1
      0.0000  30  0.00   30  0.00        1.5000      34.7000
FIRST PROFILE
      0.0000     1532.1033      31.0000     1532.6126      40.0000     1532.7605
     50.0000     1532.9249      55.0000     1533.0070      61.0000     1533.1057
     70.0000     1533.2536      75.0000     1533.3358      80.0000     1532.6736
     85.0000     1531.5010      91.0000     1529.8128     122.0000     1522.4863
    182.0000     1514.9346     243.0000     1509.0515     365.0000     1499.3001
    400.0000     1496.6314     600.0000     1485.2996     800.0000     1481.5577
   1000.0000     1481.8027    1500.0000     1485.9337    2000.0000     1491.2346
   2500.0000     1498.7060    3000.0000     1507.5180    3500.0000     1515.5786
   4000.0000     1524.2530    5000.0000     1542.0536    6000.0000     1597.0981
 -1
     60.0516  30  0.00   30  0.00        1.5000      34.7000
SECOND PROFILE
      0.0000     1530.9719      31.0000     1531.4812      40.0000     1531.6291
     50.0000     1531.7935      55.0000     1531.8756      61.0000     1531.9743
     70.0000     1532.1222      75.0000     1532.2044      80.0000     1532.2866
     85.0000     1531.6040      91.0000     1530.4214     122.0000     1522.7598
    182.0000     1513.1329     243.0000     1506.6044     365.0000     1496.3301
    400.0000     1495.3526     600.0000     1483.5014     800.0000     1481.1306
   1000.0000     1481.7439    1500.0000     1485.9631    2000.0000     1491.2782
   2500.0000     1499.2871    3000.0000     1507.5180    3500.0000     1515.7089
   4000.0000     1524.3826    5000.0000     1542.0382    6000.0000     1597.0981
 -1
    178.1539  30  0.00   30  0.00        1.5000      34.7000
THIRD PROFILE
      0.0000     1527.8083      31.0000     1528.3176      40.0000     1528.4655
     50.0000     1528.6298      55.0000     1528.7120      61.0000     1528.8106
     70.0000     1528.9585      75.0000     1527.7055      80.0000     1525.9127
     85.0000     1524.3433      91.0000     1522.7745     122.0000     1516.0499
    182.0000     1508.2561     243.0000     1503.8802     365.0000     1498.1186
    400.0000     1496.0652     600.0000     1483.9795     800.0000     1480.5540
   1000.0000     1481.2161    1500.0000     1485.6782    2000.0000     1491.2646
   2500.0000     1498.9818    3000.0000     1507.4745    3500.0000     1515.5786
   4000.0000     1524.2666    5000.0000     1542.0963    6000.0000     1597.0981
 -1
 -7
```

Fig. 7 — Sample-test-case input data cards for the VFC program

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Is program overlaid? No

Number of magnetic tapes required: one for Calcomp plots; two for Gerber plots

Other peripherals required: disk (for program storage), card reader, printer, and Calcomp 565 plotter or Gerber plotter

Number of cards in program deck: 485

Card punching code: BCD

Nature of Physical Problem

Generating Calcomp or Gerber plots of the sound-speed, sound-speed-gradient, and sound-speed-curvature profiles.

Method of Solution

See Section 2.1.3 of Volume 1.

Restrictions on Complexity of Problem

None.

Typical Running Time

It took approximately 49 seconds to load the PRFPLT object deck from the disk and execute the sample problem of Section 4.3. The plotting took 11 minutes on a Calcomp 565 plotter.

4.2 Input

4.2.1 Control Cards and Job-Request Forms for Calcomp Plots

The *control cards* required for obtaining Calcomp plots are shown in Fig. 9. Lines 4 and 5 of that figure are EQUIP cards for the Calcomp plotter and the coefficient tape generated by the VFC program respectively. The other control cards have been explained earlier.

```
TSTART  =      98.49800000
SAMPLE TEST CASE
NMONTH  =    5
NDAY    =   25
NYEAR   =   73
DPTHMX  =    8000.00000000
VMIN    =    1400.00000000
VMAX    =    1600.00000000
ZMINFL  =      -0.10000000
ZMAXFL  =       0.10000000
DMINFL  =      -0.01000000
DMAXFL  =       0.01000000
NPRINT1 =    0
NPRINT2 =    0
NPLOT   =    1
NECLR   =    1
FNCEN   =       0.53996000
ELCEN   =       1.00000000
```

Fig. 8a — The part of the printer output of the VFC program giving some input parameters of the sample test case (Fig. 7)

UNCLASSIFIED

Is program overlaid? No

Number of magnetic tapes required: one for Calcomp plots; two for Gerber plots

Other peripherals required: disk (for program storage), card reader, printer, and Calcomp 565 plotter or Gerber plotter

Number of cards in program deck: 485

Card punching code: BCD

Nature of Physical Problem

Generating Calcomp or Gerber plots of the sound-speed, sound-speed-gradient, and sound-speed-curvature profiles.

Method of Solution

See Section 2.1.3 of Volume 1.

Restrictions on Complexity of Problem

None.

Typical Running Time

It took approximately 49 seconds to load the PRFPLT object deck from the disk and execute the sample problem of Section 4.3. The plotting took 11 minutes on a Calcomp 565 plotter.

4.2 Input

4.2.1 Control Cards and Job-Request Forms for Calcomp Plots

The *control cards* required for obtaining Calcomp plots are shown in Fig. 9. Lines 4 and 5 of that figure are EQUIP cards for the Calcomp plotter and the coefficient tape generated by the VFC program respectively. The other control cards have been explained earlier.

```
TSTART  =      98.49800000
SAMPLE TEST CASE
NMONTH  =    5
NDAY    =   25
NYEAR   =   73
DPTHMX  =    8000.00000000
VMIN    =    1400.00000000
VMAX    =    1600.00000000
ZMINFL  =      -0.10000000
ZMAXFL  =       0.10000000
DMINFL  =      -0.01000000
DMAXFL  =       0.01000000
NPRINT1 =    0
NPRINT2 =    0
NPLOT   =    1
NECLR   =    1
EBCEN   =       0.53996000
ELCEN   =       1.00000000
```

Fig. 8a — The part of the printer output of the VFC program giving some input parameters of the sample test case (Fig. 7)

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LIST OF BOTTOM POINTS

NOTE---
INPUT BOTTOM POINTS WERE CORRECTED FOR EARTH CURVATURE
PRIOR TO CONVERSION TO METERS IF NECUR WAS SET TO 1

RANGE-(NM)	BOTTOM DEPTHS INPUT	METERS	FEET	FATHOMS
0.00	5340.10	5342.54	17527.30	2921.22
2.00	5310.84	5313.05	17431.22	2905.21
4.00	5448.00	5453.33	17881.60	2980.27
6.00	5554.07	5556.49	18229.98	3038.32
8.01	5471.77	5474.12	17959.65	2993.28
10.01	5579.07	5582.11	18313.96	3052.33
12.01	5554.07	5556.49	18229.90	3038.32
14.01	5680.25	5682.78	18644.24	3107.38
16.01	5665.62	5669.14	18596.20	3099.37
17.01	5725.97	5728.54	18794.37	3132.40
18.01	5702.28	5704.75	18716.32	3119.39
20.01	5800.95	5803.59	19040.59	3173.43
22.01	5665.62	5669.14	18596.20	3099.37
23.02	5632.70	5635.19	18488.10	3081.35
24.02	5570.52	5572.95	18283.91	3047.32
25.02	5583.32	5585.78	18325.98	3054.33
26.02	5546.75	5549.18	18205.86	3034.31
27.02	5625.39	5627.97	18464.09	3077.35
28.02	5407.76	5410.05	17749.47	2958.25
29.02	5546.87	5549.30	18271.93	3045.32
30.02	5590.64	5593.09	18349.98	3058.33
32.02	5592.47	5594.92	18355.99	3059.34
34.02	5535.78	5538.18	18169.84	3028.31
37.02	5568.70	5571.13	18277.94	3046.33
39.03	5576.01	5578.45	18301.94	3050.33
40.03	5640.02	5642.52	18512.13	3085.36
41.03	5627.22	5628.70	18470.10	3078.35
43.03	5632.70	5635.19	18488.10	3081.35
45.03	5623.54	5624.86	18458.15	3076.36
47.03	5559.35	5561.97	18247.89	3041.32
49.03	5488.40	5490.76	18014.26	3002.38
51.03	5318.15	5320.77	17455.22	2909.21
52.03	5297.06	5299.95	17353.14	2892.19
53.03	5332.78	5335.81	17503.26	2917.21
54.04	5310.84	5313.05	17431.22	2905.21
56.04	5660.14	5662.45	18576.20	3094.37
57.04	5777.18	5779.80	18962.53	3160.43
58.04	5731.46	5734.04	18812.46	3135.40
59.04	5596.13	5598.59	18368.01	3061.34
60.04	5698.54	5701.09	18704.39	3117.39
61.04	5682.08	5684.61	18650.25	3108.38
62.04	5696.71	5699.96	18698.29	3116.38
64.04	5702.20	5704.75	18716.32	3119.39
65.04	5671.11	5673.63	18614.22	3102.37
66.04	5742.43	5745.72	18848.42	3141.41
67.04	5672.94	5675.46	18620.23	3103.38
68.04	5438.85	5441.17	17851.55	2975.26
69.05	5594.30	5596.75	18362.00	3060.34
70.05	5682.08	5684.61	18650.25	3108.38
71.05	5652.82	5655.33	18554.16	3092.36
72.05	5696.71	5699.96	18698.29	3116.38
73.05	5656.49	5658.99	18566.18	3094.37
75.05	5771.60	5774.30	18944.51	3157.42
76.05	5800.95	5803.59	19040.59	3173.43
77.05	5702.28	5704.75	18716.35	3119.39
79.05	6267.39	6270.78	20572.05	3428.68
80.05	6329.48	6332.42	20776.26	3462.71
81.05	5881.42	5884.13	19304.84	3217.48
83.05	5543.09	5545.50	18193.84	3032.31
85.06	5305.35	5307.96	17413.19	2902.20
87.06	5248.66	5250.92	17227.05	2871.19
88.06	5438.85	5441.17	17851.55	2975.26
89.06	5429.71	5432.52	17821.54	2970.26
90.06	5619.90	5622.38	18446.06	3074.35
93.06	5179.16	5181.26	16998.85	2833.14
95.06	5246.09	5248.46	18840.44	3142.41
97.06	5746.32	5748.95	18992.55	3165.43
99.06	5799.12	5801.76	19034.58	3172.43
101.07	5744.39	5746.99	18930.55	3155.42
104.07	5468.11	5470.46	17947.63	2991.28
105.07	5394.96	5397.24	17707.44	2951.[illegible]
107.07	5918.85	5911.59	19394.92	3232.4[illegible]
108.07	6148.43	6151.40	20181.68	3363.62
109.07	6182.71	6185.43	20031.54	3338.59
112.07	5641.19	5643.87	18172.73	3195.45
113.07	5539.44	5541.85	18181.86	3030.31
114.07	5278.35	5281.15	17323.15	2887.53
116.08	6058.81	6[illegible]	19837.37	3[illegible]
117.08	6091.73	6[illegible]	19955.44	3[illegible]
118.08	5936.29	5939.04	19474.99	3247.55
119.08	6024.07	6026.92	19771.23	3295.5[illegible]
120.08	5885.09	5[illegible]	19316.84	[illegible]
122.08	5876.44	5879.18	19288.62	3179.44
124.08	5665.74	5668.25	18592.27	3110.38
126.08	5643.69	5646.18	18524.15	3087.30
128.08	5608.93	5611.40	18410.04	3068.34
130.09	5438.85	5441.17	17851.55	2975.26
178.15	5438.85	5441.17	17851.55	2975.26

MINIMUM DEPTH OF BOTTOM = 5181.2640(METERS)
MAXIMUM DEPTH OF BOTTOM = 6332.6227(METERS)
NUMBER OF BOTTOM POINTS = 88
MAXIMUM RANGE OF BOTTOM POINTS = 178.1539(NM)

Fig. 8b — The part of the printer output of the VFC program giving the bottom-profile listing

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```
*   PRINTER PLOT OF BOTTOM POINTS. RANGES MAY NOT BE EQUALLY SPACED

RANGE      DEPTH
 0.00     5342.34 ##################################
 2.00     5313.05 ##################################
 4.00     5290.33 ##################################
 6.00     5556.49 ##################################
 8.00     5474.12 ##################################
10.00     5543.11 ##################################
12.00     5556.49 ##################################
14.00     5602.76 ##################################
16.00     5669.14 ##################################
18.00     5728.54 ##################################
20.00     5784.75 ##################################
22.00     5803.59 ##################################
22.00     5669.14 ##################################
23.00     5635.19 ##################################
24.00     5572.95 ##################################
25.00     5589.76 ##################################
26.00     5549.16 ##################################
27.00     5627.87 ##################################
28.00     5410.05 ##################################
29.00     5569.30 ##################################
30.00     5593.09 ##################################
32.00     5564.92 ##################################
34.00     5538.16 ##################################
37.00     5571.13 ##################################
38.00     5578.45 ##################################
40.00     5642.52 ##################################
41.00     5629.76 ##################################
43.00     5635.19 ##################################
45.00     5628.00 ##################################
47.00     5581.97 ##################################
49.00     5498.76 ##################################
51.00     5328.37 ##################################
52.00     5289.25 ##################################
53.00     5335.01 ##################################
54.00     5313.05 ##################################
56.00     5607.65 ##################################
57.00     5779.80 ##################################
58.00     5734.04 ##################################
59.00     5598.59 ##################################
60.00     5701.09 ##################################
61.00     5664.61 ##################################
62.00     5698.26 ##################################
64.00     5784.75 ##################################
65.00     5673.63 ##################################
66.00     5745.02 ##################################
67.00     5679.46 ##################################
68.00     5441.17 ##################################
69.00     5596.75 ##################################
70.00     5684.61 ##################################
71.00     5655.33 ##################################
72.00     5699.26 ##################################
73.00     5658.99 ##################################
75.00     5774.30 ##################################
76.00     5883.59 ##################################
77.00     5784.75 ##################################
79.00     6279.38 ##################################
80.00     6332.62 ##################################
81.00     5984.13 ##################################
83.00     5545.50 ##################################
85.00     5307.56 ##################################
87.00     5258.82 ##################################
89.00     5441.17 ##################################
90.00     5432.02 ##################################
92.00     5627.36 ##################################
93.00     5141.26 ##################################
95.00     5748.26 ##################################
97.00     5789.95 ##################################
99.00     5861.76 ##################################
101.00    5766.99 ##################################
104.00    5478.46 ##################################
105.00    5397.24 ##################################
107.00    5911.59 ##################################
108.00    6131.40 ##################################
109.00    6165.63 ##################################
112.00    5843.87 ##################################
113.00    5541.85 ##################################
114.00    5941.13 ##################################
115.00    6041.69 ##################################
117.00    6094.64 ##################################
118.00    5939.04 ##################################
119.00    6026.92 ##################################
120.00    5847.80 ##################################
122.00    5839.06 ##################################
124.00    5648.26 ##################################
126.00    5646.18 ##################################
128.00    5611.40 ##################################
130.00    5441.17 ##################################
132.00    5441.17 ##################################


TEMPOP   =    2300.00000000
DPTHC    =     200.00000000
SCMN     =       1.00000000
DPCIN    =       1.00000000
VELCOR   =       1.00000000
```

Fig. 8c — The part of the printer output of the VFC program giving a printer plot of the bottom profile

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```
U.S. NAVAL RESEARCH LABORATORY - ACOUSTICS DIV.
VELOCITY FIELD CONSTRUCTION PROGRAM
INPUT AND EXTRAPOLATED VELOCITY PROFILE WITHOUT EARTH CURVATURE CORRECTION
I=INPUT DATA POINT
E=EXTRAPOLATED POINT OBTAINED FROM LEROYS EQUATION
SAMPLE TEST CASE
FIRST PROFILE
DATE  5/29/73


PROFILE    1
RANGE   :   0.0000 (NM)
LAT= 30 DEG  0.00 MIN        LONG =  30 DEG  0.00 MIN
MAXIMUM DEPTH OF OBSERVATION OF ORIGINAL DATA =   8000.0000METERS
TEMPERATURE AT MOB =        1.5000 DEGREES C
SALINITY AT MOB =      34.7000 PPT
DEEP PROFILE


THIS PROFILE WAS CORRECTED FOR EARTH CURVATURE


PROFILE NUMBER    1  NUMBER OF PTS=   27  TYPE PROFILE =1      PROFILE RANGE(NM)=       0.0000


WARNING--POINT   8HAS A CURVATURE       -0.0424 WHICH LESS THAN       -0.0100
WARNING--POINT   9HAS A GRADIENT       -0.1969WHICH IS LESS THAN       -0.1000
WARNING--POINT   9HAS A CURVATURE       -0.0170 WHICH LESS THAN       -0.0100
WARNING--POINT  10HAS A GRADIENT       -0.2450WHICH IS LESS THAN       -0.1000
WARNING--POINT  11HAS A GRADIENT       -0.2445WHICH IS LESS THAN       -0.1000
WARNING--POINT  12HAS A GRADIENT       -0.1874WHICH IS LESS THAN       -0.1000
MINIMUM VEL =   1491.7436
MAXIMUM VEL =   1599.1038
MINIMUM GRAD =  -0.2845271
MAXIMUM GRAD =   0.0379341
MINIMUM CURV =-0.042364921
MAXIMUM CURV = 0.008439369


  PRINTER PLOT OF CORRECTED PROFILE NUMBER    1


1       0.0000      1532.1033
2      31.0001      1532.6200
3      60.0001      1532.7701
4      90.0002      1532.9369
5      95.0002      1533.0202
6      81.0003      1533.1704
7      70.0004      1533.2704
8      75.0005      1533.3538
9      80.0005      1532.6928
10     85.0006      1531.5714
11     91.0007      1529.8346
12    127.0012      1522.5194
13    182.0026      1514.9778
14    243.0047      1508.1090
15    305.0105      1499.3859
16    400.0125      1496.7253
17    602.0282      1485.4393
18    800.0502      1481.7436
19   1000.0784      1482.0351
20   1500.1464      1486.2832
21   2000.3136      1491.7024
22   2500.4901      1498.2937
23   3000.7098      1504.2774
24   3500.9807      1510.4107
25   4000.2248      1525.2095
26   5000.9606      1543.2634
27   8000.0213      1599.1038
```

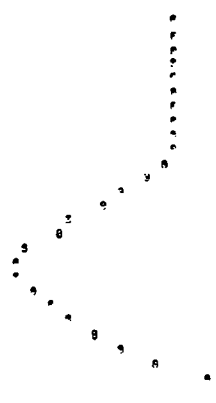

Fig. 8d — The part of the printer output of the VFC program giving the first corrected sound-speed profile

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```
U.S. NAVAL RESEARCH LABORATORY - ACOUSTICS DIV.
VELOCITY FIELD CONSTRUCTION PROGRAM
INPUT AND EXTRAPOLATED VELOCITY PROFILE WITHOUT EARTH CURVATURE CORRECTION
I=INPUT DATA POINT
E=EXTRAPOLATED POINT OBTAINED FROM LEROYS EQUATION
SAMPLE TEST CASE
SECOND PROFILE
DATE  5/25/73


PROFILE    2
RANGE       60.0518 (NM)
LAT= 38 DEG  0.00 MIN       LONG =  39 DEG  3.00 MIN
MAXIMUM DEPTH OF OBSERVATION OF ORIGINAL DATA =    8000.0000METERS
TEMPERATURE AT MDE =       1.5000 DEGREES C
SALINITY AT MLP =      34.7000 PPT
DEEP PROFILE


THIS PROFILE WAS CORRECTED FOR EARTH CURVATURE


PROFILE NUMBER    2  NUMBER OF PTS=   27  TYPE PROFILE =1      PROFILE RANGE(NM)=      60.0518

WARNING--POINT    8 HAS A CURVATURE        0.0126 WHICH EXCEEDS        0.0100
WARNING--POINT   9HAS A CURVATURE       -0.0080 WHICH LESS THAN      -0.0100
WARNING--POINT  10HAS A GRADIENT       -0.1437WHICH IS LESS THAN      -0.1000
WARNING--POINT  11HAS A GRADIENT       -0.2115WHICH IS LESS THAN      -0.1000
WARNING--POINT  12HAS A GRADIENT       -0.2363WHICH IS LESS THAN      -0.1000
WARNING--POINT  13HAS A GRADIENT       -0.1173WHICH IS LESS THAN      -0.1000
MINIMUM VEL =    1481.3164
MAXIMUM VEL =    1599.1038
MINIMUM GRAD =  -0.2367431
MAXIMUM GRAD =   0.0356348
MINIMUM CURV =-0.047968430
MAXIMUM CURV = 0.012626590


PRINTER PLOT OF CORRECTED PROFILE NUMBER    2
```

1	0.0000	1530.9719
2	31.0001	1531.4884
3	40.0001	1531.6387
4	50.0002	1531.8055
5	59.0002	1531.8888
6	61.0003	1531.9899
7	70.0004	1532.1390
8	75.0005	1532.2224
9	80.0005	1532.3058
10	85.0006	1531.6244
11	91.0007	1530.4437
12	122.0012	1522.7869
13	187.0026	1513.1761
14	243.0047	1506.6614
15	365.0105	1496.4157
16	400.0125	1493.4463
17	600.0242	1483.6410
18	800.0302	1481.3164
19	1000.0784	1481.9783
20	1500.1764	1[illegible].3120
21	2000.3136	1551.7469
22	2500.4901	1489.6759
23	3000.7058	1508.2274
24	3500.9607	1510.5411
25	4001.2548	1525.2392
26	5001.9089	1543.2480
27	8005.0213	1599.1038

Fig. 8e — The part of the printer output of the VFC program giving the second corrected sound-speed profile

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```
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VELOCITY FIELD CONSTRUCTION PROGRAM
INPUT AND EXTRAPOLATED VELOCITY PROFILE WITHOUT EARTH CURVATURE CORRECTION
I=INPUT DATA POINT
E=EXTRAPOLATED POINT OBTAINED FROM LEROYS EQUATION
SAMPLE TEST CASE
THIRD PROFILE
DATE  5/23/73


PROFILE    3
RANGE     178.1539 (NM)
LAT= 30 DEG  0.00 MIN        LONG =  30 DEG  0.00 MIN
MAXIMUM DEPTH OF OBSERVATION OF ORIGINAL DATA =    8000.0000METERS
TEMPERATURE AT MPS =       1.5000 DEGREES C
SALINITY AT MPS =      34.7000 PPT
DEEP PROFILE

THIS PROFILE WAS CORRECTED FOR EARTH CURVATURE


PROFILE NUMBER=    3  NUMBER OF PTS=   27  TYPE PROFILE =1      PROFILE RANGE(NM)=    178.1539

WARNING--PRINT    4 HAS A CURVATURE        0.0149 WHICH EXCEEDS        0.0100
WARNING--PRINT   6HAS A GRADIENT       -0.1533WHICH IS LESS THAN       -0.1000
WARNING--PRINT   7HAS A CURVATURE       -0.0594 WHICH LESS THAN       -0.0100
WARNING--PRINT   8HAS A GRADIENT       -0.3159WHICH IS LESS THAN       -0.1000
WARNING--PRINT   9HAS A CURVATURE       -0.0210 WHICH LESS THAN       -0.0100
WARNING--PRINT   9HAS A GRADIENT       -0.3497WHICH IS LESS THAN       -0.1000
WARNING--PRINT    9 HAS A CURVATURE        0.0143 WHICH EXCEEDS        0.0100
WARNING--PRINT  10HAS A GRADIENT       -0.2832WHICH IS LESS THAN       -0.1000
WARNING--PRINT   10 HAS A CURVATURE        0.0101 WHICH EXCEEDS        0.0100
WARNING--PRINT  11HAS A GRADIENT       -0.2475WHICH IS LESS THAN       -0.1000
WARNING--PRINT  12HAS A GRADIENT       -0.1934WHICH IS LESS THAN       -0.1000
MINIMUM VEL =   1480.7397
MAXIMUM VEL =   1599.1538
MINIMUM GRAD =  -0.3491482
MAXIMUM GRAD =   0.0441079
MINIMUM CURV =-0.059441241
MAXIMUM CURV = 0.018939096


   PRINTER PLOT OF CORRECTED PROFILE NUMBER    3
```

1	0.0000	1527.8063
2	31.0001	1526.3257
3	40.0001	1526.4751
4	50.0002	1526.6418
5	55.0002	1526.7252
6	61.0003	1526.8252
7	70.0004	1526.9753
8	75.0005	1527.7235
9	80.0005	1529.9314
10	85.0006	1534.3438
11	91.0007	1542.7962
12	122.0012	1516.0769
13	167.0016	1506.2991
14	243.0047	1503.9374
15	345.0155	1496.2043
16	400.0125	1495.1599
17	409.0192	1494.1151
18	509.0572	1490.7367
19	1000.0784	1481.4484
20	1500.1784	1486.0277
21	2000.3136	1491.7324
22	2500.4601	1494.5694
23	3000.7054	1508.1439
24	3500.9007	1516.4107
25	4001.2948	1525.2251
26	5001.9095	1543.3861
27	8005.0213	1599.1038

```
          88.86160 SECONDS LEFT
   TIME    =      86.83000000
   TDELTA  =      11.86000000
```

Fig. 8f — The part of the printer output of the VFC program giving the third corrected sound-speed profile

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TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JØB,	X	XXXXXX,XXXXXX,2
79	EQUIP	,	20=DF
79	EQUIP	,	3=PL
79	EQUIP	,	1=(ICØEFTAPE,11,1,999),LØ,DA
79	DISKL	Ø	ADD
	20		1
PRFPLT			41 RØJ2 25 1
	end-of-file card		
	end-of-file card		
79	LØAD,		25
79	RUN,	2	,3500
			data cards for program PRFPLT
	end-of-file card		

Fig. 9 — Control cards for the PRFPLT program for obtaining the Calcomp-plot output

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The *job-request form* should be filled out as shown in Fig. 3. In addition the user should:

1. In the second logical-unit-number space, under magnetic tapes, indicate that logical unit 1 is an input tape to be saved. This tape is the coefficient tape generated by the VFC program; its serial number should be inserted.

2. Indicate type 00 chart paper (no grid lines), the number of plots (three for the sample test case), and the approximate plot length in inches.

4.2.2 Control Cards and Job-Request Forms for Gerber Plots

Gerber plots are made on a flat-bed plotter (Gerber Model 875 drafting machine) and generally take a day for completion, whereas Calcomp plots may be obtained in about the same length of time that it takes to obtain other types of computer output with comparable central-processor running time. Short jobs are typically processed in 1 hour. The Gerber plots take a longer time because it is necessary first to obtain a magnetic tape from the CDC 3800 and then submit this tape to a Gerber-plotter operator at a separate facility within NRL. Gerber plots however are of much higher quality and resolution than Calcomp plots. In addition they may be as large as 5 by 8 feet, whereas Calcomp plots are restricted to the width of the Calcomp plotter drum (10 or 30 inches). Scale factors may be set into the Gerber plotter console to magnify or reduce the plot size.

The *control cards* required for obtaining Calcomp plots are shown in Fig. 10. Line 4 is the EQUIP card for the NRL Research Computation Center magnetic tape which contains the Calcomp-to-Gerber conversion routines. Tape serial number 3803 should always be used for this tape unless the NRL Research Computation Center indicates otherwise. Line 6 is an EQUIP card for the magnetic tape which contains the output Gerber plots. A complete description of the Gerber plotting routines and their usage is given in Refs. 4 and 5.

The *job-request form* for obtaining Gerber plots should be filled out as shown in Fig. 3. In addition the user should:

1. Perform step 1 of Section 4.2.1.

2. Indicate that logical unit 48 is an input tape to be saved and insert its serial number (3803). This logical unit corresponds to the magnetic tape containing the Gerber-plotter routines.

3. Indicate that logical unit 18 is an output tape to be saved and insert its serial number. This tape will contain the output Gerber plots. It must be supplied by the user.

4.2.3 Data Cards

The following numbers are read in by the general-purpose input routine. The card columns in which the numbers are placed are not important, but they need be entered in the following order:

	TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
1		Job		request form
2	79	JOB,	X	XXXXXX, XXXXXX, 2
3	79	EQUIP	,	20 = DF
4	79	EQUIP	,	48 = (CALCOMP/GERBER), HI, RQ
5				
6	79	EQUIP	,	18 = **, HI
7	79	EQUIP	,	1 = (CQEFTAPE, 1, 1, 999), LQ, DA
8	79	DISK	LOAD	1
9		20		4
10	P	RFPLT	G	4 R9J2 25
11				1
12			end-of-file card	
13			end-of-file card	
14	79	LOAD,	25	
15	79	RUN,	2, 3500	
16				data cards for PRFPLT
17			end-of-file card	
18				

Fig. 10 — Control cards for the PRFPLT program for obtaining Gerber plots

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DPMAXG	the maximum depth to be shown on the graph in meters, such as 2000.
VMING	the minimum velocity to be shown on the graph in meters per second, such as 1470.
VMAXG	the maximum sound speed to be shown on the graph in meters per second, such as 1610.
ZMING	the minimum vertical gradient to be shown on the graph, such as −0.5.
ZMAXG	the maximum vertical gradient to be shown on the graph, such as 0.5.
DMING	the minimum vertical curvature to be shown on the graph, such as −0.06.
DMAXG	the maximum vertical curvature to be shown on the graph, such as +0.06.
NPLOT	the number of the profile to be plotted. The first profile on the coefficient tape is 1, the second is 2, etc.

The following three title lines must appear on separate cards

TITPRO1	the first line of an 80-character alphanumeric title,
TITPRO2	the second line of an 80-character alphanumeric title,
TITPRO3	the third line of an 80-character alphanumeric title.

The numbers VMAXG, VMING, ZMAXG, ZMING, DMING, and DMAXG may be determined by examining the maximum and minimum values of sound speed, vertical gradients, and curvatures as printed by the VFC program. Also DPMAXG can be less than the maximum observed depth of a profile. If the sound speed or its derivatives exceed the limits given for the depth interval (0, DPMAXG), a warning message will be printed.

The titles TITPRO1, TITPRO2, and TITPRO3 will be written on the graph for profile NPLOT. The entries NPLOT, TITPRO1, TITPRO2, and TITPRO3 are repeated for each profile to be plotted. The entry −1 for NPLOT indicates the end of the data set.

4.3 Sample Input and Output

Figure 11 shows the data cards for generating Calcomp plots of the three profiles in the sample test case. Figure 12 is the resulting printer output. Figures 13a, 13b, and

```
2000 1470 1610 -.5 .5 -.06 .06
1
SAMPLE TEST CASE
PROFILE NO. 1
RANGE =0. NM
2
SAMPLE TEST CASE
PROFILE NO. 2
RANGE = 60.05 NM
3
SAMPLE TEST CASE
PROFILE NO. 3
RANGE = 178.15 NM
-1
```

Fig. 11 — Sample-test-case input data cards for the PRFPLT program for obtaining the Calcomp-plot output

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```
----PROGRAM PRFPLT ----

SAMPLE TEST CASE
        MAXIMUM GRAPH DEPTH (M) =    2000.0000
        MINIMUM GRAPH VELOCITY (M/S) =    1470.0000
        MAXIMUM GRAPH VELOCITY (M/S) =    1610.0000
        MINIMUM GRAPH GRADIENT (1/S) =      -0.5000
        MAXIMUM GRAPH GRADIENT (1/S) =       0.5000
        MINIMUM GRAPH CURVATURE (1/S/M) =      -0.0600
        MAXIMUM GRAPH CURVATURE (1/S/M)=       0.0600
        PLOT PROFILE NO,     1
        SAMPLE TEST CASE
        PROFILE NO. 1
             PROFILE      1
             NUMBER OF POINTS =    27
             RANGE (NM) =       0.0000
        VMIN DATA =    1481.7436
        VMAX DATA =    1533.3538
        ZMIN DATA =      -0.2845
        ZMAX DATA =       0.0379
        CMIN DATA =      -0.0424
        CMAX DATA =       0.0084

        PLOT PROFILE NO,     2
        SAMPLE TEST CASE
        PROFILE NO. 2
             PROFILE      2
             NUMBER OF POINTS =    27
             RANGE (NM) =      60.0518
        VMIN DATA =    1481.3164
        VMAX DATA =    1532.3058
        ZMIN DATA =      -0.2363
        ZMAX DATA =       0.0356
        CMIN DATA =      -0.0480
        CMAX DATA =       0.0126

        PLOT PROFILE NO,     3
        SAMPLE TEST CASE
        PROFILE NO. 3
             PROFILE      3
             NUMBER OF POINTS =    27
             RANGE (NM) =     178.1539
        VMIN DATA =    1480.7397
        VMAX DATA =    1528.9753
        ZMIN DATA =      -0.3492
        ZMAX DATA =       0.0491
        CMIN DATA =      -0.0594
        CMAX DATA =       0.0189

        ----PLOTTING COMPLETE -----
```

Fig. 12 — Printer output from the PRFPLT program for the sample test case

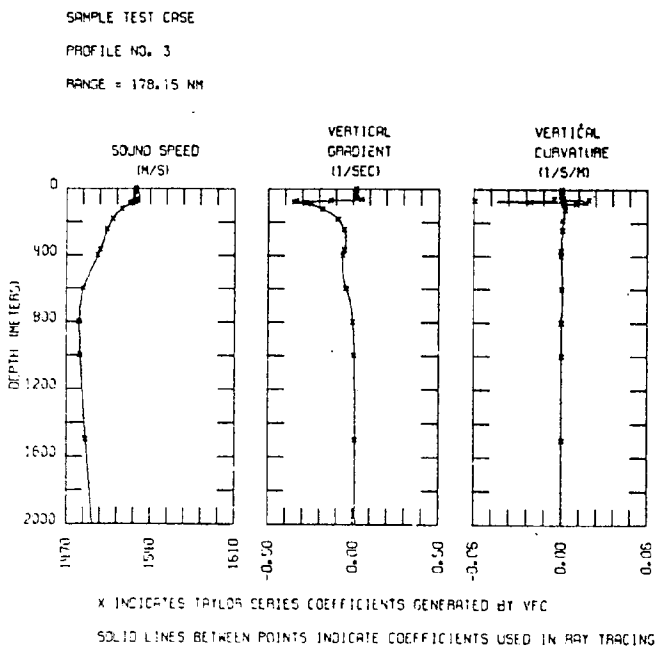

Fig. 13a — Calcomp plot from the PRFPLT program showing the first profile for the sample test case

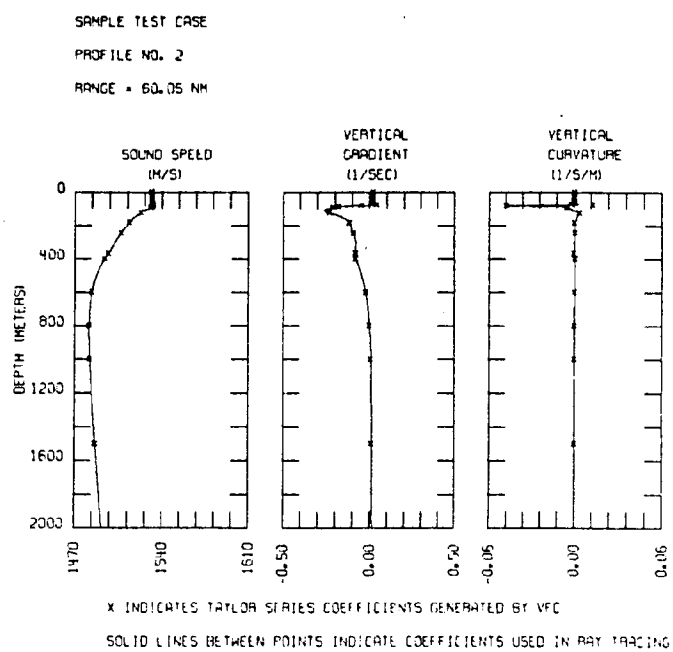

Fig. 13b — Calcomp plot from the PRFPLT program showing the second profile for the sample test case

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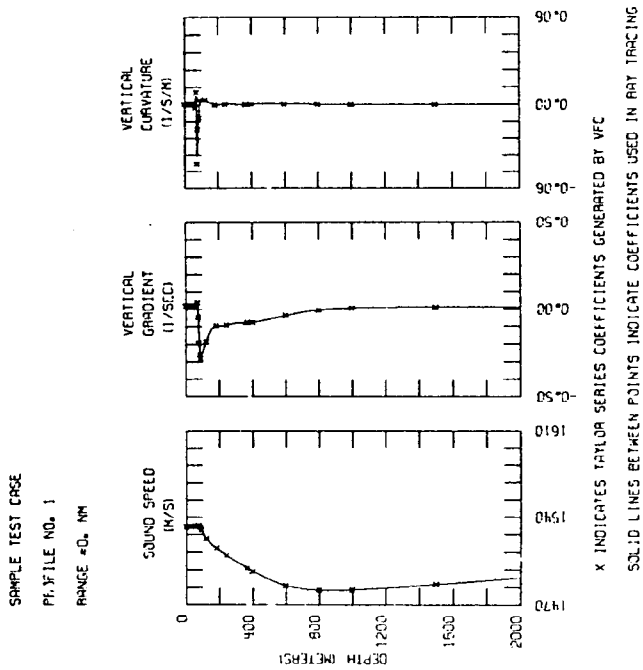

Fig. 13c — Calcomp plot from the PRFPLT program showing the third profile for the sample test case

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13c are the plots. In this example, we plotted only the first 2000 meters of each profile in order to show more clearly how the system interpolates between points in the surface duct. If the full 8000 meters were displayed, the lower 50 percent of the sound-speed profile would appear linear.

5. CONTOURING AND GENERATING THREE-DIMENSIONAL ISOMETRIC PLOTS OF THE SOUND-SPEED FIELD

5.1 Program Summary

Title of program: CTOUR

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63

High-speed store required: 27,452 (decimal) words, exclusive of system routines

Number of bits in a word: 48

Is program overlaid? No

Number of magnetic tapes required: one for Calcomp plots; two for Gerber plots

Other peripherals required: disk (for program storage), card reader, printer, and Calcomp 565 plotter or Gerber plotter

Number of cards in program deck: 1017

Card punching code: BCD

Nature of Physical Problem

Generating Calcomp or Gerber contour plots of the sound-speed field.

Method of Solution

See Section 2.1.4 of Volume 1.

Restrictions on Complexity of Problem

A maximum of 50 contour levels may be displayed. The range-and-depth grid used in plotting may have at most 101 times 101 points.

Typical Running Time

It took approximately 1 minute 12 seconds to load the CTOUR object deck from the disk and execute the sample problem of Section 5.3. The plotting took 17 minutes on a Calcomp 565 plotter.

5.2 Input

5.2.1 Control Cards and Job Request Forms for Calcomp Plots

The *control cards* required for obtaining Calcomp plots are shown in Fig. 14. Line 4 is an EQUIP card for the Calcomp plotter. The other control cards have been explained earlier.

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JQB,	X	XXXXIXX, XXXXXX, 2
79	EQUIP		,20=DF
79	EQUIP		,5=PL
79	EQUIP		,1=(ICQEFTAPE,11,1,999),LQ1,DA
79	DISKLQAD		
	20		1
	CTQUR		41 R9J21 251 1
	end-of-file card		
	end-of-file card		
79	LQAD,		25
79	RUN,		2,3500
			data cards
	end-of-file card		

Fig. 14 — Control cards for the CTOUR program for obtaining the Calcomp-plot output

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The *job-request form* for obtaining Calcomp plots should be filled out as shown in Fig. 3. In addition the user should:

1. Indicate type 00 chart paper is to be used, indicate that two plots will be generated, and insert the estimated plot length in inches (for the sample test case insert 48 inches).

2. In the second logical-unit-number space, indicate that logical unit 1 is an input tape to be saved. The serial number of the tape generated by the VFC program should be inserted.

5.2.2 Control Cards and Job-Request Forms for Gerber Plots

The *control cards* required for obtaining Calcomp plots are shown in Fig. 15.

The *job request form* for obtaining Gerber plots should be filled out as shown in Fig. 3. In addition the user should:

1. Perform step 2 of Section 5.2.1

2. In the third logical-unit-number space, indicate that logical unit 48 is an input tape to be saved. This tape contains the Gerber-plotter routines. Its serial number, assigned by the Research Computation Center, is 3803.

3. In the fourth logical-unit-number space, indicate that logical unit 18 is an output tape to be saved. This tape contains the output Gerber plots. This tape and its serial number must be supplied by the user.

5.2.3 Data Cards

The data are read in by the general-purpose input routine. The input parameters may be placed anywhere on the cards without regard to format provided they are punched in the following order:

NTAPE	the logical unit on which the coefficient tape is mounted (1 to 49).
RNGINIT	the initial range of the contour plot (0 to 10,000 n.mi.).
RDELTA	the range spacing of the grid (0 to 10,000 n.mi.), such as RNGMAX/100.
RNGMAX	the maximum range of the grid (0 to 10,000 n.mi.).
DPINIT	the initial depth of the grid in meters, such as 0.
DPDELTA	the depth spacing of the grid in meters, such as DPMAX/100.
DPMAX	the maximum depth of the grid in meters.
NPR5	a number set to 1 if grid velocities are to be printed and set to 0 if not.
XG5	the length of the abscissa axis of the contour plot (5 to 200 inches).
YG5	the length of the ordinate axis of the contour plot (5 to 9 inches).

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JOB,	X	XXXXXX,XXXXX,2
79	EQUIP	,	20=DF
79	EQUIP	,	1=(CQEFTAPE,1,1,999),LQ,DA
79	EQUIP	,	48=(CALCOMP/GERBER),HI,RQ
79	EQUIP	,	18=**,HI
79	DISKLOAD		
	20		1
C	TOUR	G	4 R9J2 25 1
	end-of-file card		
	end-of-file card		
79	LOAD,	25	
79	RUN,	2,	3500
			data cards
	end-of-file card		

Fig. 15 — Control cards for the CTOUR program for obtaining Gerber plots

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TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JQB,	X	XXXXXXXXXXXXX,12
79	EQUIP	,	20=DF
79	EQUIP	,	1=(CQEFTAPE,1,1,999),LQ,DA
79	EQUIP	,	48=(CALCQMP/GERBER),HI,RQ
79	EQUIP	,	18=**,HI
79	DISKLQAD		
	20		11
C	TQURG		4 R9J2 25 1
	end-of-file card		
	end-of-file card		
79	LQAD,	25	
79	RUN,	2,	35000
			data cards
	end-of-file card		

Fig. 15 — Control cards for the CTOUR program for obtaining Gerber plots

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NCL the number of contour levels to be plotted (−50 to 50). If NCL is less than 0, −NCL levels will be automatically selected at equal intervals of velocity. If NCL is greater than 0, NCL levels will be specified by the user.

CL(I) NCL contour levels, where I = 1 through NCL. If NCL is less than 0, these values should not be inputted.

Since the range-and-depth grid is restricted to at most 101 times 101 points, the input parameters are restricted such that

$$\text{Integer}\left(\frac{\text{RNGMAX} - \text{RNGINIT}}{\text{RDELTA}}\right) + 1 \leqslant 101$$

and

$$\text{Integer}\left(\frac{\text{DPMAX} - \text{DPINIT}}{\text{DPDELTA}}\right) + 1 \leqslant 101.$$

The following are cautions to the user:

- Check to be certain that the input parameters fall within their appropriate limits.
- If the grid size is chosen too coarsely, some of the detail present in the velocity field may be lost or misinterpreted. The user might consider contouring his field in two phases. The first phase would give a rough but overall view of the velocity field from the ocean surface to the bottom. The second phase would show the detailed structure generally present near the surface.
- The user must not attempt to contour regions of the velocity field that fall beyond the bounds of the profiles contained on the coefficient tape.

5.3 Sample Input and Output

The data card required for generating the printer output shown in Figs. 16a and 16b and the Calcomp plots shown in Figs. 17 and 18 is

1 0. 1.75 175 0 10 1000 0. 17.5 8 −30

The numbers on this card are explained in Section 5.2.3.

Figure 16a is a listing of the input parameters. Figure 16b contains the title of the test case, the number of range points (NRPTS), the number of depth points (NDPTS) which make up the grid, the grid depths in meters, and a partial listing of the range points. NUMBER is the number of a range point, and RANGE is its corresponding range in nautical miles. For brevity the printout for range numbers 10 through 97 have been omitted from Fig. 16b.

In this example, we chose to plot only the upper 1000 meters of the sound-speed field. Thirty contour levels were requested. Figure 18 is an isometric plot of the sound-speed field of Fig. 17. The lower-left-hand corner of Fig. 18 corresponds to range 0 and

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```
NTAPE    =    1
RNGINIT  =        0.00000000
RDELTA   =        1.75000000
RNGMAX   =      175.00000000
DPINIT   =        0.00000000
DPDELTA  =       10.00000000
DPMAX    =     1000.00000000
NPRS     =    0
XGS      =       17.50000000
YGS      =        8.00000000
NCL      =  -30
```

Fig. 16a — The part of the printer output of the CTOUR program listing the input parameters

depth 0. The upper-right-hand corner corresponds to a range of 175 nautical miles and a depth of 1000 meters.

6. RAY TRACING AND INTENSITY CALCULATIONS

6.1 Program Summary

Title of program: SERPENT

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63 and COMPASS (for one small routine)

High-speed store required: 36,784 (decimal) words exclusive of system routines

Number of bits in a word: 48

Is program overlaid? No

Number of magnetic tapes required: one for profile input, plus one if a transmission-loss-tape output is desired, plus one if a ray-statistics tape is desired

Other peripherals used: disk (for storage of SERPENT object deck), card reader, printer, and drum for intermediate storage

Number of cards in program deck: 3802

Card punching code: BCD

Nature of Physical Problem

Ray tracing and intensity calculations.

Method of Solution

See Section 3 of Volume 1.

Restrictions on Complexity of Problem

Two-dimensional, multiple sound-speed profiles. Linear segmented bottom. Monochromatic source. Maximum of 1500 rays per trace. Coherent and random intensities (Type I) and statistical intensities (Type II). Maximum of 250 receiver depths per trace. Specular reflection of rays from the surface and the bottom. Geometrical acoustics, with no diffraction or caustic corrections.

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U.S. NAVAL RESEARCH LABORATORY---ACOUSTICS DIV.

VELECITY CONTOUR PLOTTING ROUTINE
SAMPLE TEST CASE
NRPTS   =  101
NZPTS   =  101
GRID DEPTHS

   0.0000      10.0000      20.0000      30.0000      40.0000
  50.0000      60.0000      70.0000      80.0000      90.0000
 100.0000     110.0000     120.0000     130.0000     140.0000
 150.0000     160.0000     170.0000     180.0000     190.0000
 200.0000     210.0000     220.0000     230.0000     240.0000
 250.0000     260.0000     270.0000     280.0000     290.0000
 300.0000     310.0000     320.0000     330.0000     340.0000
 350.0000     360.0000     370.0000     380.0000     390.0000
 400.0000     410.0000     420.0000     430.0000     440.0000
 450.0000     460.0000     470.0000     480.0000     490.0000
 500.0000     510.0000     520.0000     530.0000     540.0000
 550.0000     560.0000     570.0000     580.0000     590.0000
 600.0000     610.0000     620.0000     630.0000     640.0000
 650.0000     660.0000     670.0000     680.0000     690.0000
 700.0000     710.0000     720.0000     730.0000     740.0000
 750.0000     760.0000     770.0000     780.0000     790.0000
 800.0000     810.0000     820.0000     830.0000     840.0000
 850.0000     860.0000     870.0000     880.0000     890.0000
 900.0000     910.0000     920.0000     930.0000     940.0000
 950.0000     960.0000     970.0000     980.0000     990.0000
1000.0000
    NUMBER  =    1
    RANGE   =        0.00000000
    NUMBER  =    2
    RANGE   =        1.75000000
    NUMBER  =    3
    RANGE   =        3.50000000
    NUMBER  =    4
    RANGE   =        5.25000000
    NUMBER  =    5
    RANGE   =        7.00000000
    NUMBER  =    6
    RANGE   =        8.75000000
    NUMBER  =    7
    RANGE   =       10.50000000
    NUMBER  =    8
    RANGE   =       12.25000000
    NUMBER  =    9
    RANGE   =       14.00000000
    NUMBER  =   [illegible]
    RANGE   =      169.75000000
    NUMBER  =   99
    RANGE   =      171.50000000
    NUMBER  =  100
    RANGE   =      173.25000000
    NUMBER  =  101
    RANGE   =      175.00000000
```

Fig. 16b — The part of the printer output of the CTOUR program listing the grid depths and ranges

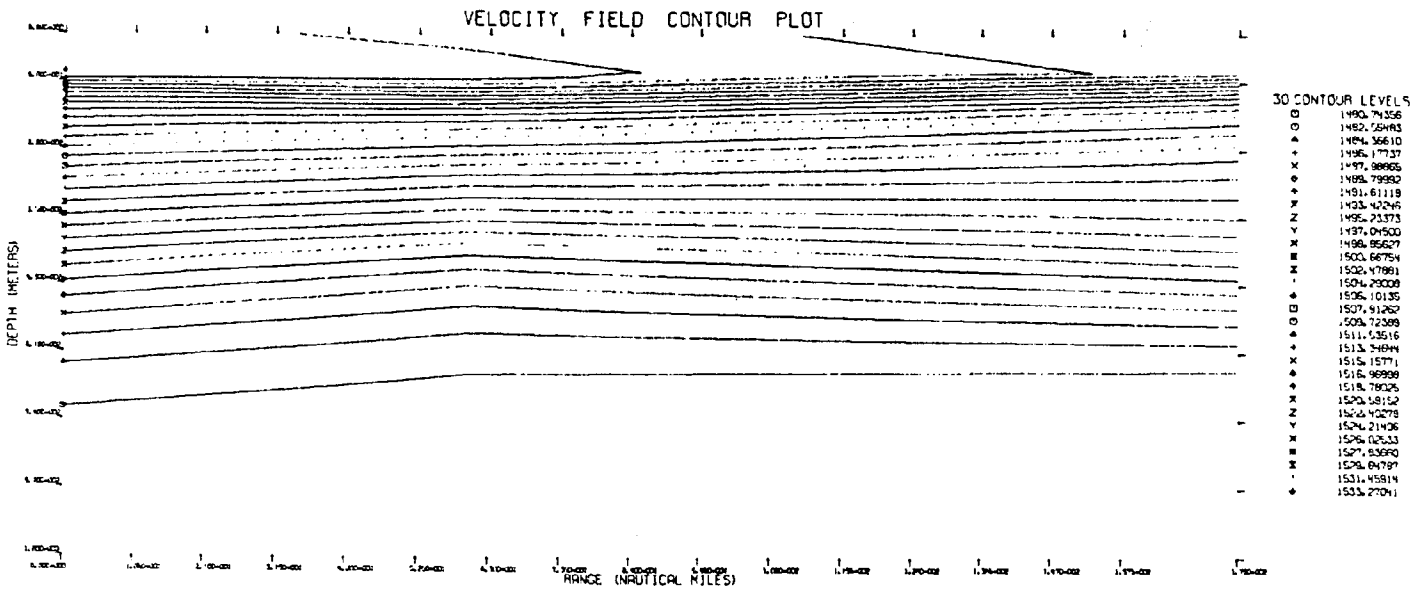

Fig. 17 — Calcomp output from the CTOUR program giving the contour plot of the sound-speed field in the sample test case

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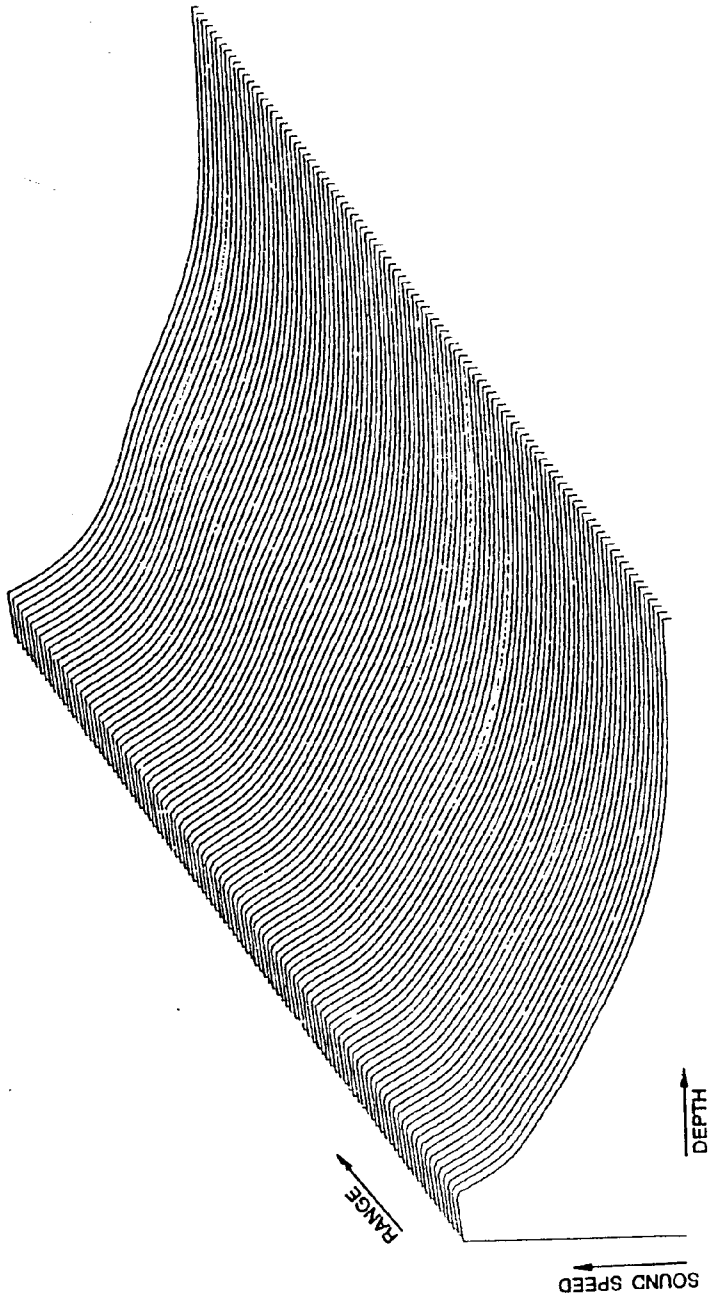

Fig. 18 — Calcomp output from the CTOUR program giving the isometric plot of the sound-speed field in the sample test case

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Typical Running Time

It took approximately 75 seconds to load the SERPENT object program from the disk and execute the sample ray-tracing problem of Section 6.3.1. Of this, 39 seconds were spent in loading and 36 seconds in execution.

Loading and executing the sample transmission-loss problem of Section 6.3.2 took approximately 218 seconds. Of this time, 158 seconds were actually spent in execution and 60 seconds were spent in loading. The transmission-loss calculation can be speeded up if the transmission-loss values are not printed. For example, running the sample problem of Section 6.3.2 without printing, but still generating, a transmission-loss tape took 149 seconds for execution, a saving of 9 seconds.

The running time for any problem depends to a large extent on the outputs desired, the complexity of ocean environment, the number of rays traced, the source angles of the rays, the ray tuning parameters used, and the speed of the computer on which the program is run.

6.2 Input

6.2.1 Control Cards and Job-Request Forms

The control cards required to obtain a ray magnetic tape are shown in Fig. 19. Line 4 shows the EQUIP card for the coefficient magnetic tape. This card is always required. Line 5 shows the EQUIP card for the ray tape. This card is required if one wishes to generate Gerber or Calcomp ray plots. Otherwise it is optional. Line 6 shows the EQUIP card for the transmission-loss tape. This card is required if the user wishes to generate transmission-loss plots using LOSSPLOT. Otherwise, it is optional.

The standard practice in running SERPENT is to trace 30 or 40 rays through the sound-speed field and generate a Calcomp ray plot. This, in effect, checks all of the input data and assures the user that SERPENT is capable of handling the problem. It also enables the user to estimate by extrapolation the amount of time that will be required to trace the rays for intensity calculations. In addition it tells the user which rays are important to his problem and which rays can be ignored in the calculation. As mentioned in Section 3.1.3.3 of Volume 1, the ray-depth distribution plots can give considerable insight into the number of rays required to solve a particular problem. No intensities are calculated in this run. They could be, but so few rays are traced that the results would be virtually meaningless. Hence for this run, the ray-tape EQUIP card is used but the transmission-loss EQUIP card is not. Next the program is run to calculate intensities (transmission losses). This requires increasing the number of rays traced to the order of several hundred. The previous run established which rays may and may not be important. For example it may have established that only those rays between approximately −10 and 10 degrees are important, because rays at steeper angles experience so many bottom and surface hits that their contribution to the intensity at a distant receiver is surely negligible. To trace these rays would be a waste of computer time and money. If this were the case, the user might trace only the rays between −10 and 10 degrees with 0.1-degree increments. The user would not generate a ray tape at this time, because writing a tape requires additional computer time and also it is likely that more than one magnetic tape would be required to hold all of the generated ray statistics. Only a transmission-loss tape would be generated.

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JOB,	X	XXXXXXXXXXXXXXXXXX,2
79	EQUIP	,	20=DF
79	EQUIP	,	1=(CAEFTAPE,1,1,9999),LQ,DA
79	EQUIP	,	2=(IRAYTAPE,1,11,999),LQ,DA } optional
79	EQUIP	,	3=(LQSSTAPE,1,1,9999),LQ,DA
79	DISKLOAD		
	20		11
	SERPENT		4 RQJ2 25
	end-of-file card		
	end-of-file card		
79	LOAD,	25	
79	RUN,	2,	3500
			data cards
	end-of-file card		

Fig. 19 — Control cards for the SERPENT program

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To obtain both ray-statistics and transmission-loss tapes, the *job-request form* should be filled out as shown in Fig. 3. In addition the user should:

1. In the first logical-unit-number space, write "DF." This indicates to the computer operators that the disk file will be used. The binary object deck for SERPENT is stored on the disk.

2. In the second logical-unit-number space, indicate that logical unit 1 is an input tape to be saved. This logical unit corresponds to the coefficient tape generated by the VFC program. Its serial number should be indicated.

3. In the third logical-unit-number space, indicate the logical-unit number of the ray-statistics tape (if one is desired). This number should be the value of the input parameter NRAYTAPE described in Section 6.2.2. The user should also indicate that it is an output tape to be saved and specify its serial number. If however the input parameter NRAYTAPE is set to 0, a ray tape will not be generated and the above information pertaining to the logical unit of the ray tape should be omitted, together with the EQUIP card corresponding to the ray tape. In Fig. 19 we assumed NRAYTAPE was set to 2.

4. In the fourth logical-unit-number space, indicate the logical-unit number of the transmission-loss tape (if one is desired). This number should be the value of the input parameter NINTAP described in Section 6.2.2. If a transmission-loss tape is not desired, the above logical unit number information should be omitted, together with the EQUIP card corresponding to the transmission-loss tape. In Fig. 19 we assumed NINTAP was set to 3.

6.2.2 Data Cards

The data cards are read in by the general-purpose input routine. With the exception of title cards, the input parameters may be placed anywhere on these cards or on any card without regard to format, provided they are arranged in the proper order as defined by the flowchart given in Fig. 20 and the parameter definitions that follow in this section.

For example, one begins by punching title card 1 using a full 80-column card. Following this, one punches the second title card. Next, one punches the depth-conversion factor DPCON, the initial depth of the source in the units specified by DPCON (DPINIT), the frequency FREQ, and the number of ray groups. These numbers do not have to be in any particular column or even on the same card. The only restrictions are that the numbers be entered in correct order and be separated by at least one blank. Next the parameters ANGINC and ANGINIT are punched for the first ray fan. If however one sets ANGINC to 0, then the parameter ANGFIN is not punched. If ANGINC is not 0, then ANGFIN must be punched (Fig. 20). This process is repeated until NGRPS fans have been defined. Next one punches the parameters AXIALINT, BEAMTILT, etc. The rounded blocks in the flowchart are decisions. The rectangular blocks indicate parameters to be punched.

Although the explanation of the input parameters corresponding to the flowchart is quite long, in most cases, all of the input parameters can be punched on four or five IBM cards (as can be seen from Fig. 21, for example). The input parameters are:

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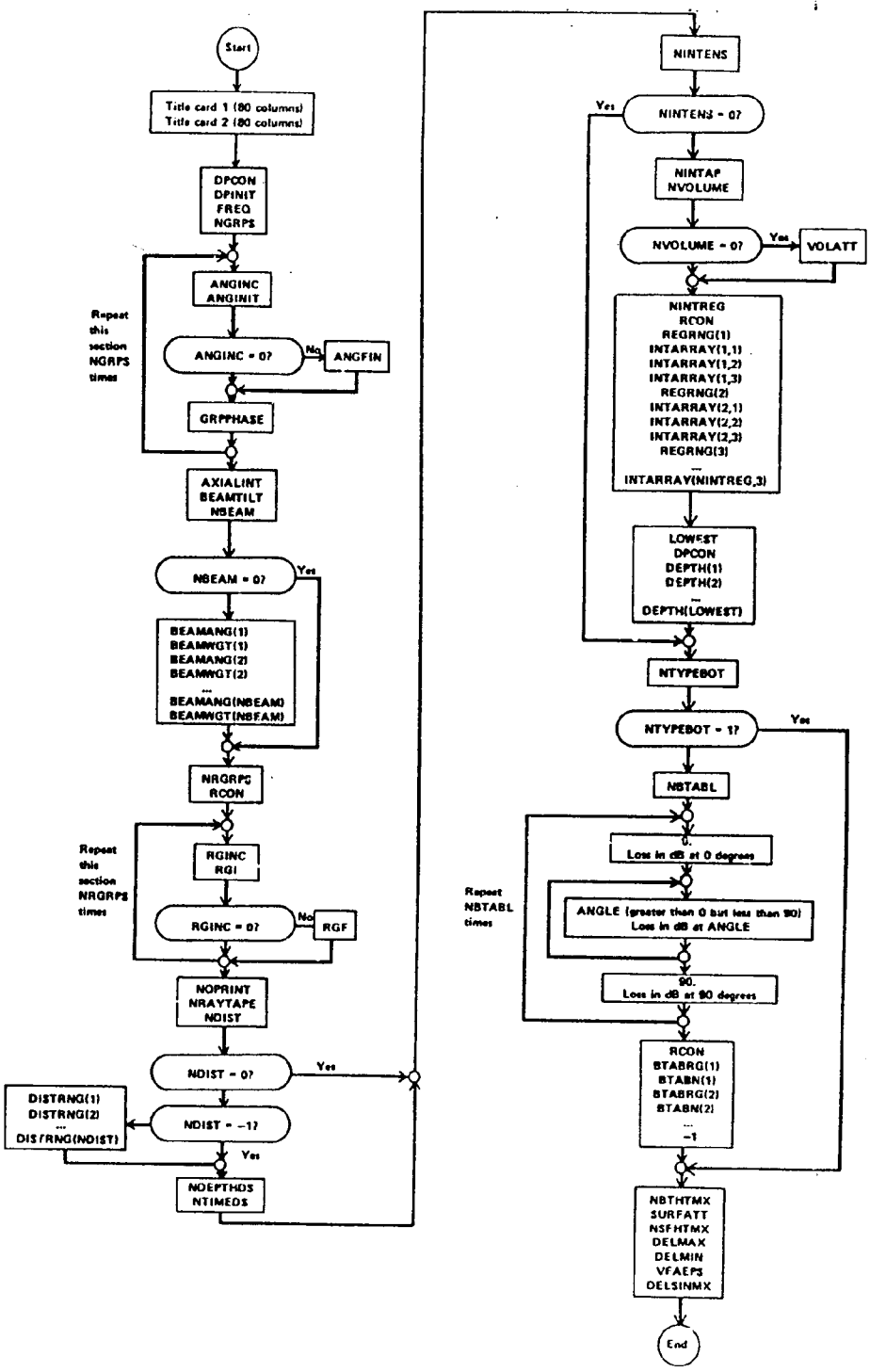

Fig. 20 — Flowchart showing the data input to the SERPENT program

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Title card 1	an 80-character title to identify the run. It requires the entire first card.
Title card 2	a title similar to title card 1.
DPCON	the factor for converting DPINIT to meters (Appendix A).
DPINIT	the depth of the ray source.
FREQ	the frequency of the source in hertz.
NGRPS	the number of ray fans. A ray fan is defined as a group of rays all of which have the same phase at the source and all of which are separated by the same angular increment. For each ray fan the user must specify the parameters ANGINC, ANGINIT, ANGFIN (if ANGINC is not 0), and GRPPHASE. Ray fans must not overlap. (The program can handle a maximum of 1500 rays.)
ANGINC	the angular increment between adjacent rays of the same fan (in degrees). If ANGINC is set to 0, the fan will consist of only one ray; its source angle is ANGINIT, and the parameter ANGFIN must not be entered. ANGINC is always positive.
ANGINIT	the minimum angle of the fan (in degrees). By convention rays directed above the horizon (up) have negative angles, while those directed below the horizon have positive angles. The horizontal ray is the 0-degree ray. The program requires $-90 < \text{ANGINIT} < \text{ANGFIN} < 90$.
ANGFIN	the maximum or final angle of the fan in degrees. This parameter is not entered if ANGINC is 0.
GRPPHASE	the phase of all ray angles in the above fan at the source in degrees. All angles in a fan are assumed to have the same phase at the source. Typically this parameter is set to 0.
AXIALINT	the axial intensity of a beam 1 yard from the source in ergs/s cm^2. If only transmission losses, rather than absolute intensities, are required, this parameter may be set to 1.
BEAMTILT	the angular tilt of the main beam lobe in degrees. A down tilt will be positive, and an up tilt will be negative. If the tilt angle is unknown, set BEAMTILT to 0. For convenience the following beam pattern is entered relative to a 0 degree tilt angle.
NBEAM	the number of points in the beam pattern. If the beam pattern is unknown, or if an omnidirectional beam pattern is to be assumed, set NBEAM to 0. In this case the program will automatically calculate the weighting factors for each ray assuming an omnidirectional source, and the beam parameters BEAMANG and BEAMWGT must not be entered. The program requires $0 \leqslant \text{NBEAM} \leqslant 50$.

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BEAMANG (I)	the angle of the Ith point in the beam pattern.
BEAMWGT (I)	the fraction of AXIALINT of a beam angle BEAMANG (I). The program automatically shifts the beam pattern so that the 0-degree angle of the unshifted beam pattern corresponds to the angle BEAMTILT. The program requires $0 \leqslant$ BEAMWGT (I) $\leqslant 1$.
NRGRPS	the number of output range groups. When the rays are traced, they will be iterated up to each of the output ranges. Each output range group is a set of equally spaced output ranges. The program has an upper limit of 1000 output ranges. When the rays are traced through the field, they are iterated up to each of the output ranges. To determine the ray statistics or perform intensity calculations at a particular range, the user must define it as an output range. The exact location of an output range is arbitrarily specified by the user. (For each of the NRGRPS output range groups the user must specify the parameters RGINC, RGI, and RGF (if RGINC is not 0). The output range groups may not overlap.)
RCON	a factor for converting RGINC, RGI, and RGF to nautical miles.
RGINC	the range increment for this output range group. If there is only one output range in this group, RGINC is set to 0 and RGF is not specified.
RGI	the initial range for this output group. The program requires RGI to be less than RGF.
RGF	the final range for this output group. If RGINC is set to 0, do not input RGF.
NOPRINT	a parameter set to 1 for the ray-statistics printout: ray depth, sine, travel time, phase, number of bottom and surface hits, number of turning points, etc. This printout will occur at each output range. The resulting printout can be quite voluminous and time consuming for large numbers of rays. NOPRINT is set to 0 if these statistics are not desired.
NRAYTAPE	a parameter set to 0 if construction of a ray tape is not desired. If it is set to a positive integer, a ray tape is constructed on logical unit NRAYTAPE. Values allowed are 1 to 59. NRAYTAPE may refer to a drum scratch unit or a magnetic tape. If it refers to a drum, the EQUIP cards must be appropriately defined. NRAYTAPE is the logical unit number of the ray tape as shown on the job-request form. Typically it is set to 2.
NDIST	a parameter set to −1 if a ray distribution plot is desired for *all* of the output ranges. If it is set to a positive integer, NDIST ray distribution plots are made for the ranges DISTRNG (I), I = 1 through NDIST (these ranges must correspond to output ranges).
NDEPTHDS	a parameter set to 1 if ray depths are desired on the distribution plots. If it is set to 0, ray depths are not plotted.

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NTIMEDS	a parameter set to 1 if ray travel times are desired on the distribution plots. If it is set to 0, ray travel times are not plotted.
NINTENS	a parameter set to 0 if intensity calculations are not desired. When it is set to 1 the intensities are calculated but not printed out. Presumably they will be written on the transmission-loss tape. When it is set to 2 the intensities are calculated and printed out at the output ranges.
NINTAP	a parameter set to a positive integer if a transmission-loss tape is desired on logical unit NINTAP (values between 1 and 59). NINTAP may refer to a drum (logical units 50 to 59) or to a magnetic tape (units 1 to 49). Typically NINTAP is set to 3. If it is set to 0, a transmission-loss tape is not constructed.
NVOLUME	a parameter set to 0 if the volume attenuation is zero in the intensity calculations. It is set to 1 if the volume attenuation will be entered as the next parameter. If it is 2, Thorp's equation is used to obtain the volume attenuation for frequency FREQ; this option should be used only if FREQ is greater than 1000.
VOLATT	the volume-attenuation coefficient in dB per kilometer.
NINTREG	the number of range intervals over which different types of intensity calculations will be made. The maximum is 6.
RCON	the factor for converting REGRNG (I) to nautical miles (Appendix A).
REGRNG (I)	the maximum range for the Ith range interval.
INTARRAY (I,1)	a parameter set to 1 if random (Type I) intensities are desired in the Ith range interval and set to 0 if they are not desired.
INTARRAY (I,2)	a parameter set to 1 if coherent (Type I) intensities are desired in the Ith range interval and set to 0 if they are not desired.
INTARRAY (I,3)	a parameter set to 1 if statistical (Type II) intensities are desired in the Ith range interval and set to 0 if they are not desired.
LOWEST	the number of receiver depths. A maximum of 250 is allowed. The receivers are assumed to be at the output ranges. Each output range has the same number of receivers, and these are located at the same depths. If a receiver depth is below the bottom, it will be ignored in the intensity calculations.
DPCON	the factor for converting DEPTH (I) to meters (Appendix A).
DEPTH (1)	the first receiver depth.
DEPTH (2)	the second receiver depth.
DEPTH (LOWEST)	the deepest receiver depth.

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NTYPEBOT	a parameter set to 1 if no bottom loss is assumed in the intensity calculations and set to 2 if bottom-loss tables will be read in.
NBTABL	the number of bottom loss tables to be read in. The maximum is 5.
ANGLE	the grazing angle with respect to the bottom (in degrees).
LOSS	the loss (in dB) for a ray incident to the bottom at ANGLE degrees. ANGLE and LOSS are entered for each point of the bottom-loss curve.
RCON	the factor for converting BTARNG (K) to nautical miles.
BTARNG (K)	a bottom-table range. Bottom table number BTABN (K) will be used for ranges greater than BTARNG (K-1) and less than or equal to BTARNG (K). BTARNG(O) = O.
BTABN (K)	a bottom-table number corresponding to the Kth bottom range. K may be as large as 100. To indicate the end of the bottom-table range data, —1 is inserted *after* the last bottom-table number.
NBTHTMX	the maximum number of bottom hits a ray is allowed to have before it is terminated, such as 10.
SURFATT	the surface-attenuation coefficient. The ratio of the intensity of a ray after striking the surface to its intensity before striking the surface. If there is no surface loss, SURFATT is 1.
NSFHTMX	the maximum number of surface hits a ray is allowed to experience before being terminated.
DELMAX	a parameter explained in Section 3.1.4.2 of Volume 1 which is typically set to 1000.
DELMIN	a parameter explained in Section 3.1.4.2 of Volume 1 which is typically set to 20.
VFAEPS	a parameter explained in Section 3.1.4.2 of Volume 1 which is typically set to 0.5.
DELSINMX	a parameter explained in Section 3.1.4.2 of Volume 1 which is typically set to 0.02.

6.3 Sample Input and Output

6.3.1 Ray Tracing

Figure 21 shows the data cards required for tracing 13 rays through the sound-speed field of the sample test case discussed earlier. We chose to trace the rays to only 130 nautical miles, because experimental transmission-loss values and bottom-profile data for greater ranges were not available. In this example the source is located at 500 feet and a frequency of 100 Hz was chosen. Because intensity calculations were not required in this run, the bottom-loss data and receiver-location information were not required. The ray angles at the source (—30 to 30 degrees in 5-degree steps) were chosen as an illustration. Figures 22a through 22e show the resulting printer output.

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SAMPLE TEST CASE
RAY TRACE RUN
.3048 500 100 1  5 -30 30 0 1 0 0 2 1 50 0 100 0 130 1 2 3 0 100 130
1 1 0 1 100 1 100 1000 20 .5 .02
```

Fig. 21 — Sample-test-case input data cards for the SERPENT-program ray-trace run

Figure 22a is a descriptive listing of the input parameters. At the bottom of the figure is some summary information extracted from the input coefficient tape.

Figure 22b describes each of the rays at the source range (0 nautical miles). All of the rays begin at the same depth but leave the source at different angles. Figure 22b also shows a ray-depth distribution plot (plot of ray depth versus initial angle at the source).

Figure 22c shows similar ray-statistics information at 50 nautical miles. In the first line the bottom depth at 50 nautical miles and the amount of computation time left before SERPENT will expire its allotted time limit are printed. Included in the top portion in this figure are the ray depths, the sine of the ray angles with respect to the horizon, the ray-travel times, the number of turning points (NTP), the number of surface hits (NSH), the number of bottom hits (NBH), and the phase of each ray up to a distance of 50 nautical miles. Following this information is a listing of bottom- and surface-hit information for each of the rays. This information includes all surface and bottom hits which occurred since the last printout range (0 nautical miles in this case).

Figure 22d shows the ray-statistics information for the 100-nautical-mile printout range. Figure 22e gives similar information for the 130-nautical-mile range. At the bottom of Figs. 22d and 22e some ray-depth and time-distribution plots are shown. When both time and depth are plotted on the same distribution plot (as in this example), the symbol S refers to the surface (0 meters) and also the maximum travel time. The symbol B refers to the bottom depth at the output range and also the minimum travel time. Each line in the plot corresponds to an angle indicated at the far left side of the plot. For example, the plot in Fig. 22e shows that the ray which left the source at 10 degrees is almost at the surface (39.1 m) at 130 nautical miles. Its travel time to 130 nautical miles is 161.4882 seconds. This is the minimum travel time for all of the rays traced.

6.3.2 Transmission-Loss Calculations

Figure 23 shows the data cards required for transmission-loss calculations. In this example 61 rays were traced at source angles between −30 and 30 degrees in 1-degree steps. Again the source was at 500 feet and a frequency of 100 Hz was considered. Doubling the number of rays, by changing the step size to 0.5 degree, did not significantly change the transmission-loss values. The receiver depth was assumed to be 2500 feet. Statistical (Type II) transmission loss was calculated at the receiver depth every nautical mile from 0 to 130 nautical miles. Two bottom-loss curves were used, based on MGS bottom-loss tables. A type 4 bottom was used from 0 to 20 nautical miles. A type 5 bottom was used from 20 to 130 nautical miles. No beam patterns were considered. A transmission-loss tape was generated. The volume attenuation was assumed to be zero,

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U.S. NAVAL RESEARCH LABORATORY---ACOUSTICS DIV.

SERPENT RAY TRACE PROGRAM

SAMPLE TEST CASE
RAY TRACE RUN


SOURCE CHARACTERISTICS

     RANGE (NM)          0.0000
     CONVERSION FACTOR FROM INPUT SOURCE DEPTH UNITS TO METERS IS        0.3048
     SOURCE DEPTH      152.4000 METERS OR     500.0000 INPUT UNITS
     FREQUENCY (CYCLES/SEC)     100.0000
     ANGULAR FREQUENCY (RAD/SEC)       628.3185
     GRP. NO.    INITIAL ANGLE      ANGLE INCREMENT  FINAL ANGLE        GRP PHASE
        1      -30.0000000D        5.0000000D       30.0000000D        0.00000000
     TOTAL NUMBER OF ANGLES =    13
     INTENSITY ON BEAM AXIS (ERGS/SEC/CM2)      1.00000+000
     AXIAL SOURCE LEVEL AT 1 YD (DB)      0.0000
     BEAM TILT ANGLE (DEGREES)          0.0000
     NUMBER OF POINTS IN BEAM PATTERN    2
     OMNIDIRECTIONAL BEAM PATTERN REQUESTED


PRINTOUT RANGE INFORMATION

     USER INPUT     2 RANGE SHOTS
     CONVERSION FACTOR FROM INPUT RANGES TO NM IS        1.0000
     GRP. NO.      INITIAL RNG      RNG INCREMENT      FINAL RNG
        1            0.0000D          50.0000          100.0000
        2          130.0000D           0.0000          130.0000
TOTAL NUMBER OF RANGE PTS =     4
MAXIMUM RANGE (NM)     130.0000
RAY TAPE REQUESTED ON LOGICAL UNIT     2
RAY DEPTH DISTRIBUTION PLOTS REQUESTED AT     3PRINTOUT RANGES
        1          0.0000
        2        100.0000
        3        130.0000
     PLOT DEPTH DISTRIBUTIONS
     PLOT TIME DISTRIBUTION
INTENSITY CALCULATION NOT REQUESTED

BOTTOM LOSS INFORMATION

     REQUESTED BOTTOM TYPE      1
     MAXIMUM NUMBER OF BOTTOM HITS ALLOWED  100


SURFACE LOSS INFORMATION
     SURFACE ATTENUATION COEFFICIENT      1.0000
     MAXIMUM NUMBER OF SURFACE HITS ALLOWED  100


MAXIMUM ITERATION( METERS)    1000.0000
MINIMUM ITERATION( METERS)      20.0000


VELOCITY FIELD ACCURACY TEST EPSILON        0.5000
MAXIMUM SINE CHANGE-SINE INC TEST           0.0200


SAMPLE TEST CASE


DATE  5/25/73
NUMBER OF PROFILES     3
NUMBER OF BOTTOM POINTS     68
MINIMUM DEPTH OF BOTTOM (METERS)    5181.7040
MAXIMUM DEPTH OF BOTTOM (METERS)    6332.6227
MAXIMUM RANGE OF BOTTOM DATA (NM)     178.1939
```

Fig. 22a — The part of the printout of the SERPENT-program ray-trace run giving the sample-test-case input parameters and some coefficient-tape information

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RANGE (NM)= 0.0000

ANG. NO.	ANGLE (DEG)	DEPTH (M)	SINE	TIME (SEC)	NTP	NSM	NBM	PHASE (RAD)
1	-30.0000	152.4000	-0.5000	0.0000	0	0	0	0.0000
2	-29.0000	152.4000	-0.4226	0.0000	0	0	0	0.0000
3	-20.0000	152.4000	-0.3420	0.0000	0	0	0	0.0000
4	-15.0000	152.4000	-0.2588	0.0000	0	0	0	0.0000
5	-10.0000	152.4000	-0.1736	0.0000	0	0	0	0.0000
6	-5.0000	152.4000	-0.0872	0.0000	0	0	0	0.0000
7	0.0000	152.4000	0.0000	0.0000	0	0	0	0.0000
8	5.0000	152.4000	0.0872	0.0000	0	0	0	0.0000
9	10.0000	152.4000	0.1736	0.0000	0	0	0	0.0000
10	15.0000	152.4000	0.2588	0.0000	0	0	0	0.0000
11	20.0000	152.4000	0.3420	0.0000	0	0	0	0.0000
12	25.0000	152.4000	0.4226	0.0000	0	0	0	0.0000
13	30.0000	152.4000	0.5000	0.0000	0	0	0	0.0000

```
                    ********************RAY DISTRIBUTION PLOT********************
        RANGE (NM) =        0.0000
        BOTTOM DEPTH (METERS)=
        TIME LEFT (SECONDS) =       80.7440
        MINIMUM TRAVEL TIME (SECONDS) =       0.0000
        MAXIMUM TRAVEL TIME (SECONDS) =       0.0000
                *= RELATIVE TRAVEL TIME,0=MINIMUM TRAVEL TIME,9= MAXIMUM TRAVEL TIME
                D=RAY DEPTH, B=BOTTOM DEPTH,S= SURFACE
                NUMBERS INDICATE RECEIVER DEPTHS
ANGLE (DEGREES)
     -30.0000     T
     -29.0000     T
     -20.0000     T
     -15.0000     T
     -10.0000     T
      -5.0000     T
       0.0000     T
       5.0000     T
      10.0000     T
      15.0000     T
      20.0000     T
      25.0000     T
      30.0000     T
```

Fig. 22b — The part of the printout of the SERPENT-program ray-trace run giving the ray statistics at 0 nautical miles from the source

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RANGE(NM)      50.0000      BOTTOM DEPTH (METERS)   5404.1495      COMPUTATION TIME LEFT (SEC)      71.3340

RANGE(KM)      92.6000
ANG. NO.  ANGLE (DEG)   DEPTH (M)        SINE        TIME (SEC) NTP  NSN  NB-     PHASE (DEG)
    1      -30.0000     667.1424     -0.4921      47.0739    0    4    4     140.9938
    2      -25.0000     702.4768     -0.4629      47.0330    0    4    4     169.1064
    3      -20.0000    5390.7796      0.1497      63.0719    2    3    2     249.5104
    4      -15.0000    4183.5722      0.2415      63.7619    0    3    2     204.4151
    5      -10.0000    4893.7561     -0.0330      62.0744    2    2    0     157.3655
    6       -5.0000    3463.0405     -0.1812      62.1149    4    0    0     175.0334
    7        0.0000    2486.7019     -0.1220      62.1973    4    0    0     262.0244
    8        5.0000    3294.6149     -0.1179      62.1242    3    0    0     190.9375
    9       10.0000    4651.2219     -0.0329      62.0499    2    1    0     176.7947
   10       15.0000    4442.2526      0.2505      63.7968    0    2    2     287.4564
   11       20.0000    4941.0506     -0.4383      66.5399    0    3    4     176.0232
   12       25.0000    2314.4459     -0.3817      67.4549    0    3    4     355.4599
   13       30.0000     328.1871     -0.4316      67.0773    0    3    4      87.0973

      THE SURFACE AND BOTTOM HITS WHICH OCCURED SINCE THE LAST PRINTOUT RANGE ARE LISTED BELOW.

   TYPE        ANGLE NUMBER      RANGE (NM)      DEPTH (METERS)
 SURFACE HIT       1              8.1447          0.0000      SINE OF INCIDENT ANGLE      =0.4850
 BOTTOM HIT        1              5.2243       5915.1335      SINE OF INCIDENT ANGLE       0.4641      BOTTOM SLOPE      2.86457-002
 SURFACE HIT       1             10.9516          0.0000      SINE OF INCIDENT ANGLE      =0.4375
 BOTTOM HIT        1             16.9305       5723.6889      SINE OF INCIDENT ANGLE       0.4076      BOTTOM SLOPE      3.25977-002
 SURFACE HIT       1             23.8319          0.0000      SINE OF INCIDENT ANGLE      =0.3892
 BOTTOM HIT        1             30.5463       5593.5737      SINE OF INCIDENT ANGLE       0.3518      BOTTOM SLOPE      4.94208-004
 SURFACE HIT       1             37.2749          0.0000      SINE OF INCIDENT ANGLE      =0.3846
 BOTTOM HIT        1             44.0996       5630.4845      SINE OF INCIDENT ANGLE       0.3493      BOTTOM SLOPE     -2.46303-003
 SURFACE HIT       2              8.1844          0.0000      SINE OF INCIDENT ANGLE      =0.4841
 BOTTOM HIT        2              6.4784       5536.9579      SINE OF INCIDENT ANGLE       0.3745      BOTTOM SLOPE     -2.22203-002
 SURFACE HIT       2             12.1895          0.0000      SINE OF INCIDENT ANGLE      =0.4414
 BOTTOM HIT        2             18.1860       5780.3938      SINE OF INCIDENT ANGLE       0.4112      BOTTOM SLOPE      2.46699-002
 SURFACE HIT       2             24.7541          0.0000      SINE OF INCIDENT ANGLE      =0.3977
 BOTTOM HIT        2             31.2432       5594.2116      SINE OF INCIDENT ANGLE       0.3652      BOTTOM SLOPE      4.94208-004
 SURFACE HIT       2             37.7458          0.0000      SINE OF INCIDENT ANGLE      =0.3972
 BOTTOM HIT        2             44.2987       5629.1937      SINE OF INCIDENT ANGLE       0.3632      BOTTOM SLOPE     -2.46303-003
 SURFACE HIT       3              8.2416          0.0000      SINE OF INCIDENT ANGLE      =0.3170
 BOTTOM HIT        3              8.1929       5444.2142      SINE OF INCIDENT ANGLE       0.2773      BOTTOM SLOPE      2.91400-002
 SURFACE HIT       3             17.4016          0.0000      SINE OF INCIDENT ANGLE      =0.2710
 BOTTOM HIT        3             26.9573       5673.1411      SINE OF INCIDENT ANGLE       0.2135      BOTTOM SLOPE      4.24763-002
 SURFACE HIT       3             38.9363          0.0000      SINE OF INCIDENT ANGLE      =0.2142
 SURFACE HIT       4              8.3470          0.0000      SINE OF INCIDENT ANGLE      =0.2224
 BOTTOM HIT        4             11.5860       5561.8076      SINE OF INCIDENT ANGLE       0.1511      BOTTOM SLOPE     -6.91374-003
 SURFACE HIT       4             22.4040          0.0000      SINE OF INCIDENT ANGLE      =0.2326
 BOTTOM HIT        4             33.2285       5560.6858      SINE OF INCIDENT ANGLE       0.1447      BOTTOM SLOPE     -1.53059-002
 SURFACE HIT       4             43.1946          0.0000      SINE OF INCIDENT ANGLE      =0.2558
 SURFACE HIT       5              8.6725          0.0000      SINE OF INCIDENT ANGLE      =0.1099
 SURFACE HIT       5             33.4638          0.0000      SINE OF INCIDENT ANGLE      =0.1142
 SURFACE HIT       9             32.1245          0.0000      SINE OF INCIDENT ANGLE      =0.1123
 BOTTOM HIT       10             16.9211       5570.4828      SINE OF INCIDENT ANGLE       0.1505      BOTTOM SLOPE     -6.91374-003
 SURFACE HIT      10             21.7093          0.0000      SINE OF INCIDENT ANGLE      =0.2328
 BOTTOM HIT       10             32.6464       5577.1868      SINE OF INCIDENT ANGLE       0.1435      BOTTOM SLOPE     -1.53059-002
 SURFACE HIT      10             42.6646          0.0000      SINE OF INCIDENT ANGLE      =0.2591
 BOTTOM HIT       11              7.7139       5486.1168      SINE OF INCIDENT ANGLE       0.2772      BOTTOM SLOPE     -2.22203-002
 SURFACE HIT      11             14.8577          0.0000      SINE OF INCIDENT ANGLE      =0.3535
 BOTTOM HIT       11             22.2641       5659.2543      SINE OF INCIDENT ANGLE       0.3138      BOTTOM SLOPE     -1.77719-002
 SURFACE HIT      11             29.1223          0.0000      SINE OF INCIDENT ANGLE      =0.3035
 BOTTOM HIT       11             35.9143       5597.8548      SINE OF INCIDENT ANGLE       0.3503      BOTTOM SLOPE      9.92705-003
 SURFACE HIT      11             42.4859          0.0000      SINE OF INCIDENT ANGLE      =0.3742
 BOTTOM HIT       11             49.4185       5457.8633      SINE OF INCIDENT ANGLE       0.3422      BOTTOM SLOPE     -4.96777-002
 BOTTOM HIT       12              6.1294       5591.3204      SINE OF INCIDENT ANGLE       0.3741      BOTTOM SLOPE     -2.22203-002
 SURFACE HIT      12             11.8574          0.0000      SINE OF INCIDENT ANGLE      =0.4412
 BOTTOM HIT       12             17.7758       5710.3629      SINE OF INCIDENT ANGLE       0.4111      BOTTOM SLOPE     -1.28323-002
 SURFACE HIT      12             23.7802          0.0000      SINE OF INCIDENT ANGLE      =0.4027
 BOTTOM HIT       12             28.7874       5532.4245      SINE OF INCIDENT ANGLE       0.4382      BOTTOM SLOPE      8.59305-002
 SURFACE HIT      12             36.7619          0.0000      SINE OF INCIDENT ANGLE      =0.3206
 BOTTOM HIT       12             44.9170       5626.5733      SINE OF INCIDENT ANGLE       0.2747      BOTTOM SLOPE     -2.46303-003
 BOTTOM HIT       13              4.0139       5498.6670      SINE OF INCIDENT ANGLE       0.4644      BOTTOM SLOPE      2.86457-002
 SURFACE HIT      13             10.0228          0.0000      SINE OF INCIDENT ANGLE      =0.4384
 BOTTOM HIT       13             16.5770       5702.3458      SINE OF INCIDENT ANGLE       0.4080      BOTTOM SLOPE      3.25977-002
 SURFACE HIT      13             23.4503          0.0000      SINE OF INCIDENT ANGLE      =0.3850
 BOTTOM HIT       13             30.1671       5593.2767      SINE OF INCIDENT ANGLE       0.3509      BOTTOM SLOPE      4.94208-004
 SURFACE HIT      13             36.8077          0.0000      SINE OF INCIDENT ANGLE      =0.3843
 BOTTOM HIT       13             43.6859       5632.1892      SINE OF INCIDENT ANGLE       0.3488      BOTTOM SLOPE     -2.46303-003
```

Fig. 22c — The part of the printout of the SERPENT-program ray-trace run giving the ray statistics at 50 nautical miles from the source

RANGE(NM) 100.0000 BOTTOM DEPTH (METERS) 5785.5083 COMPUTATION TIME LEFT (SEC) 59.7010

RANGE(KM) 185.2000

ANG. NO.	ANGLE (DEG)	DEPTH (M)	SINE	TIME (SEC)	NTP	NSH	NBH	PHASE (DEG)
1	-30.0000	1472.4260	-0.4918	135.9169	0	6	8	247.6975
2	-25.0000	2765.9844	-0.2884	135.5047	0	6	8	169.0893
3	-20.0000	5759.8918	0.1901	129.5494	0	6	5	345.6302
4	-15.0000	5146.5261	0.1510	126.8029	0	5	4	283.2175
5	-10.0000	339.1447	0.2326	124.1813	3	4	0	46.3934
6	-5.0000	3457.1128	0.1007	124.6158	7	0	0	2[illegible].4073
7	0.0000	3402.0536	0.0438	124.6176	7	8	0	2[illegible].7156
8	5.0000	3599.1760	0.0837	124.6216	6	8	0	56.[illegible]46
9	10.0000	1018.1809	0.2744	124.2765	3	3	0	126.8124
10	15.0000	477.1674	0.4076	127.8940	0	9	5	322.3349
11	20.0000	4490.9572	-0.6674	138.5377	0	9	8	275.9686
12	25.0000	5383.5915	0.2215	132.1503	0	6	6	9.8418
13	30.0000	1185.8750	-0.4937	135.9157	0	6	7	26.6333

THE SURFACE AND BOTTOM HITS WHICH OCCURED SINCE THE LAST PRINTOUT RANGE ARE LISTED BELOW.

TYPE	ANGLE NUMBER	RANGE (NM)	DEPTH (METERS)				
SURFACE HIT	1	50.7669	0.0000	SINE OF INCIDENT ANGLE	-0.3890		
BOTTOM HIT	1	57.6499	5751.7814	SINE OF INCIDENT ANGLE	0.3500	BOTTOM SLOPE	-2.46824-002
SURFACE HIT	2	50.7789	0.0000	SINE OF INCIDENT ANGLE	-0.4016		
BOTTOM HIT	2	57.4421	5761.2814	SINE OF INCIDENT ANGLE	0.3641	BOTTOM SLOPE	-2.46824-002
BOTTOM HIT	3	56.0757	5401.0014	SINE OF INCIDENT ANGLE	0.1481	BOTTOM SLOPE	-4.59777-002
SURFACE HIT	3	50.7736	0.0000	SINE OF INCIDENT ANGLE	-0.2034		
BOTTOM HIT	4	52.5147	5311.2342	SINE OF INCIDENT ANGLE	0.2087	BOTTOM SLOPE	2.46826-002
BOTTOM HIT	10	51.9488	5292.1432	SINE OF INCIDENT ANGLE	0.2095	BOTTOM SLOPE	-1.67920-002
SURFACE HIT	11	54.9044	0.0000	SINE OF INCIDENT ANGLE	-0.4513		
SURFACE HIT	12	52.9685	0.0000	SINE OF INCIDENT ANGLE	-0.3252		
SURFACE HIT	13	50.3975	0.0000	SINE OF INCIDENT ANGLE	-0.3886		
BOTTOM HIT	13	57.3056	5767.5230	SINE OF INCIDENT ANGLE	0.3493	BOTTOM SLOPE	-2.46824-002
SURFACE HIT	1	63.8209	0.0000	SINE OF INCIDENT ANGLE	-0.4297		
BOTTOM HIT	1	69.8918	5671.0944	SINE OF INCIDENT ANGLE	0.3977	BOTTOM SLOPE	4.74135-002
SURFACE HIT	1	77.4117	0.0000	SINE OF INCIDENT ANGLE	-0.3525		
BOTTOM HIT	1	84.4562	5378.8262	SINE OF INCIDENT ANGLE	0.3189	BOTTOM SLOPE	-6.42042-002
SURFACE HIT	1	89.7440	0.0000	SINE OF INCIDENT ANGLE	-0.4429		
BOTTOM HIT	1	95.4544	5756.5729	SINE OF INCIDENT ANGLE	0.4291	BOTTOM SLOPE	1.08651-002
SURFACE HIT	2	63.4245	0.0000	SINE OF INCIDENT ANGLE	-0.4390		
BOTTOM HIT	2	69.7296	5612.9447	SINE OF INCIDENT ANGLE	0.4131	BOTTOM SLOPE	4.74135-002
SURFACE HIT	2	76.4015	0.0000	SINE OF INCIDENT ANGLE	-0.3646		
BOTTOM HIT	2	83.4052	5503.8023	SINE OF INCIDENT ANGLE	0.3785	BOTTOM SLOPE	-6.42042-002
SURFACE HIT	2	88.4837	0.0000	SINE OF INCIDENT ANGLE	-0.4713		
BOTTOM HIT	2	93.8565	5406.8118	SINE OF INCIDENT ANGLE	0.4484	BOTTOM SLOPE	1.53196-001
BOTTOM HIT	3	67.7328	5514.1623	SINE OF INCIDENT ANGLE	0.2727	BOTTOM SLOPE	-1.26371-001
SURFACE HIT	3	72.7708	0.0000	SINE OF INCIDENT ANGLE	-0.4982		
BOTTOM HIT	3	78.4013	[illegible].5800	SINE OF INCIDENT ANGLE	0.4558	BOTTOM SLOPE	1.52544-001
SURFACE HIT	3	89.4441	0.0000	SINE OF INCIDENT ANGLE	-0.2645		
SURFACE HIT	4	63.1718	0.0000	SINE OF INCIDENT ANGLE	-0.2193		
BOTTOM HIT	4	75.6681	5792.4239	SINE OF INCIDENT ANGLE	0.1203	BOTTOM SLOPE	1.58049-002
SURFACE HIT	4	89.2703	0.0000	SINE OF INCIDENT ANGLE	-0.2057		
SURFACE HIT	5	66.7282	0.0000	SINE OF INCIDENT ANGLE	-0.1164		
SURFACE HIT	5	98.9124	0.0000	SINE OF INCIDENT ANGLE	-0.1195		
SURFACE HIT	9	64.8698	0.0000	SINE OF INCIDENT ANGLE	-0.1164		
SURFACE HIT	9	97.9883	0.0000	SINE OF INCIDENT ANGLE	-0.1206		
SURFACE HIT	10	68.4278	0.0000	SINE OF INCIDENT ANGLE	-0.2876		
BOTTOM HIT	10	69.7421	5657.9477	SINE OF INCIDENT ANGLE	0.2246	BOTTOM SLOPE	4.74135-002
SURFACE HIT	10	81.7066	0.0000	SINE OF INCIDENT ANGLE	-0.2190		
BOTTOM HIT	10	92.3201	5288.8084	SINE OF INCIDENT ANGLE	0.1603	BOTTOM SLOPE	-7.93365-002
SURFACE HIT	10	99.3679	0.0000	SINE OF INCIDENT ANGLE	-0.3444		
BOTTOM HIT	11	60.6618	5690.4389	SINE OF INCIDENT ANGLE	0.4216	BOTTOM SLOPE	-8.00081-003
SURFACE HIT	11	66.2097	0.0000	SINE OF INCIDENT ANGLE	-0.4665		
BOTTOM HIT	11	71.7504	5686.2482	SINE OF INCIDENT ANGLE	0.4377	BOTTOM SLOPE	2.37069-002
SURFACE HIT	11	77.8800	0.0000	SINE OF INCIDENT ANGLE	-0.4276		
BOTTOM HIT	11	83.7348	5464.6083	SINE OF INCIDENT ANGLE	0.4000	BOTTOM SLOPE	-6.42042-002
SURFACE HIT	11	88.2188	0.0000	SINE OF INCIDENT ANGLE	-0.5332		
BOTTOM HIT	11	92.5200	5260.7602	SINE OF INCIDENT ANGLE	0.5173	BOTTOM SLOPE	-7.93365-002
SURFACE HIT	11	95.4859	0.0000	SINE OF INCIDENT ANGLE	-0.6561		
BOTTOM HIT	11	99.1977	5799.4489	SINE OF INCIDENT ANGLE	0.6400	BOTTOM SLOPE	-9.34243-003
BOTTOM HIT	12	61.1369	5686.0344	SINE OF INCIDENT ANGLE	0.2770	BOTTOM SLOPE	7.98228-003
SURFACE HIT	12	69.4250	0.0000	SINE OF INCIDENT ANGLE	-0.3134		
BOTTOM HIT	12	79.3943	6291.6080	SINE OF INCIDENT ANGLE	0.2345	BOTTOM SLOPE	3.35893-002
SURFACE HIT	12	98.3262	0.0000	SINE OF INCIDENT ANGLE	-0.2712		
SURFACE HIT	13	63.4990	0.0000	SINE OF INCIDENT ANGLE	-0.4295		
BOTTOM HIT	13	69.9340	5639.7430	SINE OF INCIDENT ANGLE	0.3983	BOTTOM SLOPE	4.74135-002
SURFACE HIT	13	77.0087	0.0000	SINE OF INCIDENT ANGLE	-0.3570		
BOTTOM HIT	13	84.1239	5418.3372	SINE OF INCIDENT ANGLE	0.3171	BOTTOM SLOPE	-6.42042-002
SURFACE HIT	13	89.4632	0.0000	SINE OF INCIDENT ANGLE	-0.4592		
BOTTOM HIT	13	95.1783	5751.0168	SINE OF INCIDENT ANGLE	0.4284	BOTTOM SLOPE	1.08651-002

```
**********************RAY DISTRIBUTION PLOT**********************
RANGE (NM) =      100.0000
BOTTOM DEPTH (METERS)=   5785.5083
TIME LEFT (SECONDS) =       58.6980
MINIMUM TRAVEL TIME (SECONDS) =     124.1813
MAXIMUM TRAVEL TIME (SECONDS) =     138.5377
          T= RELATIVE TRAVEL TIME,B=MINIMUM TRAVEL TIME,S= MAXIMUM TRAVEL TIME
          D=RAY DEPTH, B=BOTTOM DEPTH,S= SURFACE
          NUMBERS INDICATE RECEIVER DEPTHS
ANGLE (DEGREES)
   -30.0000     S           T    D                                          B
   -25.0000     S            T                      T                       E
   -20.0000     S                                         T                 C
   -15.0000     S                                                 T    r    E
   -10.0000     S   D                                                       I
    -5.0000     S                                        D                * H
     0.0000     S                                         :               . E
     5.0000     S                                         D               T I
    10.0000     S          D                                               TV
    15.0000     S    D                                          T           E
    20.0000     T                                                 D       . R
    25.0000     S                                   T                    D  S
    30.0000     S           T D                                             I
************************************************************************
```

Fig. 22d — The part of the printout of the SERPENT-program ray-trace run giving the ray statistics at 100 nautical miles from the source

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*****************************************************************************************
RANGE(NM)     130.0000      BOTTOM DEPTH (METERS)   5448.4012     COMPUTATION TIME LEFT (SEC)     57.1410

RANGE(KM)     240.7600
AVG. NO.  ANGLE (DEG)   DEPTH (M)        SINE          TIME (SEC) NTP  NSH  NBH     PHASE (DEG)
   1       -30.0000    5102.8734      -0.2946        174.9549    0   10   10        141.7505
   2       -25.0000    2949.9537       0.3714        174.2036    0   10    9        120.4486
   3       -20.0000     516.2477       0.3787        148.1431    0    8    7        112.2551
   4       -15.0000     879.2237      -0.3854        165.1840    0    6    6        145.4678
   5       -10.0000     544.4034      -0.2447        161.4413    4    4    0         45.8181
   6        -5.0000    3496.4356       0.0958        161.9495    0    0    0        342.4168
   7         0.0000    3536.9711       0.0251        161.9727    9    0    0         87.8887
   8         5.0000    3631.7253       0.0787        161.4882    8    0    0        160.3841
   9        10.0000      39.6941      -0.1213        146.8191    4    3    0        114.8492
  10        15.0000    3381.0054       0.2492        183.7215    0    4    6        326.8203
  11        20.0000     109.0341       0.6092        170.8042    0   17   12         53.1812
  12        25.0000     560.3698       0.3889        174.8955    0    8    0        151.9879
  13        30.0000    5034.9736      -0.2958                    0    8    9         16.3844

      THE SURFACE AND BOTTOM HITS WHICH OCCURED SINCE THE LAST PRINTOUT RANGE ARE LISTED BELOW.

   TYPE        ANGLE NUMBER     RANGE (NM)     DEPTH (METERS)
SURFACE HIT        1          101.4326          0.0000     SINE OF INCIDENT ANGLE    +0.4431    0.4911    BOTTOM SLOPE    1.20345-001
BOTTOM HIT         1          107.8189       6091.2927     SINE OF INCIDENT ANGLE    +0.2565    0.1038    BOTTOM SLOPE   -4.58377-002
SURFACE HIT        1          119.5343          0.0000     SINE OF INCIDENT ANGLE    +0.2268    0.1094    BOTTOM SLOPE   -8.38243-002
BOTTOM HIT         1          129.4393       5496.0957     SINE OF INCIDENT ANGLE    +0.3358    0.1466    BOTTOM SLOPE   -9.38243-003
SURFACE HIT        2          104.4017          0.0000     SINE OF INCIDENT ANGLE    +0.7772    0.2012    BOTTOM SLOPE   -2.12390-002
BOTTOM HIT         2          117.6971       5998.1527     SINE OF INCIDENT ANGLE    +0.3683    0.1044    BOTTOM SLOPE   -5.33328-002
SURFACE HIT        2          120.7556          0.0000     SINE OF INCIDENT ANGLE    +0.7743    0.2008    BOTTOM SLOPE   -2.12390-002
BOTTOM HIT         3          100.4684       5794.3208     SINE OF INCIDENT ANGLE    +0.7080    0.2059    BOTTOM SLOPE    1.20345-001
SURFACE HIT        3          109.9572          0.0000     SINE OF INCIDENT ANGLE    +0.6697    0.6563    BOTTOM SLOPE    1.38786-001
BOTTOM HIT         3          120.1152       5848.3525     SINE OF INCIDENT ANGLE    -0.4544    0.4163    BOTTOM SLOPE   -8.38243-002
SURFACE HIT        3          129.7425          0.0000     SINE OF INCIDENT ANGLE    -0.9846    0.5473    BOTTOM SLOPE   -1.13592-002
BOTTOM HIT         4          137.1500       5659.8504     SINE OF INCIDENT ANGLE    +0.6042    0.2909    BOTTOM SLOPE   -9.38243-003
SURFACE HIT        4          111.4319          0.0000     SINE OF INCIDENT ANGLE    +0.2602    0.2134    BOTTOM SLOPE   -2.12390-002
BOTTOM HIT         4          121.9160       5615.4139     SINE OF INCIDENT ANGLE    +0.3173    0.4424    BOTTOM SLOPE    1.20345-001
SURFACE HIT       10          107.7830       4077.6424     SINE OF INCIDENT ANGLE    +0.4473    0.2535    BOTTOM SLOPE   -4.58337-002
BOTTOM HIT        10          123.9284          0.0000     SINE OF INCIDENT ANGLE    +0.2535    0.1481
SURFACE HIT       11          102.9675          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        11          105.8523       5598.6672     SINE OF INCIDENT ANGLE
SURFACE HIT       11          111.4081          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        11          117.9722       5017.5691     SINE OF INCIDENT ANGLE
SURFACE HIT       11          121.9414          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        11          126.8164       5847.5228     SINE OF INCIDENT ANGLE
SURFACE HIT       11          129.9224          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        12          108.9676       5746.7819     SINE OF INCIDENT ANGLE
SURFACE HIT       12          110.9324          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        12          120.3620       5876.6421     SINE OF INCIDENT ANGLE
SURFACE HIT       12          129.7245          0.0000     SINE OF INCIDENT ANGLE
SURFACE HIT       12          101.1618          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        13          107.4542       6303.6995     SINE OF INCIDENT ANGLE
SURFACE HIT       13          119.8271          0.0000     SINE OF INCIDENT ANGLE
BOTTOM HIT        13          129.1192       5523.4095     SINE OF INCIDENT ANGLE

                    ********************RAY DISTRIBUTION PLOT********************

      RANGE (NM) =      130.0000
      BOTTOM DEPTH (METERS)=   5448.4012
      TIME LEFT (SECONDS) =      51.4640
      MINIMUM TRAVEL TIME (SECONDS) =    161.4413
      MAXIMUM TRAVEL TIME (SECONDS) =    183.7215
              TM RELATIVE TRAVEL TIME,RMINIMUM TRAVEL TIME,SM MAXIMUM TRAVEL TIME
              DARAY DEPTH, 0=BOTTOM DEPTH,S= SURFACE
              NUMBERS INDICATE RECEIVER DEPTHS
ANGLE (DEGREES)
    -30.0000   S
    -25.0000   S
    -20.0000   S        D
    -15.0000   S         D
    -10.0000   S          C
     -5.0000   S
      0.0000   S
      5.0000   S
     10.0000   SD
     15.0000   S
     20.0000   T D
     25.0000   S          C
     30.0000   S
      NUMBER OF PARGRAM RT200
      TSTART     8.755000000+001        51.6370
      TEND       5.183400000+001        51.6270
      TELL       3.651200000+001        51.6180
```

Fig. 22e — The part of the printout of the SERPENT-program ray-trace run giving the ray statistics at 130 nautical miles from the source

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```
SAMPLE TEST CASE
TRANSMISSION LOSS RUN
.3048 500 100 1  1 -30 30 0 1 0 0 1 1 1 0 130 0 0 0 2 3 0 1 1 130
0 0 1 1 .3048 2500 2 2 0 2 11 2 20 5.25 30 7.75 40 9.75 55 12 90 12
0. 4. 5. 4. 7.5 5.2 10 7 15 10.8 17.5 12.7 20 13.2 25 14 90 14
1 20 1 130 2 -1 100 1 100 1000 20 .5 .02
```

Fig. 23 — Sample-test-case input data cards for the SERPENT-program transmission-loss run

because it is so small at this frequency. The rays were allowed to experience a maximum of 100 surface or bottom hits before being terminated. DELMAX, DELMIN, VFAEPS and DELSINMX were set to values which, in the past, have led to reasonable calculations, namely, 1000, 20, 0.5, and 0.02 respectively.

Figures 24a and 24b show sections of the resulting printer output. For this case we chose to print out the transmission-loss values. As a result, the program ran slower than it would have had they not been printed. The initial conditions for angles 12 through 49 and the intensities corresponding to ranges 7 through 127 nautical miles are not shown in Fig. 24b.

The printout shown in Fig. 24b indicates that when the rays had reached a range of 2 nautical miles, there were 238.5510 seconds left before the program would exceed the allotted time. It also indicates that there is only one receiver at a depth of 762 meters. A statistical (Type II) intensity calculation was carried out for this receiver, and 61 rays were included in the statistical computation. The resulting intensity (INT) was approximately 1.07×10^{-7} ergs/s cm^2. This corresponds to a measured sound level (MSL) of −69.6921 dB or a transmission loss (TLOSS) of 69.6921 dB. The corresponding transmission anomaly is −2.4586 dB. Similar information is printed for each of the printout ranges.

The bottom of Fig. 24b indicates that the program (RT 200 alias SERPENT) had 247.8 seconds (TSTART) available for computation when it began execution and had 89.7 seconds left when it finished execution. The elapsed execution time TDEL = (TSTART − TEND) was 158 seconds.

7. GENERATING RAY DIAGRAMS

7.1 Program Summary

Title of program: RAPLOT

Computer: CDC 3800. Installation: NRL

Operating system: Drum Scope 2.1

Programming language: Fortran 63

High-speed store required: 12,118 (decimal) words exclusive of system routines.

Number of bits in a word: 48

Is program overlaid? No

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U.S. NAVAL RESEARCH LABORATORY---ACOUSTICS DIV.

SERPENT RAY TRACE PROGRAM

SAMPLE TEST CASE
TRANSMISSION LOSS RUN


SOURCE CHARACTERISTICS

     RANGE (NM)          0.0000
     CONVERSION FACTOR FROM INPUT SOURCE DEPTH UNITS TO METERS IS        0.3048
     SOURCE DEPTH      197.0000 METERS OR    564.0000 INPUT UNITS
     FREQUENCY (CYCLES/SEC)      100.0000
     ANGULAR FREQUENCY (RAD/SEC)      628.3185
     GRP. NO.   INITIAL ANGLE      ANGLE INCREMENT  FINAL ANGLE        GRP PHASE
        1      -30.0000000        1.00000000       30.00000000        0.00000000
     TOTAL NUMBER OF ANGLES =    61
     INTENSITY ON REAR AXIS (ERGS/SEC/CM2)      1.00000+000
     AXIAL SOURCE LEVEL AT 1 YD (DB)          0.0000
     BEAM TILT ANGLE (DEGREES)      0.0000
     NUMBER OF POINTS IN BEAM PATTERN      0
     BIDIRECTIONAL BEAM PATTERN REQUESTED


PRINTOUT RANGE INFORMATION

     USER INPUT     1 RANGE GROUPS
     CONVERSION FACTOR FROM INPUT RANGES TO NM IS        1.0000
     GRP. NO.      INITIAL RAD      RAD INCREMENT      FINAL RAD
        1           0.00000          1.00000          130.00000
TOTAL NUMBER OF RANGE PTS =  131
MAXIMUM RANGE (NM)      130.0000
     INDIVIDUAL RAY STATISTICS WILL NOT BE PRINTED
NO RAY TAPE REQUESTED
RAY DISTRIBUTION PLOTS NOT REQUESTED
INTENSITY CALCULATIONS AND PRINTOUT REQUESTED
LOGICAL UNIT FOR TRANSMISSION LOSSES = 3
     VOLUME ATTENUATION NOT REQUESTED
     NUMBER OF INTENSITY REGIONS     1
     REGION RANGE   TYPE I RANDOM,   TYPE I COHERENT,   TYPE II
        130.0000       0                 0                 1

RECEIVER INFORMATION

     NUMBER OF RECEIVER DEPTHS     1
     NO.       DEPTH (METERS)    DEPTH (INPUT UNITS)
        1         762.0000        2500.0000


BOTTOM LOSS INFORMATION

     REQUESTED BOTTOM TYPE     2
          2 BOTTOM LOSS TABLES WERE INPUT

          TABLE     1
               GRAZING ANGLE (DEG) VS LOSS (DB)

                    0   2.000   1   2.000   2   2.000   3   2.000   4   2.000
                    5   2.000   6   2.000   7   2.000   8   2.000   9   2.000
                   10   2.000  11   2.000  12   2.301  13   2.772  14   3.003
                   15   3.444  16   3.806  17   4.147  18   4.526  19   4.889
                   20   5.250  21   5.508  22   5.798  23   6.000  24   6.250
                   25   6.500  26   6.750  27   7.000  28   7.250  29   7.500
                   30   7.750  31   7.950  32   8.150  33   8.350  34   8.550
                   35   8.750  36   8.950  37   9.150  38   9.350  39   9.550
                   40   9.750  41   9.900  42  10.050  43  10.200  44  10.350
                   45  10.500  46  10.650  47  10.800  48  10.950  49  11.100
                   50  11.250  51  11.400  52  11.550  53  11.700  54  11.850
                   55  12.000  56  12.000  57  12.000  58  12.000  59  12.000
                   60  12.000  61  12.000  62  12.000  63  12.000  64  12.000
                   65  12.000  66  12.000  67  12.000  68  12.000  69  12.000
                   70  12.000  71  12.000  72  12.000  73  12.000  74  12.000
                   75  12.000  76  12.000  77  12.000  78  12.000  79  12.000
                   80  12.000  81  12.000  82  12.000  83  12.000  84  12.000
                   85  12.000  86  12.000  87  12.000  88  12.000  89  12.000
                   90  12.000

          TABLE     2
               GRAZING ANGLE (DEG) VS LOSS (DB)

                    0   4.000   1   4.000   2   4.000   3   4.000   4   4.000
                    5   4.000   6   4.000   7   4.000   8   5.500   9   6.200
                   10   7.000  11   7.750  12   8.570  13   9.286  14  10.040
                   15  10.800  16  11.500  17  12.320  18  12.800  19  13.000
                   20  13.200  21  13.300  22  13.570  23  13.600  24  13.800
                   25  14.000  26  14.000  27  14.000  28  14.000  29  14.000
                   30  14.000  31  14.000  32  14.000  33  14.000  34  14.000
                   35  14.000  36  14.000  37  14.000  38  14.000  39  14.000
                   40  14.000  41  14.000  42  14.000  43  14.000  44  14.000
                   45  14.000  46  14.000  47  14.000  48  14.000  49  14.000
                   50  14.000  51  14.000  52  14.000  53  14.000  54  14.000
                   55  14.000  56  14.000  57  14.000  58  14.000  59  14.000
                   60  14.000  61  14.000  62  14.000  63  14.000  64  14.000
                   65  14.000  66  14.000  67  14.000  68  14.000  69  14.000
                   70  14.000  71  14.000  72  14.000  73  14.000  74  14.000
                   75  14.000  76  14.000  77  14.000  78  14.000  79  14.000
                   80  14.000  81  14.000  82  14.000  83  14.000  84  14.000
                   85  14.000  86  14.000  87  14.000  88  14.000  89  14.000
                   90  14.000
          USE BOTTOM LOSS TABLE   1 TO     20.0000 (NAUTICAL MILES) OR     20.0000 (INPUT UNITS)
          USE BOTTOM LOSS TABLE   2 TO    130.0000 (NAUTICAL MILES) OR    130.0000 (INPUT UNITS)
     MAXIMUM NUMBER OF BOTTOM HITS ALLOWED  100


SURFACE LOSS INFORMATION
     SURFACE ATTENUATION COEFFICIENT       1.0000
     MAXIMUM NUMBER OF SURFACE HITS ALLOWED  100


MAXIMUM ITERATIONS (METERS)     1000.0000
MINIMUM ITERATIONS (METERS)       20.0000


VELOCITY FIELD ACCURACY TEST EPSILON        0.5000
MAXIMUM SINE CHANGE-SINE INC TEST           0.0200
```

Fig. 24a — The part of the printout of the SERPENT-program transmission-loss run giving the sample-test-case input parameters, including bottom-loss curves

```
SAMPLE TEST CASE

DATE  5/25/73
NUMBER OF PROFILES     3
NUMBER OF BOTTOM POINTS     66
MINIMUM DEPTH OF BOTTOM (METERS)    3181.2040
MAXIMUM DEPTH OF BOTTOM (METERS)    6332.6227
MAXIMUM RANGE OF BOTTOM DATA (NM)    176.1519

      RANGE (NM)=      0.0000
ANG. NO.  ANGLE (DEG)   DEPTH (M)        SINF        TINF (SEC) WTP  XSN  XBW    PWASE (RAD)
    1      -30.0000    152.4000       -0.5009        0.0000    0    0    0        0.0000
    2      -29.0000    152.4000       -0.4940        0.0000    0    0    0        0.0000
    3      -28.0000    152.4000       -0.4695        0.0000    0    0    0        0.0000
    4      -27.0000    152.4000       -0.4540        0.0000    0    0    0        0.0000
    5      -26.0000    152.4000       -0.4364        0.0000    0    0    0        0.0000
    6      -25.0000    152.4000       -0.4226        0.0000    0    0    0        0.0000
    7      -24.0000    152.4000       -0.4067        0.0000    0    0    0        0.0000
    8      -23.0000    152.4000       -0.3997        0.0000    0    0    0        0.0000
    9      -22.0000    152.4000       -0.3946        0.0000    0    0    0        0.0000
   10      -21.0000    152.4000       -0.3504        0.0000    0    0    0        0.0000
   11      -20.0000    152.4000       -0.3475        0.0000    0    0    0        0.0000
   29       18.0000    152.4000        0.3040        0.0000    0    0    0        0.0000
   30       19.0000    152.4000        0.3256        0.0000    0    0    0        0.0000
   31       20.0000    152.4000        0.3428        0.0000    0    0    0        0.0000
   32       21.0000    152.4000        0.3584        0.0000    0    0    0        0.0000
   33       22.0000    152.4000        0.3746        0.0000    0    0    0        0.0000
   34       23.0000    152.4000        0.3997        0.0000    0    0    0        0.0000
   35       24.0000    152.4000        0.4067        0.0000    0    0    0        0.0000
   36       25.0000    152.4000        0.4226        0.0000    0    0    0        0.0000
   37       26.0000    152.4000        0.4364        0.0000    0    0    0        0.0000
   38       27.0000    152.4000        0.4540        0.0000    0    0    0        0.0000
   39       28.0000    152.4000        0.4695        0.0000    0    0    0        0.0000
   40       29.0000    152.4000        0.4840        0.0000    0    0    0        0.0000
   41       30.0000    152.4000        0.5009        0.0000    0    0    0        0.0000

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      1.0000
      TIME LEFT (SECONDS)     2395.5000
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   2.722404001-007      -69.6434        69.6434       -8.4867

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      2.0000
      TIME LEFT (SECONDS)     2390.9510
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   1.873470176-007      -69.4021        69.4021       -2.4588

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      3.0000
      TIME LEFT (SECONDS)     2387.0124
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   4.469254964-008      -73.4976        73.4976       -2.1749

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      4.0000
      TIME LEFT (SECONDS)     2383.3030
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   1.058490264-008      -77.5246        77.5246       -0.9446

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      5.0000
      TIME LEFT (SECONDS)     2380.0440
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   0.995548103-009      -81.9518        81.9518        1.4423

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)      6.0000
      TIME LEFT (SECONDS)     2367.1000
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        61   2.412084097-009      -86.1741        86.1741        4.4830

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)    128.0000
      TIME LEFT (SECONDS)     93.8220
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        60   2.859239021-010      -94.4629        94.4629       -11.4113

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)    129.0000
      TIME LEFT (SECONDS)     91.8670
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        60   2.418262441-010      -94.1650        94.1650       -12.1769

                    ********************INTENSITY CALCULATIONS********************
      RANGE (NM)    130.0000
      TIME LEFT (SECONDS)     89.8530
NO. REC  DEPTH (M)  TYPE  NO. ARRIV  INT (ERGS/SEC/SQCM)  MSL (DB)        TLOSS (DB)  TANGP (DB)
  1      762.0000   II        60   2.359668652-010      -95.9080        95.9080       -12.5010
      END OF PROGRAM RT200
      YSTART      2.478118000-002        89.7250
      YEND        0.972008000-001        89.7175
      YLEN        1.580819000-002        89.7080
```

Fig. 24b — The part of the printout of the SERPENT-program transmission-loss run giving coefficient-tape information, initial ray angles at the source, and intensities and transmission losses at 1-nautical-mile increments

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Number of magnetic tapes required: one for the ray-statistics tape plus one if Gerber plots are requested.

What other peripherals are required: disk (for program storage), card reader, printer, and Gerber plotter or Calcomp 565 plotter.

Number of cards in program deck: 573

Card punching code: BCD

Nature of Physical Problem

To generate plots of ray depth versus range.

Method of Solution

See Section 3.2 of Volume 1.

Restrictions on Complexity of Problem

The length of the ordinate (depth) axis is fixed at 9 inches.

Typical Running Time

It took approximately 47 seconds to load the RAPLOT object deck from the disk and execute the sample problem of Section 7.3.

7.2 Input

7.2.1 Control Cards and Job-Request Forms for Calcomp Plots

The *control cards* required for obtaining Calcomp ray plots are shown in Fig. 25. The format for these cards was discussed earlier.

The *job-request form* should be filled out as shown in Fig. 3. In addition the user should:

1. Indicate that type 00 chart paper will be used and the approximate length of the plot (30 inches for the sample test case). The number of plots should equal the input parameter NPLOTS described in Section 7.2.3.

2. Indicate in the second logical-unit-number box that logical unit 1 is an input tape to be saved. This logical unit corresponds to the ray-statistics tape generated by SERPENT. Its serial number should be inserted in the appropriate space.

7.2.2 Control Cards and Job-Request Forms for Gerber Plots

The *control cards* required for obtaining Gerber ray plots are shown in Fig. 26.

The *job-request form* should be filled out as shown in Fig. 3. In addition the user should:

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	Job		request form
79	JOB,	X	XXXXXX, XXXXXX, 12
79	EQUIP,		20 = DF
79	EQUIP,		5 = PL
79	EQUIP,		1 = (RAYTAPE, 1, 11, 999), LQ, DA
79	DISKL		ØAD
	20		1
RAPLOT			41 RØJ21 251 1
	end-of-file card		
	end-of-file card		
79	LØAD,		25 1
79	RUN,		2, 3500
			data cards
	end-of-file card		

Fig. 25 — Control cards for the RAPLOT program for obtaining the Calcomp-plot output

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	TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
1		Job		request form
2	79	JØB,	X	XXXXXXXX, XXXXXX, 2
3	79	EØUIP		, 20 = DF
4	79	EØUIP		, 48 = (CALCØMP/GERBER), HI, RØ
5	79	EØUIP		, 18 = **, HI
6	79	EØUIP		, 1 = (RAYTAPE, 1, 1, 999), LØ, DA
7	79	DISK	LØAD	
8		20		11
9	RAPLØT		6	4 R9J2 25 1
10		end	- of	- file card
11		end	- of	- file card
12	79	LØAD,	25	
13	79	RUN,	2, 3500	
14				data cards for RAPLØT program
15		end	- of	- file card
16				
17				

Fig. 26 — Control cards for the RAPLOT program for obtaining Gerber plots

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1. Perform step 2 of Section 7.2.1.

2. Indicate in the third logical-unit-number box that logical unit 48 is an input tape to be saved and specify 3803 as its serial number. This tape contains the Gerber plotter routines.

3. Indicate in the fourth logical-unit-number box that logical unit 18 is an output tape to be saved and insert its serial number. This tape will contain the output Gerber plots for plotting at an off-line facility.

7.2.3 Data Cards

The following numbers are read in by the general-purpose input routine, with the exceptions of the parameters PLTIT, XTIT, and YTIT, which require full 80-column cards. The numbers should be entered in the following order:

NPLOTS	the total number of separate ray plots to be generated. This is the only number allowed on the first data card.
PLTIT	a plot title (the entire second data card). This title will be written on the top of the ray plot.
XTIT	an abscissa-axis title, such as RANGE (NM). This title uses the entire third data card.
YTIT	an ordinate-axis title, such as DEPTH (METERS). This title uses the entire fourth data card.
XLNGTH	length of the abscissa axis in inches. (The length of the ordinate is fixed at 9 inches.)
XMPIN	the number of meters per inch along the abscissa axis.
XUPIN	the number of graph units per inch along the abscissa axis. This parameter sets up the scale for the abscissa axis and allows the user to illustrate his ray diagrams in whichever units he chooses: nautical miles, kiloyards, etc.
YMPIN	the number of meters per inch along the ordinate axis.
YUPIN	the number of graph units per inch along the ordinate axis.
NGRPS	the number of ray groups. If NGRPS is 0, all of the rays on the ray tape will be plotted.

The following two parameters will be entered for each of the NGRPS ray groups. If NGRPS is 0 these parameters are not entered.

INIT	the initial ray angle number for the group. The angle numbers referred to here are the angle numbers printed by SERPENT (Fig. 22b, first column). If a group has only one ray, INIT should be set to minus the ray angle number and the parameter FIN omitted.
FIN	the final ray angle number for the group.

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The preceding parameters with the exception of NPLOTS, namely PLTIT, XTIT, ..., FIN, are repeated for each plot to be generated. Thus the user can plot different sets of ray angles on separate plots. The user should also note that

XLNGTH X XMPIN = total illustrated length of plot in meters,

XLNGTH X XUPIN = total illustrated length of plot in units given in XTIT,

and

XMPIN/XUPIN = number of meters per graph unit.

For example, if the user desires to generate a plot showing 10 nautical miles per inch and having a total length of 30 inches, he would set XTIT = RANGE (NM), XMPIN = 18520, XLNGTH = 30, and XUPIN = 10.

7.3 Sample Input and Output

Figure 27 shows the data cards required for generating the printer output shown in Fig. 28 and the Calcomp plot shown in Fig. 29. In this example we chose to plot all of the traced rays, rather than select out specific rays, for a distance of 130 nautical miles. Since the depth axis has a length of 9 inches and the maximum bottom depth in this example is 6332.6 meters, we set YMPIN to 704 (9 X 704 = 6336). Since all of the rays were traced, NGRPS was set to 0.

```
1
SAMPLE TEST CASE.13 RAYS FROM -30 TO 30 DEGREES IN 5 DEGREE STEPS
RANGE (NAUTICAL MILES)
DEPTH (METERS)
13 18520 10 704 704 0
```

Fig. 27 — Sample-test-case input data cards for the RAPLOT program for obtaining the Calcomp-plot output

8. GENERATING TRANSMISSION-LOSS PLOTS

8.1 Program Summary

Title of program: LOSSPLOT

Computer: CDC 3800. Installation: NRL

Operating System: Drum Scope 2.1

Programming language: Fortran 63

High-speed store required: 19,543 (decimal) words exclusive of system routines

Number of bits per word: 48

Is program overlaid? No

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```
USER REQUESTED    1PLOTS

SAMPLE TEST CASE

INITIAL SOURCE RANGE (NM)=        0.0000
INITIAL SOURCE DEPTH (M) =      152.4000
INC FREQ (RAD/SEC) =      628.3185
FREQUENCY (HZ) =     100.0000
NUMBER OF ANGLES =    13
INITIAL SOURCE LEVEL (DB)=        0.0000
ANGLES BY RAYS ARE --
-30.0000      -25.0000      -20.0000      -15.0000      -10.0000
-5.0000        0.0000        5.0000       10.0000       15.0000
20.0000       25.0000       30.0000
     BOTTOM RANGE (NM)  BOTTOM DEPTH (M)

          0.0000          5342.3367
          2.0011          5313.8525
          4.0027          5450.9281
          6.0038          5504.4888
          8.0054          5474.1185
         10.0065          5502.1124
         12.0076          5556.4888
         14.0083          5602.7804
         16.0104          5668.1378
         17.0109          5728.5417
         18.0120          5734.9504
         20.0131          5803.9895
         22.0142          5868.1378
         23.0153          5635.1886
         24.0158          5972.0544
         25.0163          5985.7751
         26.0169          5549.1824

         90.0588          5622.[illegible]
         93.0610          5181.2640
         95.0621          5748.6799
         97.0632          5788.0462
         99.0648          5801.7579
        101.0659          5766.9864
        104.0681          5470.4553
        105.0687          5397.2429
        107.0697          5911.5807
        109.0708          6151.3954
        109.5714          6105.6314
        112.0730          5943.8663
        113.0741          5541.8468
        114.0746          5481.1535
        116.0757          6481.6890
        117.0763          6594.6409
        118.0774          5939.8442
        119.0779          6026.9165
        120.0785          5987.7987
        122.0796          5859.9845
        124.0812          5468.9757
        126.0823          5446.1744
        129.0839          5411.5977
        139.0890          5441.1702
        170.1539          5441.1722
     NUMBER OF BOTTOM POINTS =    84
     MINIMUM BOTTOM DEPTH (M) =    5181.2640
     MAXIMUM BOTTOM DEPTH (M) =    6332.8727
     MAXIMUM RANGE OF BOTTOM (NM) =     170.1539
SAMPLE TEST CASE.13 RAYS FROM -30 TO 30 DEGREES IN 5 DEGREE STEPS
RANGE (NAUTICAL MILES)
DEPTH (METERS)
     X-AXIS LENGTH (INCHES) =      13.0000
     X-AXIS SCALE =  10520.0000  M PER INCH
     X-AXIS SCALE (LABEL UNITS/IN) =      10.0000
     Y-AXIS LENGTH (INCHES) =       9.0000
     Y-AXIS SCALE =    784.0000 M PER INCH
     Y-AXIS SCALE Y (LABEL UNITS/INCH) =    784.0000
     THE FOLLOWING RAYS WILL BE PLOTTED
     RAY NUMBER    1 ANGLE (DEGREES)    -30.0000
     RAY NUMBER    2 ANGLE (DEGREES)    -25.0000
     RAY NUMBER    3 ANGLE (DEGREES)    -20.0000
     RAY NUMBER    4 ANGLE (DEGREES)    -15.0000
     RAY NUMBER    5 ANGLE (DEGREES)    -10.0000
     RAY NUMBER    6 ANGLE (DEGREES)     -5.0000
     RAY NUMBER    7 ANGLE (DEGREES)      0.0000
     RAY NUMBER    8 ANGLE (DEGREES)      5.0000
     RAY NUMBER    9 ANGLE (DEGREES)     10.0000
     RAY NUMBER   10 ANGLE (DEGREES)     15.0000
     RAY NUMBER   11 ANGLE (DEGREES)     20.0000
     RAY NUMBER   12 ANGLE (DEGREES)     25.0000
     RAY NUMBER   13 ANGLE (DEGREES)     30.0000
     EL          1.2094898E+001
```

Fig. 28 — Printer output from the RAPLOT program for the sample test case. Some of the bottom depths are omitted for brevity.

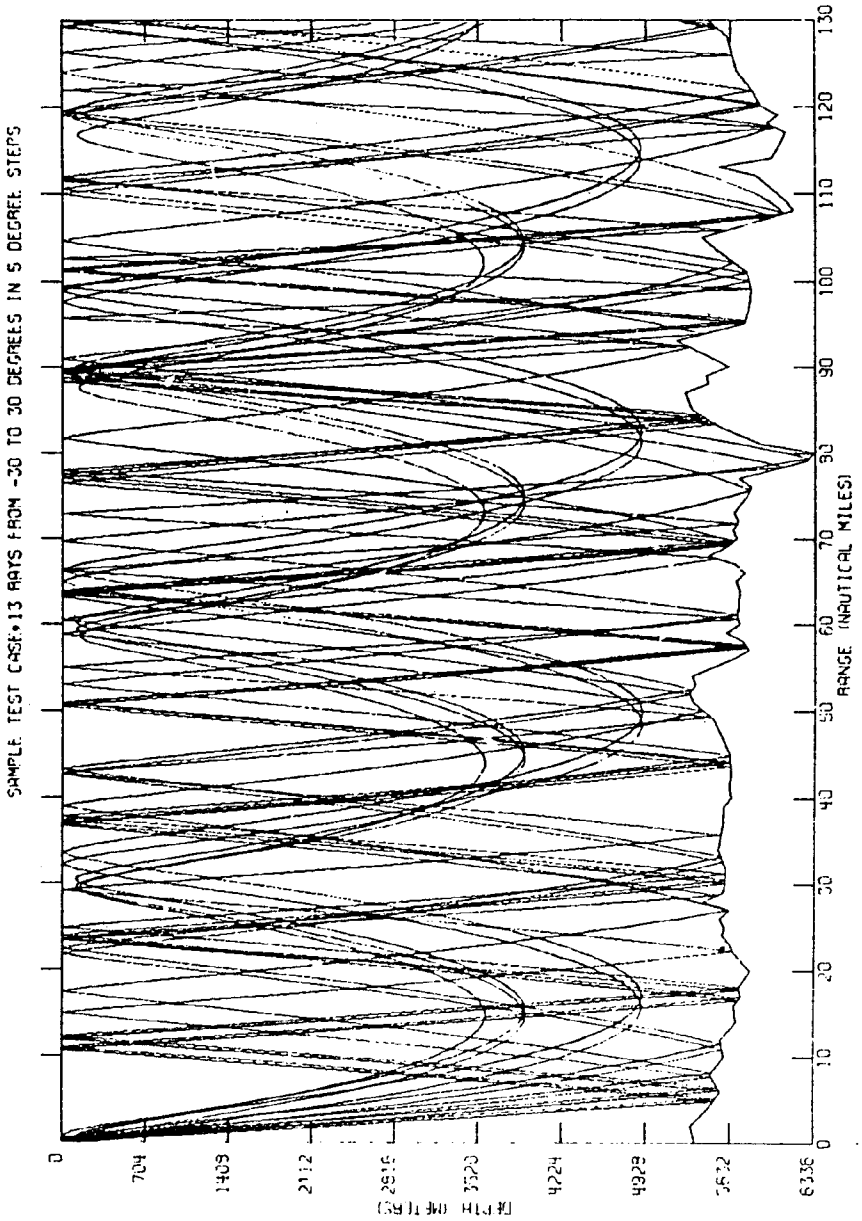

Fig. 29 — Calcomp plot from the RAPLOT program for the sample test case

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Number of magnetic tapes required: one for transmission-loss-data input, plus one if Gerber plots are desired.

Other peripherals used: disk (for program storage), card reader, printer, and Gerber plotter or Calcomp 565 plotter.

Number of cards in program deck: 617

Card punching code: BCD

Nature of Physical Problem

To generate plots of transmission-loss versus range. Calculated, experimental, and/or reference curves may be plotted on the same graph.

Method of Solution

See Section 3.3 of Volume 1.

Restrictions on Complexity of Problem

The maximum height of a graph is 10 inches. A maximum of ten receiver depths may be shown on a single graph.

Typical Running Time

It took approximately 42 seconds to load LOSSPLOT from the disk and execute the sample problem of Section 8.3. Plotting took 6 minutes.

8.2 Input

8.2.1 Control Cards and Job-Request Forms for Calcomp Plots

The *control cards* required for obtaining Calcomp plots are shown in Fig. 30.

The *job-request form* should be filled out as shown in Fig. 3. In addition, the user should:

1. In the second logical-unit space, insert the value of the input parameter NINTAP (described in Sections 6.2.2 and 8.2.3). This logical unit corresponds to the transmission-loss tape generated by SERPENT. It should be designated as an input tape to be saved. The EQUIP card on line 5 of Fig. 30 assumes NINTAP was set to 1. If NINTAP is set to 0, the user should omit the EQUIP card and the above specification.

2. Indicate that type 00 chart paper will be used for plotting and that only one plot will be generated. Also indicate the length of the plot in inches. This length depends on the input parameter NXAXIS described in Section 8.2.3.

8.2.2 Control Cards and Job-Request Forms for Gerber Plots

The *control cards* required for obtaining Gerber transmission-loss plots are shown in Fig. 31.

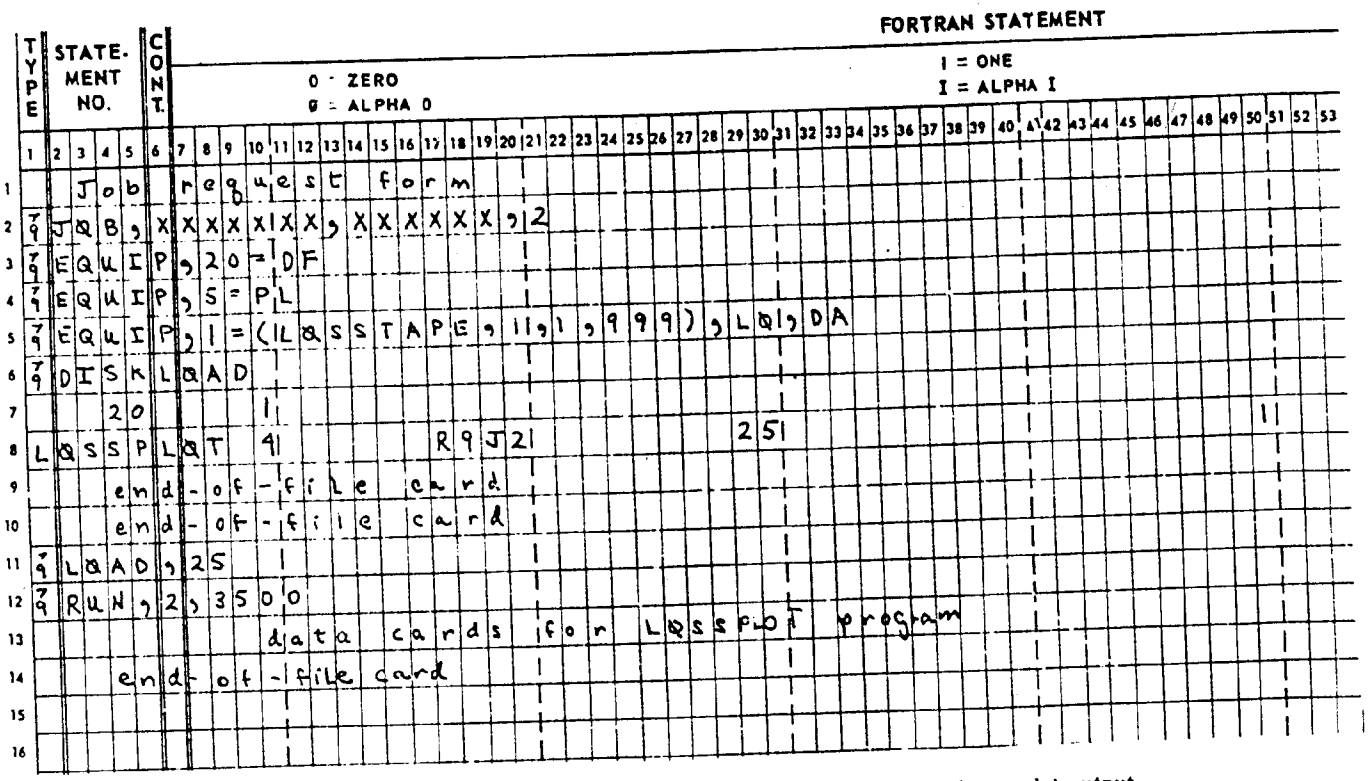

Fig. 30 — Control cards for the LOSSPLOT program for obtaining the Calcomp-plot output

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TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I)
	JOB	b	request form
7 9	JØB,	X	XXXXIXX, XXXXXX, 2
7 9	EQUIP	,	20 = DF
7 9	EQUIP	,	1 = (LØSSTAPE, 1, 1, 999), LØ, DA
7 9	EQUIP	,	48 = (CALCØMP / GERBER), HI, RØ
7 9	EQUIP	,	18 = ** , HI
7 9	DISK	LØAD	
	20		11 R9J21 251 11
		end	-of-file card
		end	-of-file card
7 9	LØAD,	25	1
7 9	RUN,	2,	3500
			data cards for LØSSPLOT
		end	-of-file card

Fig. 31 — Control cards for the LOSSPLOT program for obtaining Gerber plots

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The *job-request form* should be filled out as shown in Fig. 3. In addition, the user should:

1. Perform step 1 of Section 8.2.1.

2. In the third logical-unit-number space, indicate that logical unit 48 is an input tape to be saved and that its number is 3803. This tape contains the Gerber plotter routines.

3. In the fourth logical-unit-number space, indicate that logical unit 18 is an output tape to be saved and specify its serial number. This tape will contain the output Gerber plots for plotting at an off-line facility.

8.2.3 Data Cards

The data input should be in the following order:

TITLE1 a title having up to 80 characters. This title is written on the plot. TITLE1 is punched on the first data card.

TITLE2 another title having up to 80 characters. TITLE2 is punched on the second data card. It is written on the plot under TITLE1.

TITLE3 another title having 80 characters. It is punched on the third data card.

XTIT a title such as RANGE (NM) for the abscissa axis. XTIT is written on the plot next to the abscissa axis, and it should be punched on the third data card.

YTIT a title similar to XTIT but for the ordinate axis, such as TRANSMISSION LOSS (DB).

The following parameters are read by the general-purpose input routine. They should be separated by at least one blank.

SIZE the symbol size in inches for the titles on the abscissa and ordinate axes, such as 0.14.

XTIT1 the abscissa location of TITLE1 in inches relative to the lower-left-hand corner of the plot, such as 3.

YTIT1 the relative location of the ordinate of TITLE1, such as 2.

TITS1 the size in inches of symbols in TITLE1, such as 0.14.

XTIT2 a location similar to XTIT1 but for TITLE2, such as 3.

YTIT2 a location similar to YTIT1 but for TITLE2, such as 1.5.

TITS2 the size in inches of symbols in TITLE2, such as 0.14.

XTIT3 a location similar to XTIT1 but for TITLE3, such as 3.

YTIT3 a location similar to YTIT1 but for TITLE3, such as 1.

TITS3 the size in inches of symbols in TITLE3, such as 0.14.

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RPI	the range of the beginning of graph in the units shown on the final plot, such as 0.
RPF	the range shown at the end of the plot, such as 130 nautical miles.
RMPU	the number of meters per graph unit. For example, if the graph shows nautical miles, 1852 should be used.
DBTOP	the least loss in dB to be shown on the graph, such as 70. This corresponds to the top of the graph.
DBBOT	the greatest loss in dB to be shown on the graph, such as 130. This corresponds to the bottom of the graph.
NXAXIS	the length of the abscissa axis in inches. This must be an integer, such as 13.
NYAXIS	the length of the ordinate axis in inches. This must be an integer, such as 10. The maximum length is 10 inches.
NREF	a parameter set to 1 if a reference (or experimental) data curve will be entered for comparison with the predicted values. If NREF is set to 0, no curve will be entered, in which case the parameters LINERF, MARKRF, REFSIZ, RCON, REF(I), and DBREF(I) and the end-of-data indicator −1 should not be entered.
LINERF	a parameter set to 1 if lines will be drawn between reference curve points designated by symbols, set to 0 if lines will be drawn between reference curve points but no symbols will be used to designate the points, and set to −1 if only symbols will be drawn at the reference points and no lines will be drawn.
MARKRF	symbol reference numbers for reference curve points. These correspond to standard Calcomp integer codes (Fig. 32). These numbers must lie between 0 and 31. If no symbols are used, MARKRF is set to −1.
REFSIZ	the symbol size for the reference curve. If REFSIZ is set to −1, no symbol will be used.
RCON	the factor for converting the input ranges REF(I) to nautical miles (Appendix A).
REF(I)	range of the Ith reference point.
DBREF(I)	dB loss of the Ith reference point.

REF(I) and DBREF(I) are repeated for each point of the reference curve. A value −1 for REF(I) indicates the end of the reference curve data.

NINTAP	logical-unit number of the input loss tape. Typically NINTAP is set to 1. If only the reference curve is to be plotted, however, NINTAP should be set to 0 and the following parameters should not be entered.
NCURVES	the total number of receiver depths to be plotted on one graph. A maximum of ten receiver depths may be shown on one graph.

The following parameters should be repeated NCURVES times.

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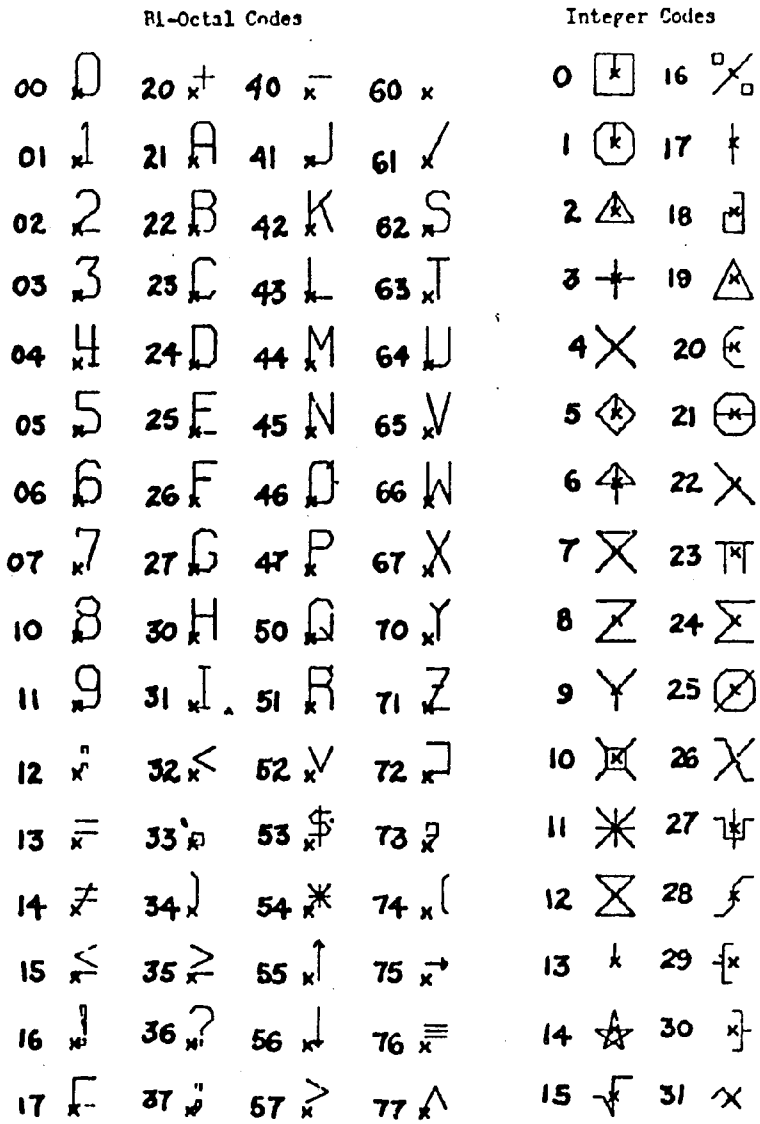

Fig. 32 — Characters available in the CDC-3800 plotting routines. The small x is a reference point and is not plotted. Upon completion of the characters having integer codes 15 through 31 the pen is not at the reference point

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NRNUM(I) the receiver number associated with the Ith curve. These numbers correspond the receiver numbers shown in the SERPENT printout.

NTYPE(I) an indicator of the type of transmission loss to be used for the Ith curve: 1 for random (Type I), 2 for coherent (Type I), and 3 for statistical (Type II).

Next the following two parameters are entered.

TYPSIZ the symbol size in inches for the transmission-loss curves predicted by SERPENT, such as 0.07.

LTYPE an indicator of the method of connecting points of the predicted curves: 1 for lines between symbols, 0 for lines but no symbols, and −1 for just symbols and no lines.

8.3 Sample Input and Output

Figure 33 shows the data cards required to generate the printer output of Fig. 34 and the Calcomp plot shown in Fig. 35. The input includes the experimental transmission-loss measurements. Figure 35 shows a comparison between GRASS's calculated values and the experimental measurements. The exact location at which the bottom changed from type 4 to type 5 was not known. It was reported to be at a distance less than 40 nautical miles, but this is only a very rough estimate. We chose to use 20 nautical miles, because this distance gave better agreement between experimental and calculated values of transmission loss than 30 or 40 nautical miles. We expect that the relatively large differences occurring between 40 and 50 nautical miles are due to not knowing the bottom-loss curves very well.

9. REFERENCES

1. J.D. Roberts, Jr., "A Disk File Library Management System for the CDC-3800 813 Disk File," NRL Memorandum Report 2331 (Computer Bulletin 24), Sept. 1971 (AD-731 050); Also Addendum to NRL Memorandum Report 2331, Dec. 1971 (AD-736 927).

2. A. Hassitt, "Design and Implementation of a General-Purpose Input Routine," Comm. ACM 7, 350 (1964).

3. C.C. Leroy, "Development of Simple Equations for Accurate and More Realistic Calculation of the Speed of Sound in Seawater," J. Acoust. Soc. Am. 46, 216-226 (1969).

4. F.D. Clarke and L.V. Blake, "Fortran Subroutines for Conversion of Calcomp Plot Programs to Gerber-Plotter Magnetic-Tape Output," NRL Memorandum Report 2377 (Computer Bulletin 26), Dec. 1971 (AD-736 919).

5. L.V. Blake, "Fortran Subroutines for Conversion of Calcomp Plot Programs to Gerber-Plotter Paper-Tape Punching," NRL Memorandum Report 2299 Aug. 1971 (AD-887 393L).

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```
SAMPLE TEST CASE- EXPERIMENTAL AND CALCULATED TRANSMISSION LOSSES
AN X DENOTES AN EXPERIMENTAL VALUE
A SQUARE DENOTES A CALCULATED VALUE
RANGE (NM)
TRANSMISSION LOSS (DB)
.14 3 2 .14 3 1.5 .14 3 1 .14
0 130 1852 70 130 13
10 1 -1 4 .07 .49374
2.75 80.63 4.25 82.25 5.75 82.12 7.25 83.13 8.75 80.63
10.25 81.88 11.75 83.37 13.25 86. 14.75 85.37 16.25 82.62
17.75 86.5 21.5 86.75 23. 84.87 24.5 87.75 26. 88.25
27.5 87 29 88 30.5 89.5 32 91.12 33.5 88.87
35 88.25 36.5 87.75 40 86.62 41.5 88.37 43 91.88
45.5 90.75 46 91.5 47.5 92.25 50.5 92.5 52 91.75
53.5 87.62 58.75 91.12 60.25 90 61.75 92 63.25 93.5
68.62 88.75 70.12 94.38 71.62 88.62 73.13 96 74.62 94.12
76.25 95.37 77.75 97.37 79.25 97.37 82.25 95.37 83.75 98.37
85.25 95.12 86.75 96.88 88.25 98. 89.75 97.87 91.25 95.13
94.25 98 95.75 96.88 97.25 96.5 98.75 98.13 100.25 98.5
101.75 99.5 103.25 98.62 104.75 98.37 106.25 98.75 107.75 98.75
109.25 96.12 112.25 96.5 113.75 95.87 115.25 96.62 116.75 88.87
118.25 91.88 119.75 97.5 121.25 93.62 122.75 92. 124.25 91.25
125.75 91.12 127.25 89.5 128.87 97.12 130.37 95. 131.87 92.87
133.37 98.87 134.87 93.37 136.37 94.26 137.87 106.12 139.37 108.87
140.87 111.12 142.37 113.12 143.87 112.62 146. 114.37 149. 110.75
150.5 110.5 152. 109.62 153.5 112.25 155 111.5 156.5 112.12
158. 111.75 159.5 111.5 161 110.37 163.25 107.5 164.75 105.75
166.25 101.87 167.75 99.75 169.25 96.12 172.25 98.37 173.75 96
175.25 93.13 176.75 93.25 178.25 93.5 182.50 95.12 184 96.12
187 93.25 188.5 92.5 190 92.62 191.5 94.12 193 97.87
194.5 93.5 196 95.12 197.5 99.38 201 98.13 202.5 93.13
204 98.5 217.12 108.5 218.62 102.62 220.12 102.62 221.62 101.62
223.12 102.5 224.62 98.37 226.12 96.88 227.62 95.87 229.12 95.5
230.62 95.37 233.5 94.5 236.5 96.5 238. 95.75 239.5 97.62
241 97.62 242.5 98.62 244 96.62 245.5 94.75 247 96.5
248.5 98.5 251.75 100.12 253.25 96.12 254.75 94.87 256.25 97
257.75 96.62 259.25 97.75 260.75 102.25 262.25 109.37
-1
1 1 1 3 .07 -1
```

Fig. 33 — Sample-test-case input data cards for the LOSSPLOT program, including experimental measurements of the transmission loss

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```
SAMPLE TEST CASE- EXPERIMENTAL AND CALCULATED TRANSMISSION LOSSES
AX = EXPRTES AX EXPERIMENTAL VALUE
TRANSMISSION LOSS (DB)
RANGE (YD)
FIRL        1.4000000000-001
YIIT1       3.6900000000+000
YIIT1       2.0000000000+000
TITS1       1.4000000000-001
YIIT2       3.6900000000+000
YIIT2       1.5000000000+000
TITS2       1.4000000000-001
YIIT3       3.6900000000+000
YIIT3       1.0000000000+000
TITS3       1.4000000000-001
SPI         0.0000000000+000
SPF         1.4000000000+002
SPCL        1.0520000000+003
DEPEP       7.6000000000+001
DEPCT       1.3000000000+002
NAXIS       13
NYXIS       10
NCF         1
LINEAR      -1
NRAGE       1
RPSIZ       7.0000000000-002
SCRN        4.9374000000-001
    1        2.7500          1.5978          90.6300
    2        4.2500          2.2984          92.2500
    3        5.7500          2.6397          92.1700
    4        7.2500          3.5704          93.1300
    5        8.7500          4.3702          90.6300
    6       10.2500          5.0409          91.0500
    7       11.7500          5.4514          93.3700
    8       13.2500          6.5421          90.8000
    9       14.7500          7.2427          95.3700
   10       16.2500          8.0933          92.6200
   11       17.7500          8.7619          96.5000
   12       21.5000         10.6154          96.7500
   13       24.0000         11.4569          94.8700
   14       24.5000         12.0964          97.7500
   15       28.0000         12.8372          98.2500
   16       29.5000         13.5779          97.7500
   17       29.6000         14.4185          98.0000
   18       30.5000         15.0591          99.5000
   19       32.0000         15.7997          91.1200
   20       33.5000         16.5403          98.6700
   21       35.0000         17.2809          96.2500
   22       36.5000         18.0215          97.7500
   23       40.0000         19.7494          96.4200
   24       41.5000         20.4902
   163     184.0000         92.0457          94.1700
   164     187.0000         92.8294          93.2500
   167     188.5000         93.0700          92.5000
   168     190.0000         93.8184          92.6200
   169     191.5000         94.5512          94.1200
   170     193.0000         95.2918          97.0700
   171     194.5000         96.0324          93.5000
   172     196.0000         96.7733          99.1200
   173     197.5000         97.5137          99.3800
   174     201.0000         99.2417          96.1300
   175     202.5000         99.9823          93.1300
   176     204.0000        100.7229          98.5000
   177     217.1200        107.2004         100.5000
   178     219.6700        107.9414         102.6200
   179     220.1200        108.6820         102.6200
   180     221.6700        109.4227         101.6200
   181     224.1200        110.1633         102.5000
   182     224.6700        110.9039          96.3700
   183     226.1200        111.6445          96.8000
   184     227.6200        112.3851          95.6700
   185     229.1200        113.1257          95.5000
   186     230.6700        113.8663          95.3700
   187     233.5000        115.2463          94.5000
   188     236.5000        116.7499          96.5000
   189     238.0000        117.5101          95.7500
   190     239.5000        118.2507          97.6200
   191     241.0000        118.9913          97.6200
   192     242.5000        119.7319          98.6200
   193     244.0000        120.4726          98.6200
   194     245.5000        121.2132          94.7500
   195     247.0000        121.9538          96.5000
   196     248.5000        122.6944          98.5000
   197     251.7500        124.2990         100.1200
   198     253.2500        125.0397          96.1200
   199     254.7500        125.7803          94.8700
   200     256.2500        126.5209          97.0000
   201     257.7500        127.2615          96.6200
   202     259.2500        128.0021          97.7500
   203     260.7500        128.7427         102.2500
   204     262.2500        129.4833         100.3700
NINTAP      1
NCURVES     1
NCURB       1
TYPE        3
SYMBL       0
TYPSIZ      7.0000000000-002
LTYPE       -1
```

Fig. 34 — Printer output from the LOSSPLOT program for the sample test case

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SOURCE DEPTH (M) = 152.4

SOURCE FREQUENCY (HZ) = 100.0

RECEIVER NUMBER	RECEIVER DEPTH (M)	RECEIVER SYMBOL	LOSS TYPE
1	762.0	□	II

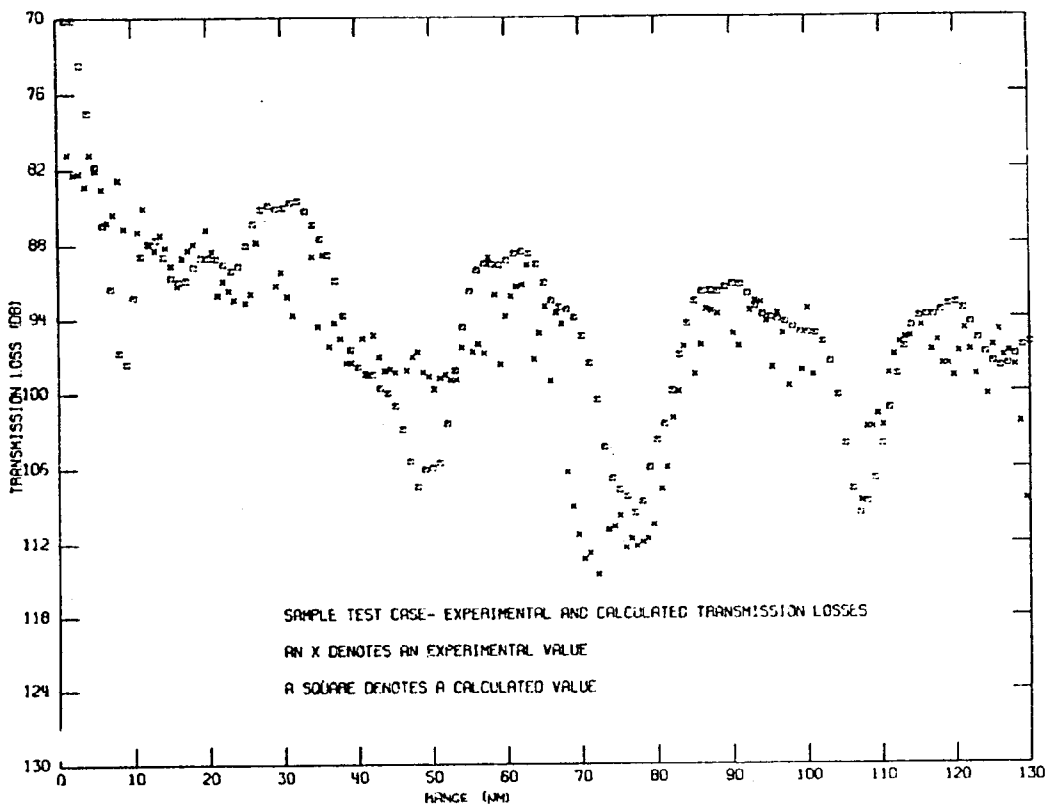

Fig. 35 — Calcomp plot from the LOSSPLOT program comparing the experimental and calculated transmission-loss values for the sample test case

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Appendix A

UNITS AND CONVERSION FACTORS

Most of the GRASS programs perform their calculations using metric units. The user may, however, enter his input data in other units by supplying, in addition to the data, the conversion factors required to transform them to the units used by the program.

The following table contains the most commonly used conversion factors:

Input Units	Conversion Factors to Program Units	
	Meters	Nautical Miles
1 meter	1	0.53996×10^{-3}
1 kilometer	1000	0.53996
1 foot	0.3048	1.6458×10^{-4}
1 kilofoot	304.8	0.16458
1 nautical mile	1852	1
1 fathom	1.8288	9.8747×10^{-4}
1 yard	0.9144	0.49374×10^{-3}
1 kiloyard	914.4	0.49374

Note: This appendix was adapted in part from D. Halliday and R. Resnick, *Physics for Students of Engineering and Science*, Part II, Wiley, New York, second edition, 1962, Appendix H, p. 14.

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