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1976 P MARSH
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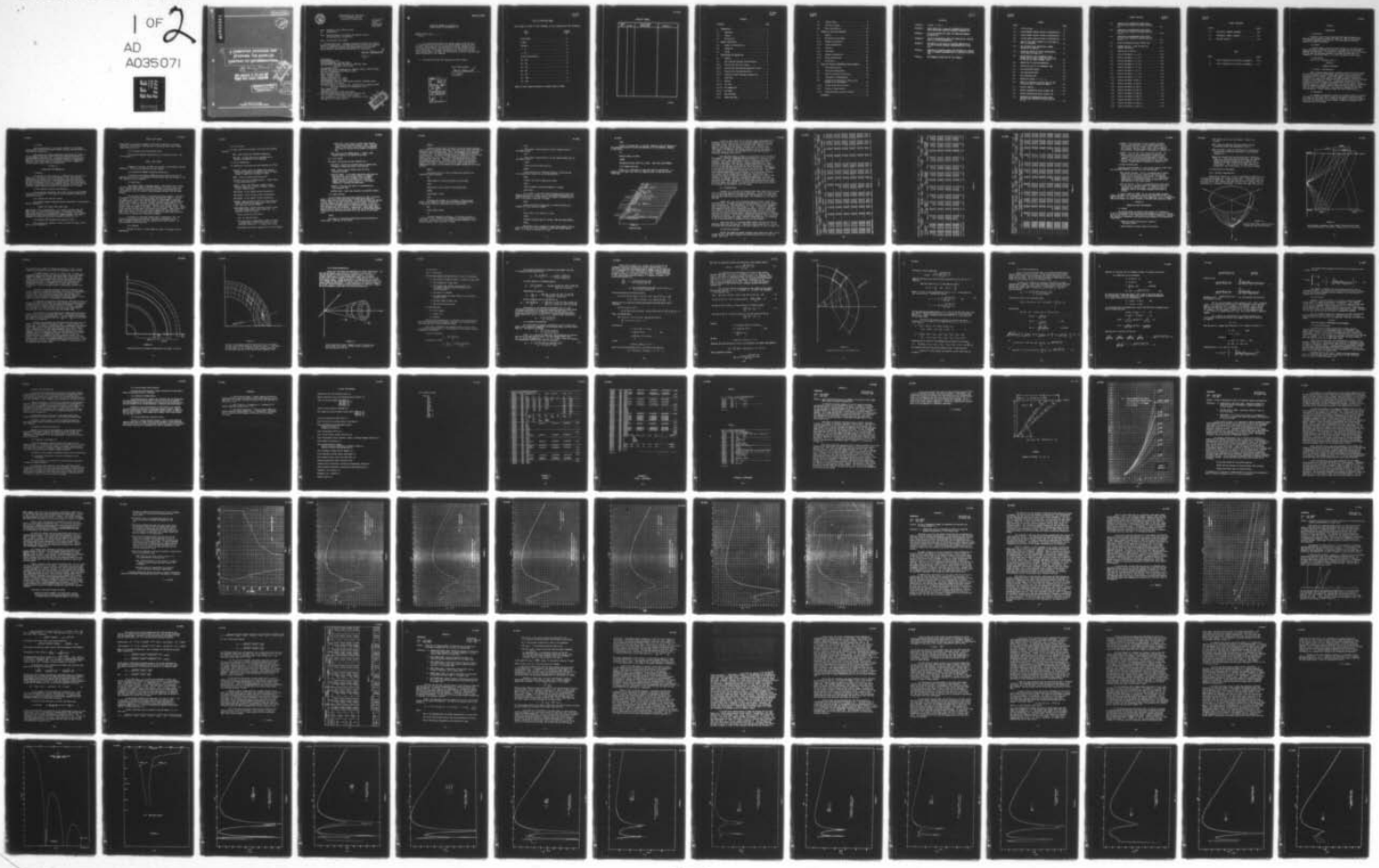

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A COMPUTER PROGRAM FOR STUDYING THE DOPPLER CONTENT OF REVERBERATION (U)

NAVORD Ordnance Data _____
A Computer . . . . . .

1. This publication documents the computer program called DOP which is a mathematical tool used in the study of the doppler content of reverberation. The program has been used primarily with the characteristics of the Torpedo MK 46, however, the characteristics of other acoustic systems can be substituted. The program was authored by Mr. Philip Marsh of the Naval Undersea Center, San Diego, and any questions relating to interpretations should be addressed to his attention.

2. This publication does not supersede any other document.

Naval Undersea Center

M. O. Heinrich
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SECTION I

INTRODUCTION

1.1 Background

Torpedoes are the prime conventional antisubmarine weapons and they use acoustic systems to detect the submarine. Some of these systems use frequency dependent characteristics of the returned echo from the submarine to enhance performance.

1.2 Purpose

A digital computer program has been developed at the Naval Undersea Center (NUC) which facilitates the analysis of systems that use frequency dependent characteristics. The program is called DOP and is used in conjunction with two other NUC developed programs called SONAR and RAYSRT which are documented in references 1 and 2. This report documents the DOP program.

1.3 Publications

See list of references, page 32.

SECTION II

GENERAL DESCRIPTION

2.1 Doppler in Reverberation

When a single-frequency pulse is emitted from an active sonar system on a moving platform, the reverberation seen by the system is spread due in large part to doppler effects. Program DOP computes the spectrum of such reverberation in a refractive medium. The doppler content is computed as a function of the speed of the sonar platform and (optionally) of circular turning or motion of the scatterers, or both. In addition, the spectrum of the original pulse can be included as a spreading effect, since even a "single-frequency" pulse has a harmonic content due to its finite duration. The energy level is computed in frequency bands of specified width at specified times relative to the transmitted pulse. Four values are computed for each band/time combination: surface, bottom, volume, and total reverberation.

2.2 Boundaries

For boundary reverberation (surface or horizontal bottom), increments are summed in random phase from all areas of the boundary returning energy in a given band at a given time. Scattering strength is a function of grazing angle, and all combinations of paths (direct, refracted, reflected) to the scattering areas are included.

2.3 Volume

Volume reverberation is, at present, computed in an unbounded uniform medium, summing contributions from all volumes returning energy in a given band at a given time.

Both boundary and volume computations consider two-way losses in the environment and average transmit and receive beam-pattern losses to each incremental scattering unit. In addition, optional filtering can be applied to each band and TVG (Time Varied Gain) action can be applied at each time. Also, total energy in all bands at each time is computed for surface, bottom, volume, and total reverberation.

SECTION III

INSTRUCTIONS FOR RUNNING DOP

3.1 General

The program is written primarily in FORTRAN IV for execution on a UNIVAC 1110. The program is not self-contained in that there are some functions and subroutines that must be supplied by the user to match the particular system being studied. (The program has been exercised here at NUC with the characteristics of the Torpedo MK 46 Mod 1 and an experimental torpedo.) A description of these user supplied routines, the input data, and ancillary programs necessary or useful to the execution of DOP follows.

3.2 User Supplied Functions and Subroutines

For any specific application, one or more of the following FORTRAN functions will be required. Since they are vehicle dependent, they must be supplied by the user.

3.2.1 Function OXL (Off-axis Losses)

This routine computes transducer pattern attenuation in any direction. The call sequence is:

```
VALUE = OXL (IFLAG, COSA, COSB, COSC)
```

where IFLAG is 0 for receive pattern, 1 for transmit and COSA, COSB, and COSC are the X, Y, and Z direction cosines in the direction of interest. Other values necessary for the computation, e.g. transducer type, frequency, sound velocity, etc. may be supplied via a COMMON statement. The value returned is a fraction of the on-axis intensity, from 0.0 to 1.0.

3.2.2 Function RRF (Reverberation Rejection Filter)

This routine will interpose a filter to modify the energy in each band. The call sequence is:

VALUE = RRF (FREQ)

where FREQ is the center frequency of the band in question. The value returned is the fraction of energy which is passed by the filter in that band, from 0.0 to 1.0.

3.2.3 Function TVG (Time Variable Gain)

This routine computes receiver gain as a function of time. The call sequence is:

GAIN = TVGF (TIME)

Examples of OXL, RRF, and TVGF are provided in the program listings, Appendix G. These are unrelated to any real system.

3.2.4 Subroutine SPRCMP (Spreading Computation)

In addition to the above, SPRCMP may be provided by the user to generate one or more of the spreading function tables when the program is run. The subroutine has no arguments.

3.3 Input Data

Input data to DOP is from two sources: the output file of sorted ray data from programs SONAR and RAYSRT (references 1 & 2) and input data cards. Besides the sorted ray data returned from insonified portions of the boundaries, the file contains eleven parameters passed from the SONAR program.

The card input format is free-form with blanks ignored. Variables are punched in fields of arbitrary length, separated by commas. Data may be integer, real (including a decimal point) or alpha-numeric (appearing between single quotes). Note that no check is made for the appropriateness of any piece of data to any name. Neither names nor numbers may be split between cards. All data cards appear literally in the printed output. Two kinds of data may appear on the cards: option fields and data fields. Option fields contain only the name of the option to be invoked. These options may modify the form or content of input data, computation, and output data. Data fields consist of a variable name followed by an equal sign and one or more values, as appropriate, separated by commas.

For option or data names longer than six characters, only the first six characters are interpreted. Additional characters may be used to improve readability, but are ignored by the input routine. All data variables are initially zero.

3.3.1 Options

Options for DOP are listed below for input, for output, and for computation.

3.3.1.1 For Input

For input, there are two options, which have the following meanings:

- GO - Stop reading data and begin computation.
- NO TAPE - No input data file is provided and no boundary reverberation will be computed.

3.3.1.2 For Computation

For computation, the options and their meanings are listed below:

- CENTER - Doppler bands are computed such that the transmitted frequency is centered in one of the bands instead of appearing at the edge of a band.
- END - Stop all program activity and exit.
- FILTER (Used only with SPREAD option) - Apply filter to the spread output data.
- KNOTS - Compute the intensity in bands of equal apparent range rate or "knots of doppler" instead of equal frequency range.
- NO BOTTOM - Do not compute bottom reverberation.
- NO SURFACE - Do not compute surface reverberation.
- NO VOLUME - Do not compute volume reverberation.
- SPREAD - Apply spreading function to output data and change the format of the output data listing. (See note under data variable BSPRED.)
- TIME COMPUTATION - Compute additional values of time for which reverberation is to be determined. The additional values of time are:
  - Ping interval (See PING below.)
  - 1/2 Δt (See DELT below.)
  - For every path or combination of paths to surface or bottom whose earliest arrival time is t, the additional values are: t, $t+1/2\Delta t$, and $t-1/2\Delta t$.
  - Seventeen fixed values ranging from .01 to 2.0 seconds.

- Additional values every 1/2 second from 2 seconds to the value of the PING interval, NOTE: The total number of time entries read from cards and computed as a result of the use of this option is limited to 400.

- TVG (used only with SPREAD option) - Apply a time-varying function to the spread output data.

3.3.1.3 For Output

For output, the options and their meanings are:

- NO PRINT - Suppress the printed output of doppler data. Printing of input data cards is not affected.

- PLOT - Write a tape of doppler data for use by subsequent programs.

- RELATIVE BANDS - If the KNOTS computation option has not been specified, print the band limits in kilohertz relative to the source frequency; with the KNOTS computation option, print band limits in knots of doppler relative to vehicle speed; i.e. zero doppler (unspread) is returned from dead ahead.

- TOTALS - Print only the totals of reverberation at each requested time.

- (PRINT EVERY - Under Data Variables also modifies output.)

3.3.2 Data Variables

In the following listing of data variables for DOP, an asterisk (which is NOT part of the name) denotes variables whose values are normally taken from the input data tape. If the same variables are supplied on cards, however, the data from the cards would be used. It should be noted that some values which could be changed are implicit in the ray data supplied by the SONAR program and that changing these values by card would be meaningless and misleading. Examples are: source depth (DO), sound velocity of medium at the source depth (CO) and bottom depth (DBTTM). (Please note that the second character of CO, DO, and FO is the numeral zero.)

ALPHC*

The product of attenuation coefficient and sound velocity at source depth. Units are dB per second.

BSPRED

Spreading function table for bottom. Since the bottom scatterers would usually be considered stationary, this table would usually represent the spectrum of the transmitted pulse. NOTE: The appearance in the data deck of BSPRED, SSPRED, or VSPRED makes the use of the SPREAD option redundant and unnecessary. Each table is entered as half a symmetrical table of an odd number of entries. First value is the proportion of energy in a band remaining after spreading. Next value is the proportion spread to the two neighboring bands, etc. Therefore, twice the total of all values entered should equal one plus the first value. Each of the tables has a maximum of 150 values. Failure to include all three tables with the SPREAD option causes a call to SPRCMP in an attempt to generate the missing table(s).

BWIDTH

Band width in hertz or knots as appropriate, based on the computation option selected.

CO*

Sound velocity in yards per second at source depth.

DATE*

Alpha-numeric date, maximum of two machine words.

DBTTM*

Bottom depth in feet.

DELT

Effective pulse length, Δt, in seconds. Effective pulse length is the length of a square pulse with the same energy content as the pulse of interest, which may not be a square pulse.

DO*

Source depth in feet.

FO

Transmit frequency in kilohertz. If no value is supplied, 1 kilohertz is used. Although this parameter is not supplied from the input tape, it is implicit in the ray data from the attenuation values (and the spreading loss correction, if used).

IDC*

Alpha-numeric identification as on the "constant card" of the SONAR program.

IDV*

Alpha-numeric identification as on the "semi-variable card" of the SONAR program.

LOGMV*

Volume scattering coefficient, dB.

NBEAM

Coded description of transducer patterns, if more than one can be generated; intended for use by subroutine OXL.

OMEGA

Platform turn rate in degrees per second.

PING*

Interval between successive transmits in seconds.

PRINT EVERY

For a value n, print only every nth doppler band at each time. Bands to be printed are chosen so as to include the band containing the transmit frequency as its lower bound or its center, if CENTER option is used. If no value is supplied, 1 is used.

PULSE

Coded description of pulse shape, if several options exist. Intended for use by subroutine SPRCMP.

S*

Source level in dB relative to 1 yard.

SSPRED

Spreading function table for surface. (See note under BSPRED.)

THTMAX

Approximate value in degrees of largest angle (between velocity vector and sound rays) to be considered in computing unspread doppler bands. If no value is supplied, 90 is used.

TIME

Values of elapsed time, in seconds, (measured from the midpoint of the transmitted pulse) at which reverberation is to be computed. Maximum of 400 values.

VS

Vehicle speed, in knots.

VSPRED

Spreading function table for volume. (See note under BSPRED).

3.3.3 Sample Data Deck

Figure 3-1 illustrates an input card deck for program DOP. It assumes that at least four files (or complete sets) of data are on the input tape.

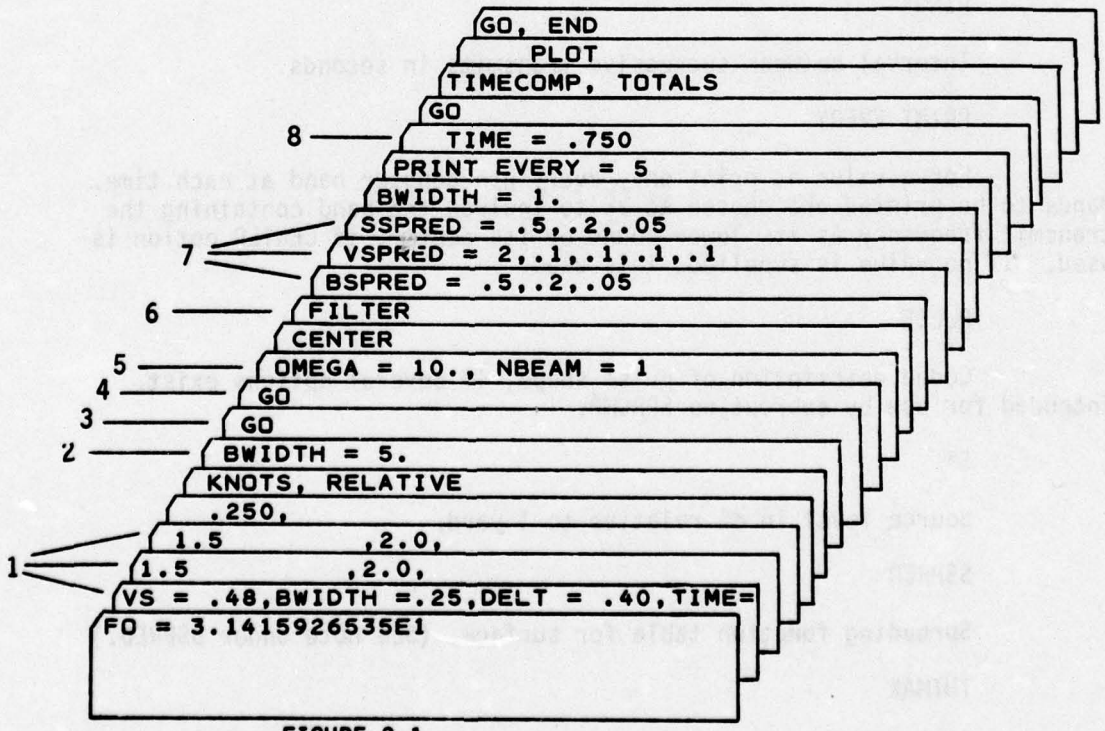

FIGURE 3-1

A DOP DATA DECK

In such a case, each file on the input tape (corresponding to different "semi-variable" cards in the original SONAR program deck) is processed in turn. Options and data variables from cards are retained until over written from the tape or from new cards. (Please note, however, that options once invoked or turned "on" can not be turned "off" again.) In general, the program proceeds until an END option is read from a card, or until the last data file on the tape has been processed, whichever occurs first.

The indicated cards in Figure 3-1 illustrate certain features of the program. Cards at 1 exemplify the continuation of a string of values on several cards. Also, note that of the six values of time, two are repeated. The program sorts values of time in ascending order and eliminates duplicates. The card at 2 redefines band width as 5. knots although it had been set to .25 knots on the second card of the deck. Card at 3 marks the end of card data for file 1 on the tape. The card at 4 indicates that all the same data is to be used for File 2. At 5 NBEAM is used because the hypothetical torpedo has two transmit beams. Some sonar problems might never use this feature. At 6 invocation of FILTER will cause a call to require RRF to modify the level of each band. Without this option, no RRF would be required. Similarly, if one of the variables at 7 was not supplied, a subroutine SPRCMP would have been called by the program. The card at 8 replaces all of the values of TIME previously read. Note throughout, the free, even arbitrary use of blanks which, we repeat, are ignored. Also note that values used on these cards are arbitrary and unrelated to any real system.

3.4 Program Output

Figures 3-2, 3-3, and 3-4 illustrate the output from Files 1, 3, and 4 of an input tape used with the sample input deck. In addition, the input deck, up to the GO option, or between successive GO options, is listed on a separate page before each output data page. No illustration of this page is provided.

Figures 3-2, 3-3, and 3-4 show the three principal formats for the output data. The pages are mostly self-explanatory. One point, however, should be mentioned. The appearance of .00 dB in a column seems ambiguous, since it may mean zero dB or zero energy (- dB). In practice, however, this ambiguity should rarely present any difficulty. The truly empty bands will always lie at the top or the bottom of a column of data. Unless the first or last nonvoid band has exactly zero dB, which can usually be determined from the band and column totals, leading and trailing zeros in a column represent zero energy. This form of printout was chosen in lieu of printing an arbitrary large negative number, because it made the page less cluttered. It has to date presented no problems to users of the program.

Three data decks, to programs SONAR, RAYSRT, and DOP were used to generate Figures 3-2, 3-3 and 3-4. These are listed in Appendix A. It will be noticed that the DOP data deck is not quite identical to that in Figure 3-1.

3.5 Ancillary Programs

Besides the SONAR and RAYSRT programs which produce the input file of sorted ray data, two other programs exist which may be of help to the user of DOP. These are:

PROGRAM 800003 -- DOPPLER CONTENT OF REVERBERATION IDC REVERB IDV DOPLER DATE 07/23/76 PAGE 1 OF 1

V.S, KTS.	C.O, YDS./SEC.	F.O, KHZ.	D.O, FT.	S, DB.	XI, DEG.	OMEGA, DEG./SEC.	P.I., SEC.	DEL. T, SEC.	D. BTM., FT.
45.00	1625.41	31.4159	750.0000	100.00	-2.000	.000	2.0000	.0400	4000.0000

FREQUENCY BAND, KILOHERTZ		TIME = .25000000				TIME = 1.50000000				TIME = 2.00000000			
FROM-	TO-	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL
32.4109	32.4059	.00	.00	-23.28	-23.28	.00	.00	-51.15	-51.15	.00	.00	-58.56	-58.56
32.4059	32.4009	.00	.00	-26.63	-26.63	.00	.00	-54.50	-54.50	.00	.00	-61.91	-61.91
32.4009	32.3959	.00	.00	-29.63	-29.63	.00	.00	-57.49	-57.49	.00	.00	-64.91	-64.91
32.3959	32.3909	.00	.00	-32.47	-32.47	.00	.00	-60.33	-60.33	.00	.00	-67.75	-67.75
32.3909	32.3859	.00	.00	-35.26	-35.26	.00	.00	-63.12	-63.12	.00	.00	-70.54	-70.54
32.3859	32.3809	.00	.00	-38.06	-38.06	.00	.00	-65.92	-65.92	.00	.00	-73.34	-73.34
32.3809	32.3759	.00	.00	-40.91	-40.91	.00	.00	-68.78	-68.78	.00	.00	-76.19	-76.19
32.3759	32.3709	.00	.00	-43.87	-43.87	.00	.00	-71.73	-71.73	.00	.00	-79.15	-79.15
32.3709	32.3659	.00	.00	-46.95	-46.95	-72.03	.00	-74.82	-70.19	.00	.00	-82.23	-82.23
32.3659	32.3609	.00	.00	-50.21	-50.21	-71.36	.00	-78.08	-70.50	.00	.00	-85.49	-85.49
32.3609	32.3559	.00	.00	-53.71	-53.71	-77.60	.00	-81.57	-76.14	.00	.00	-88.99	-88.99
32.3559	32.3509	.00	.00	-57.50	-57.50	-82.58	.00	-85.36	-80.74	.00	.00	-92.78	-92.78
32.3509	32.3459	.00	.00	-61.70	-61.70	-87.61	.00	-89.56	-85.47	.00	.00	-96.98	-96.98
32.3459	32.3409	.00	.00	-66.47	-66.47	-93.17	.00	-94.34	-90.71	.00	.00	-101.75	-101.75
32.3409	32.3359	.00	.00	-72.05	-72.05	-99.87	.00	-99.92	-96.88	.00	.00	-107.33	-107.33
32.3359	32.3309	.00	.00	-77.12	-77.12	-108.99	.00	-104.99	-103.53	.00	.00	-112.40	-112.40
32.3309	32.3259	.00	.00	-75.85	-75.85	-122.84	.00	-103.72	-103.66	.00	.00	-111.13	-111.13
32.3259	32.3209	.00	.00	-72.35	-72.35	-141.65	.00	-100.22	-100.22	.00	.00	-107.63	-107.63
32.3209	32.3159	.00	.00	-69.54	-69.54	-120.97	.00	-97.41	-97.39	.00	.00	-104.82	-104.82
32.3159	32.3109	.00	.00	-67.31	-67.31	-111.57	.00	-95.18	-95.08	.00	.00	-102.59	-102.59
32.3109	32.3059	.00	.00	-65.49	-65.49	-106.04	.00	-93.35	-93.13	.00	.00	-100.77	-100.77
32.3059	32.3009	.00	.00	-63.98	-63.98	-102.53	.00	-91.85	-91.49	.00	.00	-99.26	-99.26
32.3009	32.2959	.00	.00	-62.74	-62.74	-99.95	.00	-90.60	-90.12	.00	.00	-98.02	-98.02
32.2959	32.2909	.00	.00	-61.70	-61.70	-98.01	.00	-89.57	-88.99	.00	.00	-96.98	-96.98
32.2909	32.2859	.00	.00	-60.86	-60.86	-96.55	.00	-88.72	-88.06	.00	.00	-96.14	-96.14
32.2859	32.2809	.00	.00	-60.17	-60.17	-95.41	.00	-88.03	-87.30	.00	.00	-95.45	-95.45
32.2809	32.2759	.00	.00	-59.61	-59.61	-94.53	.00	-87.48	-86.69	.00	.00	-94.89	-94.89
32.2759	32.2709	.00	.00	-59.18	-59.18	-93.85	.00	-87.04	-86.22	.00	.00	-94.46	-94.46
TOTAL REVERBERATION		.00	.00	-20.39	-20.39	-67.88	.00	-48.25	-48.21	.00	.00	-55.67	-55.67

Figure 3-2

PROGRAM 800003 -- DOPPLER CONTENT OF REVERBERATION IDC REVERB IDV DOPL 2 DATE 07/23/76 PAGE 1 OF 1

V.S, KTS.	C.O, YDS./SEC.	F.O, KHZ.	D.O, FT.	S, DB.	XI, DEG.	OMEGA, DEG./SEC.	P.I., SEC.	DEL. T, SEC.	D. BTM., FT.
45.00	1636.20	31.4159	500.0000	100.00	-2.000	10.000	2.0000	.0400	4000.0000

DOPPLER BAND, KNOTS		TIME = .75000000 PURE TONE				TIME = .75000000 AFTER SPREADING				TIME = .75000000 SPREAD WITH FILTER			
FROM-	TO-	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL
5.5000	4.5000	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5000	-.5000	.00	.00	.00	.00	-61.60	.00	-48.62	-48.41	-101.60	.00	-88.62	-88.41
-4.5000	-5.5000	-57.17	.00	-58.75	-54.88	-55.55	.00	-48.43	-47.66	-95.55	.00	-88.43	-87.66
-9.5000	-10.5000	-65.89	.00	-66.94	-63.37	-64.33	.00	-64.09	-61.20	-104.33	.00	-104.09	-101.20
-14.5000	-15.5000	-78.55	.00	-77.50	-74.98	-76.63	.00	-75.29	-72.90	-116.63	.00	-115.29	-112.90
-19.5000	-20.5000	-77.96	.00	-76.78	-74.32	-78.17	.00	-77.32	-74.72	-118.17	.00	-117.32	-114.72
-24.5000	-25.5000	-84.81	.00	-84.25	-81.51	-84.10	.00	-82.40	-80.15	-124.10	.00	-122.40	-120.15
-29.5000	-30.5000	-92.36	.00	-90.03	-88.03	-91.32	.00	-88.41	-86.62	-131.32	.00	-128.41	-126.62
-34.5000	-35.5000	-89.16	.00	-86.00	-84.29	-89.33	.00	-86.47	-84.66	-129.33	.00	-126.47	-124.66
-39.5000	-40.5000	-89.64	.00	-86.61	-84.86	-89.75	.00	-86.80	-85.02	-129.75	.00	-126.80	-125.02
-44.5000	-45.5000	-95.58	.00	-89.87	-88.83	-94.34	.00	-89.63	-88.37	-134.34	.00	-129.63	-128.37
-49.5000	-50.5000	-101.06	.00	-95.29	-94.27	-100.71	.00	-94.49	-93.56	-119.36	.00	-113.14	-112.21
-54.5000	-55.5000	-108.88	.00	-103.38	-102.30	-108.06	.00	-101.57	-100.69	-123.73	.00	-117.23	-116.35
-59.5000	-60.5000	-120.76	.00	-116.18	-114.88	-118.63	.00	-111.71	-110.91	-132.56	.00	-125.65	-124.84
-64.5000	-65.5000	-126.05	.00	-121.79	-120.40	-125.89	.00	-121.65	-120.26	-138.61	.00	-134.36	-132.98
-69.5000	-70.5000	-128.01	.00	-123.87	-122.45	-128.07	.00	-123.93	-122.51	-139.84	.00	-135.71	-134.29
-74.5000	-75.5000	-137.85	.00	-135.01	-133.19	-136.21	.00	-131.04	-129.89	-147.22	.00	-142.05	-140.90
-79.5000	-80.5000	-142.21	.00	-138.86	-137.21	-142.28	.00	-139.74	-137.82	-152.65	.00	-150.11	-148.19
-84.5000	-85.5000	-145.60	.00	-146.01	-142.79	-145.36	.00	-143.19	-141.13	-155.18	.00	-153.01	-150.95
-89.5000	-90.5000	.00	.00	-150.08	-150.08	-161.67	.00	-152.72	-152.20	-171.01	.00	-162.05	-161.53
-94.5000	-95.5000	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TOTAL REVERBERATION		-45.36	.00	-38.46	-37.65	-45.36	.00	-38.46	-37.65	-85.35	.00	-78.46	-77.64

FIGURE 3-3

PROGRAM 800003 -- DOPPLER CONTENT OF REVERBERATION IDC REVERB IDV DOPL 3 DATE 07/23/76 PAGE 1 OF 1

V.S, KTS.	C.O, YDS./SEC.	F.O, KNZ.	D.O, FT.	S, DB.	XI, DEG.	OMEGA, DEG./SEC.	P.I., SEC.	DEL. T, SEC.	D. BTM., FT.
45.00	1679.30	31.4159	275.0000	100.00	-2.000	10.000	2.0000	.0400	4000.0000

TOTAL REVERBERATION FROM 101 BANDS, EACH OF 1.000 KNOTS BANDWIDTH

	PURE TONE				AFTER SPREADING				SPREAD WITH FILTER AND TVG			
TIME	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL	SURFACE	BOTTOM	VOLUME	TOTAL
.02000000	.00	.00	1.13	1.13	.00	.00	1.13	1.13	.00	.00	-48.48	-48.48
.05000000	.00	.00	-8.34	-8.34	.00	.00	-8.34	-8.34	.00	.00	-57.44	-57.44
.08918396	.00	.00	-13.89	-13.89	.00	.00	-13.89	-13.89	.00	.00	-62.41	-62.41
.10000000	-15.98	.00	-14.99	-12.45	-15.98	.00	-14.99	-12.45	-53.74	.00	-63.36	-53.29
.10918396	-15.90	.00	-15.83	-12.85	-15.90	.00	-15.83	-12.85	-53.59	.00	-64.08	-53.22
.12918395	-15.80	.00	-17.45	-13.54	-15.80	.00	-17.45	-13.54	-53.32	.00	-65.45	-53.06
.20000000	-26.71	.00	-21.74	-20.54	-26.71	.00	-21.74	-20.54	-73.82	.00	-68.94	-67.72
.30000000	-31.57	.00	-25.90	-24.86	-31.57	.00	-25.90	-24.86	-77.82	.00	-72.18	-71.13
.40000000	-25.75	.00	-29.00	-24.07	-25.75	.00	-29.00	-24.07	-71.28	.00	-74.52	-69.59
.50000000	-24.96	.00	-31.53	-24.08	-24.96	.00	-31.53	-24.08	-69.82	.00	-76.40	-68.96
.60000000	-25.87	.00	-33.69	-25.20	-25.87	.00	-33.69	-25.20	-70.19	.00	-77.99	-69.52
.70000000	-27.37	.00	-35.59	-26.76	-27.37	.00	-35.59	-26.76	-71.19	.00	-79.40	-70.58
.75000000	-28.58	.00	-36.47	-27.92	-28.58	.00	-36.47	-27.92	-72.17	.00	-80.05	-71.51
.80000000	-29.42	.00	-37.31	-28.77	-29.42	.00	-37.31	-28.77	-72.80	.00	-80.67	-72.14
.90000000	-32.61	.00	-38.88	-31.69	-32.61	.00	-38.88	-31.69	-75.57	.00	-81.83	-74.65
1.00000000	-35.24	.00	-40.33	-34.07	-35.24	.00	-40.33	-34.07	-77.84	.00	-82.92	-76.66
1.20000000	-39.67	.00	-42.98	-38.01	-39.67	.00	-42.98	-38.01	-81.61	.00	-84.91	-79.94
1.40000001	-44.11	.00	-45.39	-41.69	-44.11	.00	-45.39	-41.69	-85.47	.00	-86.75	-83.05
1.50918451	-45.20	.00	-46.63	-42.85	-45.20	.00	-46.63	-42.85	-86.29	.00	-87.71	-83.93
1.52918451	-45.50	-68.71	-46.86	-43.10	-45.50	-68.71	-46.86	-43.10	-86.53	-98.67	-87.88	-83.99
1.54918450	-46.21	-65.83	-47.08	-43.59	-46.21	-65.83	-47.08	-43.59	-87.20	-96.52	-88.06	-84.32
1.59999999	-48.27	-67.81	-47.65	-44.91	-48.27	-67.81	-47.65	-44.91	-89.13	-101.25	-88.50	-85.67
1.61836843	-48.82	-68.88	-47.85	-45.28	-48.82	-68.88	-47.85	-45.28	-89.64	-102.51	-88.66	-86.01
1.63836843	-49.37	-70.16	-48.08	-45.65	-49.37	-70.16	-48.08	-45.65	-90.14	-103.70	-88.84	-86.35
1.65836842	-49.86	-71.44	-48.30	-45.99	-49.86	-71.44	-48.30	-45.99	-90.58	-104.75	-89.01	-86.65
1.72755235	-51.28	-73.47	-49.09	-47.03	-51.28	-73.47	-49.09	-47.03	-91.85	-107.38	-89.65	-87.55
1.74755235	-51.64	-72.28	-49.32	-47.30	-51.64	-72.28	-49.32	-47.30	-92.16	-106.16	-89.83	-87.77
1.76755235	-51.95	-71.42	-49.55	-47.56	-51.95	-71.42	-49.55	-47.56	-92.43	-105.37	-90.02	-87.97
1.80000000	-52.43	-71.13	-49.93	-47.97	-52.43	-71.13	-49.93	-47.97	-92.84	-106.34	-90.33	-88.33
2.00000000	-54.96	-70.84	-52.26	-50.35	-54.96	-70.84	-52.26	-50.35	-94.96	-109.21	-92.25	-90.33

FIGURE 3-4

- DENFSP - This program may be used to prepare spreading function tables for DOP. It will combine (convolve) a spectrum and a density function and/or convert a spectrum into a density function. Print, punch, and plot options are available. Program DENSFP is documented in reference (3).

- SRNBT4 - This uses the 'plot' output tape from DOP. The program prints or plots reverberation in doppler bands. It can translate the data into broader bands than were computed. It can also plot selected bands vs. time, and plot or punch cards for enabling level for use by the SONAR program. Program SRNBT4 is documented in reference (3).

3.6 Other Considerations

Although standard FORTRAN IV is the primary language of DOP, there are two UNIVAC FORTRAN V features which have been employed:

- The INCLUDE Statement - This is a convenient way of adding blocks of cards to several routines, insuring that such blocks will be identical in each routine. For compilers without this or an analogous feature, it is a comparatively simple matter to duplicate the blocks of cards and to add them physically in the proper places.

- The FLD Function - This is a bit-manipulating function which is used only in subroutine INPUT for assembling individual characters into variable names. For compilers without a comparable feature, an assembly-language routine must be written.

As used in subroutine INPUT, the two constants NWORD and NCHAR contain the number of bits per machine word and the number of bits per alpha-numeric character. For the UNIVAC 1110, these numbers are 36 and 6 respectively. They can be changed via a data statement in the BLOCK DATA subroutine, INBLK.

SECTION IV

THEORETICAL BASIS AND PROCEDURE

4.1 General

The thinking which led through various models of reverberation to the one implemented in DOP has been covered extensively in earlier informal works by A.B. Poynter. Five of these works are inlcuded as Appendices B through F. The conventions, assumptions, and simplifications employed in the program are listed below:

- Both the surface and bottom are treated as horizontal planes.

- The platform's velocity vector is horizontal.

- The medium varies only with depth. There is no current.
- All times are measured from the midpoint of the transmitted pulse (see Appendices C and D).
- No allowance is made for differences in transmit and receive paths caused by translation of the platform (Appendix E).
- When the transmit and receive paths are of different types, e.g. one direct and one reflected, the boundary scattering strength between paths is taken as the average of the back scattering strengths for the two single paths. This is one of the least defensible assumptions, and investigation in this area is needed.

4.2 Description of the Models

4.2.1 Boundary Reverberation

Refer now to Figure 4-1. A ray is considered as emanating from a source at some depth, d_0, located on the Z axis. Since sound velocity is a function of depth only, a ray lies entirely in a vertical plane, and the locus of all rays leaving the source at an initial angle θ_0 from the horizontal is a surface of revolution. If these rays reach the surface,

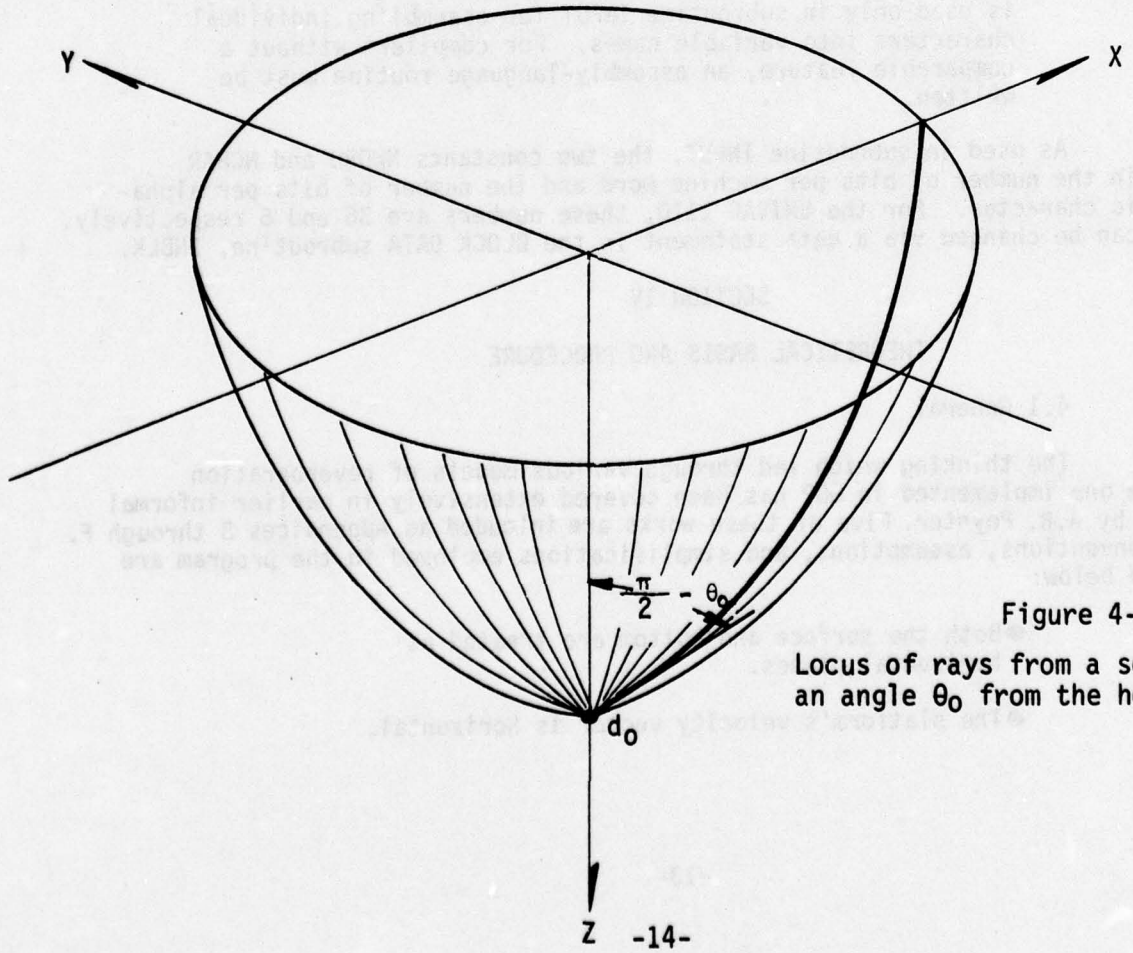

Figure 4-1

Locus of rays from a source at d_0 at an angle θ_0 from the horizontal.

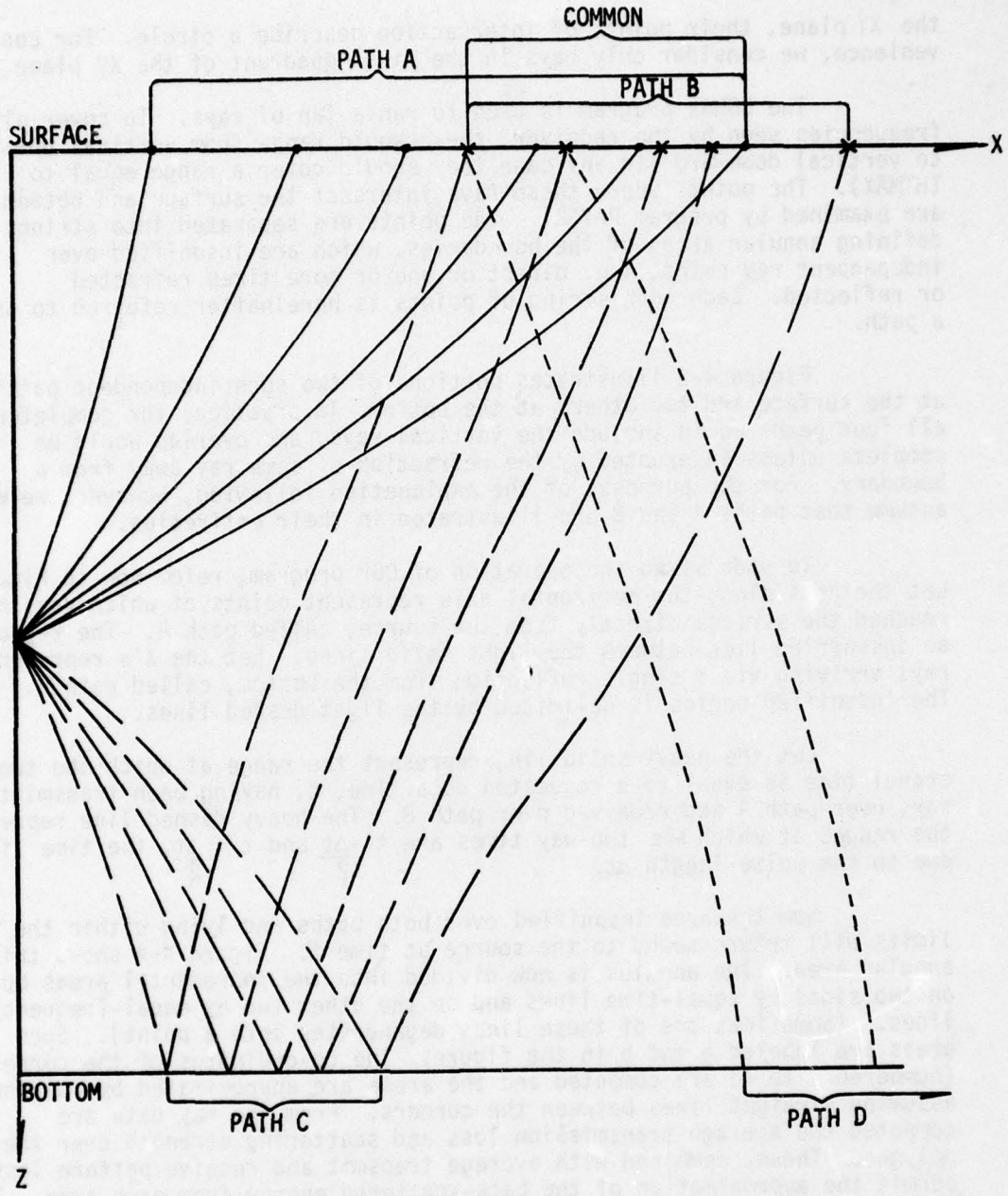

FIGURE 4-2

Two different ray-bundles, called "paths" (direct path and singly bottom-reflected path) insonifying a common portion of the surface.

the XY plane, their points of intersection describe a circle. For convenience, we consider only rays in the first quadrant of the XY plane.

The SONAR program is used to run a fan of rays. To cover all frequencies seen by the receiver, these would range from vertical upward to vertical downward (In any case they should cover a range equal to ± THTMAX). The points where these rays intersect the surface and bottom are examined by program RAYSRT. The points are separated into strings defining annular areas of the boundaries, which are insonified over independent ray paths, i.e. direct or one or more times refracted or reflected. Each such string of points is hereinafter referred to as a path.

Figure 4-2 illustrates portions of two such independent paths at the surface and two others at the bottom. In practice, for completeness, all four paths would include the vertical rays, and overlap would be complete unless interupted by the refraction of some ray away from a boundary. For the purposes of the explanation following, however, we will assume that paths A and B are illustrated in their entireties.

To understand the operation of DOP program, refer now to Figure 4-3. Let the dots along the horizontal axis represent points at which rays have reached the surface directly from the source, called path A. The region so insonified lies between the light solid lines. Let the X's represent rays arriving via a single reflection from the bottom, called path B. The insonified region is delimited by the light dashed lines.

Let the heavy solid line represent the range at which the two-way travel time is equal to a requested data time, t, having been transmitted, say, over path A and received over path B. The heavy dashed line represents the ranges at which the two-way times are $t - \frac{\Delta t}{2}$ and $t + \frac{\Delta t}{2}$, the time limits due to the pulse length Δt.

Now the area insonified over both paths and lying within the time limits will return sound to the source at time t. Figure 4-4 shows this annular area. The annulus is now divided into the incremental areas bounded on two sides by equal-time lines and on the other two by equal-frequency lines. (Sometimes one of these lines degenerates into a point). Such areas are labeled a and b in the figure. The co-ordinates of the corners (numbered 1 to 4) are computed and the areas are approximated by polygons, assuming straight lines between the corners. From the ray data are computed the average transmission loss and scattering strength over the polygon. These, combined with average transmit and receive pattern losses, permit the approximation of the back-scattered energy from each area. These contributions, expressed in intensities, are summed in random phase within the requested time and band limits.

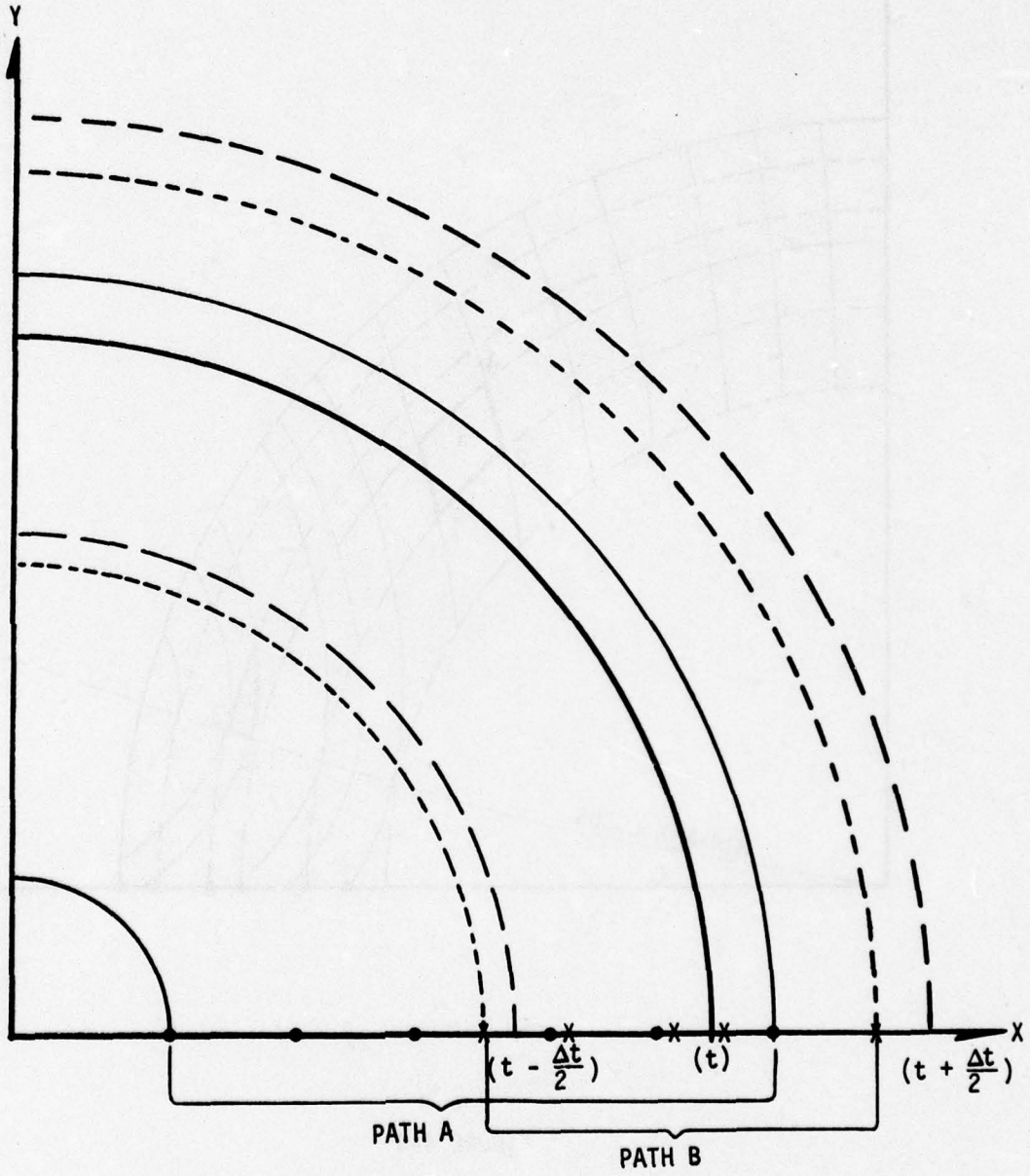

FIGURE 4-3

Insonified portion of surface corresponding to ray paths in Figure 6.

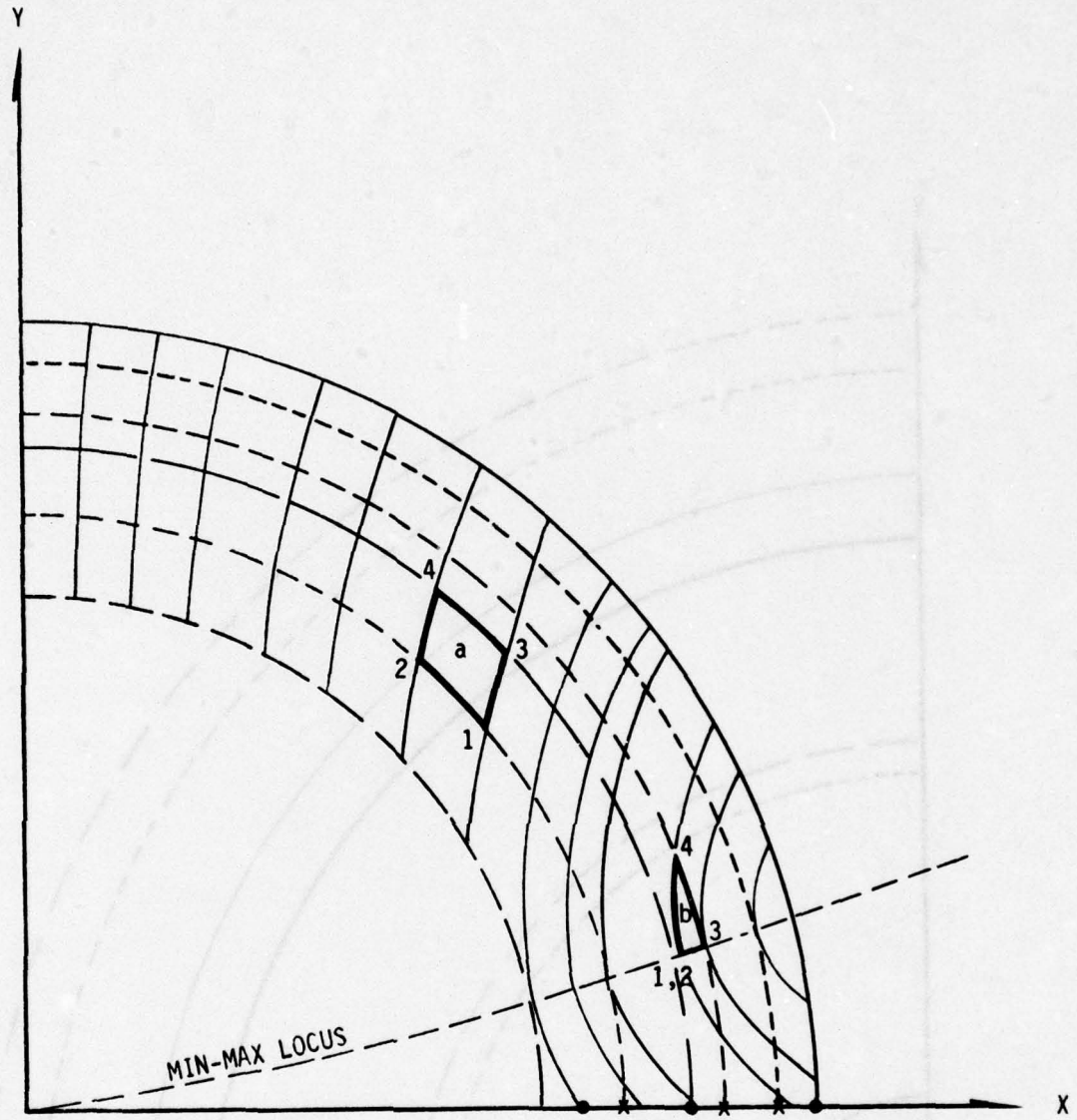

FIGURE 4-4

The part of the common insonified region which also lies between the time limits returns energy to the source at time t. This region has been broken up into incremental areas, bounded on two sides by equal-time lines and on two sides by equal-frequency lines.

4.2.2 Volume Reverberation

Figure 4-5 illustrates the computation of volume reverberation. For the straight-running case, the return in a band at a given time, t, is from the frustum of a hollow cone with spherical bases. The cone is divided radially about its face forming small areas, and the pattern losses to each area are combined to yield an average pattern loss for the iso-frequency volume. Volume reverberation is computed using this pattern loss, average two way transmission losses, volume of the hollow frustum, and volume scattering coefficient. In the turning case the insonified volume is not a cone, and the transmit and receive directions are different. However, the basic procedure is the same as for the non-turning case.

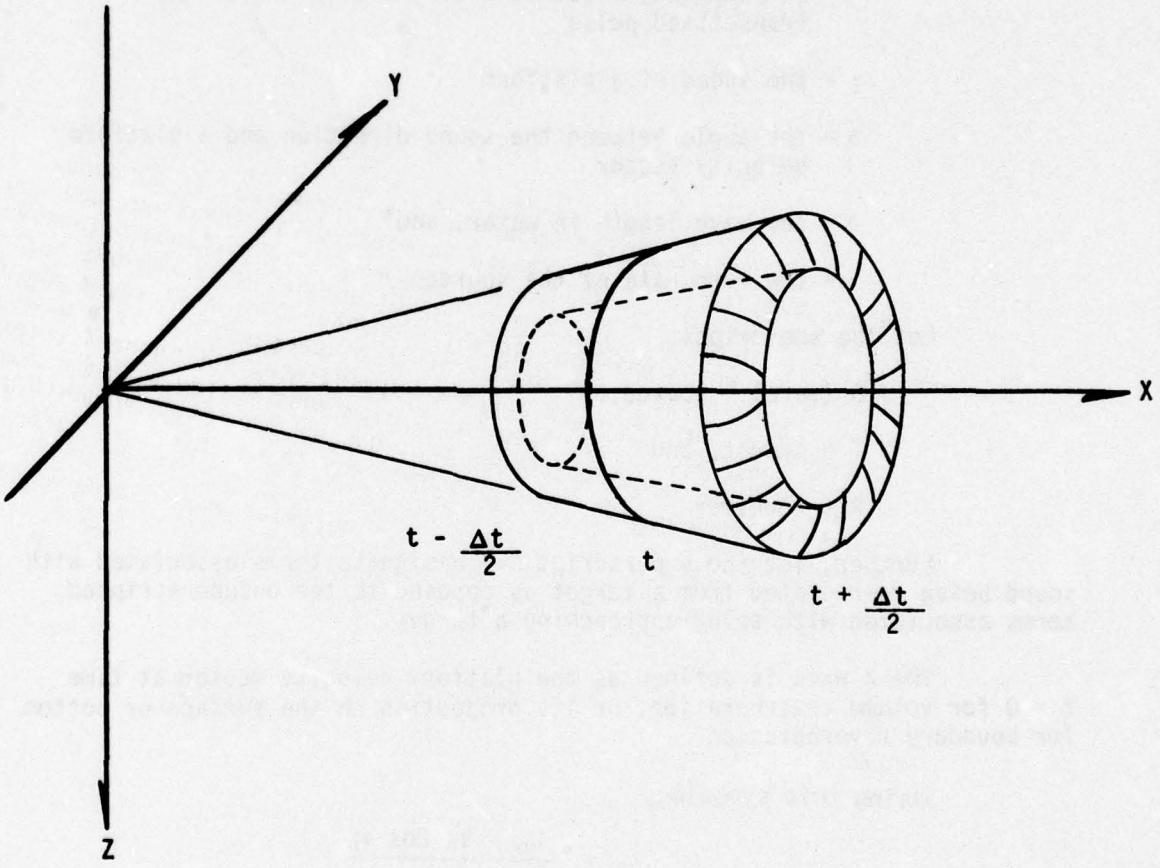

FIGURE 4-5

Volume insonified at time t between two equal-frequency cones and two equal-time spheres. Pattern losses are measured to each area marked on the end.

4.3 Equations

4.3.1 Preliminary

The following symbols and definitions are used in this section:

C = the velocity of sound in water, a function of water depth

f = the frequency of a sound wave

t = the elapsed time at which reverberation is to be computed, measured from the midpoint of the transmitted pulse

V = the speed of a platform

γ = the angle between the sound direction and a platform velocity vector

λ = the wave length in water, and

ω = the turn rate of the source

Let the subscripts

0 (zero) = source,

T = target, and

R = receiver

Further, let the superscript "*" designate terms associated with sound being re-radiated from a target as opposed to the unsuperscripted terms associated with sound approaching a target.

The X axis is defined as the platform velocity vector at time t = 0 for volume reverberation, or its projection on the surface or bottom for boundary reverberation.

Using this symbology

$$\lambda_0 = \frac{C_0 - V_0 \cos \gamma_0}{f_0}$$

Approaching a target

$$\lambda_T = \frac{C_T}{C_0}\lambda_0 = \frac{C_T (C_0 - V_0 \cos \gamma_0)}{C_0 f_0}$$

The frequency observed by a receiver on the target, and that re-radiated into the water will be

$$f_T = \frac{C_T - V_T \cos \gamma_T}{\lambda_T} = f_0 \frac{C_0 (C_T - V_T \cos \gamma_T)}{C_T (C_0 - V_0 \cos \gamma_0)}$$

The wave length of re-radiated sound is

$$\lambda_T^* = \frac{C_T^* - V_T \cos \gamma_T^*}{f_T} = \frac{C_T (C_0 - V_0 \cos \gamma_0) \ (C_T^* - V_T \cos \gamma_T^*)}{f_0 C_0 \ (C_T - V_T \cos \gamma_T)}$$

approaching the receiver,

$$\lambda_R = \frac{C_R}{C_T^*} \lambda_T^* = \frac{C_R C_T \ (C_0 - V_0 \cos \gamma_0) \ (C_T^* - V_T \cos \gamma_T^*)}{f_0 C_0 C_T^* \ (C_T - V_T \cos \gamma_T)}$$

and the frequency seen by the receiver is

$$f_R = \frac{C_R - V_R \cos \gamma_R}{\lambda_R} = f_0 \frac{C_0 C_T^* \ (C_T - V_T \cos \gamma_T) \ (C_R - V_R \cos \gamma_R)}{C_R C_T \ (C_0 - V_0 \cos \gamma_0) \ (C_T^* - V_T \cos \gamma_T^*)}$$

Simplifying, in the vicinity of the target, $C^*_T = C_T$, and considering reverberation as being from motionless scatterers (their motion is handled statistically as "spreading" in the returned sound) $V_T = 0$. Also, we are interested only in the monostatic case (source and receiver at the same point), so $C_R = C_0$ and $V_R = V_0$. Applying these identities we have

$$f_R = f_0 \frac{C_0 - V_0 \cos \gamma_R}{C_0 - V_0 \cos \gamma_0} \tag{1}$$

4.3.2 Boundary Reverberation

For calculations of boundary reverberation, we will resolve the angle γ into its spherical components, the horizontal angle ϕ and the vertical angle, θ. The equation now becomes

$$f_R = \frac{C_0 - V_0 \cos \theta_R \cos \phi_R}{C_0 - V_0 \cos \theta_0 \cos \phi_0}$$

Since C is a function of depth only, the transmitted and received rays are in the same vertical plane. For the straight-running case, $\phi_R = \pi + \phi_0$ but in general $\phi_R = \pi + \phi_0 - \omega t$. Finally, then, the frequency of reverberation received from a point on a boundary,

$$f_R = f_0 \frac{C_0 + V_0 \cos \theta_R \cos (\phi_0 - \omega t)}{C_0 - V_0 \cos \theta_0 \cos \phi_0} \tag{2}$$

Refer again to Figure 4-4. In order to be certain that all incremental areas are assigned to the correct frequency bands, it is important to know what iso-frequency line is tangent to an iso-time line. This is equivalent to finding the maximum or minimum frequency occurring at a given time. It is clear from Figure 4-4 that all the variables of equation (2) except ϕ_0 have been given fixed values. Therefore, we find at what azimuth angle received frequency is a maximum or minimum. Differentiating equation (2),

$$\frac{df_R}{d\phi_0} = -f_0 \frac{V_0 \cos\theta_R \sin(\phi_0 - \omega t)}{C_0 - V_0 \cos\theta_0 \cos\phi_0}$$

$$-f_0 \frac{C_0 + V_0 \cos\theta_R \cos(\phi_0 - \omega t)}{(C_0 - V_0 \cos\theta_0 \cos\phi_0)^2} V_0 \cos\theta_0 \sin\phi_0 = 0$$

Clearing fractions and rearranging terms,

$$V_0^2 \cos\theta_0 \cos\theta_R \left[\sin\phi_0 \cos(\phi_0 - \omega t) - \cos\phi_0 \sin(\phi_0 - \omega t)\right]$$
$$+ C_0 V_0 \left[\cos\theta_R \sin(\phi_0 - \omega t) + \cos\theta_0 \sin\phi_0\right] = 0$$

Reducing the first term and expanding the second term using the sin (a-b) identity,

$$V_0^2 \cos\theta_0 \cos\theta_R \sin\omega t$$
$$+ C_0 V_0 (\cos\theta_R \sin\phi_0 \cos\omega t - \cos\theta_R \cos\phi_0 \sin\omega t + \cos\theta_0 \sin\phi_0) = 0$$

Again rearranging terms

$$(\cos\theta_R \cos\omega t + \cos\theta_0) \sin\phi_0 - \cos\theta_R \sin\omega t \cos\phi_0$$
$$+ \frac{V_0}{C_0} \cos\theta_0 \cos\theta_R \sin\omega t = 0$$

Substituting

$$a = \cos\theta_R \cos\omega t + \cos\theta_0 ,$$

$$b = \cos\theta_R \sin\omega t , \quad \text{and}$$

$$c = \frac{V_0}{C_0} \cos\theta_0 \cos\theta \sin\omega t ,$$

we have

$$a \sin\phi_0 - b\cos\phi_0 + c = 0$$

Squaring and substituting for $\sin^2\phi_0$ we arrive at the quadratic

$$(a^2 + b^2) \cos^2\phi_0 - 2bc \cos\phi + c^2 - a^2 = 0$$

Set into the quadratic formula and simplified, this becomes finally

$$\text{Cos } \phi_0 = \frac{bc \pm a\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2} \qquad (4)$$

To understand the significance of the sign of the radical, consider that when $\omega = 0$, $\sin \omega t = 0$, and $\cos \phi_0 = \pm 1$. That is, the locus of the points of tangency between iso-time and iso-frequency lines (the min-max locus) is the X axis. Also, in this case the iso-frequency line for $f = f_0$ is the Y axis, with greater frequencies to the right, lesser frequencies to the left. Thus it is seen that the positive and negative signs define ϕ_0 for frequency maximum and minima, respectively.

We will now find the co-ordinates of the corners of the insonified polygon labeled 1, 2, 4, 3 in Figure 4-6. At time t and frequency f , from equation (2),

$$f_R C_0 - f_R V_0 \text{ Cos } \theta_0 \text{ Cos } \phi_0 = f_0 C_0 + f_0 V_0 \text{ Cos } \theta_R \text{ Cos } (\phi_0 - \omega t) \quad , \text{ or}$$

$$f_0 \text{ Cos } \theta_R \text{ Cos } (\phi_0 - \omega t) + f_R \text{ Cos } \theta_0 \text{ Cos } \phi_0 - \frac{f_R C_0 - f_0 C_0}{V_0} = 0 \quad , \text{ or}$$

$$f_0 \text{ Cos } \theta_R (\text{Cos } \omega t \text{ Cos } \phi_0 + \text{Sin } \omega t \text{ Sin } \phi_0) + f_R \text{ Cos } \theta_0 \text{ Cos } \phi_0 - \frac{C_0}{V_0}(f_R - f_0) = 0 \quad , \text{ or}$$

$$(f_0 \text{ Cos } \theta_R \text{ Cos } \omega t + f_R \text{ Cos } \theta_0) \text{ Cos } \phi_0 + (f_0 \text{ Cos } \theta_R \text{ Sin } \omega t) \text{ Sin } \phi_0 - \frac{C_0}{V_0}(f_R - f_0) = 0$$

Setting

$$a = f_0 \text{ Cos } \theta_R \text{ Cos } \omega t + f_R \text{ Cos } \theta_0 \ ,$$

$$b = f_0 \text{ Cos } \theta_R \text{ Sin } \omega t \quad , \text{ and}$$

$$c = \frac{C_0}{V_0}(f_R - f_0) \quad ,$$

we have

$$a \text{ Cos } \phi_0 + b \text{ Sin } \phi_0 - c = 0$$

Squaring and substituting for $\sin^2 \phi_0$ as previously, we obtain the quadratic

$$(a^2 + b^2) \text{ Cos } \phi - 2ac \text{ Cos } \phi_0 + c^2 - b^2 = 0,$$

and by quadratic formula

$$\text{Cos } \phi_0 = \frac{ac \pm b\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}$$

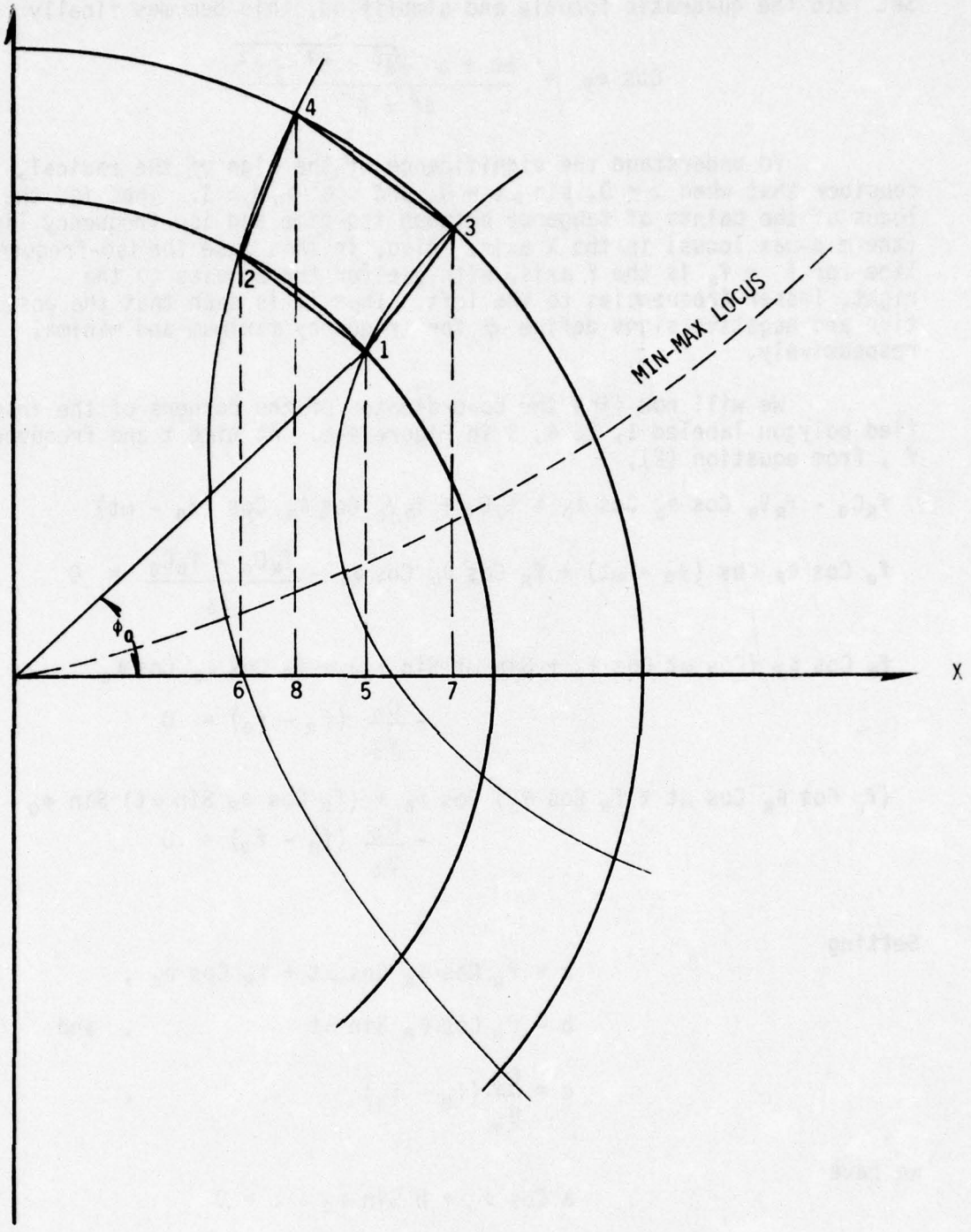

FIGURE 4-6

Finding the value of an incremental area.

Similarly it can be shown that

$$\text{Sin } \phi_0 = \frac{bc \mp a\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}$$

opposite polarity of the radicals being required by the Sin ϕ^2+ Cos ϕ^2 = 1 identity.

Now from Figure 4-6, it is seen that for point 1

$$\text{Cos } \phi_0 = \frac{X_1}{X_t} \quad \text{and} \quad \text{Sin } \phi_0 = \frac{Y_1}{X_t}$$

where x_t is the x value associated with time t, i.e. x_t is the radius of the iso-time circle. Therefore for point 1

$$X_1 = X_t \frac{ac \pm b\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2} \quad \text{and} \tag{5}$$

$$Y_1 = X_t \frac{bc \mp a\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}$$

From considering the geometry when $\omega = 0$, it can be seen that the upper signs are used for insonified polygons which are clockwise of the min-max locus when $f_R > f_0$, counter clockwise of the locus when $f_R < f_0$, and conversely for the lower signs.

The area of the polygon in Figure 4-6 is clearly the sum of trapezoids 2, 4, 8, 6 and 4, 3, 7, 8 less the sum of 2, 1, 5, 6 and 1, 3, 7, 5. That is,

$$A = \tfrac{1}{2}(X_4 - X_2)(Y_4 + Y_2) + \tfrac{1}{2}(X_3 - X_4)(Y_3 + Y_4)$$
$$- \tfrac{1}{2}(X_1 - X_2)(Y_1 + Y_2) - \tfrac{1}{2}(X_3 - X_1)(Y_3 + Y_1) \quad \text{or}$$

$$A = \tfrac{1}{2}(X_4Y_4 + X_4Y_2 - X_2Y_4 - X_2Y_2 + X_3Y_3 + X_3Y_4 - X_4Y_3 - X_4Y_4$$
$$- X_1Y_1 - X_1Y_2 + X_2Y_1 + X_2Y_2 - X_3Y_3 - X_3Y_1 + X_1Y_3 + X_1Y_1)$$

Consolidating, we arrive at the computational form used in the program:

$$A = \left|\tfrac{1}{2}\left[(X_4Y_2 + X_3Y_4 + X_2Y_1 + X_1Y_3) - (X_2Y_4 + X_4Y_3 + X_1Y_2 + X_3Y_1)\right]\right| \tag{6}$$

The taking of absolute value avoids negative areas in some quadrants.

Equation 6 is quite general and computes correct areas even for triangles.

4.3.3 Volume Reverberation

Now in the straight-running case, as has been mentioned before, the iso-frequency surface is a cone. In the turning case, this surface becomes quite complex, even discontinuous for certain combinations of frequency and turn angle. We will now derive a method of expressing the volume within an iso-frequency surface in the general case.

To begin with, equation (2) is equally applicable to volume reverberation. However, in the simplified model, using a uniform unbounded medium, the transmit and receive paths will necessarily be the same for the straight running case. In any case, θ_R will equal θ_0. Thus the equation becomes

$$f_R = f_0 \frac{C_0 + V_0 \cos\theta_0 \cos(\phi_0 - \omega t)}{C_0 - V_0 \cos\theta_0 \cos\phi_0}$$

clearing the fraction and rearranging terms

$$\cos\theta_0 \left[f_0 \cos(\phi_0 - \omega t) + f_R \cos\phi_0\right] = \frac{C_0}{V_0}(f_R - f_0)$$

Substituting

$$\cos(\phi_0 - \omega t) = \cos\phi_0 \cos\omega t + \sin\phi_0 \sin\omega t,$$

$$\cos\phi_0 = \frac{X}{\sqrt{X^2 + Y^2}},$$

$$\sin\phi_0 = \frac{Y}{\sqrt{X^2 + Y^2}}, \text{ and}$$

$$\cos\theta_0 = \frac{\sqrt{X^2 + Y^2}}{\sqrt{X^2 + Y^2 + Z^2}}, \text{ we obtain}$$

$$\frac{\sqrt{X^2 + Y^2}}{\sqrt{X^2 + Y^2 + Z^2}}\left[f_0\left(\frac{X}{\sqrt{X^2 + Y^2}}\cos\omega t + \frac{Y}{\sqrt{X^2 + Y^2}}\sin\omega t\right) + f_R \frac{X}{\sqrt{X^2 + Y^2}}\right] = \frac{C_0}{V_0}(f_R - f_0)$$

or

$$f_0(X\cos\omega t + Y\sin\omega t) + f_R X = \frac{C_0}{V_0}(f_R - f_0)\sqrt{X^2 + Y^2 + Z^2}$$

or

$$X(f_0\cos t + f_R) + Y(f_0 \sin\omega t) = \frac{C_0}{V_0}(f_R - f_0)\sqrt{X^2 + Y^2 + Z^2} \qquad (7)$$

Equation (7) describes the iso-frequency surface in cartesian coordinates.

For simplicity let us substitute

$$a = f_0 \cos \omega t + f_R \quad ,$$

$$b = f_0 \sin \omega t \quad , \text{ and}$$

$$c = \frac{C_0}{V_0} (f_R - f_0) \quad , \text{ yielding}$$

$$aX + bY = c \sqrt{X^2 + Y^2 + Z^2} \qquad (8)$$

By rotating axes through some angle δ, the Y term of the above equation can be eliminated. Using the superscript "prime" to denote measurements in a rotated system and the transformations

$$X' = X \cos \delta + Y \sin \delta \quad \text{and}$$

$$Y' = Y \cos \delta - X \sin \delta \quad ,$$

it can be seen that to eliminate the Y term in the left half of equation (8), δ must be chosen such that

$$a \sin \delta + b \cos \delta = 0 \quad , \text{ or}$$

$$a^2 \sin^2 \delta = b^2 \cos^2 \delta \quad , \text{ or}$$

$$\sin^2 \delta = \frac{b^2}{a^2 + b^2} \text{ and } \cos^2 \delta = \frac{a^2}{a^2 + b^2} \quad , \text{ or}$$

$$\sin \delta = \frac{-b}{\sqrt{a^2 + b^2}} \text{ and } \cos \delta = \frac{a}{\sqrt{a^2 + b^2}}$$

applying this to equation (8) we have

$$\frac{a^2 X'}{\sqrt{a^2 + b^2}} - \frac{abY'}{\sqrt{a^2 + b^2}} + \frac{abY'}{\sqrt{a^2 + b^2}} + \frac{b^2 X'}{\sqrt{a^2 + b^2}} = c \sqrt{(X')^2 + (Y')^2 + Z^2} \quad , \text{ or}$$

$$\frac{a^2 + b^2}{\sqrt{a^2 + b^2}} X' = c \sqrt{(X')^2 + (Y')^2 + Z^2} \quad , \text{ or}$$

$$\frac{X'}{\sqrt{(X')^2 + (Y')^2 + Z^2}} = \frac{c}{\sqrt{a^2 + b^2}}$$

Resubstituting,

$$\frac{X'}{\sqrt{(X')^2 + (Y')^2 + Z^2}} = \frac{\frac{C_0}{V_0}(f_R - f_0)}{\sqrt{(f_0 \cos \omega t + f_R)^2 + f_0^2 \sin^2 \omega t}}$$, or

$$\frac{X'}{\sqrt{(X')^2 + (Y')^2 + Z^2}} = \frac{\frac{C_0}{V_0}(f_R - f_0)}{\sqrt{f_0^2 + f_R^2 + 2f_R f_0 \cos \omega t}}$$

remembering that $\sqrt{(X')^2 + (Y')^2 + Z^2} = C_0 t$, the distance that the sound has traveled in time t.

But the left hand member of this equation is cos γ', the X' direction cosine. For a particular set of values of the parameters in the right-hand member of the equation, cosγ', and hence γ' are constant. Thus it can be seen that for each time, t, the intersection of the iso-frequency surface of frequency f_R and the sphere of radius $C_0 t$ is a circle centered on the X' axis, which is at angle δ from the X axis. This circle defines a spherical segment.

Let us define our differential of the volume enclosed by an iso-frequency surface as the area of this segment times the differential of range or

$$dv = A\, dr$$

Now the area of a segment with thickness of h of a sphere of radious r is

$$A = 2\pi r h \qquad \text{where}$$

$$h = r - r \cos \gamma$$

Therefore

$$A = 2\pi r^2 (1 - \cos \gamma) \quad , \text{and}$$

$$dv = 2\pi r^2 (1 - \cos \gamma)\, dr$$

Substituting for r, dr, and Cos γ we have

$$dv = 2\pi C_0^3 t^2 \left[1 - \frac{\frac{C_0}{V_0}(f_R - f_0)}{\sqrt{f_0^2 + f_R^2 + 2f_R f_0 \cos \omega t}} \right] dt$$

The volume returning energy from within the iso-frequency surface at time t will be

$$V = 2\pi C_o^3 \int_{t - \frac{\Delta t}{2}}^{t + \frac{\Delta t}{2}} t^2 \left[1 - \frac{\frac{C_o}{V_o (f_R - f_o)}}{\sqrt{f_o^2 + f_R^2 + 2 f_R f_o \cos \omega t}} \right] dt \qquad (9)$$

The integral in equation (9) has no analytic solution, but is evaluated digitally. The volume returning energy within any band, obviously, would be the difference between two such integrals at the two values of f_R representing the band limits.

4.4 Verification

Appendix F gives the results of an extensive comparison between various models for computing the boundary reverberation. This compares results only for straight-running cases. In addition, comparisons were made in 1973 with an independent model developed by Dr. J. H. Slaton of the Naval Undersea Center for a limited number of turning cases. These revealed several difficulties in the turning case which have been corrected. Agreement was very good, considering the difference in mathematical approach.

For the straight-running case, comparisons of volume reverberation with the method described in reference 1 have been excellent. This was expected because of the similarity in assumptions in the two very simplified models.

SECTION V

AREAS FOR POSSIBLE IMPROVEMENTS AND REFINEMENTS

5.1 Volume Reverberation

The simulation of volume reverberation includes two gross simplifications; the medium is homogeneous, and it is unbounded. Thus, several known features of particular environments cannot be realistically approximated. In particular, returns from scattering layers, returns from regions of greater or lesser focusing, e.g. caustics, and returns over multiple paths are ignored. Still it is hoped that the model can supply numbers of the right order of magnitude in some useful cases.

Almost from the beginning, the three-dimensional analogue of the boundary calculations was recognized as more realistic. A preliminary study was made in 1967 by M.M. Jacoby of NUC, which outlined the geometric problems of computing incremental volumes. Although precise formulae have still not been developed, the problems seem mainly those of bookkeeping; that is, of ensuring that the entire insonified volume is accounted for. The calculations would also be very costly in computer time.

Implementations of this model: tedious and time-consuming to write and check-out, but require only re-writing of one DOP subroutine, plus the changes in SONAR mentioned in 5.2.

5.2 Multi-path Reverberation

The current model approximates the ray-path losses when transmit and receive paths are not the same. The approximation is simply the average of the two-way losses over each single path. Now the transmitted and reflected rays have different spreading loss even over the same (reciprocal) path. The difference is small, however, rarely amounting to so much as 0.2 dB.

Another discrepancy is in the implicit averaging of the scattering strengths. The tacit assumption (not to be dignified as an approximation) is that scattering strength from one path into another is the average of the back scattering strengths for the two paths. In the absence of a good theoretical or empirical alternative, this assumption was allowed to stand. There is a need for a single expression of scattering strength in all directions from an incident ray.

Incorporating such an expression in DOP would require that scattering strength be removed from total losses passed by program SONAR.

Assesment of these changes: given the scattering expression, the latter change would be an easy matter; the former would not be much more difficult.

5.3 Vehicle Translation During Ping

Appendix E discusses the consequences of using the same ray-path for transmit and receive, ignoring the translation of the vehicle. This change is of secondary importance, but should probably be included for completeness if the changes in 5.2 were implemented. It would be easy under these circumstances.

5.4 "Spreading" of Reverberation

There are theoretical reasons to believe that doppler shifts caused by motions of scatterers, particularily at the surface, are a function of grazing angle. No such provision is made in this model. Incorporation of this feature would require a fundamental change in the handling of boundary "spreading" and probably minor changes in SONAR and RAYSRT.

Difficulty of these changes: moderately lengthy, but not complicated.

5.5 Preferential Orientation of Vehicle with Respect to the Environment.

Real environments are non-uniform in every direction, not merely in depth as currently modeled.

The following three additions to the model would take account of some non-uniformities. All would come under the heading of major revisions. In addition, it is clear that, conditions being different at all points and times in the environment, a single ping cycle would no longer give a general description of reverberation. The changes would, however, make possible the calculation of ranges of values that might be expected.

5.5.1 Current and/or Wind Direction

Only DOP would need revision. Doppler content due to both vehicle motion and scatterer motion is affected.

5.5.2 Sloping or Broken Bottom

The SONAR program can compute rays reflected from any bottom made of plane segments which reflect rays in the vertical plane of incidence. Such bottom segments must be perpendicular to the plane containing the rays, and such bottoms are of limited usefulness in modeling real environments.

Spreading losses and directions of reflections can be computed for rays striking any analytically describable bottom. However a properly general treatment would require considerable changes not only in SONAR and DOP, but also in RAYSRT. These changes would seem of little value without also the ones in 5.5.3.

5.5.3 Three-dimensional Velocity Profiles

The use of velocity profiles varying in two or three dimensions requires completely new SONAR, RAYSRT and DOP programs; no mere adaptation would suffice. While ray tracing programs already exist and could be adapted, the running times would be increased by an order of magnitude, at least.

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000002  000  2
000003  000  36.      7.      8.      9.
000004  000  4-90.    1.5     0.      -31.4    -90.     9.       0.       0.
000005  000  4-82.    -1.5    10.     -25.7    0.       9.       0.       19.8
000006  000  4-77.    -5.     20.     -22.3    0.                10.      22.9
000007  000  4-68.    -16.5   30.     -19.6                      12.      25.3
000008  000  4-60.    -24.    40.     -17.2                      14.      27.1
000009  000  4-53.    -28.    50.     -14.9                      16.      28.3
000010  000  4-48.    -30.    60.     -12.9                      18.      29.3
000011  000  4-40.    -32.    70.     -11.1                      20.      30.1
000012  000  4-30.    -34.    80.     -9.2                       25.      31.4
000013  000  4-9.     -37.    90.     -7.6                       30.      32.
000014  000  40.      -43.    90.                                40.      31.6
000015  000  40.                                                 50.      27.4
000016  000  D                                                   90.      22.8
000017  000  31.      2.      3.      5.
000018  000  4 -180.  0.      0.      0.       0.       0.       0.       0.
000019  000  D  180.  0.      10.     0.       200.     0.       200.     0.
000020  000  3 4.     10.
000021  000  4 0.     0.      0.      9000.
000022  000  D 10.    0.      9000.   4000.
000023  000  C11.     12.
000024  000  50.              2820421.4         -.27303767        69.502715        3.70
000025  000  525.
000026  000  550.
000027  000  5100.
000028  000  5150.
000029  000  5180.
000030  000  5190.
000031  000  5200.                                                                 3.70
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000033  000  5208.50815       2820421.4         -.27303767        69.502715
000034  000  5215.
000035  000  5225.
000036  000  5235.
000037  000  5245.
000038  000  5250.00149       2820409.3         -.29729444        70.631276        3.71
000039  000  5265.
000040  000  5280.
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000044  000  5320.
000045  000  5350.                                                                 4.31
000046  000  5380.
000047  000  5403.                                                                 4.78
000048  000  5430.
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000051  000  5491.16777       2680549.1         811.65644         164.15731
000052  000  5492.00578       4796782.1         -.06451453        -3334.0923       5.50
000053  000  5520.
000054  000  5550.                                                                 5.68
000055  000  5570.
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APPENDIX A

FIGURE 1

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000061  000  5700.                                                          6.02
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000065  000  5783.34800      2641521.0      -1.1518146       254.37530
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000075  000  51400.
000076  000  51510.9659      2629880.5      0.11624671       503.65531
000077  000  51537.3904      2629909.7      -.49887228       514.51595
000078  000  51543.5479      2629909.7      -.49887228       514.51595
000079  000  51650.0650      2618522.7      0.0839802        760.02509       6.41
000080  000  51900.
000081  000  51968.                                                         6.58
000082  000  52280.0753      2618522.7      0.0839802        760.02509
000083  000  52297.                                                         6.71
000084  000  52400.
000085  000  52500.1493      2622869.3      -.031541745      1029.0237       6.72
000086  000  52790.8537      2621997.8      0.22062943       916.17354
000087  000  52936.2060      2670552.4      -.011193266      2234.7494       6.79
000088  000  53500.                                                         6.77
000089  000  53904.                                                         6.76
000090  000  E4000.                                                         6.77
000091  000  6DOPLER  750.   119.    17.     -2.     2.9                    020040
000092  000  7-90.    90.    1.
000093  000  7        MAXN
000094  000  7        MAXP
000095  000  7        DEPTHN
000096  000  7        DEPTHP
000097  000  +
000098  000  6DOPL 2  500.   119.    17.     -2.     2.9                    020040
000099  000  GLIST
000100  000  6DOPL 3  275.   119.    17.     -2.     2.9                    020040
000101  000  +
000102  000  GLIST
000103  000  ,

END ELT.
```

APPENDIX A

FIGURE 1 (CONTINUED)

FIGURE 2

```
@       ELT,IL   A.TEST-PROBLEM/DOP-RAYSRT
ELTOT7 RLI870 09/24-14:39:18-(,0)
000001      000          PLOT
000002      000   0.          4000.
000003      000   +
000004      000   0.          4000.
000005      000   +
000006      000   0.          4000.
000007      000   +

END ELT.
```

FIGURE 3

```
@ELT,IL A.TEST-PROBLEM/DOP-DOP
ELTOT7 RLI870 07/23-12:45:50-(,0)
000001      000   FO = 3.1415926535 E1
000002      000   VS= 45., BWIDTH = .25, DELT = .040, TIME =
000003      000   1.5       ,2.0
000004      000   1.5       ,2.0
000005      000   .250
000006      000    THTMAX = 30.
000007      000   BWIDTH = 5.
000008      000   GO
000009      000   THTMAX = 180.
000010      000   KNOTS,RELATIVE
000011      000   OMEGA = 10., NBEAM = 1
000012      000   CENTER
000013      000   FILTER
000014      000   VSPRED=.2,.1,.1,.1,.1
000015      000   SSPRED = .5,.125,.0625,.03125,.015625,.015625
000016      000   BSPRED=.5,.2,.05
000017      000   BWIDTH = 1.
000018      000   PRINT EVERY = 5
000019      000     TIME = .750
000020      000   GO
000021      000   TIMECOMP, TOTALS
000022      000   TVG
000023      000          PLOT
000024      000   GO
000025      000   GO, END

END ELT.
```

APPENDIX A (CONTINUED)

APPENDIX B

MEMORANDUM

P80203/ABP:pas
18 January 1965

From: Code P80203
To: Code P802

Subject: Error from Using 10 $\log_{10}\tau$ as a Measure of Effective Train Length When Computing Boundary Reverberation.

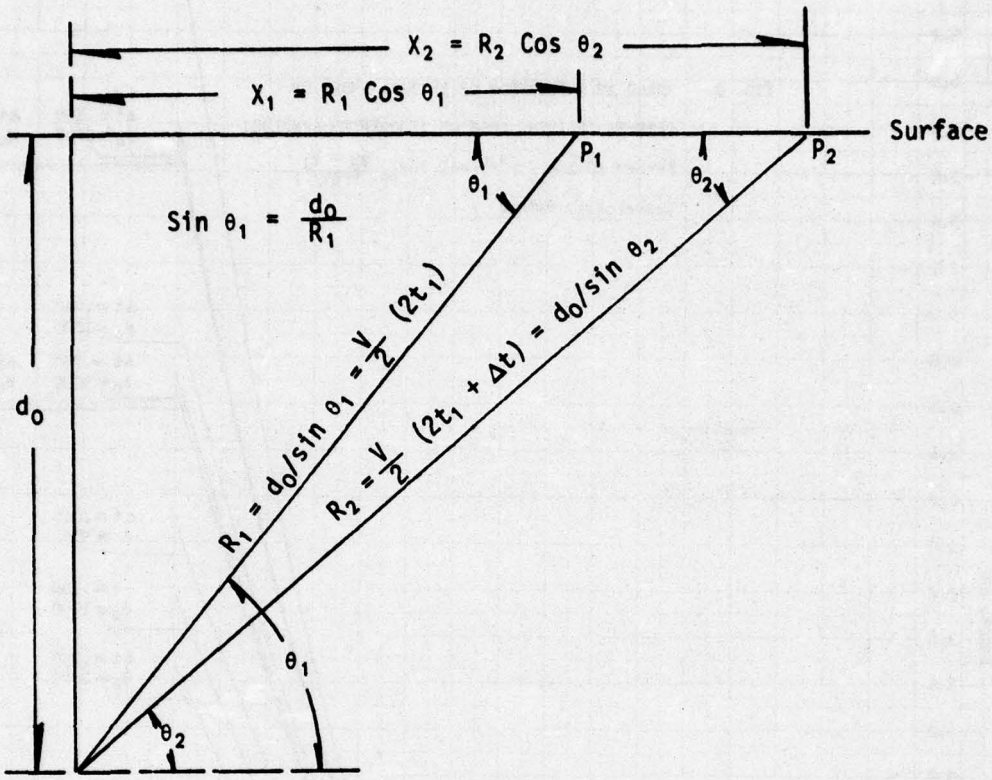
In mathematical models commonly in use for computing boundary reverberation levels in dB, a factor of 10 $\log_{10}\tau$ is added in to account for the fact that an insonified annulus of finite width returns energy to the transducer at the same instant of time. In this context τ is taken to be $V(\Delta t)/2$ where V is the velocity of sound and Δt is the ping length in seconds. It is rather obvious that τ is an accurate measure of annulus width only when the transmission path is essentially horizontal. Since analyses are contemplated for applications in which long pings and steep paths are involved, it seemed desirable to investigate the magnitude of errors which might accrue.

Some simple calculations were made after the fashion indicated in Figure 1, assuming an isotropic medium (V = 5000 ft/sec). Starting with a source depth and an initial ray angle relative to the horizontal, the slant range (R_1) to surface intercept was computed along with the horizontal range (X_1) to this point and the two-way travel time. If time is measured from the end of transmission, this two-way travel time ($2t_1$) would identify the instant when the trailing edge of the wave train will return energy from point P_1. At this same instant the leading edge of the wave train will be returning energy from point (P_2) for which the horizontal range (X_2) can be found on the basis of a slant range (R_2) consistent with a two-way travel time of $2t_2 = 2t_1 + \Delta t$. The width of the insonified annulus is $\tau^* = X_2 - X_1$. A measure of the dB error involved by using τ instead of τ^* is given by $10 \log_{10} \frac{\tau^*}{\tau}$.

Such calculations were carried out over a range of values for Q_1 of 20° through 80° for combinations of conditions that can be obtained from source depths of 500, 1000, 2000, and 5000 feet, and ping lengths of .040, .100, and .250 seconds. The results are plotted in Figure 2. The error as plotted is the number of dB that should be added to values computed when 10 log τ is used. It appears that the error from this source is negligible when the significant paths are less than 20° from the horizontal as is the case for the directional systems we have previously analyzed in circular search. Even when a refractive environment is considered, the uncertainty in using an average velocity in computing τ should not increase the error appreciably. As expected, the inaccuracy mounts rapidly with increasing path angles above 20° and with increasing source depth. However, the decrease in error as the ping length becomes longer was not anticipated. This trend occurs because in the ratio $\frac{\tau^*}{\tau}$ the numerator increases less rapidly than does the denominator with increasing ping length.

If the annulus width itself were the only potential source of error, it would be possible to devise a correction procedure. Unfortunately, the contribution of each unit width of the insonified area to the reverberation level is not necessarily the same since the transmission and vertical pattern losses may vary substantially for the different paths involved. Nor in general can a total error be computed by summing the independent errors for each of the factors handled separately. A method for assessing the composite error will be presented in a subsequent memorandum.

A. B. POYNTER



$$P_2 P_1 = R_1^2 + R_2^2 - 2R_1R_2 \cos (\theta_1 - \theta_2)$$

FIGURE 1

Method for finding $\tau^* = X_2 - X_1$

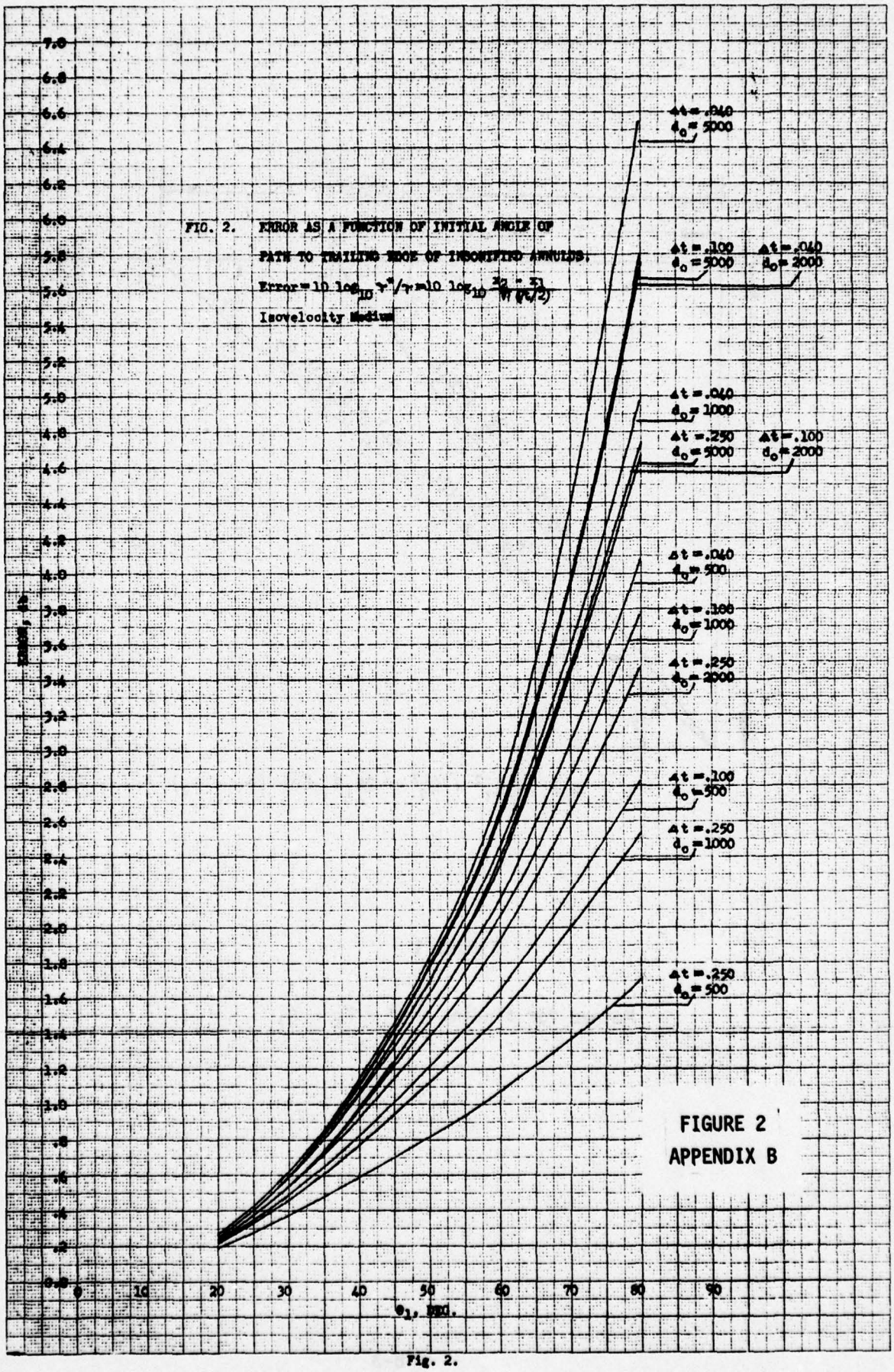


FIGURE 2
APPENDIX B

Fig. 2.

APPENDIX C

MEMORANDUM

P80203/ABP:pas
20 January 1965

From: Code P80203
To: Code P802

Subject: Review of Mathematical Model for Computing Boundary Reverberation.

References: A. NAVORD Report 5606 (NOTS 1818) - Analytical Methods for Predicting Acoustic Performance of Homing Torpedoes in Circular Search.

B. TPR 246 (NOTS TP 2498) - Analytical Studies of Sonar in Refractive Water.

C. P80203 Memo, "Error from Using 10 $\log_{10}\tau$ as a Measure of Effective Train Length when Computing Boundary Reverberation," of 18 January 1965.

In the analytical work, it is necessary to develop mathematical models of the phenomenon to be studied so that quantitative results can be computed. These models are seldom exact, either because the process is not completely understood or because of a desire to avoid complexities which do not materially affect the results. The models may be adequate for the purpose originally intended, but it is dangerous to extend their use to new situations without reassessing their adequacy. The surface and bottom reverberation equations used in our computer programs are cases in point. The equations in general use are those given in References A and B.

For boundary reverberation a ray is traced to the surface (or bottom) and the expected reverberation level at the time in the ping cycle corresponding to the two-way travel time is computed, using: the transmission loss over this path; vertical pattern losses based on the initial ray angle, and a scattering coefficient per unit area based on the grazing angle at which the ray strikes the surface. Since the annular ring on the surface which returns energy at the time in question is unlikely to be unit distance wide, an additional term ($10\log_{10}\tau$) is added (τ = half the train length = $V(\Delta t)/2$ where V is the velocity of sound and Δt is the ping duration in seconds). The equation was formulated in the context of fairly shallow systems using relatively short pings and highly directional transducers oriented to emphasize horizontal coverage. For such systems the equation could be expected to yield acceptable accuracy. Future applications may involve one or more of the following:

- Long ping lengths for correlation detection
- Broad vertical patterns to provide greater depth coverage
- Steep paths (deep source or bottom bounce)

In preparation for such work it seems advisable to re-examine the mathematical model to ascertain whether or not it is still satisfactory.

In Reference C it was shown that 10 $\log_{10}\tau$ may not adequately account for the linear extent of the insonified area of the boundary which returns energy at the same instant of time. Moreover, when this annulus has considerable width, as is the case for the longer pings, the contribution of various parts of the insonified area to the total energy return may be substantially different because of variations in transmission loss, pattern loss, and even in the scattering coefficient for the different paths involved. To better account for these things and to provide a reference for assessing the accuracy of the model now in use, modifications were made in the computational procedures.

The key to the method is the temporary assumption that 10 $\log_{10}\tau = 0$. This is equivalent to saying that a ping length is chosen so that the insonified annulus at the boundary is 1-yard wide. This is consistent with the way in which the scattering coefficient is given as a function of grazing angle, and, over such a distance, no change in transmission or pattern loss need be considered. Otherwise, the desired sets of environmental conditions and equipment parameters are used. A whole family of rays are run from the selected source depth to the surface, and reverberation levels are computed as before. However, instead of plotting reverberation level versus two-way travel time as is usual, both reverberation and travel time are plotted against the horizontal range at which each ray strikes the surface. If the beginning of transmission is taken as zero time, any selected time ($2t_i$) on the two-way time curve will identify the horizontal range at the surface from which the leading edge of the wave train is returning reverberation. It follows that $2t_i - \Delta t$ identifies the range from which the trailing edge is returning energy at the same instant. Integrating the reverberation curve between these two limits should give the actual reverberation level quite accurately. It should be noted that the values in the one-yard increments must be converted from dB to intensity before summing and then reconverted. Reasonable accuracy can be achieved with much less work by using average values for range increments several yards wide and multiplying each average value by the number of yards in the increment before summing.

After sufficient points have been determined in this manner, the values of reverberation can be replotted against elapsed time to yield the type of presentation generally desired. To obtain comparable results from the original model, one can rerun the computer program using the appropriate value for 10 $\log_{10}\tau$ as determined by the ping length of the transmission. It is more efficient, however, to return to the working curves and add 10 $\log_{10}\tau$ to the values of the reverberation curve for $\tau = 1$ at the range determined by the travel time curve at the elapsed times for which data are desired.

Surface reverberation levels were computed by the two methods using parameters for the Torpedo MK 46 Mod 0 in circular search. Attenuation by the RRF was not considered. The source depth was assumed to be 750 feet. The velocity profile for the environment is shown in Figure 1A. The new computer program which permits use of a continuous gradient profile was used. The comparative results for a 40-ms ping are shown in Figure 2. The vertical patterns, of course, dominate the shape of the curves at times less than one second. The integration procedure would normally be expected to lower the peaks and fill in the troughs as well as to shift them slightly. The fact that the peaks in this case are lower for the curve obtained via the old

model suggests that the 10 log τ correction is insufficient, particularly at the shorter times which would be identified with steeper paths. It might be kept in mind that the curve obtained by means of the original equation has the same shape as would the 10 log τ = 0 curve. The initial ray angles associated with a few points on this curve are shown as a matter of interest.

Figure 3 shows the comparative reverberation levels that would obtain if a ping length of 250-ms were used. It is clear that one must be very careful in computing reverberation levels when long pings are used; the two curves are substantially different. The integrated curve was not determined at times less than .55 seconds because before that time all of the ping has not reached the surface.

For both ping lengths, the curves would match more closely if tl curves obtained by means of the original model were advanced in time by one-half the ping length. This follows since the computed ray path would then, in effect, intercept the surface near the middle of the insonified area and the transmission loss, vertical pattern loss, and scattering coefficient would be more representative of the area as a whole than is the case when the ray falls at one end of the insonified area. Figures 4 and 5 compare the results when this subterfuge is used for the .040 and .250 ping lengths, respectively.

As a further check, additional calculations were made for a non-turning vehicle at 500 feet in an environment characterized by velocity Profile B shown in Figure 1. Our old computer program based on linear-gradient layers was used in this instance. Other parameters were unchanged. The results are similar to those from the first set of calculations. Figure 6 compares the 40-ms ping data from the integrated method with that from the original model after the latter had been advanced in time by half the ping length.

Figure 7 presents similar data for the 250-ms ping. Part A, on the left shows the results out to 1.4 seconds. Calculations for this case were carried out to about 7.5 seconds, and the curves (after translation) remain in close agreement until about 6.7 seconds. For this elapsed time the paths involved are from rays that start out below the horizontal and are refracted back toward the surface by the positive velocity gradients which characterize this environment below 170 feet. The ray having a two-way travel time of 6.705 seconds and subsequent ones having slightly steeper initial angles, reverse at depths where the velocity gradient becomes less positive. This results in an abrupt increase in transmission loss and a resulting drop in reverberation level as indicated in Figure 7B (recall that the curve based on the original model has been advanced by 0.125 seconds.) In the vicinity of such anomalies the integrated method offers the only approach for computing expected values of boundary reverberation levels with reasonable accuracy.

Some general observations appear warranted:

- Within the limits imposed by the input data, accurate expected levels of surface reverberation as a function of elapsed time can be computed by means of ray tracing

programs by summing the contributions of 1-yard increments of the insonified annulus which contribute at the same instant.

- At present, this can be accomplished manually, but it may be possible to program the computer to this end.

- The present mathematical model can yield results which are reasonably accurate over the elapsed time interval during which the sound paths are such that $10 \log_{10} \tau$ is a good measure of the width of the insonified annulus and the change in transmission loss, pattern losses, etc. over this annulus is not appreciable.

- The accuracy attainable and/or the time interval over which a given accuracy can be maintained will be increased if, in effect, the elapsed time is measured from the middle of the transmittal ping. If time is measured from the beginning of transmission the computed two-way travel time to the surface for each ray should be increased by $\Delta t/2$ to obtain the time consistent with the computed reverberation level.

- Even if the technique in the above paragraph is used, errors may become substantial when:

    - The paths are very steep so that $10 \log_{10} \tau$ is not a good measure of annulus width;

    - The insonified annulus is wide enough to encompass a spread of paths through the minor lobes of the transducer;

    - In the vicinity of transmission loss anomalies (either substantial focusing or defocusing)

The above observations should also apply to bottom reverberation, except that additional complications may arise if the bottom is irregular.

A. B. POYNTER

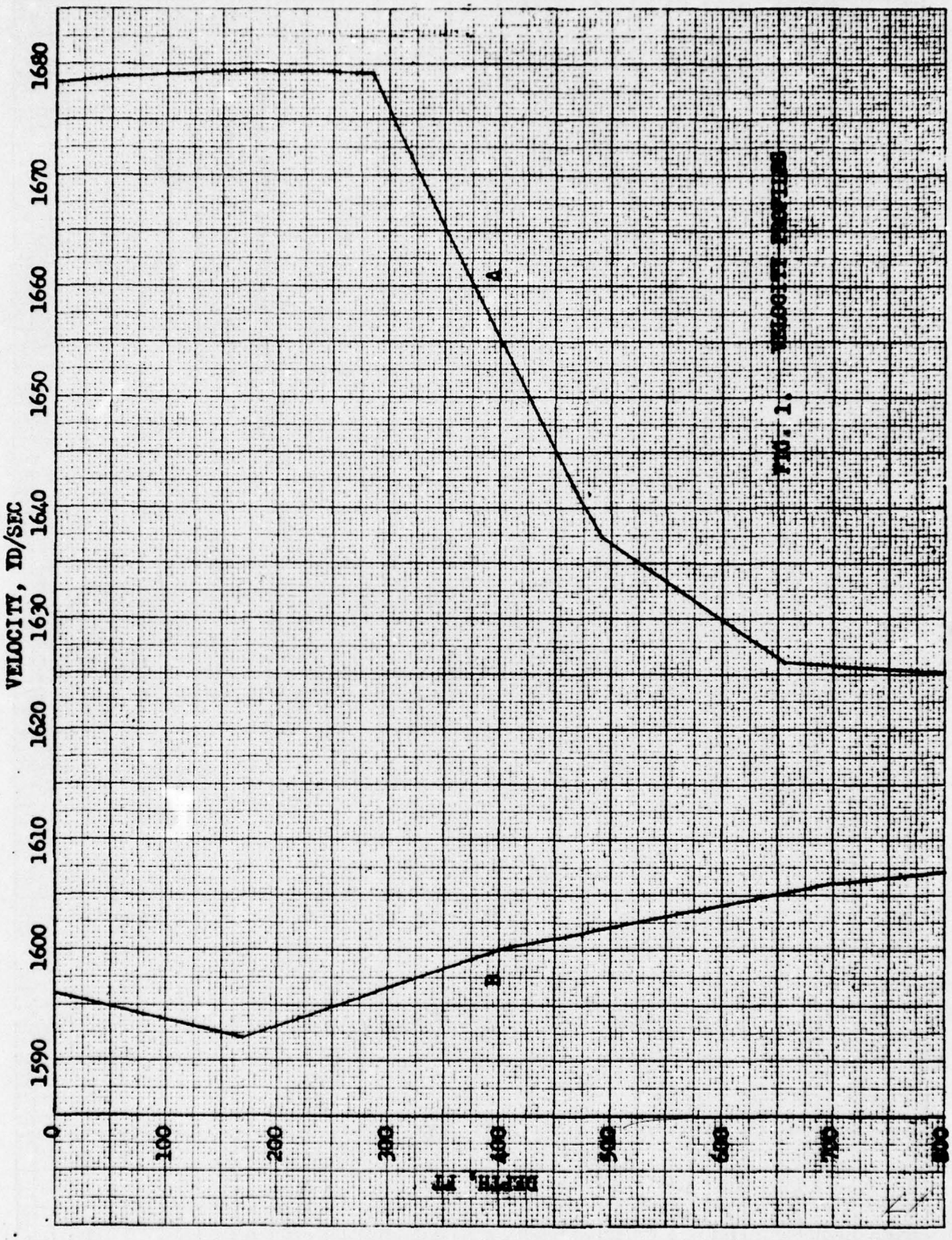


FIG. 1. [illegible]

Fig. 1.

APPENDIX C

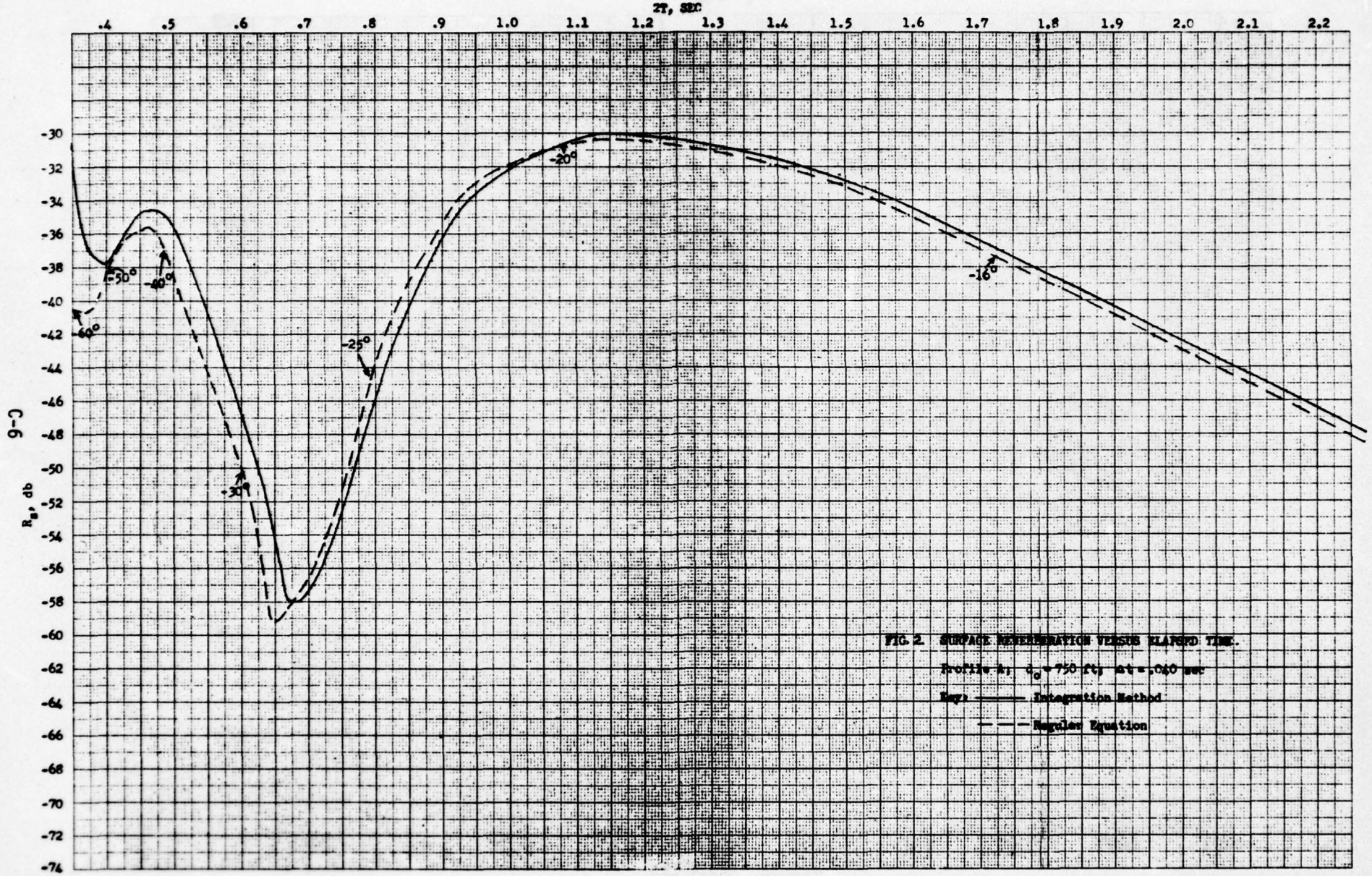


FIG. 2. SURFACE REVERBERATION VERSUS ELAPSED TIME.

Profile A; d_o = 750 ft; Δt = .040 sec

Key: ——— Integration Method

— — — Regular Equation

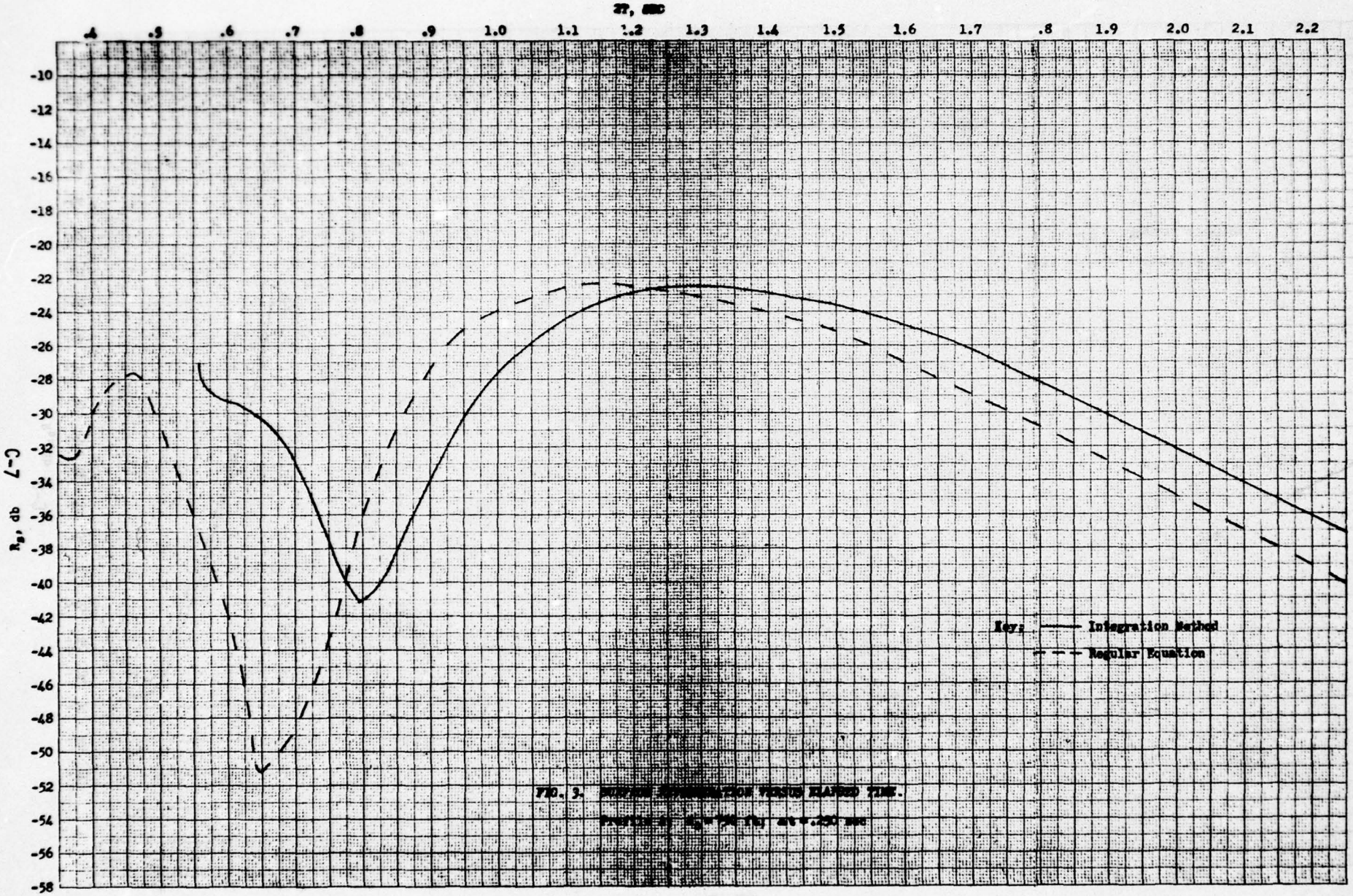


FIG. 3. [illegible] CORRELATION VERSUS ELAPSED TIME.

Portion of [illegible] flight at t=.250 sec

APPENDIX C

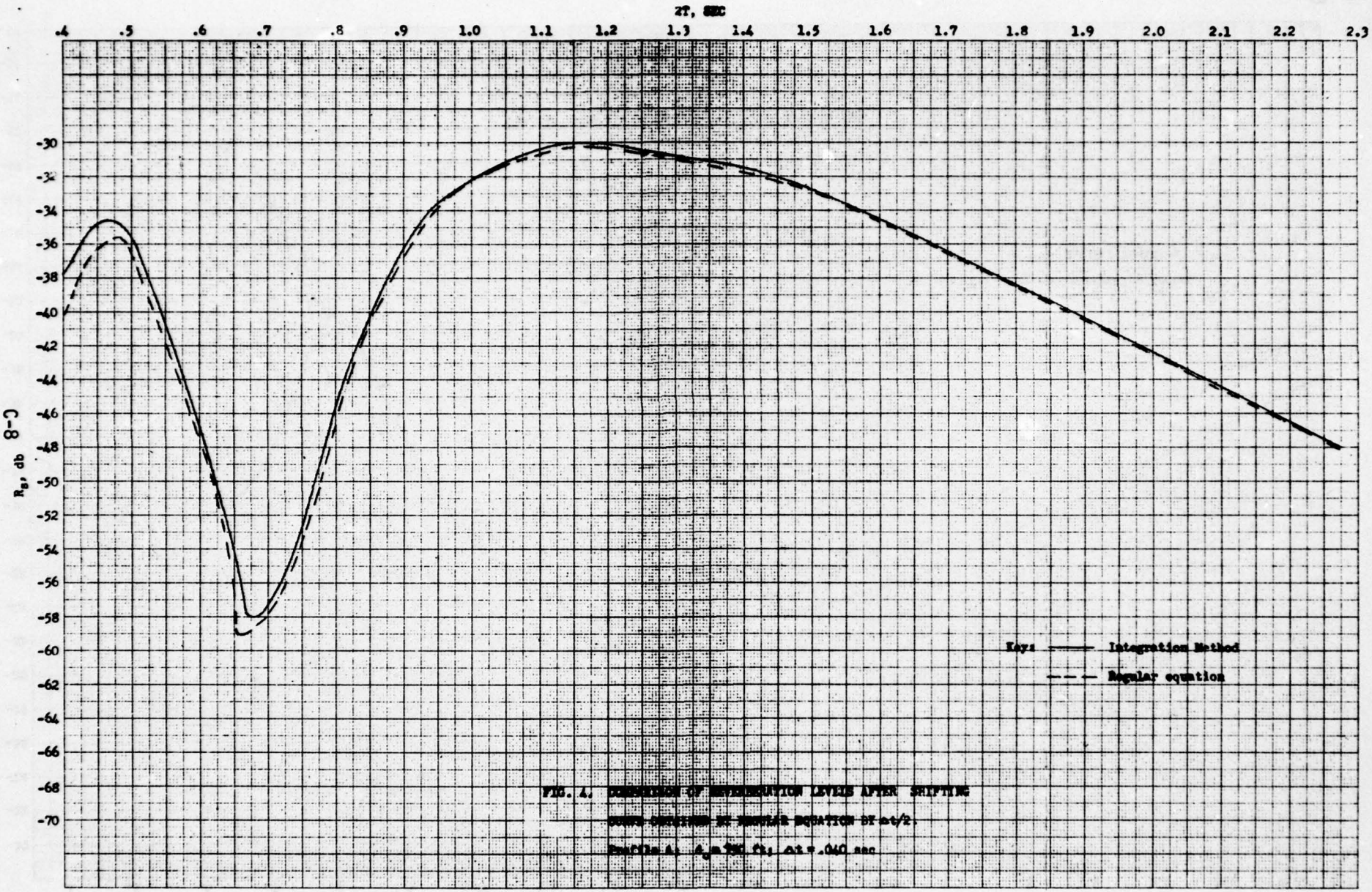


FIG. 4. COMPARISON OF REVERBERATION LEVELS AFTER SHIFTING
CURVE OBTAINED BY REGULAR EQUATION BY $\Delta t/2$.
Profile A; A_p = 250 ft; Δt = .040 sec

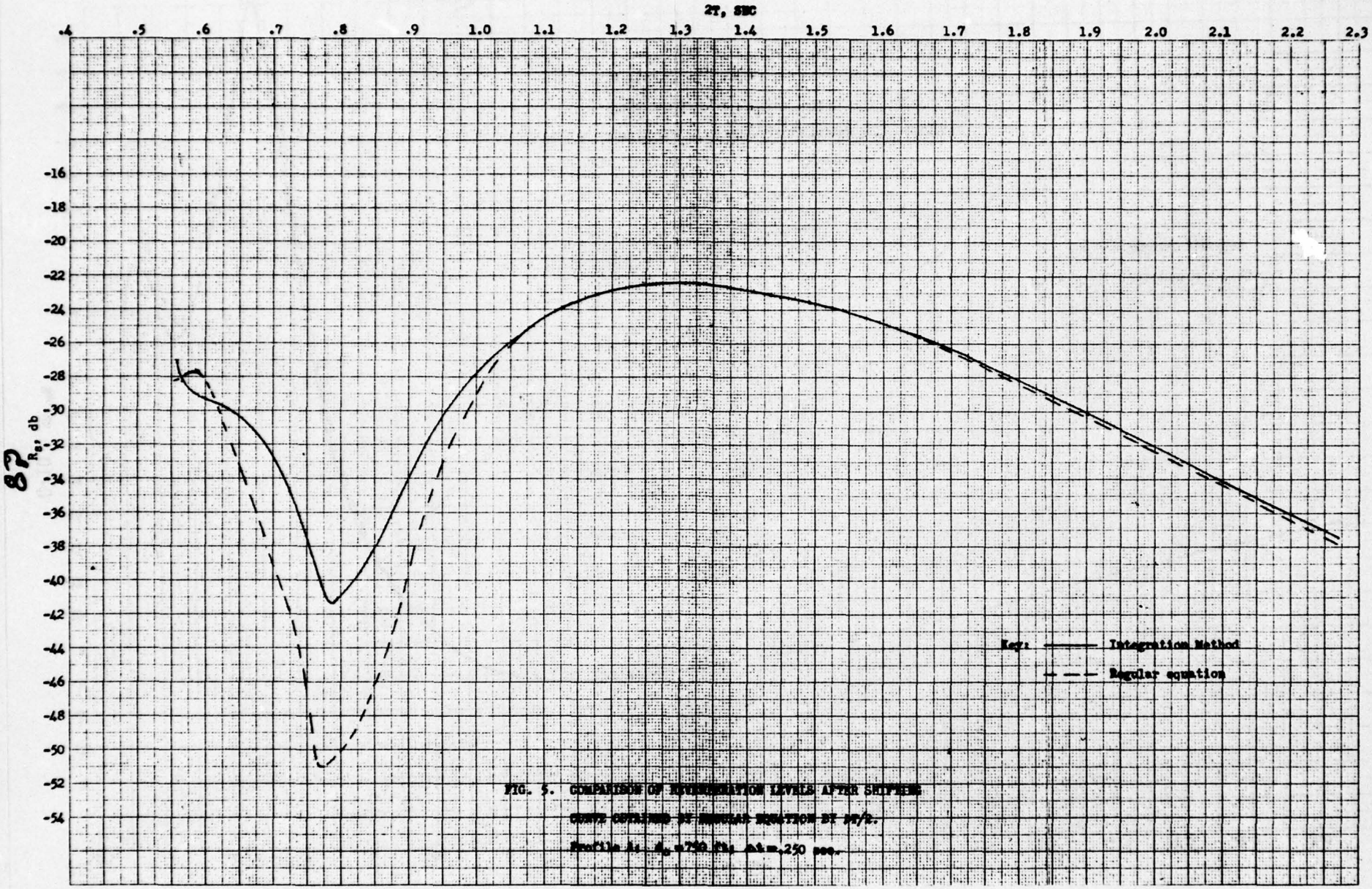


FIG. 5. COMPARISON OF RESPONSE LEVELS AFTER SHIFTING
CURVE OBTAINED BY REGULAR EQUATION BY $\Delta t/2$.
Profile A: A_0 =750 ft; Δt = .250 sec.

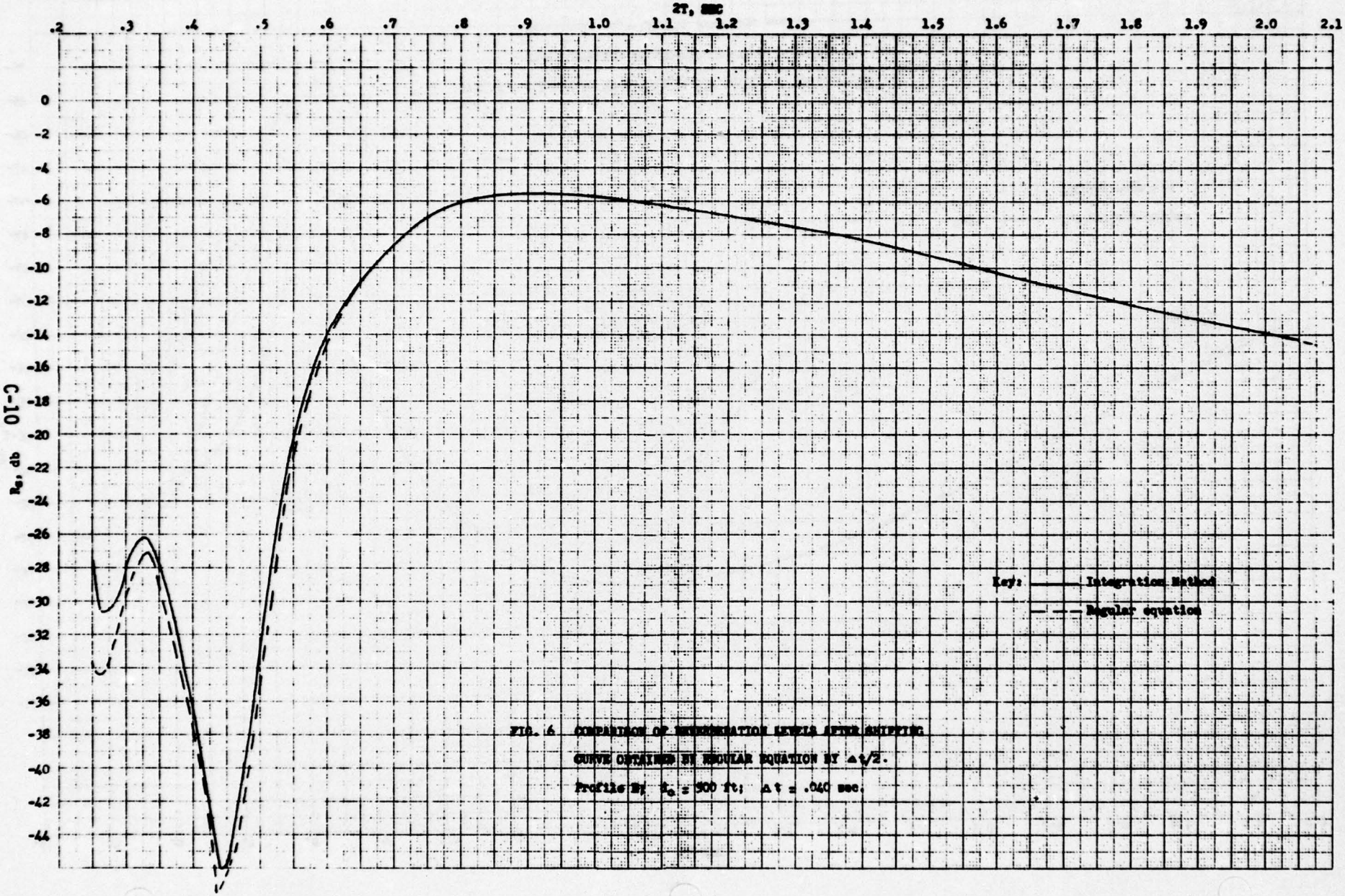


FIG. 6 COMPARISON OF DECONVOLUTION LEVELS AFTER SHIFTING CURVE OBTAINED BY REGULAR EQUATION BY $\Delta t/2$.
Profile B; h_o = 900 ft; Δt = .040 sec.

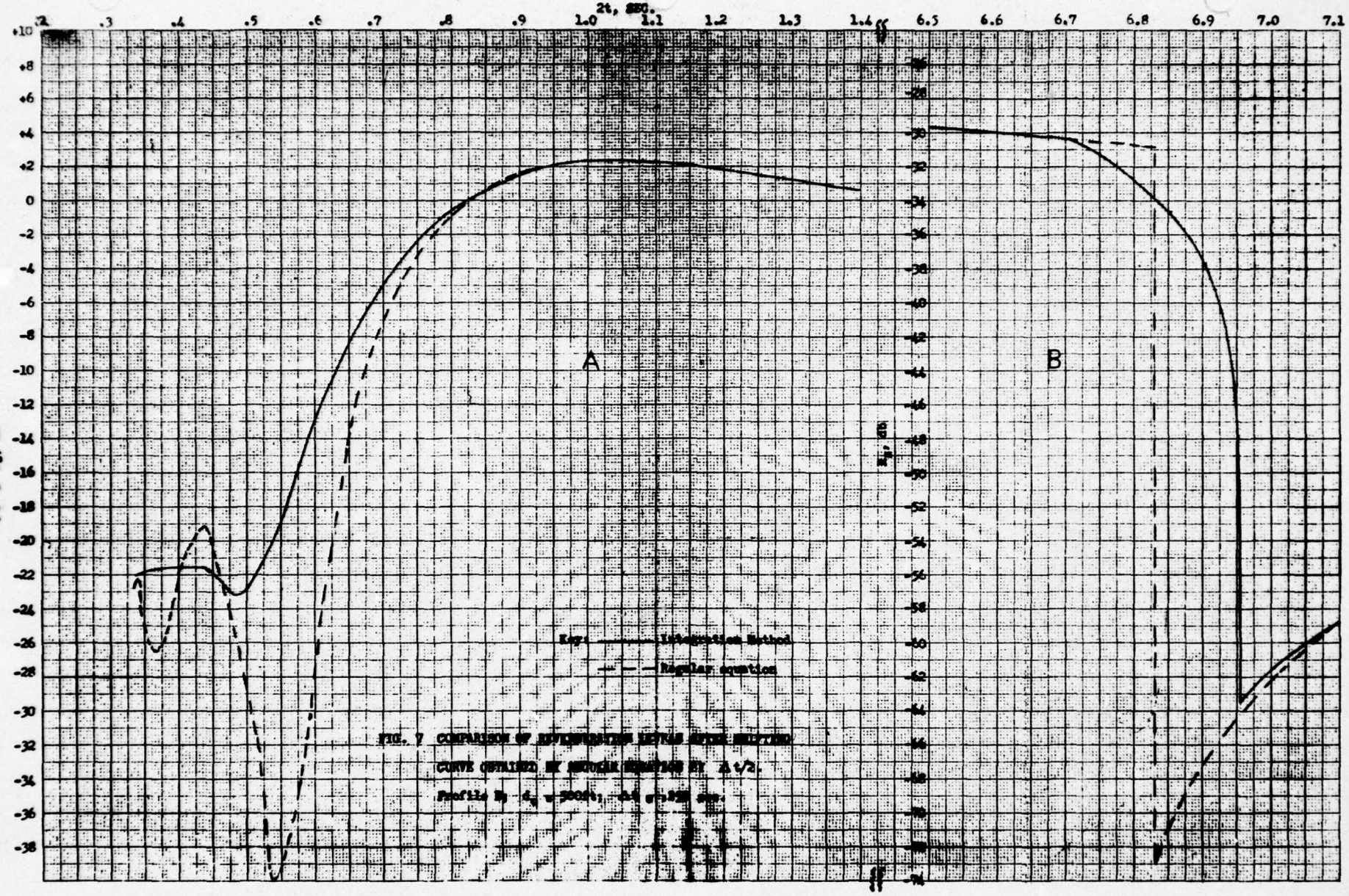


FIG. 7 COMPARISON OF [illegible] CURVE OBTAINED BY [illegible] BY $\Delta t/2$.

Profile No. [illegible]

APPENDIX C

APPENDIX D

MEMORANDUM

P80203/ABP:pas
25 January 1965

From: Code P80203
To: Code P802

Subject: Review of Mathematical Model for Computing the Expected Level of Volume Reverberation.

Reference: A. P80203 Memo "Review of Mathematical Model for Computing Boundary Reverberation," of 20 January 1965.

Reference A discussed the problems associated with the mathematical model for computing boundary reverberation. It was pointed out that the model currently in use in our computer programs generally gives reasonable accuracy over a large portion of the ping cycle provided time is measured from the middle of the transmittal ping. The errors may still be appreciable over the time intervals during which the paths to the surface are quite steep and involve transmission through the minor lobe structure of the transducer, and/or exhibit anomalous transmission loss. A method is delineated by which errors can be reduced by summing the contributions from narrow increments of the insonified annulus.

The model currently in use for calculating volume reverberation in dB again involves the addition of a factor $10 \log_{10} \tau = 10 \log V (\Delta t/2)$ to account for the lateral extent of the insonified region which returns energy to the transducer at the same instant of time. (V is the velocity of sound and Δt is the ping duration in seconds.) Since for volume reverberation the insonified region is a spherical shell, the lateral extent is measured radially. Thus $10 \log_{10} \tau$ is a reasonably accurate measure of the thickness of this shell providing the value chosen for V is a good average value for the environment being considered. Since in general the velocity is not constant throughout the volume of interest, there are resulting errors. However, the percentage variation in velocity is so slight that the errors from this source can be expected to be less than 0.2 dB, an insignificant amount in view of our inaccurate knowledge of the scattering coefficients which obtain.

A somewhat more significant error can result from the variation in transmission loss over the shell width, particularly for long pings. To obtain a measure of the inaccuracy, calculations of volume reverberation were made for two postulated ping lengths in an environment with an average velocity taken to be 1660 yd/sec. The levels computed with values of $10 \log_{10} \tau$ appropriate for the selected ping lengths were compared with those obtained by a modification of the integration method described in Reference A with $10 \log_{10} \tau$ set at zero. The levels were plotted as functions of elapsed time measured from the beginning of the transmission. The $10 \log_{10} \tau = 0$ curve can be integrated over the ping length in seconds except that the resulting intensity is multiplied by a factor of 0.83 before reconverting to dB to account for the fact that one millisecond is equivalent to an 0.83-yard shell thickness when V has the value previously selected.

The results for ping lengths of 0.040 and 0.250 seconds are shown in Figure 1. As was the case for boundary reverberation, the corresponding curves from the two methods would be in much better agreement if the one for the integrated method were shifted back in time by half the ping length. This is equivalent to measuring elapsed time from the middle of the transmission. When this is done, there is still a residual error at the very short times due to the fact that the spreading loss at short ranges is changing rapidly. The integration method accounts for the fact that the latter portion of the ping is contributing a considerably greater portion of energy to the reverberation level. The errors for short pings do not seem large enough to justify the additional work of using the integration method.

Our analyses in the past have involved systems with ping lengths of .040 seconds or shorter. The elapsed time for both interference and echo levels was taken to be the two-way travel time for the paths being computed. For the short pings this is roughly equivalent to measuring time from the transmission mid-point. Consequently, the results of the analysis can be considered valid insofar as the factors discussed here are concerned.

There is, however, a basic weakness in our volume reverberation model which may be really serious, especially if performance analyses of long-range systems are attempted. Moreover, there is no means at hand for ascertaining what errors might be involved. This situation arises because the present model for volume reverberation is based on the assumption of an insonified shell over expanding in time in an infinite, uniform medium. It is well known that an ocean is neither infinite in extent nor uniform in its acoustic properties. From whatever transducer position the sound paths will, at one time or another, intercept the surface or bottom, and variation in the physical properties of the water results in differences in transmission loss depending on which path is considered. Furthermore, the volume scattering coefficient in general is not constant over any sizable volume of water, and is often observed to be a rather strong function of depth and time of day (deep scattering layer migration). To further complicate the situation, the paths in various directions are weighted in accordance with the three-dimensional transducer patterns.

The difficulty of realistically delineating the distribution of acoustic properties over a large volume coupled with the even greater difficulty of integrating the return from the entire spherical shell has no doubt led to the common use of the simplified model. Its use can be rationalized as follows. While it is true that the transmission loss to various portions of the insonified shell may be substantially different due to refraction, the integration process will average out such effects. Similarly the variation in scattering coefficient will average out in the integration so that selection of a constant value consistent with the volume being considered should suffice. When the insonified spherical shell is truncated by a boundary, energy aside from the backscattered as boundary reverberation or lost in the reflection mechanism will be returned to the water to insonify volume scatterers. If one can assume that boundary losses are offset by the multiple paths that are set up, the truncating of the sphere can be ignored.

There is little doubt that in a qualitative sense these trends can be expected. There is no available evidence, however, that they quantitatively balance out within acceptable limits. Faith that they will do so deteriorates further when one considers that directional transducer patterns may weight the return from anomalous regions so that their contribution is grossly out of proportion to their share of the total volume. The depth and orientation of the transducer as well as the patterns themselves can be significant factors. For example, if there is a pronounced deep scattering layer, the behavior of the volume reverberation level with elapsed time can be expected to be quite different when a transducer is oriented vertically than when it is oriented horizontally.

One can also argue that the need for a more complex and realistic model for estimating volume reverberation is not great on the basis that most systems have TVG thresholds which protect them against volume reverberation at short range, boundary reverberation is likely to exceed volume reverberation at intermediate ranges, and noise will be the dominant interference at long ranges. While this reasoning may be valid for many (if not most) situations analyzed to date, there is no assurance that it will always hold. Volume scattering coefficients above average when coupled with long pings may raise this type of interference to new prominence in some important situations. The point is, no one can be sure that the simple model is adequate in new applications unless there is a comprehensive model available with which to compare results. Efforts by able mathematical physicists to develop a more realistic approach to the problem of estimating volume reverberation should be solicited. A companion problem of great difficulty is the development of a practical method for estimating the doppler spectrum of both boundary and volume reverberation. Such information is needed for assessing performance of systems which employ doppler discrimination.

In the meantime, the best that one can do is to continue using the present method, taking care that the elapsed time is measured from the middle of the transmitted ping and then adjusted, if desired, to the same time base used in computing boundary reverberation and echo level. It is clear that the expected values of both the echo level and threshold must be figured on the same time base for valid results. It is worth noting that for elongated echoes (long pings or other reasons) the applicable threshold level may vary appreciably depending on which portion of the echo leads to the detection.

A. B. POYNTER

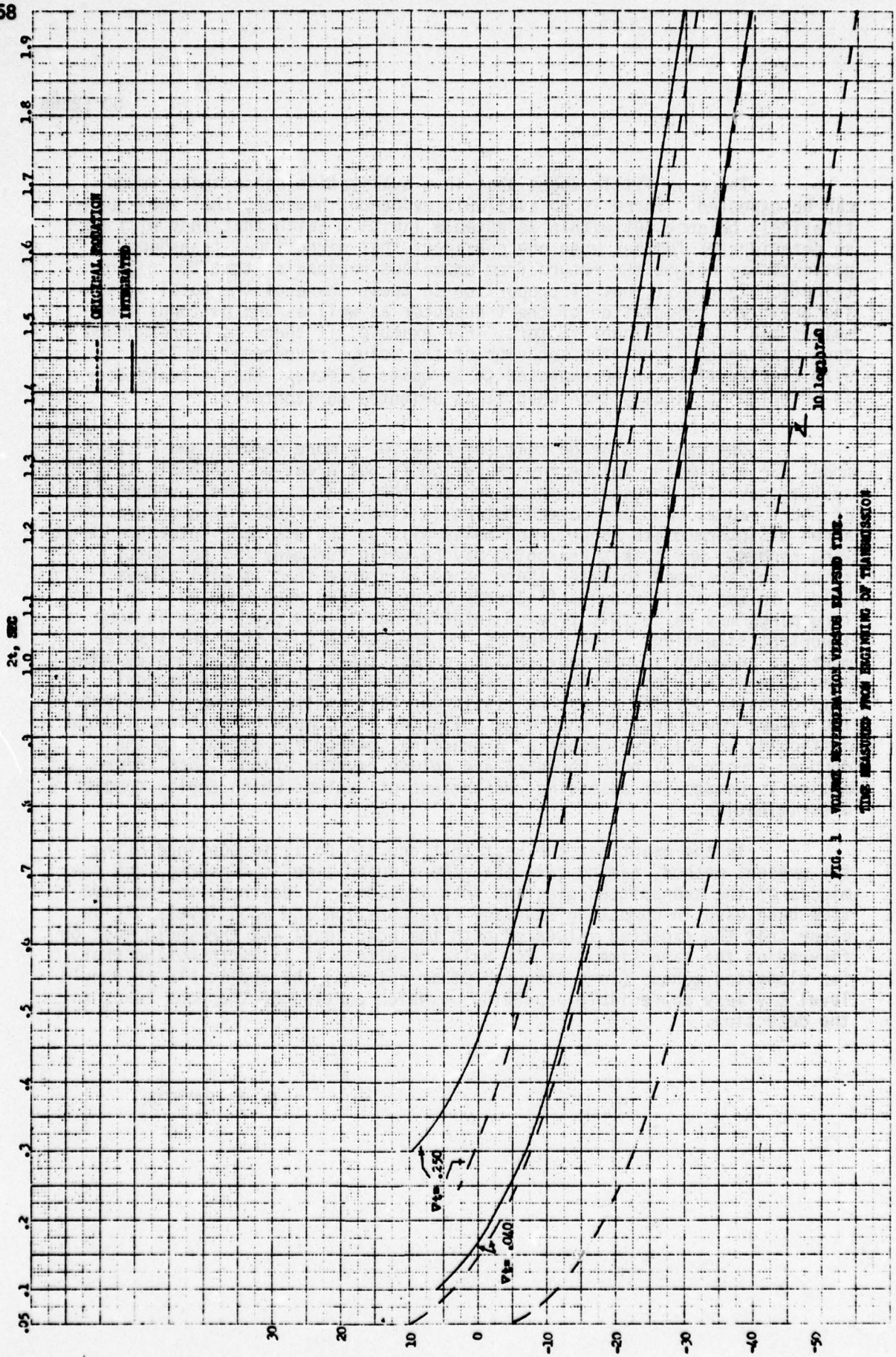


Fig. 1 VOLUME EXTRACTION VERSUS ELAPSED TIME.
TIME MEASURED FROM BEGINNING OF TRANSMISSION

APPENDIX E

MEMORANDUM

P80203/ABP:sln
24 November 1965

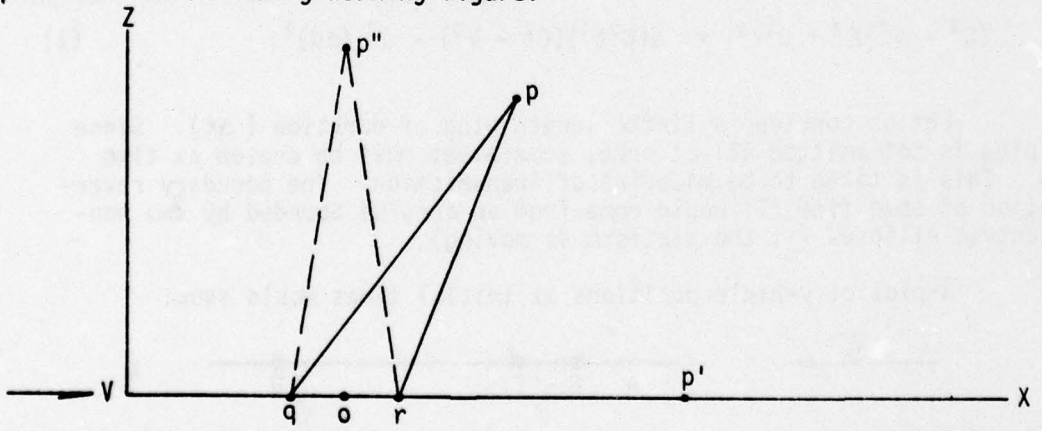
From: Code P80203
To: Code P802

Subject: Assessment of the Effect of Platform Translation on the Area Returning Boundary Reverberation at a Given Time.

Math models for computing expected levels of reverberation nearly always include the concept that the return at any given time comes from scatterers contained in a sphere-like shell. The outer and inner surfaces are determined by the sound velocity multiplied by one-way travel times (equal to one-half the elapsed time in the ping cycle) plus and minus one-fourth of the ping duration. This concept fits volume reverberation at least for times less that that required for the expanding shell to be truncated by the surface or bottom. The area returning boundary reverberation is considered to be bounded by the traces of the shell boundaries on the surface or bottom. These traces will be concentric circles if the shell is truly spherical.

The approach is clearly realistic if the transducer is stationary and the sound velocity is a function only of depth. It is desirable to have some quantitative indication of the error introduced if the transducer is mounted on a moving platform. For practical cases it can be assumed that the velocity of the platform will be small in comparison with the sound velocity.

Assume that the platform is moving at a constant velocity (V) directed horizontally along the X-axis in an oceanographic coordinate system. The X-axis is taken to be at platform depth. Since the velocity of sound in the whole ocean really varies over a range of only about 10% it is reasonable to assume, as a first approximation in determining range, that the sound velocity (C) is a constant in a limited volume of water. Consider the X-Z plane in the following working figure:



Let q be the position of the platform at transmission of a particular part of the ping and r be the platform position when return is received from a point (p) after some elapsed (t). We know that the distance traveled over qpr = tC = qp'r = qp"r. The locus of all p in this plane is an ellipse with foci at q and r. If the origin is placed half-way between q and r, the equation of the ellipse is $x^2/a^2 + z^2/b^2 = 1$.

When the point is on the X-axis (at p'), z = 0 and a = op' = Ct/2. It is also known that qo = or = Vt/2. When the point is at p", X = 0, and qp" = p"r = Ct/2. Therefore,

$$b = \sqrt{(Ct/2)^2 - (Vt/2)^2} = (t/2)\sqrt{C^2 - V^2}$$

The distance from either focus to the origin should be:

$$\sqrt{C^2t^2/4 - (C^2t^2/4 - V^2t^2/4)} = \sqrt{V^2t^2/4} = Vt/2$$

which checks with what was known directly from the movement of the platform.

The equation of this ellipse is $\frac{X^2}{C^2t^2/4} + \frac{Z^2}{t^2/4(C^2 - V^2)} = 1$

The eccentricity of such an ellipse is $e = \sqrt{(a^2 - b^2)/a^2} = V/C$. Now C is of the order of 5000 ft/sec while a V of 15 knots is approximately 25 ft/sec. In this case e = 25/5000 = .005. For a 45-knot V, e would be three times larger or about .015. Therefore, circular assumption is not bad.

If excursions in the Y direction are allowed, the insonified area would be the surface of an ellipsoid

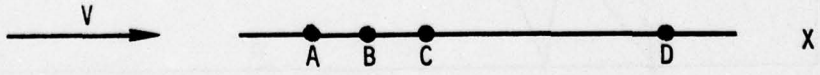
$$\frac{X^2}{C^2t^2/4} + \frac{Y^2}{(t^2/4)(C^2 - V^2)} + \frac{Z^2}{(t^2/4)(C^2 - V^2)} = 1$$

The trace of this ellipsoid intersecting a horizontal plane (e.g. surface or bottom) would be an ellipse with the same eccentricity previously computed. The equation of such an ellipse may be found by substituting (Δd), the depth differential between the platform and the boundary in question, for Z in the equation above. The new X - Y plane now coincides with the surface or bottom, and the equation for the ellipse can be expressed in the form

$$(C^2 - V^2)X^2 + C^2Y^2 = \tfrac{1}{4}(C^2t^2)(C^2 - V^2) - C^2(\Delta d)^2. \qquad (1)$$

Let us consider a finite length ping of duration (Δt). Since the ping is not emitted all at once, some event must be chosen as time zero. This is taken to be midpoint of transmission. The boundary reverberation at some time (T) would come from an annulus bounded by two non-concentric ellipses (if the platform is moving).

A plot of vehicle positions at initial times would show:



where A is the position at transmission of the leading edge of ping; B is the position at t = 0; C is the position at transmission of the trailing edge; and D is the position when reverberation is returned at time T. The distances A to C = (Δt)V; A to D V(T + Δt/2); and C to D = V(T - Δt/2). By alternately substituting T + Δt/2 and T - Δt/2 for the t in Eq. (1), one finds the equation for the two ellipses when the origin for each is halfway between their respective foci.

The origin of the ellipse stemming from the trailing edge of the ping will be located $V(\Delta t/2)$ further along the X-axis than the one associated with the leading edge. Choosing an origin appropriate to the midpoint of the ping and substituting in Eq. (1), one obtains the following equations:

Leading edge: $(C^2 - V^2)\left[X + V(\Delta t/4)\right]^2 + C^2Y^2 = \left[C^2(T + \Delta t/2)^2/4\right](C^2 - V^2) - C^2(\Delta d)^2$

Trailing edge: $(C^2 - V^2)\left[X - V(\Delta t/4)\right]^2 + C^2Y^2 = \left[C^2(T - t/2)^2/4\right](C^2 - V^2) - C^2(\Delta d)^2$

When y is 0 and letting subscripts L and T designate the leading and trailing edges, respectively:

$$X_L = \pm \sqrt{(C^2/4)(T + \Delta t/2)^2 - C^2(\Delta d)^2/(C^2 - V^2)} - V(\Delta t/4)$$

$$X_T = \pm \sqrt{(C^2/4)(T - \Delta t/2)^2 - C^2(\Delta d)^2(C^2 - V^2)} + V(\Delta t/4)$$

Using primes to differentiate between concepts, the similar equations for the concentric circle approximation with the origin at the same place (halfway between the midpoint of transmission and the point of reception) would be:

$$X'_L = \pm \sqrt{(C^2/4)(T + \Delta t/2)^2 - (\Delta d)^2}$$

and

$$X'_T = \pm \sqrt{(C^2/4)(T - t/2)^2 - (\Delta d)^2}$$

It is clear that $X_L < X'_L$ first, by the quantity $V(\Delta t/4)$, and then by the amount the evaluation of the square root term is reduced because $(\Delta d)^2$ is multiplied by $C^2/(C^2 - V^2)$ rather than by C^2. Now $V(\Delta t/4)$ will be small in practical situations. For a platform velocity of 45 knots and at Δt of 0.25 seconds, $V(\Delta t/4) < 5$ feet. The other term is more difficult to evaluate since it depends on so many factors. At V = 45 knots, $C^2/(C^2 - V^2)$ is the order of 1.00025. However, the extent to which this factor modifies X_L depends not only on Δd, but also on Δt and the value of T for which the evaluation is desired. At the times for which the evaluation is important, the first term under the square root will be much larger than the second, so the difference in X_L and X'_L will be small.

In the forward direction the differences in X_T and X'_T (when Y = 0) is less than in the case of the leading edge since the correction for translating the origin from the center of the ellipse to the center of the circle changes sign. The two factors causing the difference tend to compensate rather than add. In the -X direction the opposite trend is seen and $-X_T$ is affected more than $-X_L$.

Another interesting case to evaluate is the one where X = 0. In this case

$$Y_L = \pm \sqrt{(C^2/4)(T + \Delta t/2)^2 - (\Delta d)^2 - (V^2/4)(T + \Delta t/2)^2 - \left[(C^2 - V^2)/C^2\right](V\,\Delta t/4)^2}$$

$$Y_T = \pm \sqrt{(C^2/4)(T + \Delta t/2)^2 - (\Delta d)^2 - (V^2/4)(T - \Delta t/2)^2 + [(C^2 - V^2)/C^2](V\,\Delta t/4)^2}$$

For the circular approximation

$$Y'_L = \pm \sqrt{(C^2/4)(T + \Delta t/2)^2 - (\Delta d)^2}$$

$$Y'_L = \pm \sqrt{(C^2/4)(T - \Delta t/2)^2 - (\Delta d)^2}$$

The difference between the corresponding Y and Y' expressions comes from the two additional terms under the square root in the equations for Y. As long as V remains very small in comparison with C, the Y values will not be materially smaller than the Y' values.

In a JP training assignment, Lee Sheldon numerically evaluated the error to be expected in a variety of cases by computing the X-axis intercepts of the ellipses and circle approximations, with the center of the circles taken as the origin. It is in this dimension that the errors are maximum. Vehicle speeds of 45 and 15 knots were assumed. Results are shown in Table 1 when the sound velocity is considered to be a constant 5,000 ft/sec and the ping duration is 0.25 sec. Three elapsed times were examined in combination with two depth differentials between vehicle and boundary. Table 2 shows some results obtained by using ray tracing data in a refracting medium.

On the basis of these data, it would appear that for vehicle speeds less than say 50 knots the circular approximation of the boundaries of the annulus returning reverberation at a given time introduces only very minor errors. These are certainly negligible in the light of other sources of error, such as in the determination of the scattering coefficients. The maximum error in X occurs to the rear of the vehicle where pattern discrimination generally is high.

Another study by Charles Williams, a summer employee, showed that, for vehicle speeds up to 50 knots, the difference between the initial path angles from the respective vehicle positions at transmission and reception of reverberation from selected points on the surface amounted to less than 1° for a wide variety of situations. The errors were largest when geometries and elapsed times were such that the effective paths were steep. Since, in computing boundary reverberation, the circular approximation uses what is essentially a median of these two angles for both transmission and reception in computing pattern losses, the circular assumption should provide an adequate model for most practical cases.

All of the above discussion assumes that the boundaries and vehicle velocity vector are horizontal. The situation is much more complicated when one or both of these conditions are not applicable. Work in this area is needed.

A. B. POYNTER

TABLE I

C = 5000 ft/sec; Δt = 0.25 sec; Errors Computed with Ellipse as Standard

PARAMETERS			CIRCLES ± X-AXIS		ELLIPSES + X-AXIS				ELLIPSES - X-AXIS			
							% ERROR				% ERROR	
y ft/sec	d ft.	T sec.	X_L yd.	X_T yd.	X_L yd.	X_T yd.	X_L	X_T	X_L yd.	X_T yd.	X_L	X_T
25.33	250	0.250	301.18	62.50	300.53	63.02	+0.18	-0.83	301.68	61.97	-0.35	+1.69
		1.000	933.79	724.39	933.18	724.85	+0.07	-0.06	934.23	723.79	-0.11	+0.15
(15 kt)		10.000	8437.09	8228.74	8435.83	8228.56	+0.01	0.01	8436.88	8227.50	0.01	+0.01
	3000	1.425	817.56	416.67	816.94	417.12	+0.08	-0.11	817.99	416.07	-0.05	+0.25
		2.625	2061.97	1827.64	2061.25	1827.99	+0.03	-0.02	2062.30	1826.94	-0.02	+0.04
		10.000	8378.03	8168.18	8376.78	8167.99	+0.01	0.01	8377.83	8166.94	0.01	+0.02
76.0	250	0.250	301.18	62.50	299.53	64.01	+0.55	-2.36	302.70	60.89	-0.50	+2.64
		1.000	933.79	724.39	931.99	725.80	+0.19	-0.19	935.16	722.64	-0.15	+0.24
(45 kt)		10.000	8437.09	8228.74	8433.55	8228.42	+0.04	0.01	8436.72	8225.26	0.01	+0.04
	3000	1.425	817.56	416.67	815.65	417.88	+0.23	-0.29	818.81	414.71	-0.15	+0.47
		2.625	2061.97	1827.64	2059.86	1828.74	+0.10	-0.12	2063.02	1825.57	-0.05	+0.11
		10.000	8378.03	8168.18	8374.49	8167.86	+0.04	0.01	8377.66	8164.69	0.01	+0.04

TABLE II

Refracting Medium; Δt = 0.25 sec; Errors Computed with Ellipse as Standard

76.0	3000	1.875	1307.0	1035.0	1305.0	1035.6	+0.15	-0.06	1308.1	1032.4	-0.08	+0.06
(45 kt)		2.625	2032.0	1799.0	2030.0	1800.1	+0.10	-0.06	2033.1	1796.9	-0.05	+0.12
		11.000	9118.5	8911.0	9116.9	8911.8	+0.02	.01	9120.1	8908.7	-0.02	+0.03

APPENDIX F

MEMORANDUM

P3502/ABP:dd
Reg No. P3502-136
15 April 1968

From: Code P35021
To: Code P3502

Subject: Comparison of Computer Models for Obtaining the Expected Level of Boundary Reverberation as a Function of Elapsed Time.

References:
A. NAVORD Conf Report 5606, "Analytical Methods for Predicting the Acoustic Performance of Homing Torpedoes in Circular Search" (NOTS 1818) of 26 July 1957.

B. NOTS P80203 memo, "Review of Mathematical Model for Computing Boundary Reverberation", of 20 January 1965.

C. NOTS P80203 memo, "Error from Using 10 $\log_{10}\tau$ as a measure of Effective Train Length when Computing Boundary Reverberation", of 18 January 1965.

D. NUWC P35021 memo, "Integration of Power under a Curve Plotted in Decibels", of 10 January 1968.

E. NAVORD Report 4962, "A Study of the Effects of Refraction on Reverberation (NOTS 1284) of 7 November 1955.

F. NOTS P80203 memo "Doppler Content of Boundary Reverberation Due to Vehicle Translation-Refractive Environment Case" of 21 December 1965.

Over the last few years various aspects of the problem of computing the expected level of boundary reverberation in a refractive medium have been re-examined. The purpose of this memorandum is to compare the results obtained from four models selected as being practical for computer application and to assess their relative accuracy. In general, the accuracy to be anticipated increases with the complexity. The study is made in terms of surface reverberation. In the case of a flat bottom, bottom reverberation is computed in an identical fashion.

Model I has been used since the inception of our first ray-tracing program and was based on Reference A. The form of the equation used in the program is

$$R_s = S - 2H + 10 \log_{10} m_s - J_s + 10 \log_{10} \tau + 10 \log_{10} \frac{X}{\cos \theta_0}$$

where

- R_s is the expected level of surface reverberation at a given time
- S is the on-axis source level in dB re one microbar at one yard
- 2H is the two-way transmission loss along the ray path

- $10 \log_{10} m_s$ is the surface scattering coefficient in dB as a function of grazing angle of the ray path at the surface
- J_s is the boundary reverberation index of the transducer
- $10 \log_{10} \tau$ is the effective annulus width in dB
- $10 \log_{10} \frac{X}{\cos \theta_0}$ allows for the fact that horizontal spreading is compensated for in the outgoing direction by the fact that the whole annulus back-scatters toward the source. Here X is the horizontal range traversed by the ray to boundary intercept, and θ_0 is the ray angle at the source.

In this model $10 \log_{10} \tau = \frac{V(\Delta t)}{2}$ where V is the nominal velocity of sound (1667 yd./sec.) and Δt is the ping duration in seconds.

It was shown in Reference B that the model produces the best results if the elapsed time T is considered to be measured from the midpoint of transmission so that, in effect, T = 2t, the two-way travel time of the ray being run. This ray then reaches the surface near the mid-range of the insonified annulus so that the associated value of transmission loss, J_s, and grazing angle are reasonable representative for the annulus as a whole.

Reference C showed that τ was not a good measure of annulus width where steep paths are involved. Model II is a simple attempt to improve this situation. The only change from Model I is to compute

$$\tau = \frac{V_s}{2} \frac{t}{\cos \theta_s}$$

where V_s is the velocity at the surface and θ_s is the grazing angle of the path at the surface. This is largely an intuitive "fix", and it is being tried here for the first time. Obviously, both models I and II get into trouble when $T = 2t_{\theta_c} < 2t_{-90°} + \Delta t/2$ because the full ping is not insonifying the surface. In Model II a test was made to ascertain whether or not this criterion was being met. If not, it was assumed that the paths would be sufficiently steep to approximate straight lines. Since τ would equal the horizontal range to surface intercept of the leading edge,

$$\tau \approx \frac{\overline{V}}{2} \left(2t_{\theta_0} + \frac{\Delta t}{2}\right) \cos \theta_0 .$$

$\overline{V}$ is the average velocity over these straight paths and can be found by dividing the source depth by the one-way travel time of the -90° ray.

As pointed out in Reference B, the above models in some situations could be expected to give inaccurate results for long pings even if the annulus width were modeled adequately. Values of transmission loss, vertical pattern losses, and grazing angle found by tracing a ray to any single point in a wide annulus cannot be expected to represent those over the full annulus, particularly in regions where one or more of the parameters is varying rapidly. Moreover, at elapsed times sufficiently short so that all of the ping has not insonified the surface, the ray path for which the two-way

travel time is computed no longer reaches the surface near the mid-point of the annulus. These difficulties are overcome in the next model. Model III in this study follows the scheme delineated in Reference B and computes boundary reverberation levels as in Model I with 10 log set to zero. This is equivalent to a one-yard annulus width. From the data produced by the ray-tracing program, both the two-way travel time (2t) and computed reverberation level (R_o) are plotted as functions of the horizontal range (x) to surface intercept as determined for each ray path. For each desired elapsed time (T), which can be selected at will, the limits of the true annulus corresponding to Δt is found by evaluating x on the time curve for $T - \frac{\Delta t}{2}$ and $T + \frac{\Delta t}{2}$.

The actual reverberation level at time T is then found by summing in random phase the contributions of each one-yard increment between the above limits as shown by the R curve. The summation was a hand operation in Reference B but it was computerized in this study in the manner delineated in Reference D.

These first three models all require a table input to account for the weighting effect of the horizontal patterns on the reverberation return. These data are combined with vertical pattern losses and a geometric correction for transducer pitch to give J_s the boundary reverberation index of the transducer. NUWC computer program 819001 is available for generating the data for the table showing the average weighting effects of the horizontal patterns. For a non-turning transducer, this is a single value. The equations for evaluation J_s were developed in Reference E. Because of certain simplifications introduced in the concept, the accuracy of the results is suspect when the transducer axis is tilted considerably and/or when the steep sound paths are producing the reverberation at time T. The basic simplifications are the assumptions that pattern effects can be obtained when only the patterns in the cardinal planes are known and that the variables can be separated for integration.

Model IV uses a different approach. The concept was developed in Reference F for the purpose of computing the boundary reverberation returned in doppler bands when the doppler is introduced by own vehicle speed. Briefly, the insonified annulus is divided into incremental areas bounded on two sides by equal doppler lines and on the other two sides by equal travel-time circles. Rays are traced to the corners of these little areas yielding the coordinates of the corners in space so that the areas of each can be computed. Other ray data permit evaluation of the transmission loss, scattering strength, and the transmit and receive pattern losses needed to ascertain the back-scatter received from each incremental area. When these contributions are summed in random phase (expressed in intensities) for each doppler band, one gets the reverberation levels as might be observed by a system which processes signals in narrow frequency bands. The summation of contributions from all bands gives the total surface reverberation received. (The first three models yield only the total reverberation as might be observed in

noted in Figure 1. These data are useful in interpreting the reverberation levels which will be shown later. Transducer pitch angles of 0° and 10° up were used. The same table of scattering coefficients versus grazing angle were used in Models I through III. These values were each reduced by $10\log_{10}2\pi$ for Model IV so that they would reflect scattering strength as required in that model. Computations were made for all four models using each of two quite different sound-velocity profiles in order to see that the conclusions arrived at from comparing the results obtained from the four models were not prejudiced by some over-riding characteristic of the profile. The velocity profiles are shown in Figure 2. A transmit frequency of 20 kHz was chosen, and an appropriate table giving the attenuation losses as a function of depth was input with each profile. Ping durations of 40 and 250 milliseconds were considered. Model IV assumed a horizontally-directed, straight-running platform at a 40-kt. speed, and reverberation was computed in 1/4-kt. doppler bands. The vehicle speed is an artifax here since we are interested only in the total return. It was selected to insure sufficiently small area increments to yield good accuracy. Actually, the results can apply to a stationary system since speed is not considered in the other three models. A 120-dB source level was used in all cases. The transducer is assumed to be at a 1000-ft. depth.

It proved to be impracticable to show the results for all four models on a single graph because of the clutter. Consequently, for each combination of environment, ping length, and pitch angle, two figures will be used. The first will compare the data from Models I, II, and III. On the second graph the data from Model III will be repeated and compared with that from Model IV. This is a natural grouping for our purpose in that the first three models assume common values for J_s. Then by comparing the most accurate of these models with the doppler-band method, one should be able to obtain an idea of the accuracy with which we now evaluate J_s.

Figure 3 shows the surface reverberation levels computed in Environment A for a 40-ms ping and a 0° pitch angle. With the source at a 1000-ft. depth the middle of the ping has a two-way travel time to the surface of about 0.405 seconds via a vertical path (θ_o = -90°). The velocity profile is dominated by negative gradients and the -15° ray is very nearly the last to reach the surface. The 3.8-sec. ping interval was selected with this in mind. The combined vertical patterns largely determine the peaks and valleys in the respective reverberation curves. Of course, the trailing off of the reverberation at times greater than about 1.7 seconds is caused by the transmission loss increasing more rapidly than the pattern losses are decreasing. In addition, the scattering coefficient tends to be smaller at the lower grazing angles. All three models tend to be in good agreement beyond about 1.05 seconds when the major lobes of the vertical patterns govern. The integrated method (Model III) tends to smooth out the narrow peaks and valleys generated by the other two models. It is undoubtedly the more accurate since it does not consider the particular values of pattern and transmission loss associated with a data point as being necessarily representative of the entire annulus returning reverberation at that elapsed time. The cosine correction to the annulus width used in Model II seems to yield good agreement with the integrated model over the broad minor lobe. (The surface velocity used in Model II is not significantly different than the nominal velocity used in the first model). However, it tends to drastically over-compensate on the other minor lobe as can be expected; the cosine is rapidly approaching zero as the path angle approaches -90°.

The results for the 250-ms ping under otherwise similar conditions are presented in Figure 4. The curves for Models I and II have the same shape as in Figure 3; they are merely at a higher level because of the longer ping. The agreement between the three models is still good beyond about 1.2 seconds, but the importance of the integrated method when long pings are used is quite evident at shorter elapsed times. The results of its use are most striking in modeling the onset of boundary reverberation. The flat portion of Model III curve centered at about T = 0.35 is due to the narrow lobe being fully covered by some portion of the effective train length while the rest is contributing negligible return. With the quarter-second ping the broad minor lobe dominates the return until such time that the contribution from the major lobe begins to build up.

Figure 5 shows the corresponding data for the 40 ms-ping in Environment A when the transducer is pitched up 10°. The gross effect is to make the peaks and valleys in the expected level of reverberation more narrow than was the case when the transducer was directed horizontally. This is to be expected since each path making a particular angle with the transducer axis is 10° steeper in the oceanographic coordinate system and returns reverberation at a shorter elapsed time. The difference in results for the three models are of the same order as were found for the horizontally-directed transducer.

Figure 6 shows the results under the same conditions as in the preceding paragraph except that the ping duration is increased to 250 ms. As anticipated, the integration method (Model III) gives a decidedly different curve than the other two models at times less than one second. This model permits development of the onset of the surface reverberation starting where

$$T > 2t_{-90°} - \frac{\Delta t}{2}$$

The flat portion starting at 0.3 seconds covers the time region where the narrow minor lobe alone is contributing a substantial return. The level then rises as the next lobe also contributes. The drop-off starting at about 0.52 seconds is caused by the narrow minor lobe dropping out of the picture. The next flat portion occurs when only the second lobe is contributing materially. The shape of the remaining portion of the curve is rather obvious.

The next group of figures (Figure 7-10, inclusive) compare the results from the same three models when Environment B applies. Note that the dB scale has been changed. The two-way travel time from 1000 feet to the surface via a vertical path is about 0.418 seconds. Surface reverberation is continuous thereafter to an elapsed time greater than the ping interval which was taken as 10 seconds. The path yielding this two-way travel time to the surface has an initial path angle of approximately +3.7° with respect to the horizontal. At the scale plotted there is no discernible difference in the results from Models I, II, and III at elapsed times beyond 1.6 seconds. Therefore, only the first portion of the ping interval is shown in these figures.

For Environment B the coincidence of the three curves begins shortly after the major lobe of the patterns assume dominance. This occurs at an earlier time than in Environment A for a given pitch angle since refraction is such that a ray with a given initial angle will tend to reach the surface much sooner. Also, in the case of Environment B, the reverberation declines at a lower rate after the peak is reached so that the integrated curve does not begin to rise above the levels shown for the other two models later in the ping cycle as occurred to some degree in the case of the first environment.

At the shorter elapsed times, the differences in the three curves tend to be quite similar (for each of the four combinations of ping length and pitch angle) to those prevailing for the same combination when Environment A applied. Model III, the integration method, tends to smooth out the peaks and valleys as shown for the other two models, particularly when they are narrow with respect to the ping duration. This method also is better in modeling the onset of boundary reverberation. For the shorter ping, the annulus width correction applied in Model II appears to compensate adequately in the region of the broader minor lobe, but it tends to overcompensate when the paths become steep enough for Cos θ_0 to become very small. The introduction of a 10° up pitch produces about the same effect in both environments.

Now we turn to the interesting task of comparing the results of the integrated method with those of the doppler-band model. Figure 11 shows the data obtained in Environment A for a zero pitch angle and a pulse length of 40 ms. The larger scale again is used for clarity. Earlier, the hypothesis was advanced that agreement between data from the two models at the longer elapsed times (where flat paths obtain) would be a good indication that the doppler-band program (Model IV) was functioning as intended. The agreement is reasonably close over the region dominated by the major lobes of the patterns, but there remains a slight difference at 3.8 seconds. However, in this environment the path angles yielding this elapsed time is still over 15° off the transducer axis. As anticipated, some rather substantial differences are observed in the region dominated by the minor lobes of the patterns. Since there is little reason to suspect that Model IV is materially less accurate in this region than in any other, the evidence tends to substantiate fears that the current method for evaluating J_s is in error when large off-axis path-angles are involved. In this example (as in subsequent ones where the transducer is oriented horizontally) the differences in reverberation levels at the peaks are rather moderate (no more than 2 dB). The wide troughs are something else again. The higher minimums observed in Model IV results are believed due to the complexity of the minor lobe structure. For the results shown in Figure 11, all of the incremental areas contributing a return at an elapsed time of about one second are not subjected to maximum pattern loss. Of course, in practical applications the actual values in the valleys are not likely to be important since the interference level probably will be dominated by volume reverberation or noise at corresponding times.

Figure 12 shows comparable data when the ping duration is increased to 250 ms. The reverberation levels agree to about the same degree as for the shorter pulse over the peaks, and the differences in the valleys have been reduced. The narrow peaks and the valleys have been smoothed considerably.

Figures 13 and 14 compare the results from Models III and IV for ping lengths of 40 and 250 ms, respectively, when the transducer is pitched 10° up. Environment A still applies. The extent of the agreement between the respective curves is substantially the same as for the comparable cases when zero pitch was used except at the shortest times shown. It is felt that when path angles are involved which approach-90° the geometric correction factor,

$$-10 \log_{10} [\cos (\theta_0 - \xi)/\cos \theta_0]$$

(where ξ is the transducer pitch angle)

in J_s over-compensates and makes the levels a few dB higher than they should be for Model III. At the longest times (where the initial path angles are approaching -15°) the angles with respect to the transducer axis are approaching -5°. One might expect the two curves to coincide. The one for the integrated method is still a few tenths of a dB above the other one as it was for the zero pitch cases. This leads one to suspect that the $\cos (\theta_0 - \xi) / \cos \theta_0$ correction is slightly over-compensating even at these angles.

Figures 15 through 18 compare data from Model III and IV for the various combinations of pulse lengths and pitch angles when Environment B applies. In all four figures the two curves come into coincidence near or before an elapsed time of about 1.9 seconds which, in Environment B, corresponds to an ititial path angle of approximately -12 degrees. For zero pitch, Figure 15 and 16, the agreement persists to the 10-second ping interval which corresponds to a path angle of approximately +4 degrees. This is the most convincing evidence that Model IV is properly programmed since it is under these conditions that J_s should be most accurate.

For pitch angles of 10 degrees up, Figures 17 and 18, the near perfect coincidence begins near 1.7-sec. elapsed time, corresponding to a path angle of about -13.5 degrees. Note, however, that this corresponds to -3.5 degrees from the transducer axis. On the basis of path angle alone one might think that coincidence should occur earlier. It is suspected that the delay is caused by the $\text{Cos}\ (\theta_0 - \xi)/\text{Cos}\ \theta_0$ term in J_s over-compensating for the pitch. The agreement persists to about an elapsed time of 7 seconds, at which time the reverberation level computed by means of the integration method begins to fall slightly below that computed by Model IV. At 7 seconds the initial path angle is about +0.6 degrees while the angle with respect to the transducer axis is approximately +10.6 degrees. It seems possible that the slight divergence from 7 to 10 seconds results from the $\text{Cos}\ (\theta_0 - \xi)/\text{Cos}\ \theta_0$ correction to J_s tending to under-compensate at appreciable off-axis angles when the sign of the pitch angle is opposite that of the path angle. However, the evidence is by no means conclusive since the divergence does not increase consistently as the elapsed time approaches 10 seconds. The differences are so slight that they well may be due to errors in the numerical integration process in one or both models. Although data points are taken at relatively short intervals, they are still at finite intervals apart, and linear interpolation is used.

For the relatively short elapsed times (less than 1.5 sec.), the differences in results from the two models in Environment B are essentially the same as they were when Environment A was used with one exception. For both ping lengths with zero pitch, the minor lobe at minimum time for the integrated method (Model III) is a little over one dB lower than for the doppler method for Environment B computations. For Environment A the difference is about the same amount but in the opposite direction. This is attributed to the fact that we changed the constant pattern value assumed for the back portion of the pattern as was announced earlier. The transition was most severe when Environment A was used, and these results are considered to be unreliable. For the 10 degree up pitch, this portion of the vertical pattern does not come into play in Model III.

It was decided to make one further effort to clarify the effect of transducer pitch by computing a case involving a 40 degree up attitude. As other conditions it was decided that Environment B and a 40-ms ping would combine to produce the most useful results. Remaining parameters have the same values used throughout the study. Figure 19 compares the results produced by means of Models III and IV. The on-axis ray ($\theta_0 = -40°$) reaches the surface at T = .647593 sec. At this pitch angle, at least in Model III, the major lobe of the pattern controls the reverberation

level over a relatively small portion of the total ping interval. The first minor lobe above the transducer axis controls the level of the peak following the onset of surface reverberation. The first minor lobe below the axis governs the reverberation level over the last 75% of the 10-sec. ping interval. It is difficult to visualize physically just how the patterns interact in Model IV.

In comparing the results from the two models, it is noted first that the two curves coincide only briefly at a time centered about T = 0.85 sec. This corresponds to an initial path angle in the vertical plane of -29.1 degrees or +10.9 degrees with respect to the transducer axis. At times shorter than this the curves diverge with the integrated method giving the higher values. At about 0.43 sec. the separation is nearly 8 dB. At times greater than 0.85 seconds, the curves cross and there again is an increasing difference but with the integrated method yielding the lower values. The large difference in the vicinity of 1.9 seconds can be attributed to the fact that the null in the vertical plane patterns is not characteristic of the whole annulus which returns reverberation at times of this order. If this region is discounted, then the remainder of the ping cycle shows a very gradual increase in the difference between the two curves from about 1.7 dB at 2.5 sec. to 2.8 dB at 10 sec.

The above data would seem to support certain conclusions. In the first place, the doppler-band method (Model IV) is working properly. Although it is judged to be the most accurate way of computing the expected level of boundary reverberation, it increases the computing time by a factor of ten over that required by any of the other methods. Therefore, its general use as part of the ray tracing program is not recommended. It should be a separate program reserved for special cases. Even then it requires insertion of appropriate equations for the transducer patterns for obtaining pattern losses in any directions. Alternately, one could use a matrix of measured patterns in such a large number of planes that accurate results could be obtained by interpolation.

The other three models have in common the inaccuracy resulting from errors in computing values of the boundary reverberation index, for various geometries which obtain, as functions of transducer depth and elapsed time in the ping cycle. The evidence is that the errors inherent in the present method of computing J_s are small for path angles falling in the major lobe of the transducer when the pitch angle is not much greater than 10 degrees from the horizontal. For small pitch angles, the error in the first minor lobe may be tolerable in veiw of the usual uncertainty as to the proper values to assign for the scattering coefficient per unit area. Paths falling in the nulls between pattern lobes lead to values for J_s which are too high, but in general the boundary reverberation at corresponding times will be below other types of interference and is of no practical consequence. Model I, the method presently incorporated in our ray tracing program, also suffers from underestimating the width of the insonified annulus as the paths become steeper. Model II will improve this situation over a considerable range of path angles, but this improvement is unimportant relative to another source of error common to both models I and II. Here we refer to the assumption that values of J_s and transmission loss computed to a single point in the annulus are characteristic of the entire insonified area.

Except for very short pings, this assumption can introduce substantial errors when the rate of change of one or more of these parameters is large. On this basis it seems logical to adopt the integration method (Model III) as the regular routine in the ray tracing programs. Surprisingly enough, this can be accomplished without a significant increase in run time on the computer. With a suitable selection of rays, accurate modeling of the expected level of boundary reverberation should be achieved within the accuracy inherent in J_s. If an improved method of evaluating this factor is found, the benefits will automatically accrue in the reverberation computation.

Because of the other variables involved, it is difficult to pin down the actual errors in J_s by comparing the reverberation levels computed by means of Models III and IV. During the course of this study, a technique was envisioned whereby J_s could be investigated directly.

A. B. POYNTER

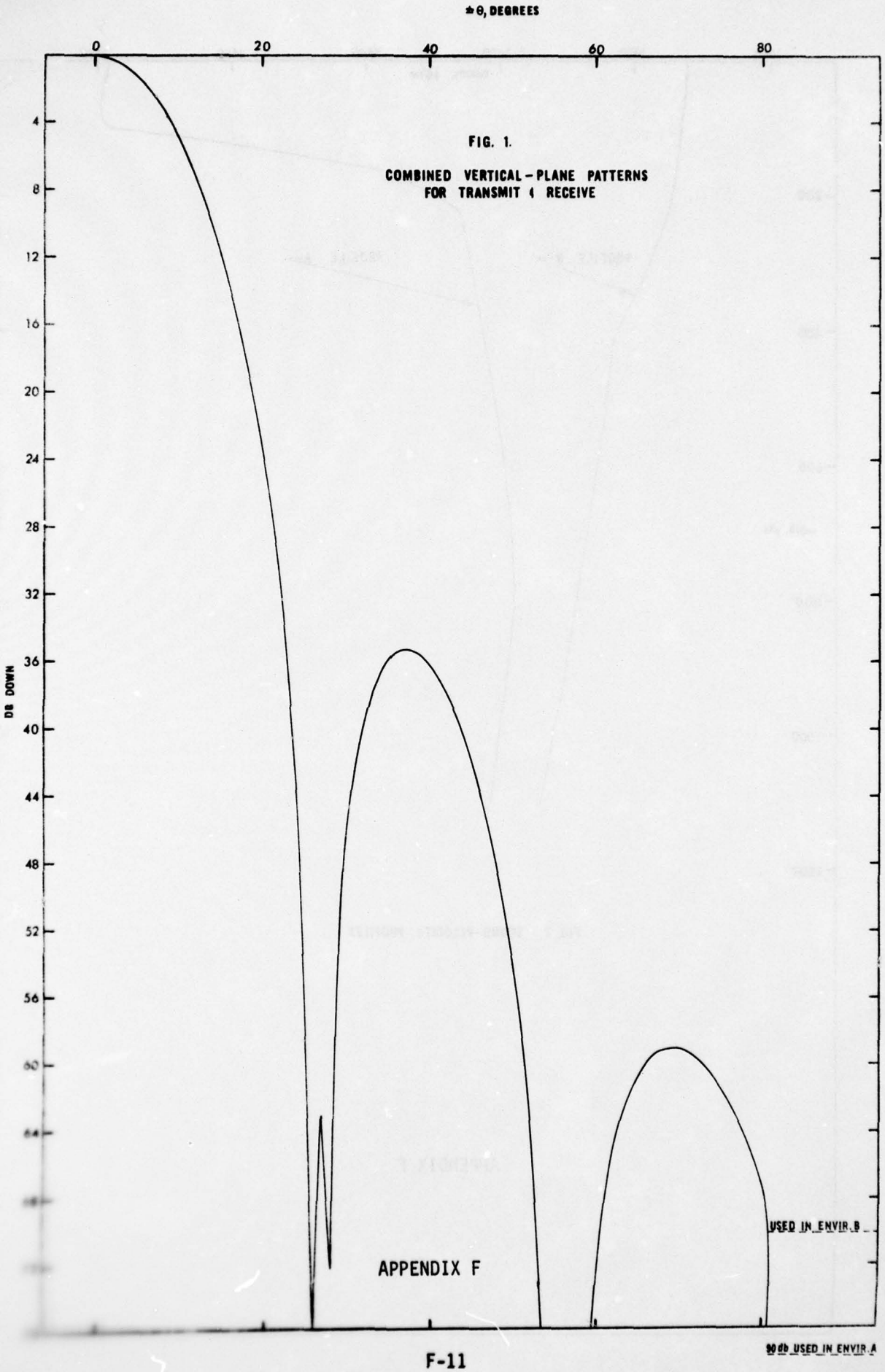


FIG. 1.

COMBINED VERTICAL-PLANE PATTERNS
FOR TRANSMIT & RECEIVE

APPENDIX F

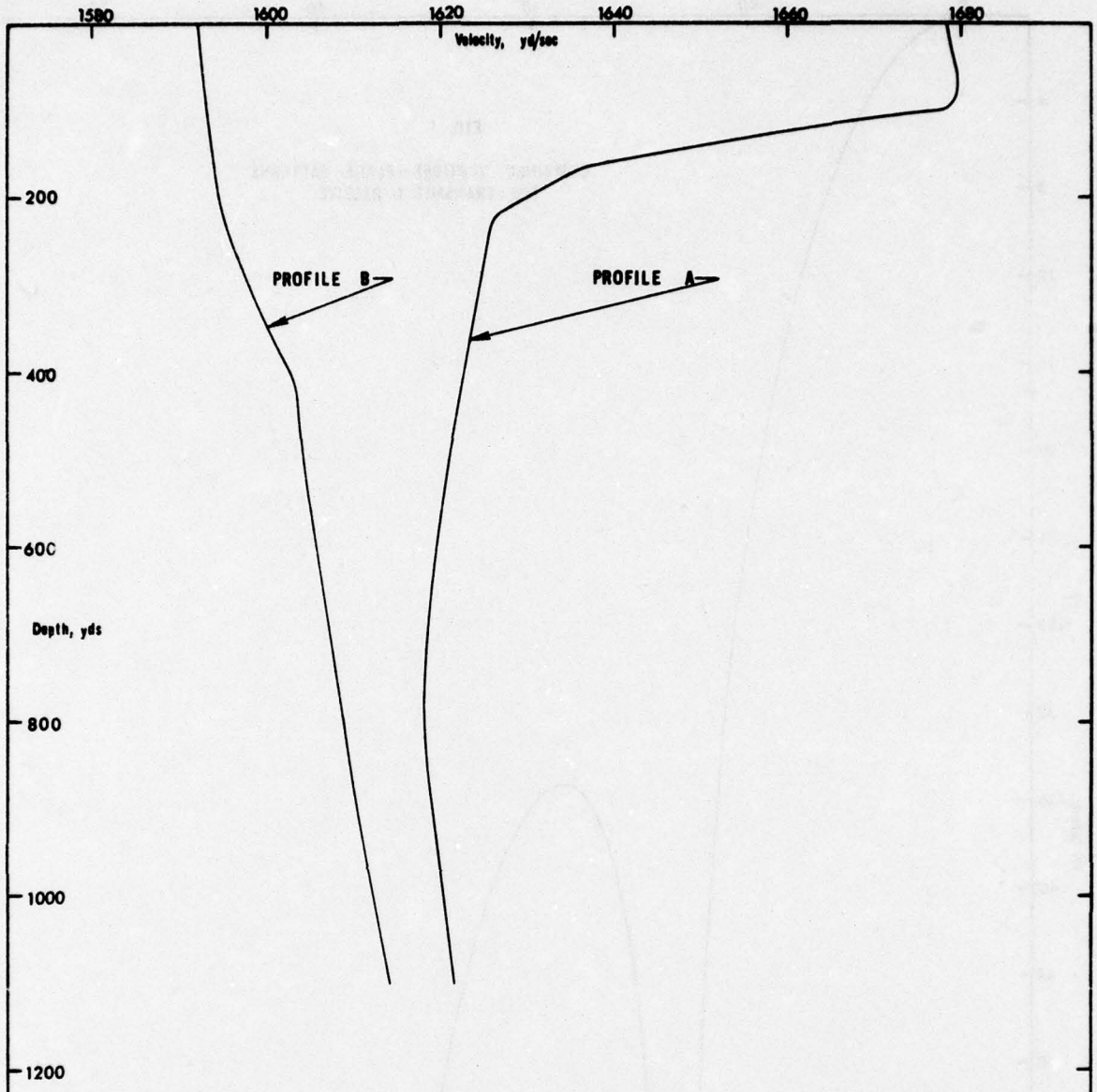


FIG. 2 SOUND-VELOCITY PROFILES

APPENDIX F

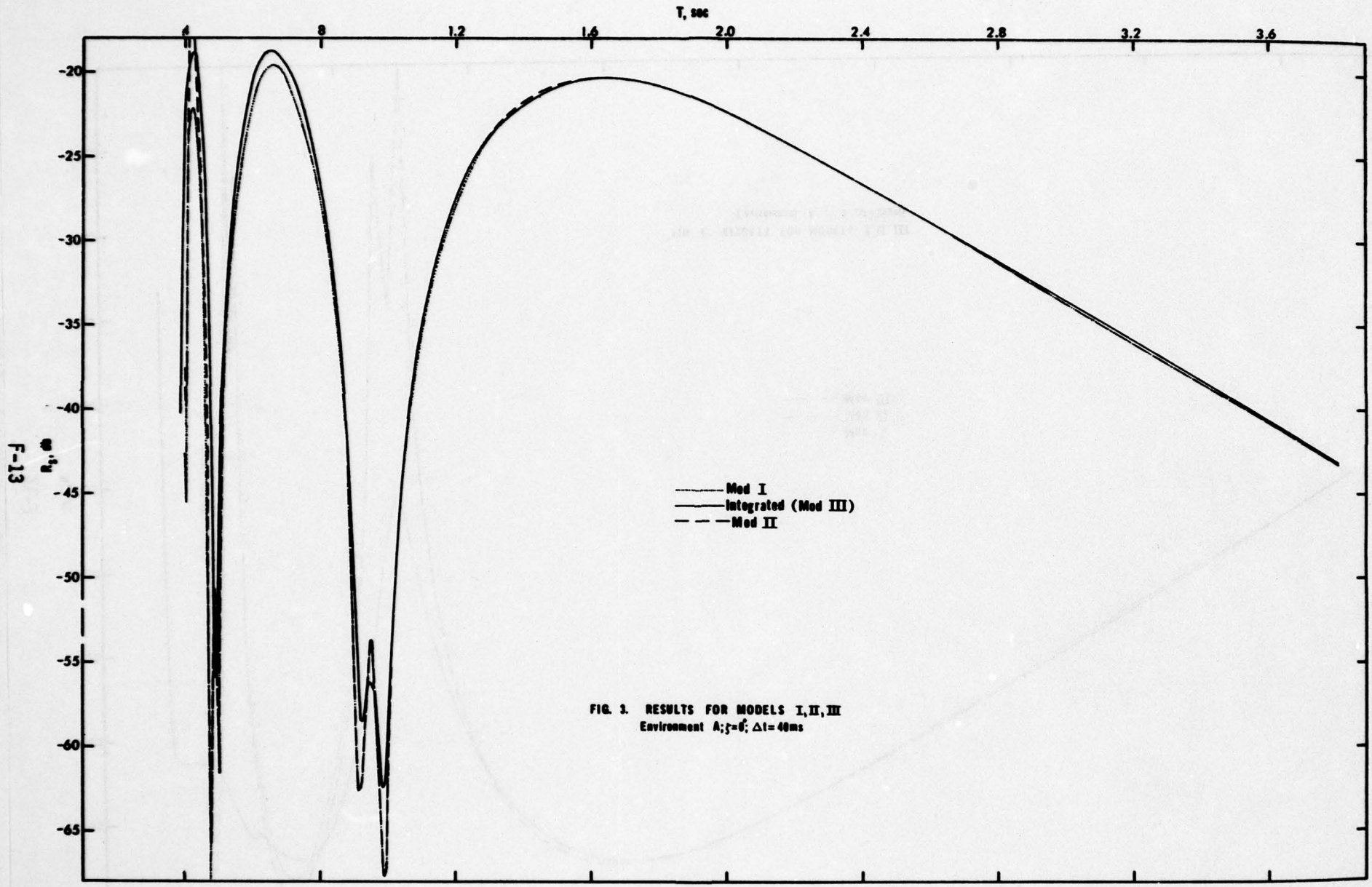


FIG. 3. RESULTS FOR MODELS I, II, III
Environment A; $\zeta = 0^\circ$; $\Delta t = 40$ms

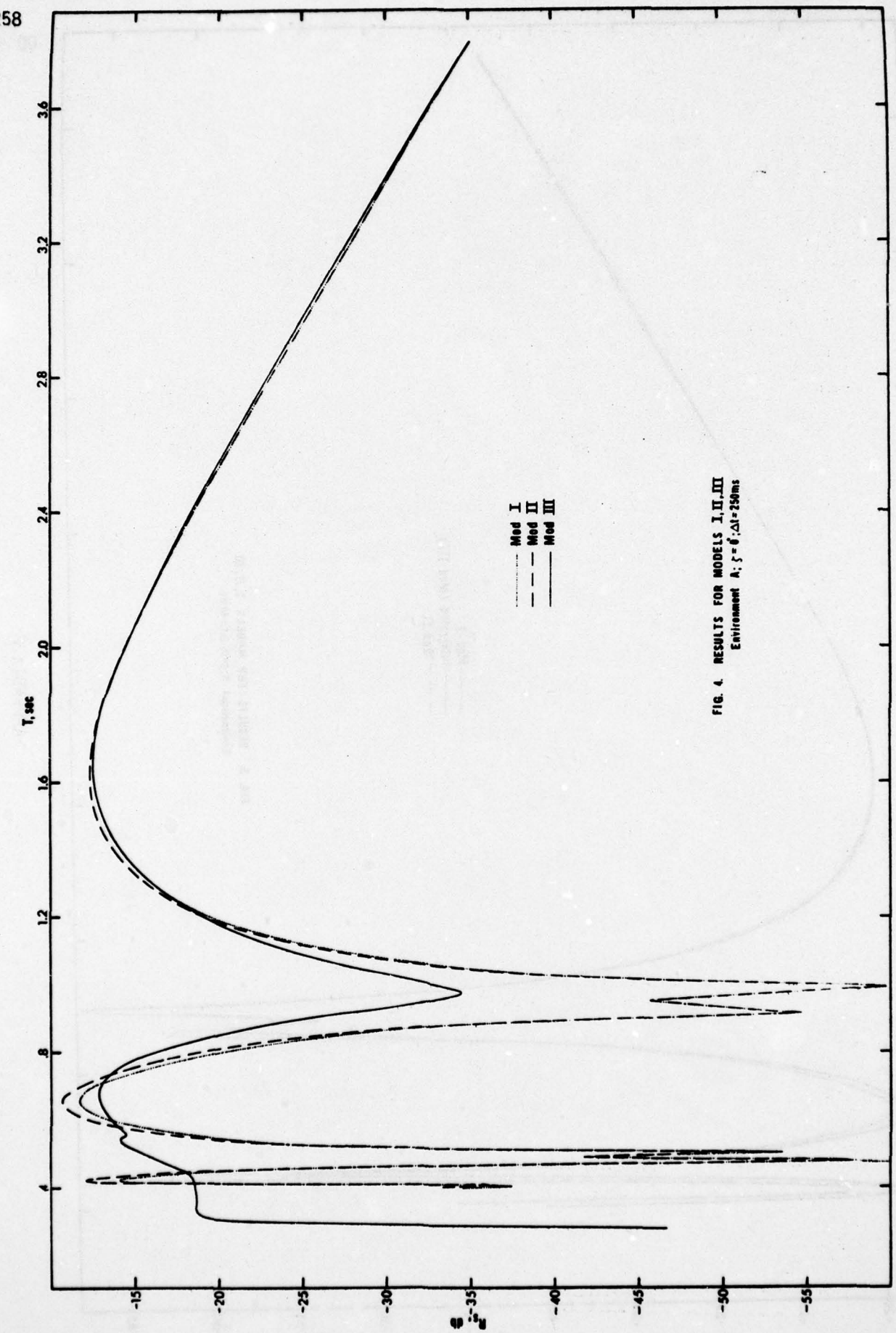


FIG. 4. RESULTS FOR MODELS I, II, III
Environment A; $\zeta = 0$; $\Delta t = 250$ms

APPENDIX F

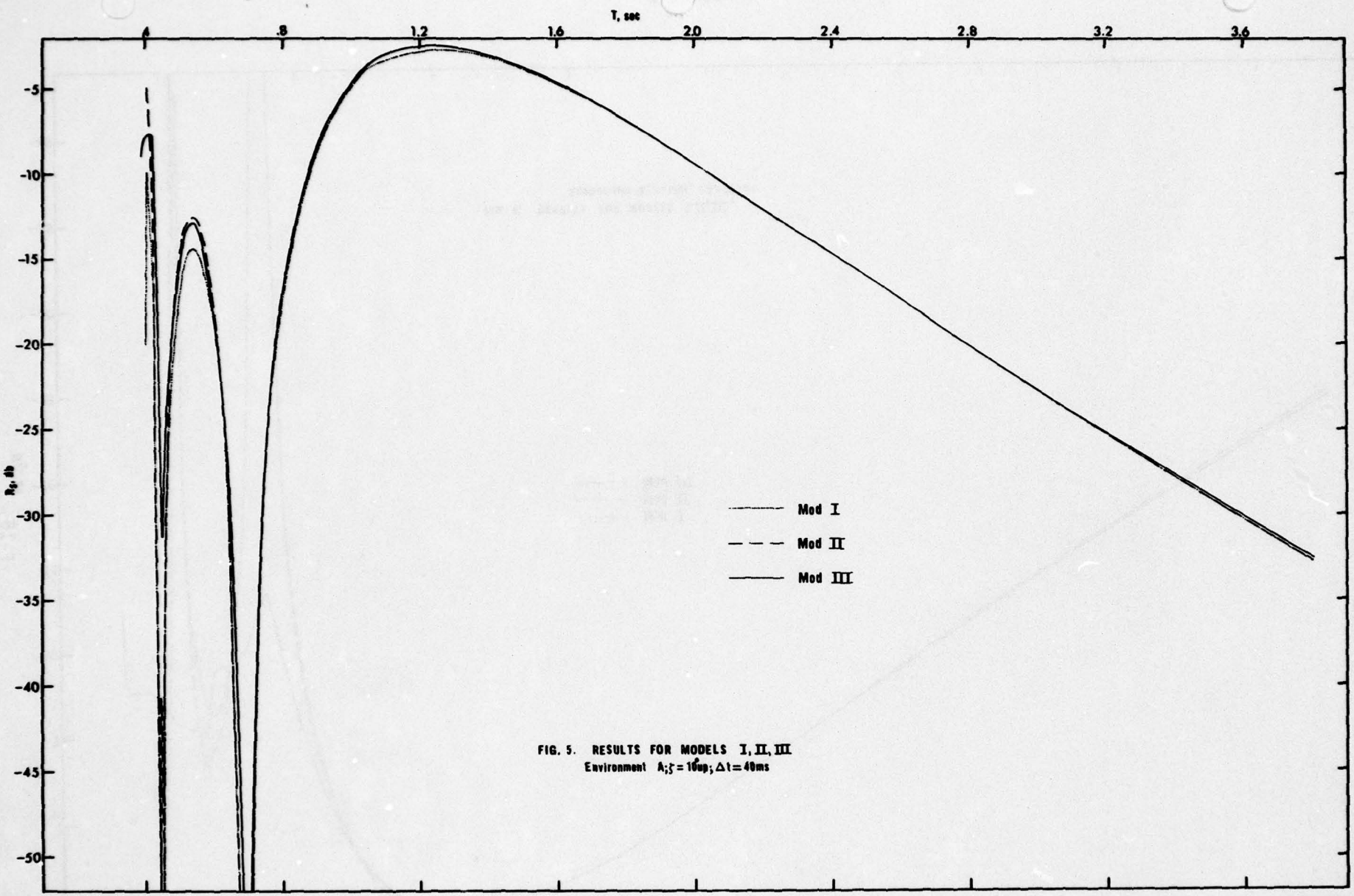


FIG. 5. RESULTS FOR MODELS I, II, III
Environment A; $\zeta = 10^{\circ}$; $\Delta t = 40$ms

APPENDIX F

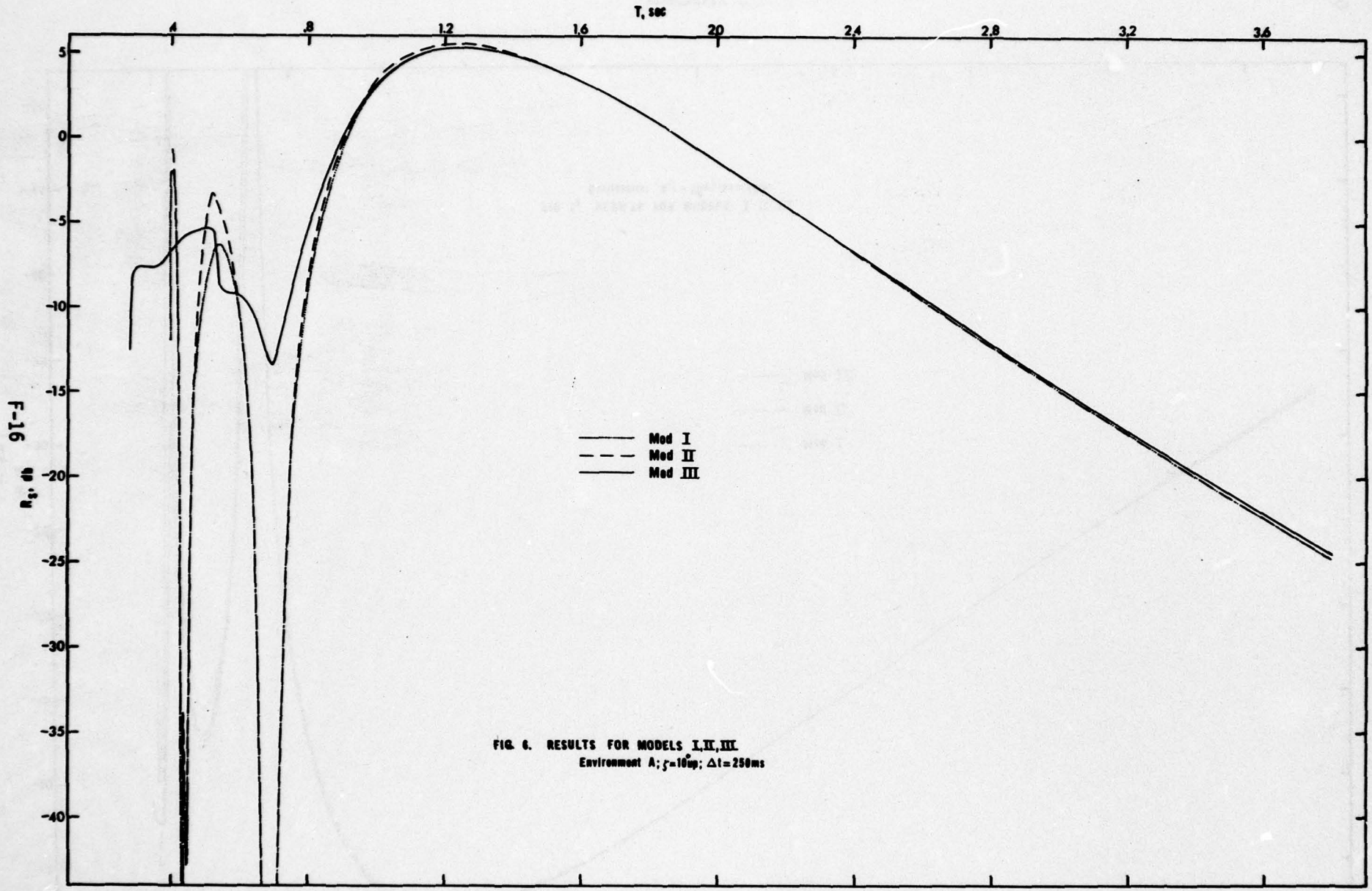


FIG. 6. RESULTS FOR MODELS I, II, III.
Environment A; ζ=10°; Δt=250ms

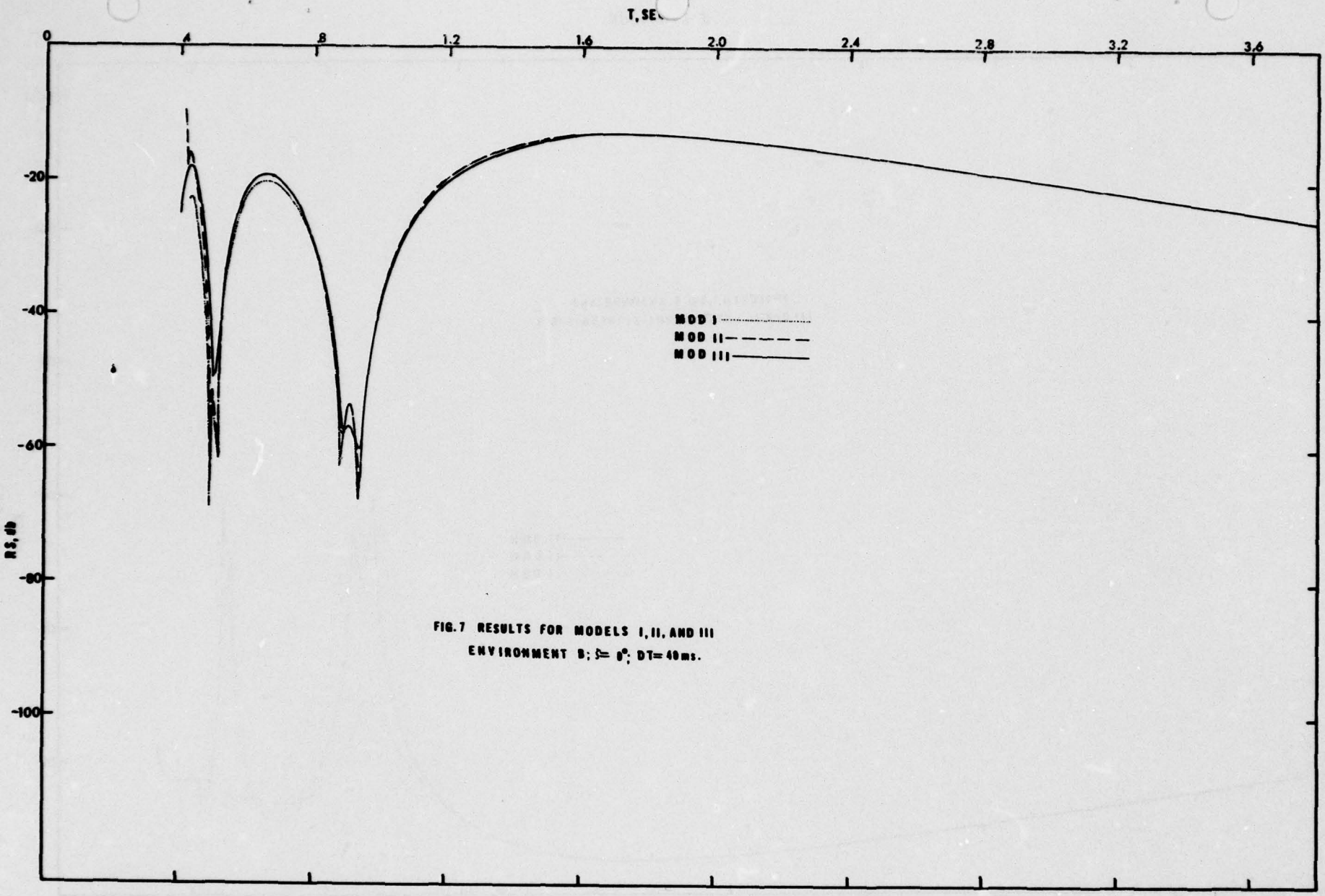


FIG. 7 RESULTS FOR MODELS I, II, AND III
ENVIRONMENT B; $\gtrsim$ 0°; DT= 40 ms.

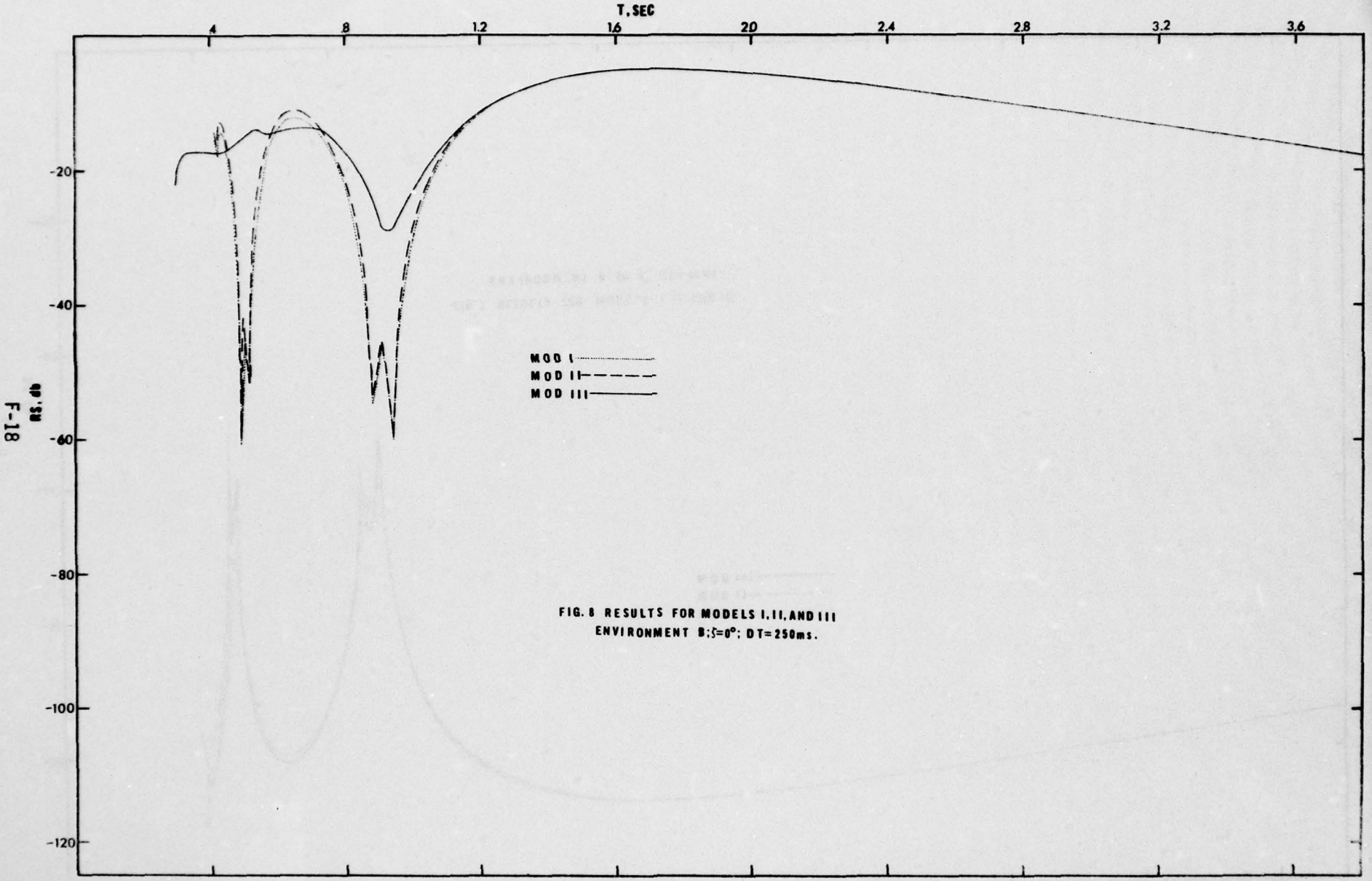


FIG. 8 RESULTS FOR MODELS I, II, AND III
ENVIRONMENT B; δ=0°; DT=250ms.

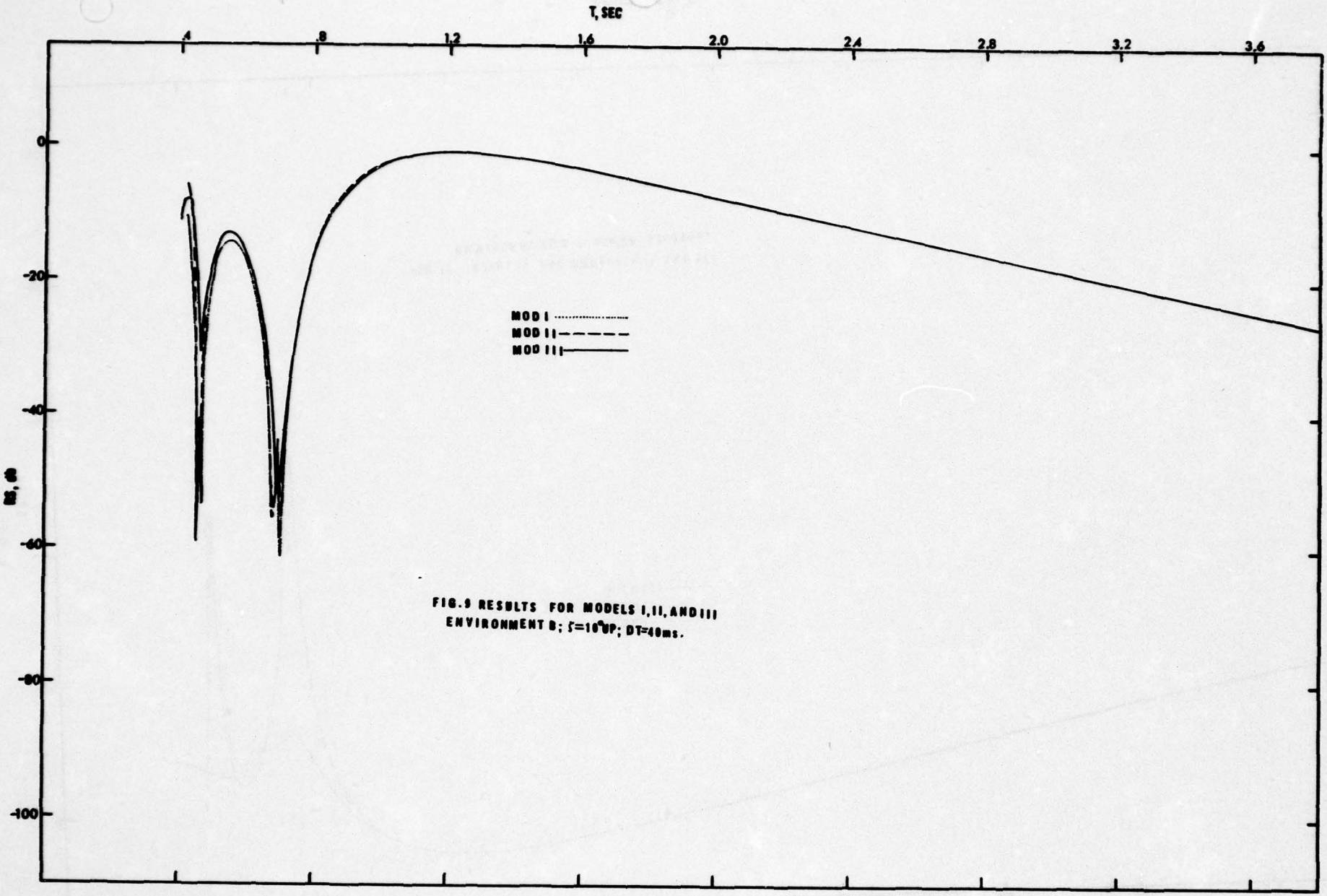


FIG. 9 RESULTS FOR MODELS I, II, AND III
ENVIRONMENT B; ζ=10°UP; DT=40ms.

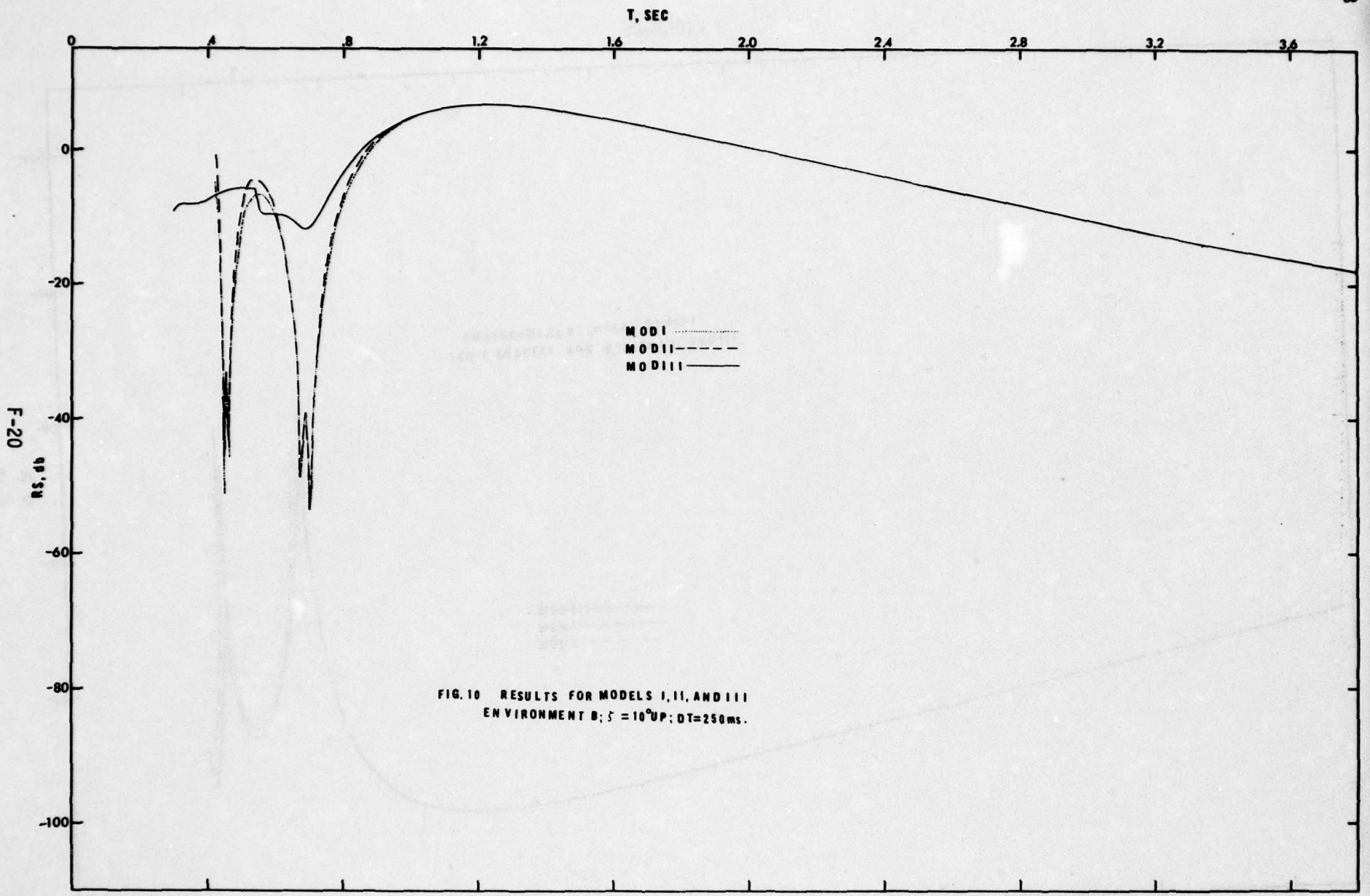


FIG. 10 RESULTS FOR MODELS I, II, AND III
ENVIRONMENT B; $\delta = 10^{\circ}$UP; DT=250ms.

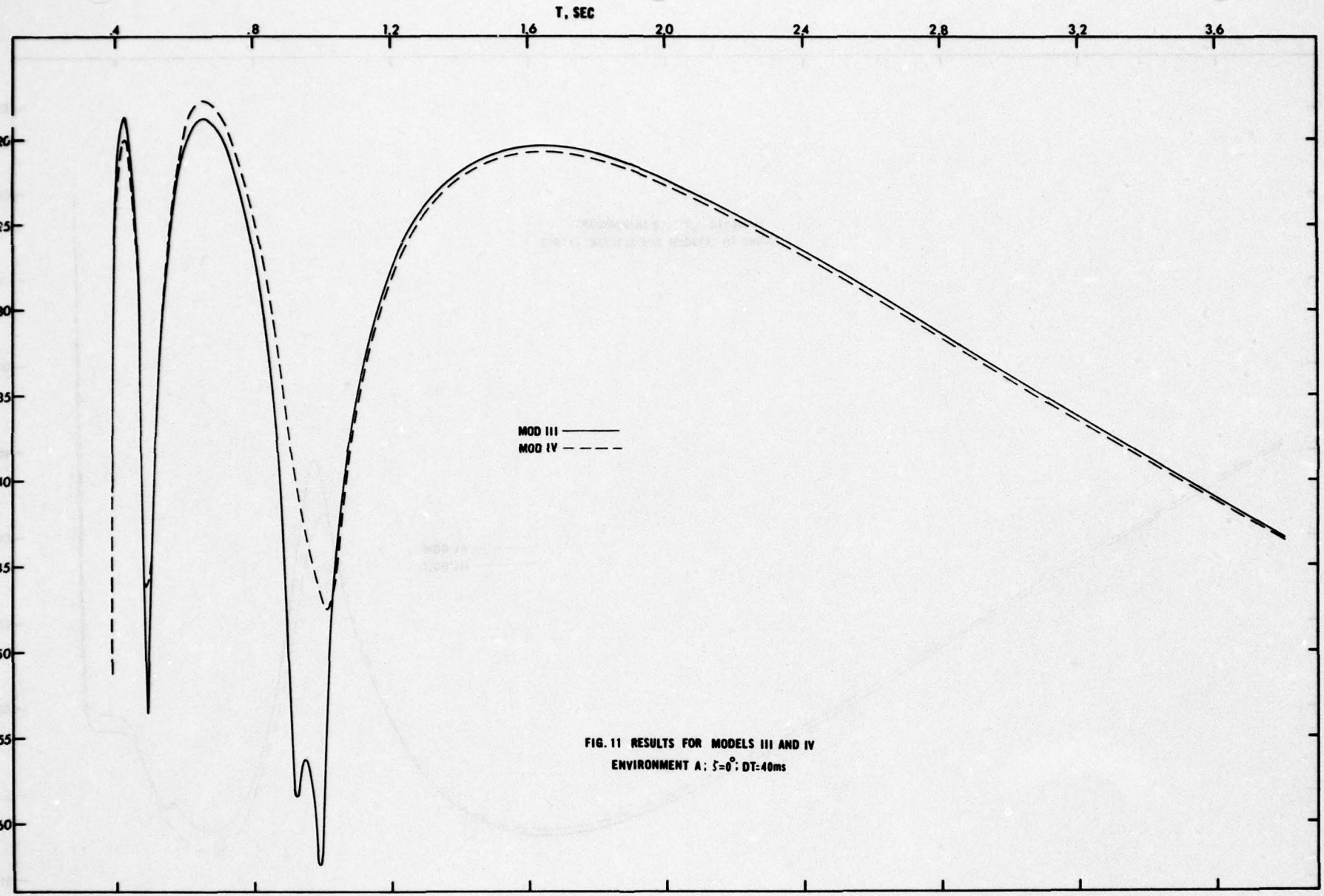


FIG. 11 RESULTS FOR MODELS III AND IV
ENVIRONMENT A; ζ=0°; DT=40ms

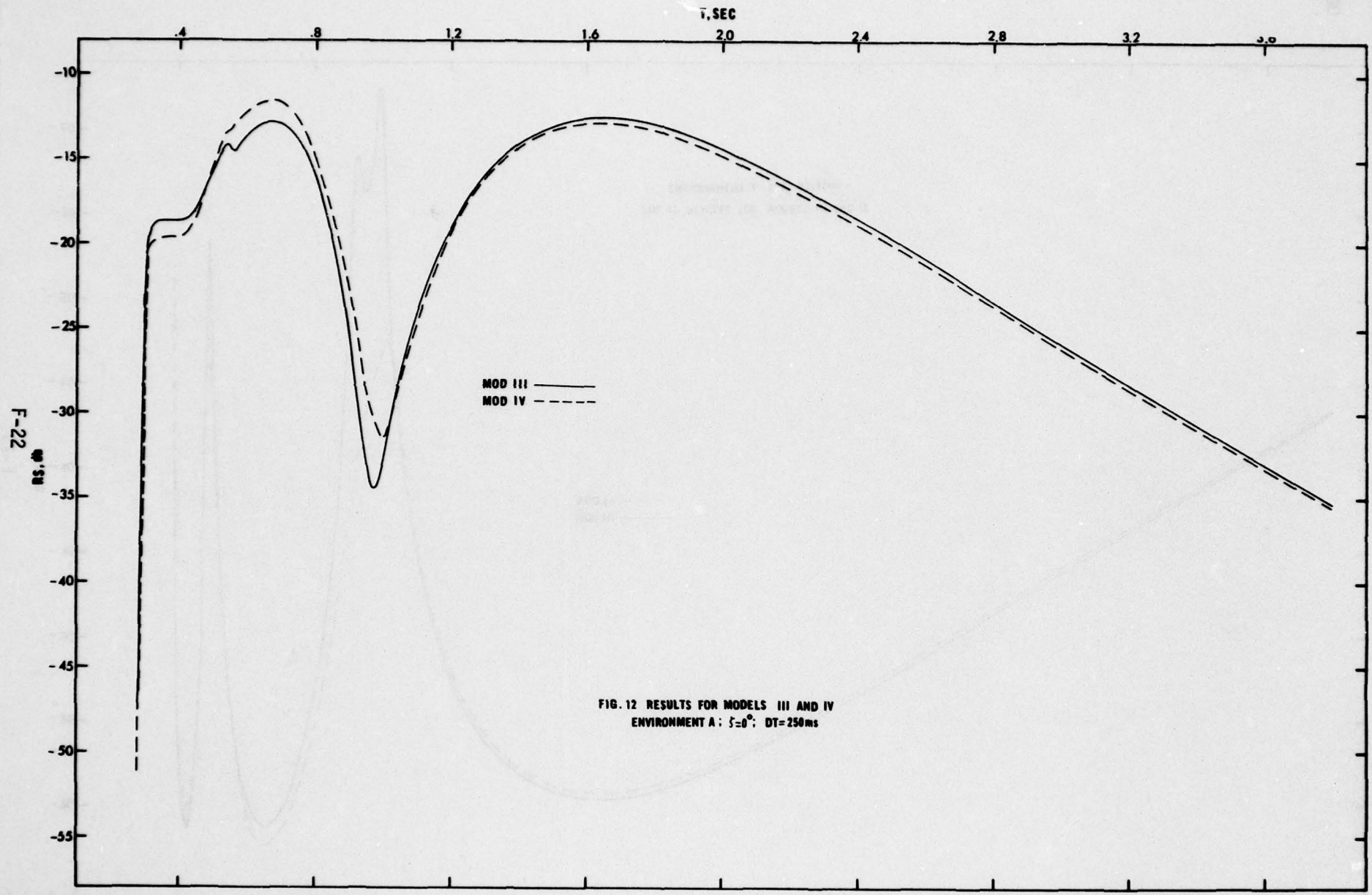


FIG. 12 RESULTS FOR MODELS III AND IV
ENVIRONMENT A; ζ=0°; DT=250ms

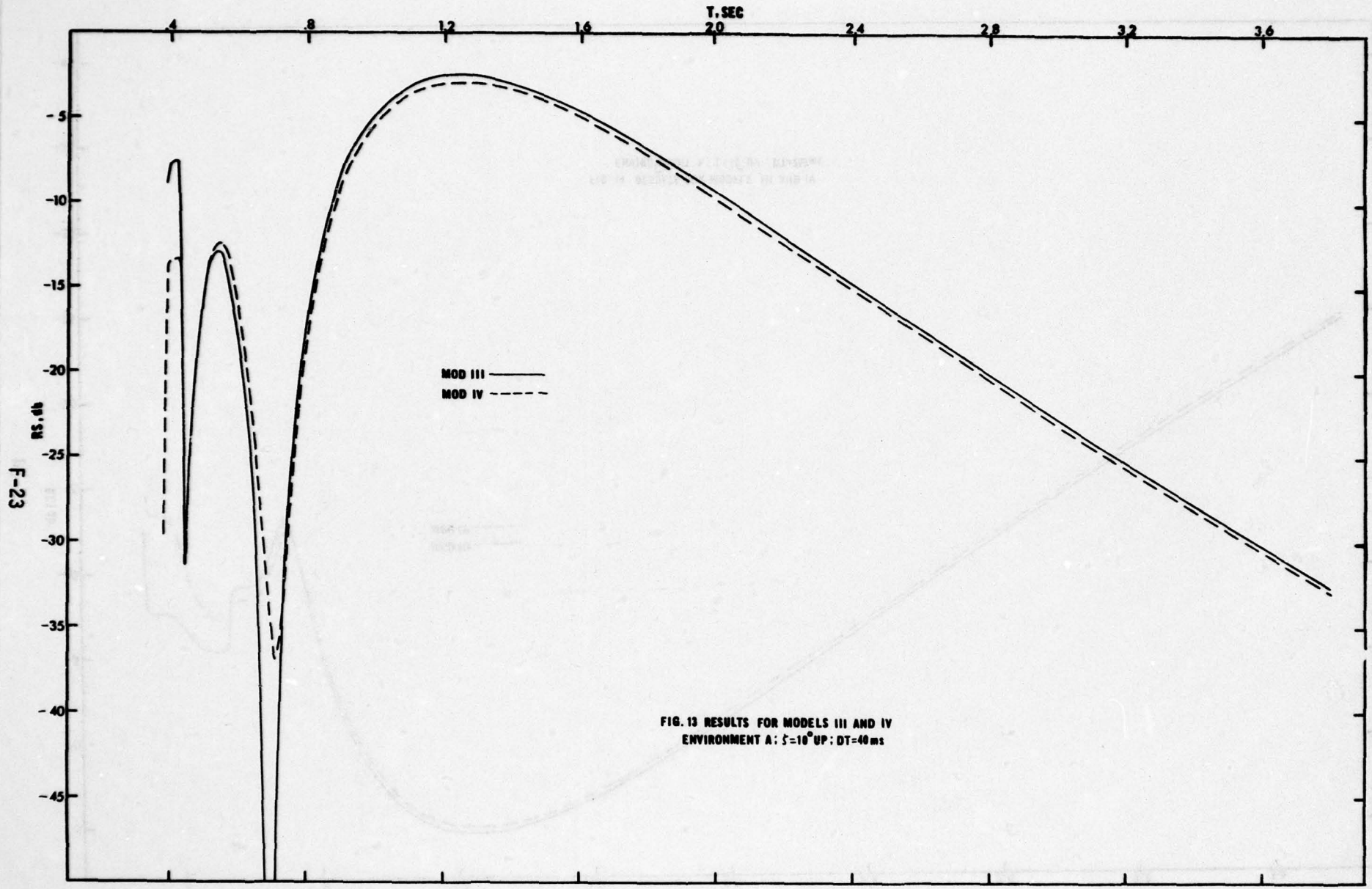


FIG. 13 RESULTS FOR MODELS III AND IV
ENVIRONMENT A: δ=10° UP; DT=40 ms

APPENDIX F

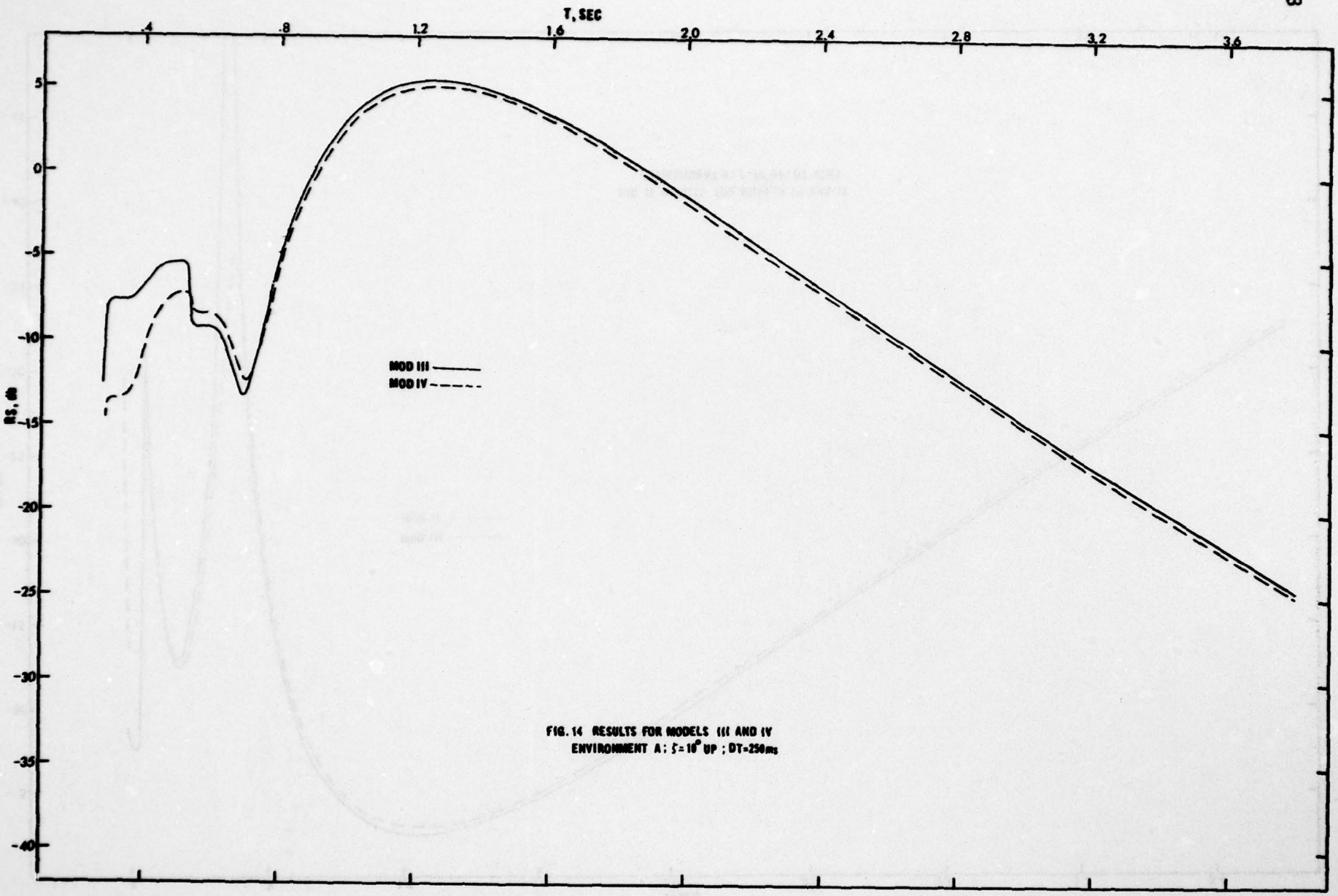


FIG. 14 RESULTS FOR MODELS III AND IV
ENVIRONMENT A: $\zeta = 10^{\circ}$ UP ; DT=250ms

AD-A035 071 NAVAL SEA SYSTEMS COMMAND WASHINGTON D C F/G 17/1
A COMPUTER PROGRAM FOR STUDYING THE DOPPLER CONTENT OF REVERBER--ETC(U)
1976 P MARSH
UNCLASSIFIED NAVSEA-0D-52258 NL

2 OF 2
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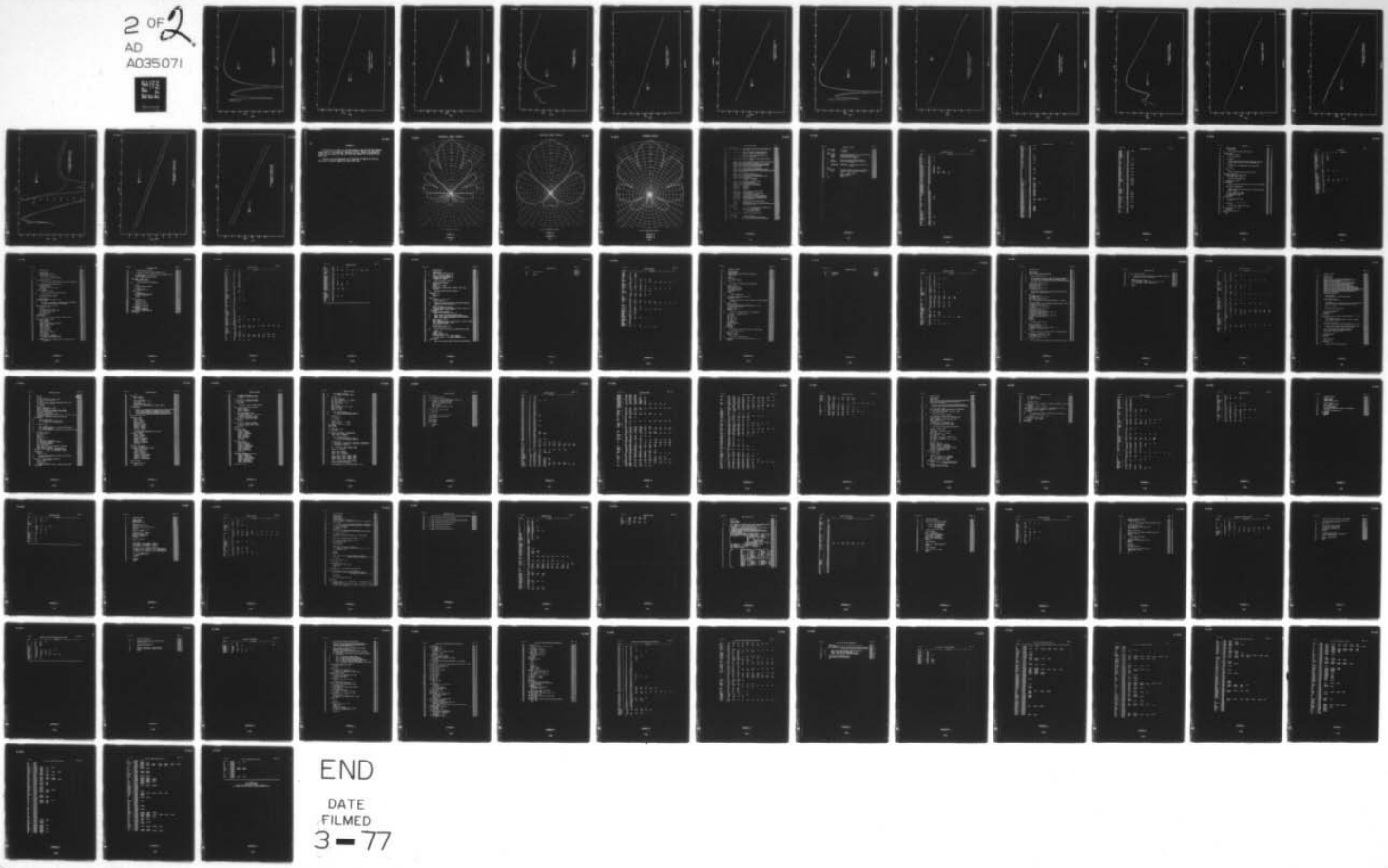
A035071



END

DATE
FILMED
3-77

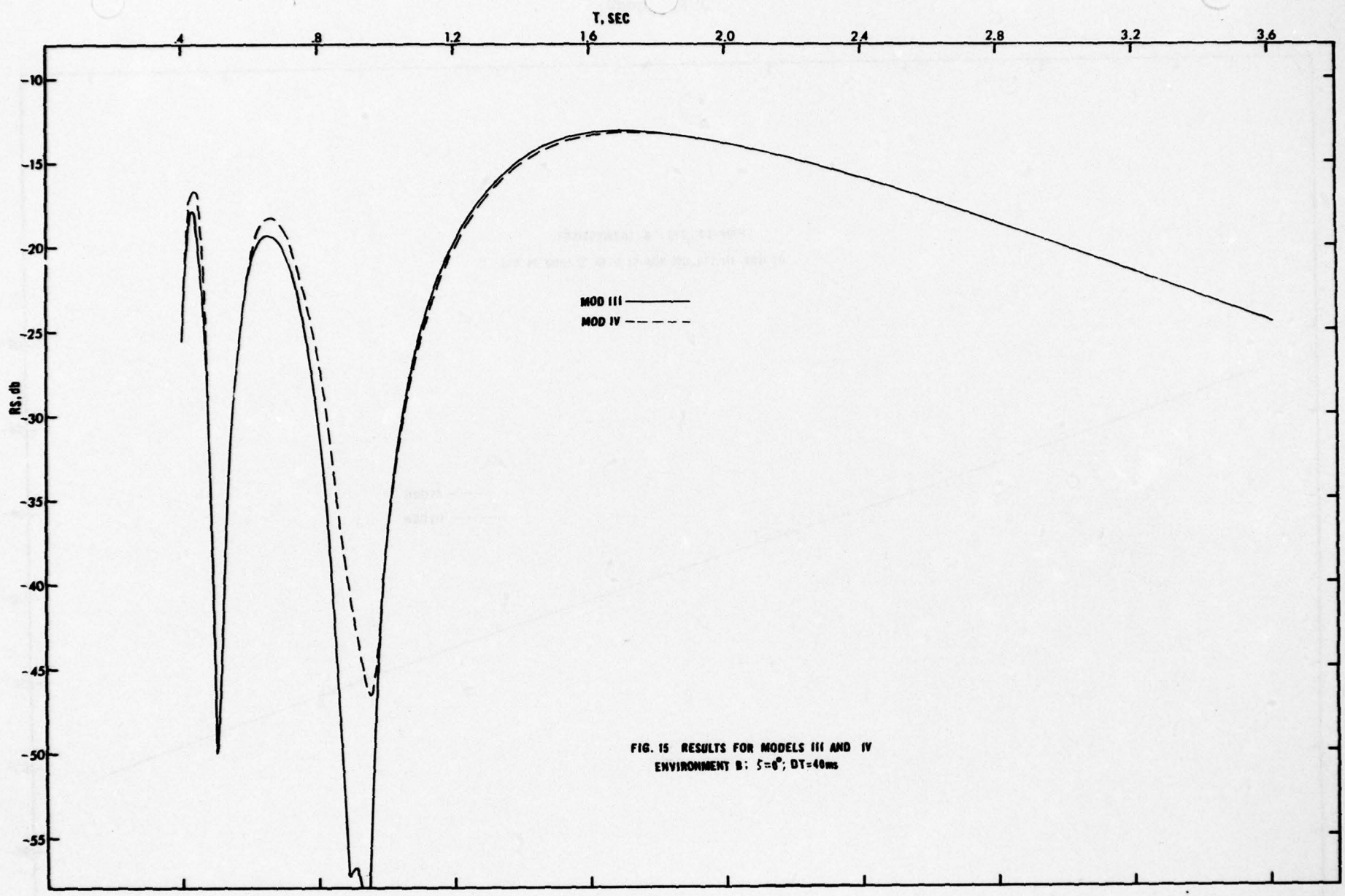


FIG. 15 RESULTS FOR MODELS III AND IV
ENVIRONMENT B: $\zeta=0°$; DT=40ms

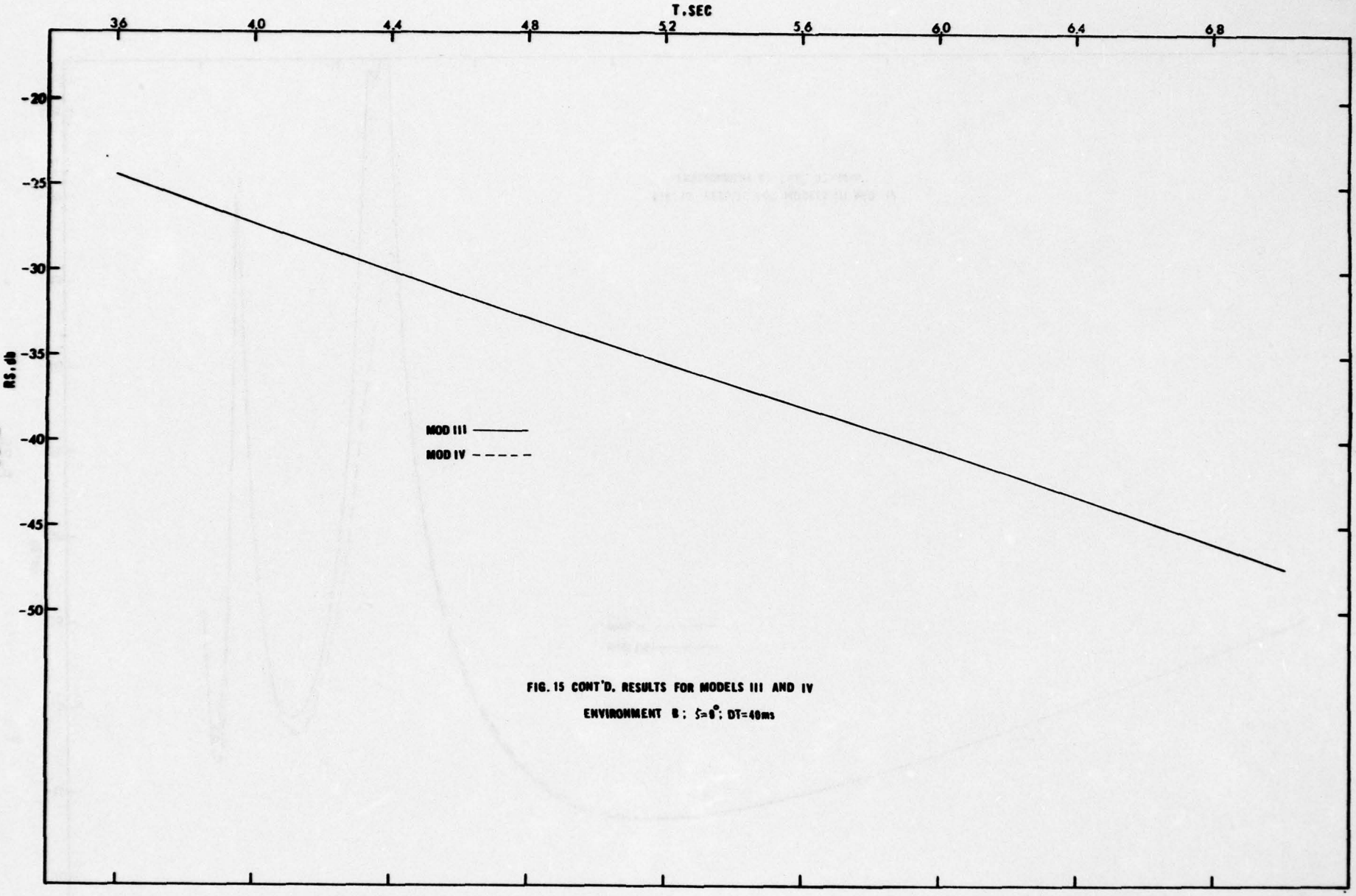


FIG. 15 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta=0^{\circ}$; DT=40ms

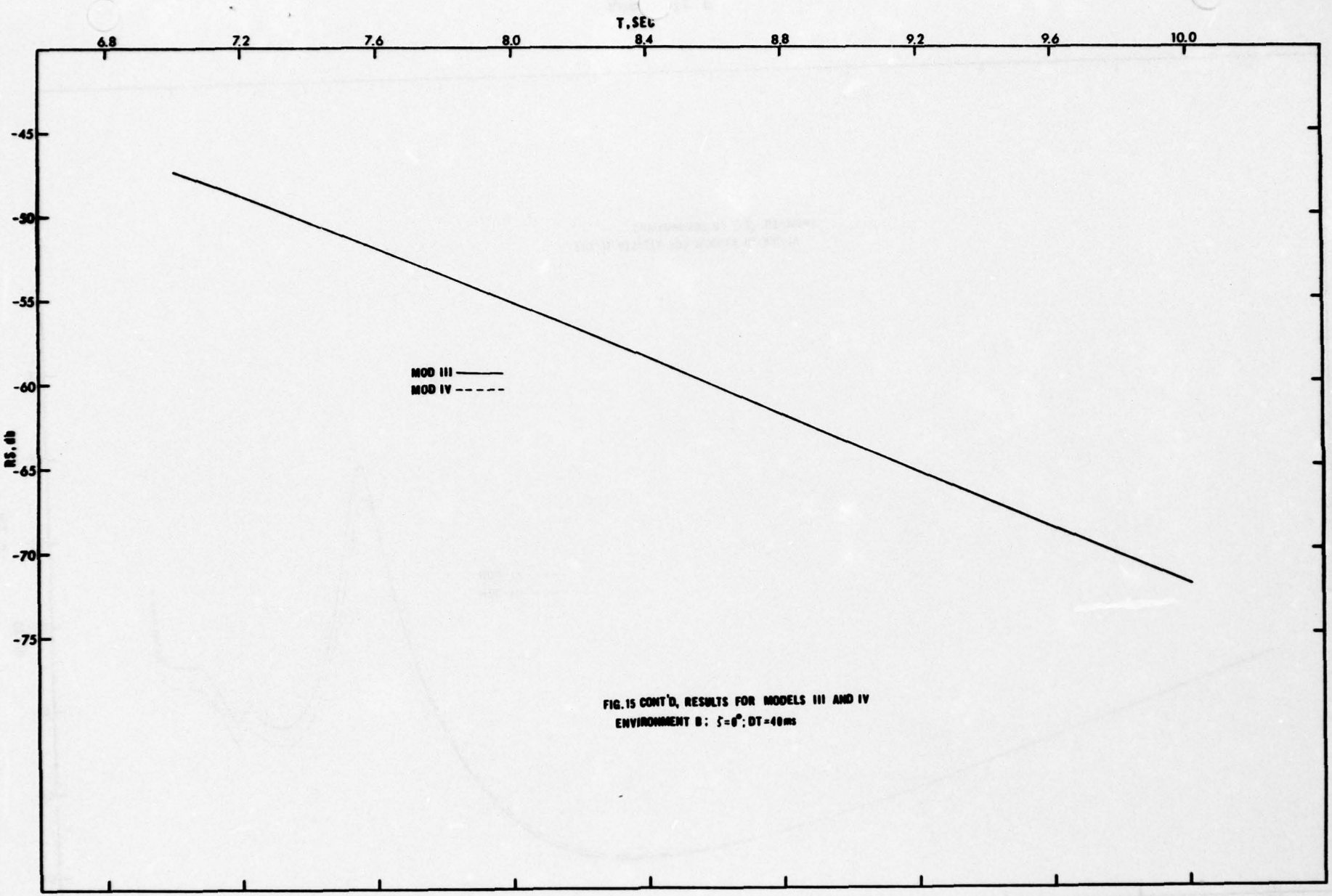


FIG. 15 CONT'D, RESULTS FOR MODELS III AND IV
ENVIRONMENT B: $\zeta = 0^{\circ}$; DT = 40 ms

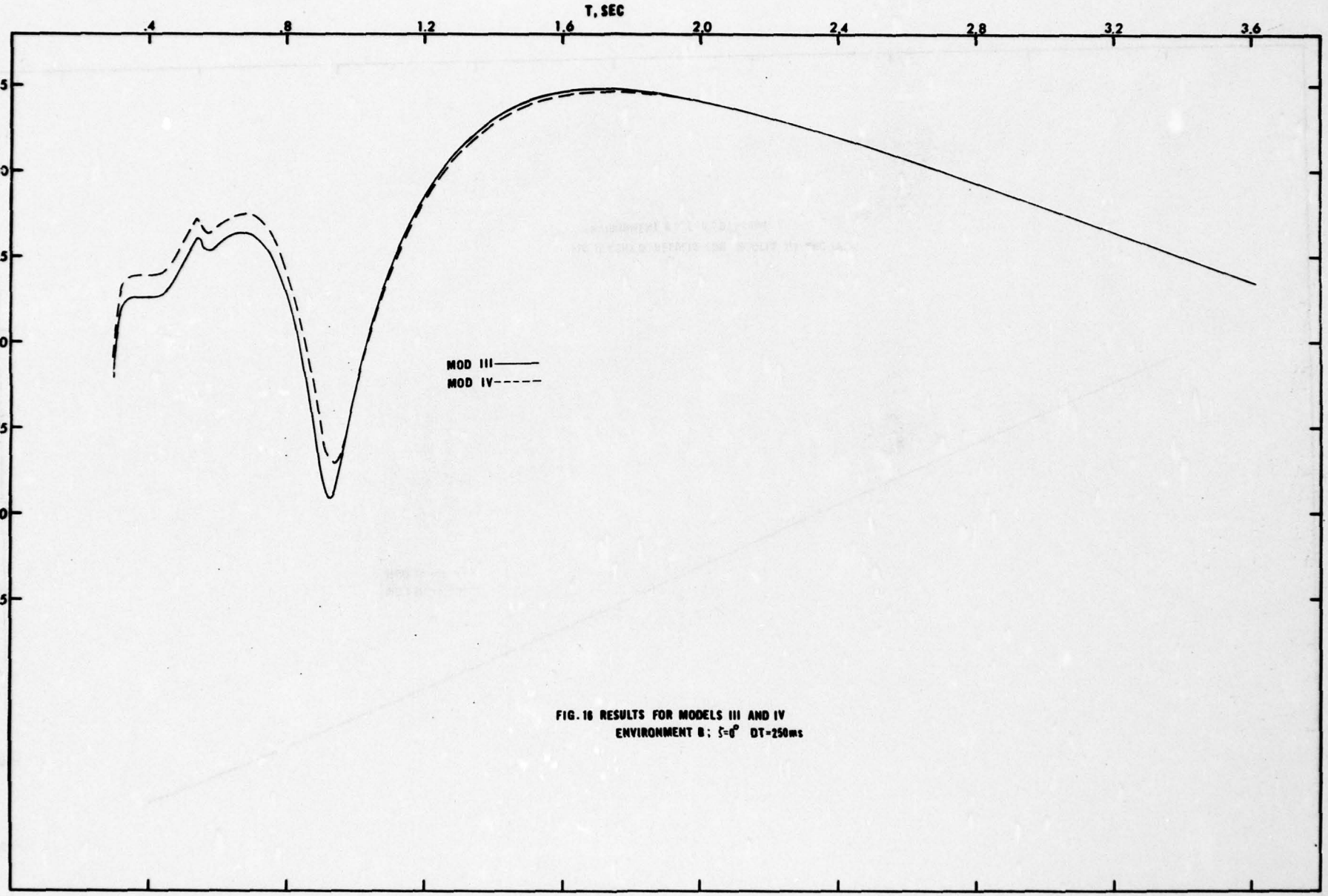


FIG. 16 RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta=0^{\circ}$ DT=250ms

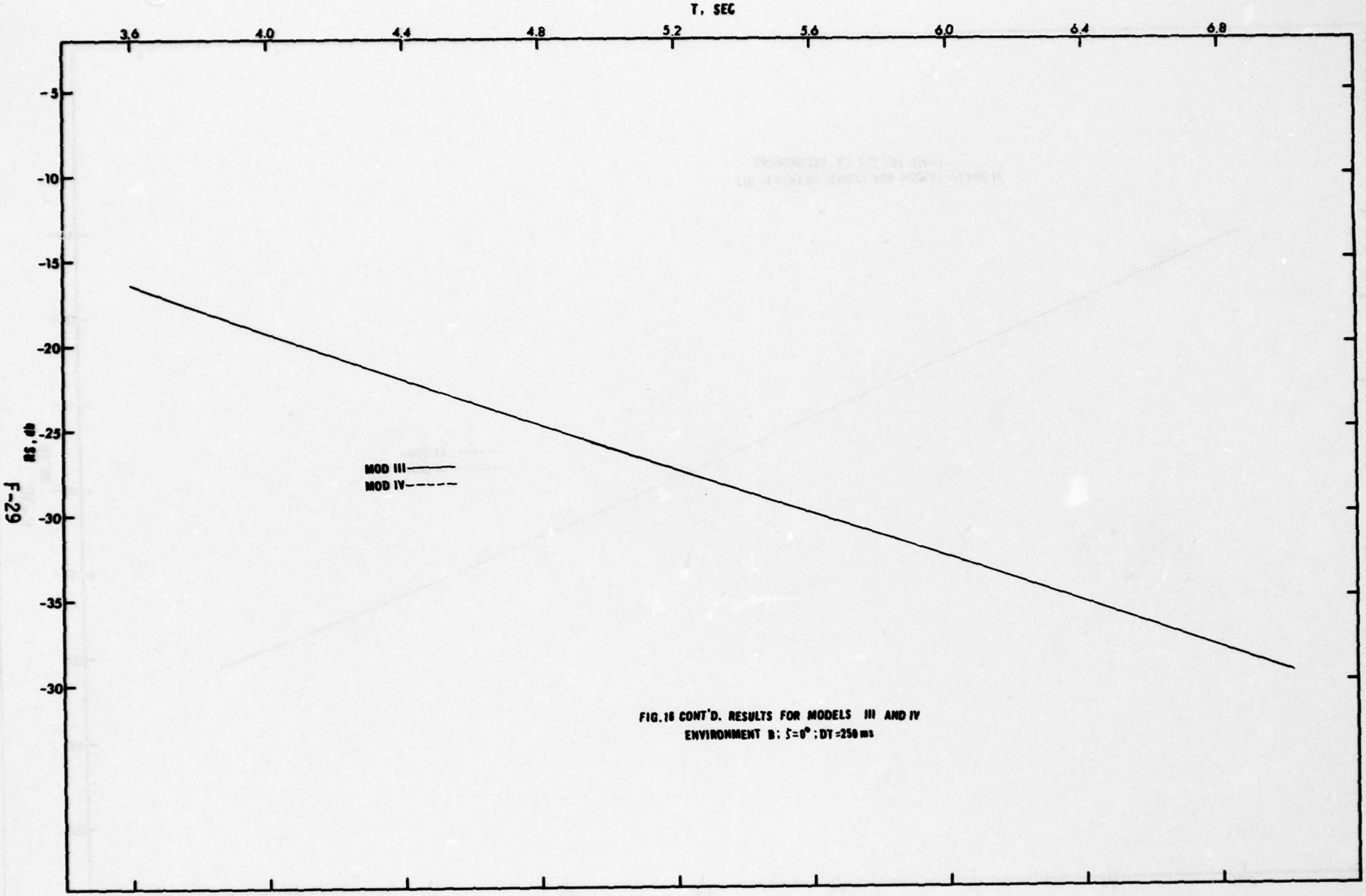


FIG. 16 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta = 0°$; DT = 250 ms

FIG.18 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B: $\zeta=0^{\circ}$; DT=250ms

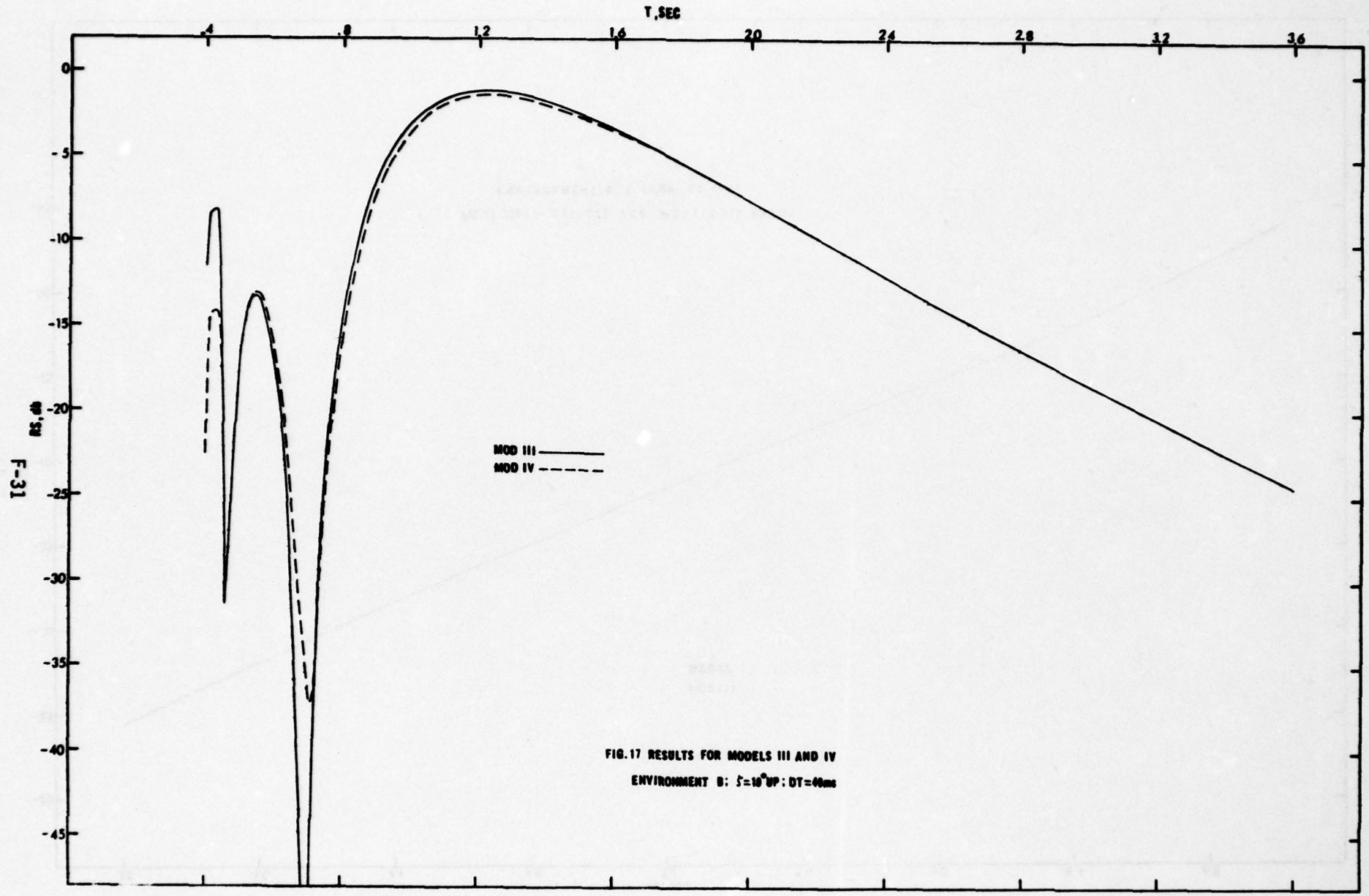


FIG. 17 RESULTS FOR MODELS III AND IV
ENVIRONMENT B: $\dot{S}$=18°UP; DT=40ms

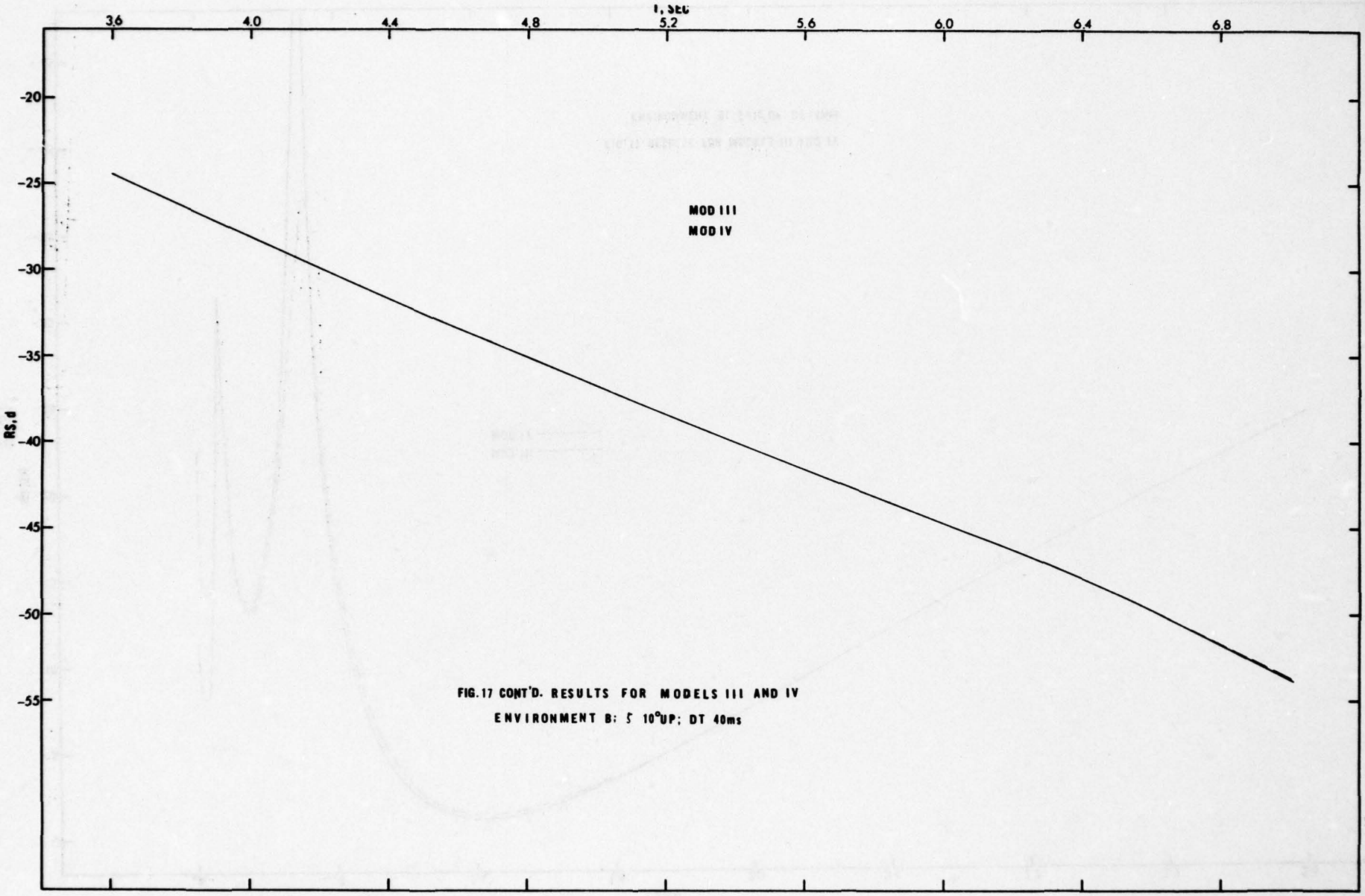


FIG. 17 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B: 5 10°UP; DT 40ms

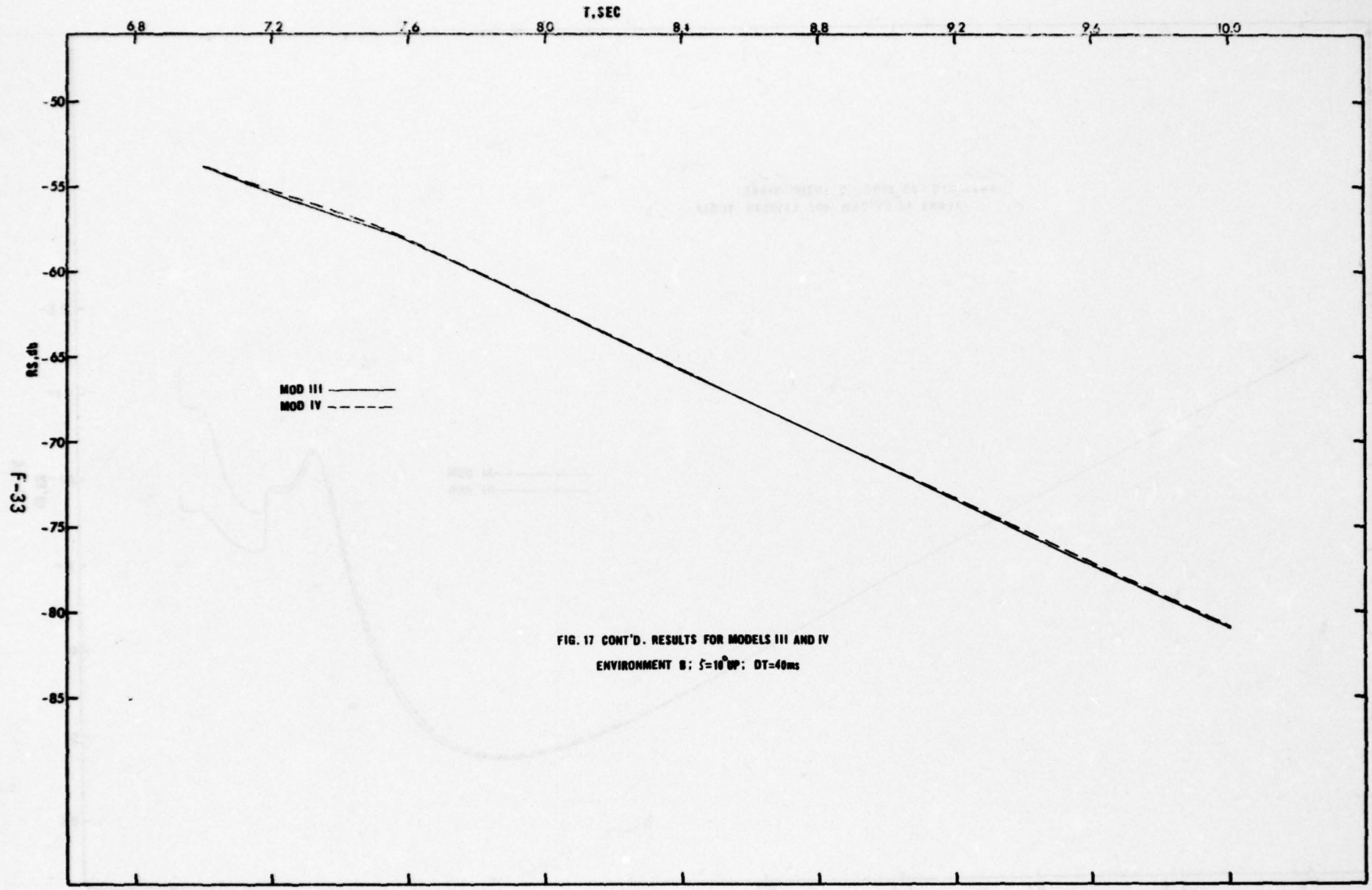


FIG. 17 CONT'D. RESULTS FOR MODELS III AND IV

ENVIRONMENT B; ζ=10°UP; DT=40ms

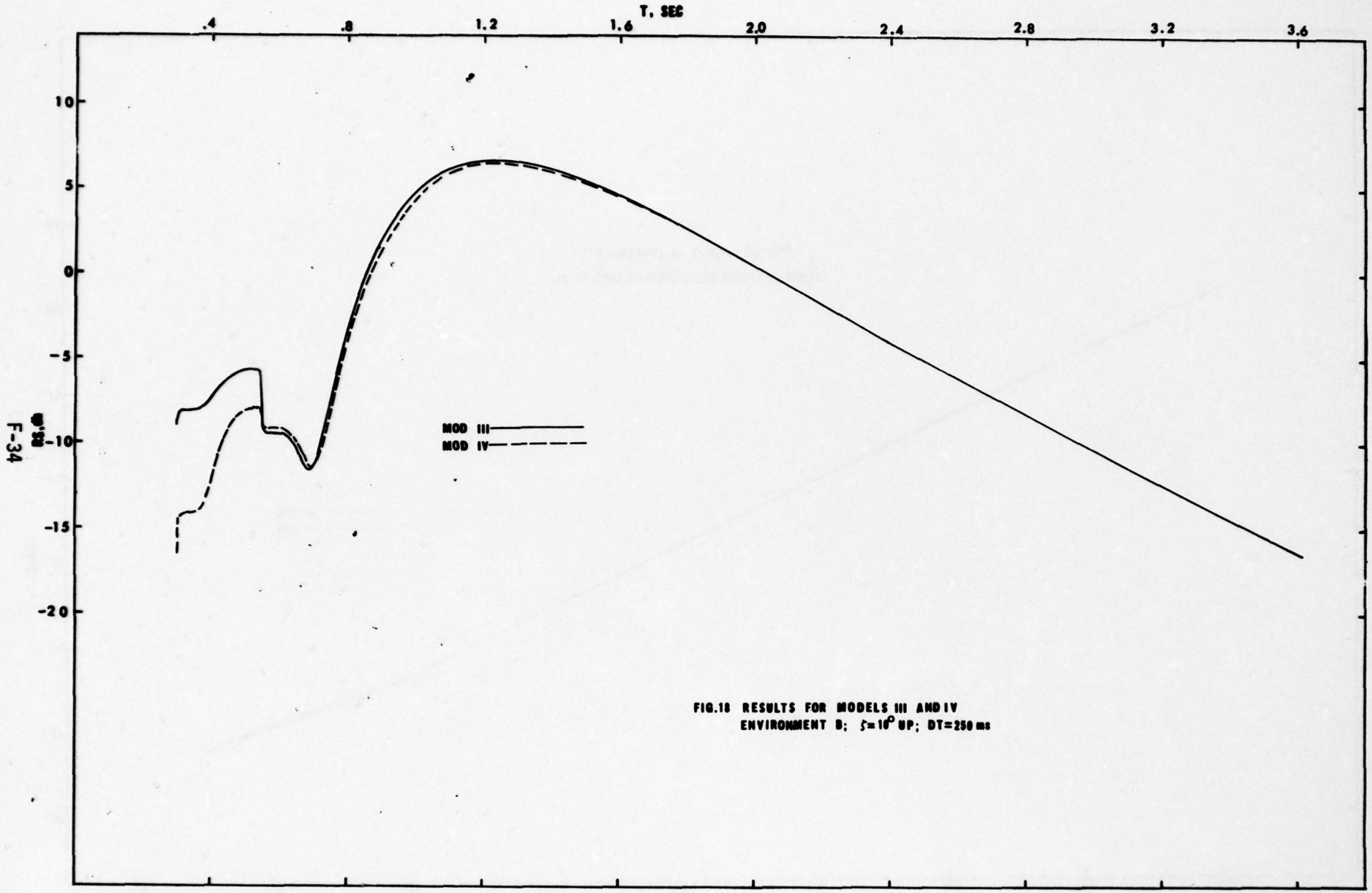


FIG.18 RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta = 10^{\circ}$ UP; DT=250 ms

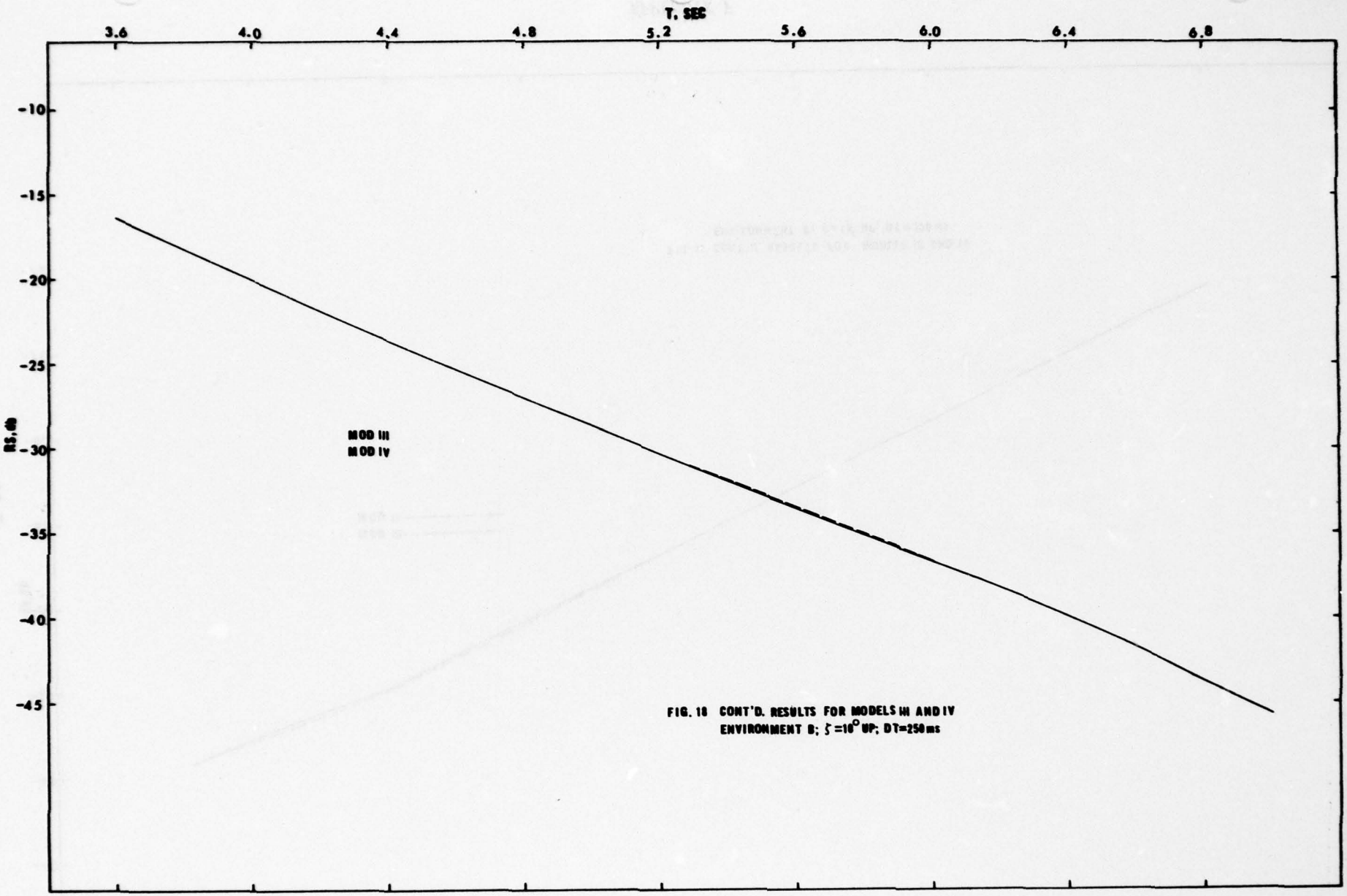


FIG. 18 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta = 10^{\circ}$ UP; DT=250 ms

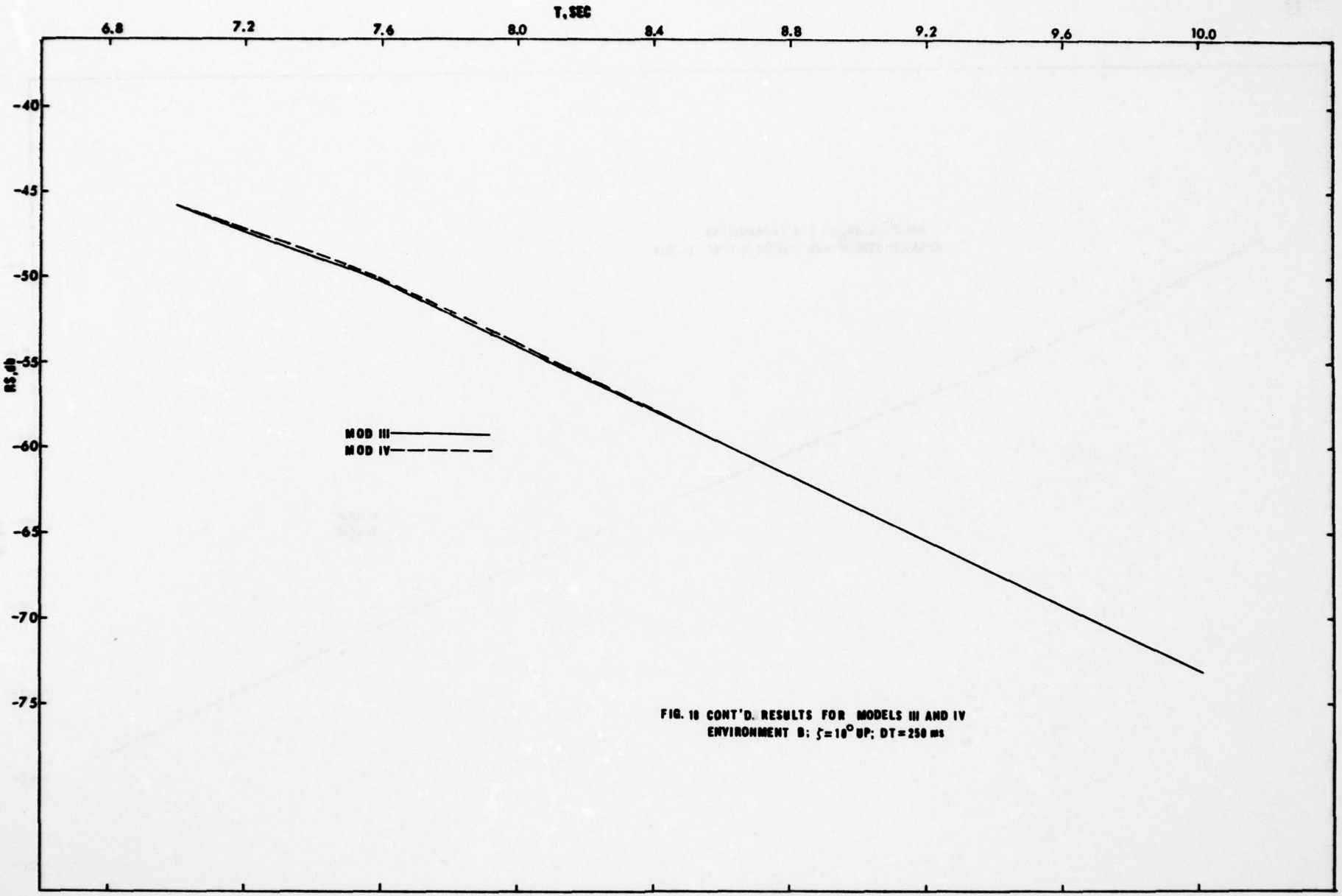


FIG. 18 CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta = 10^{\circ}$ BP; DT = 250 ms

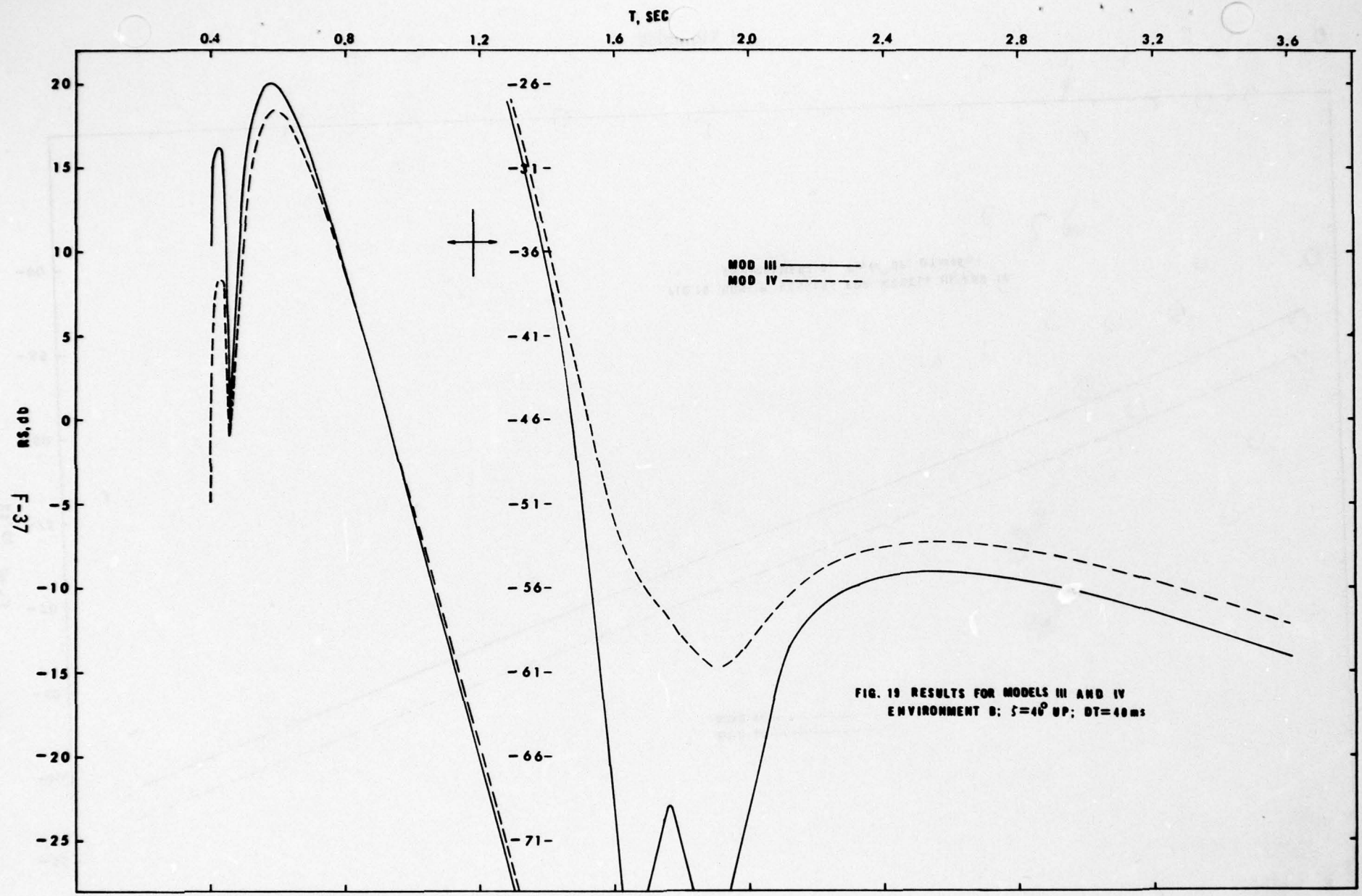


FIG. 19 RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $S=40^{\circ}$ UP; DT=40 ms

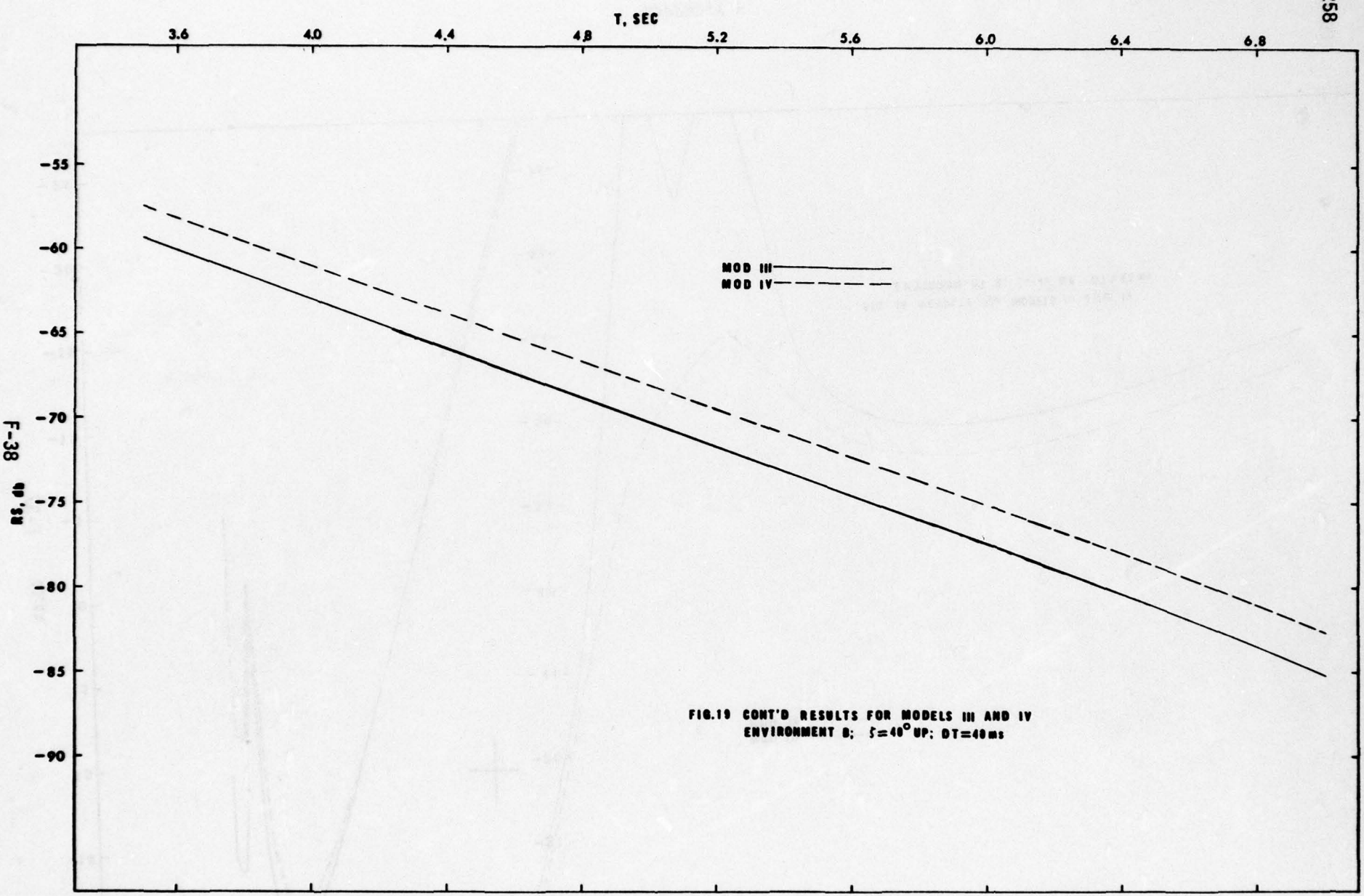


FIG.19 CONT'D RESULTS FOR MODELS III AND IV
ENVIRONMENT B; $\zeta = 40^\circ$ UP; DT=40 ms

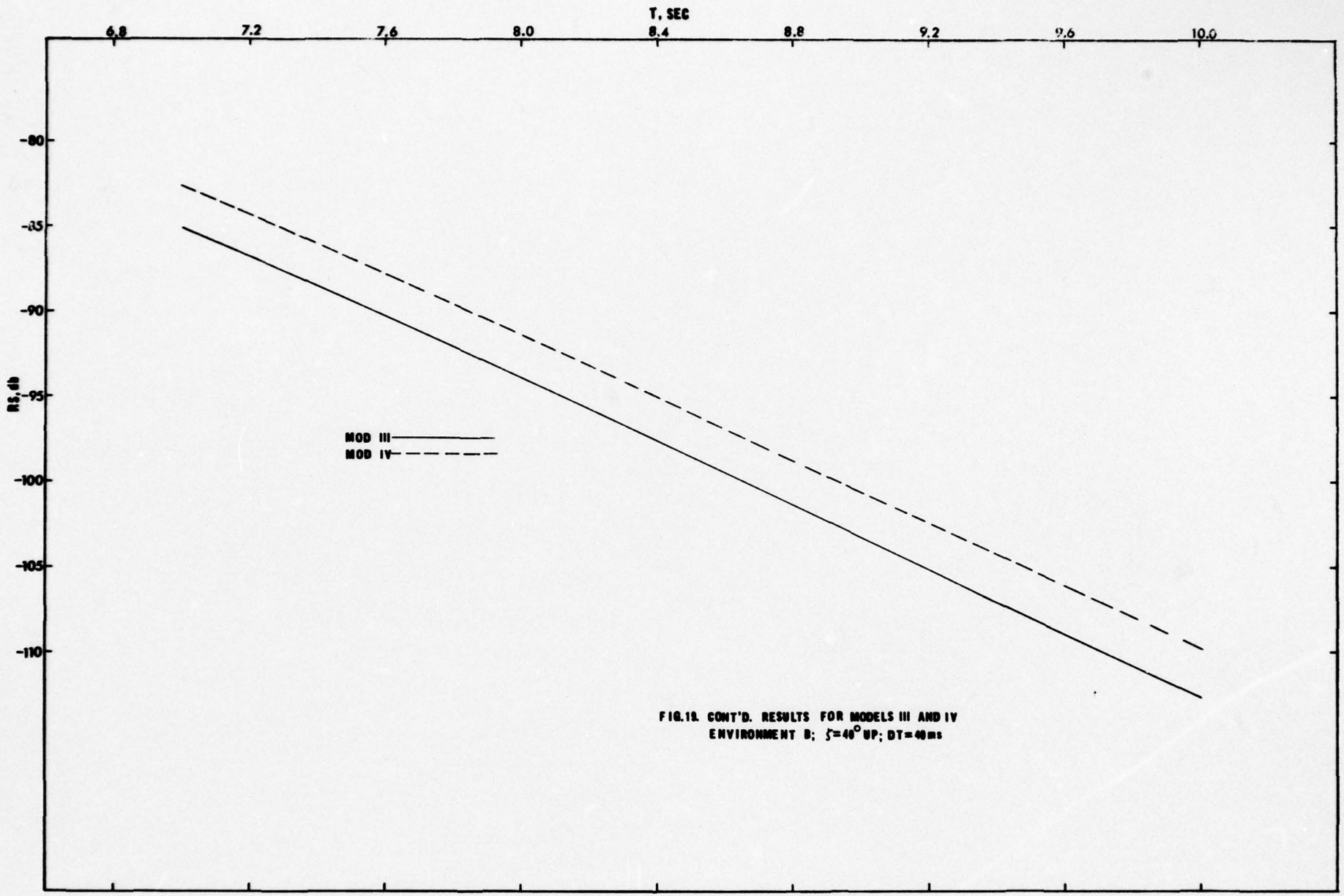


FIG.19. CONT'D. RESULTS FOR MODELS III AND IV
ENVIRONMENT B; ζ=40° UP; DT=40 ms

APPENDIX G

Following are listings for the DOP program as used for the test problem whose output is illustrated in Figures 3-1 to 3-3. There is no subroutine, SPRCMP and the sample OXL, RRF, and TVGF were created for illustrative purposes only.

Patterns from the listed OXL are illustrated in Figures G-1 thru G-3. They are all radially symmetrical about their axes.

OD 52258

HORIZONTAL, BROAD, STRAIGHT

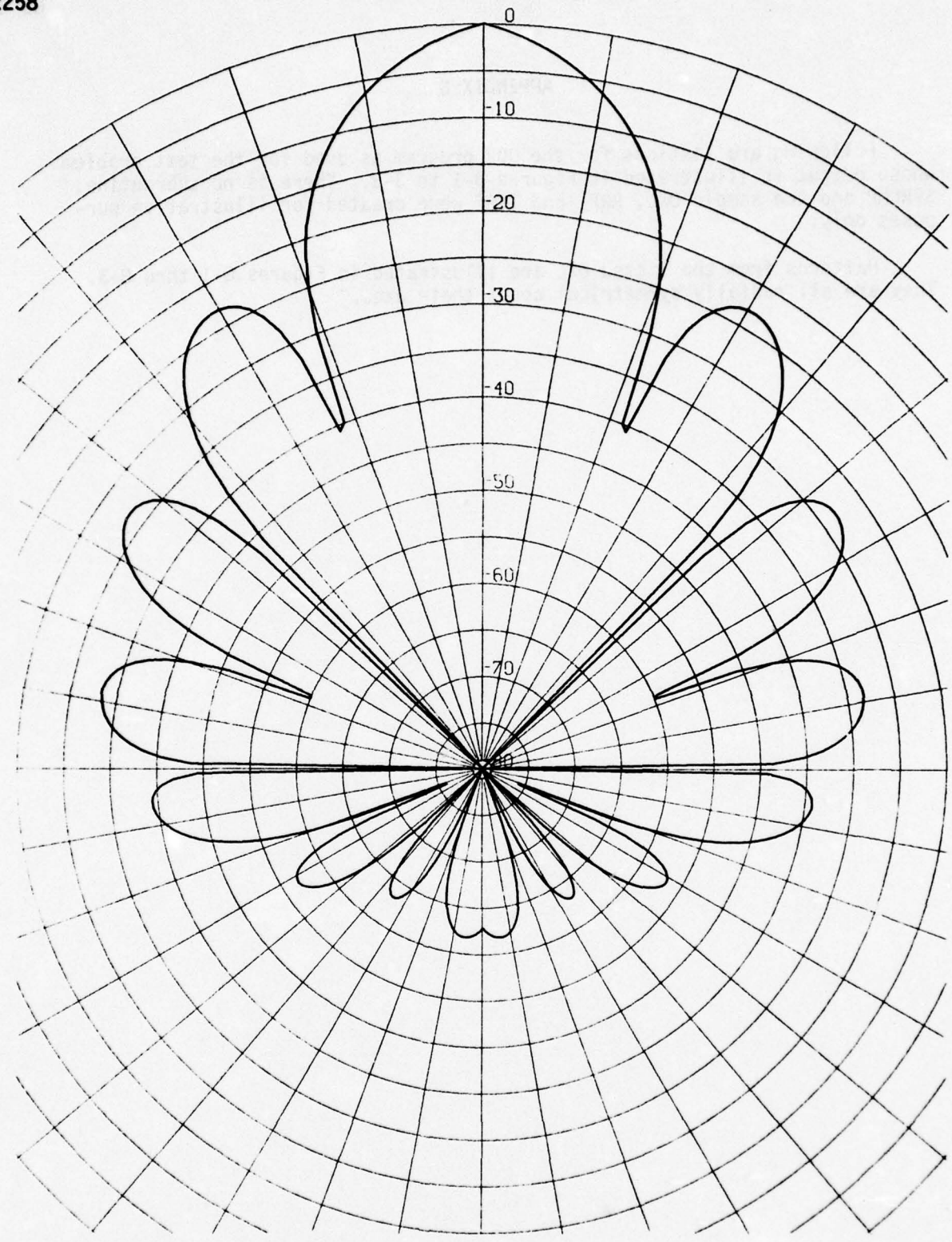
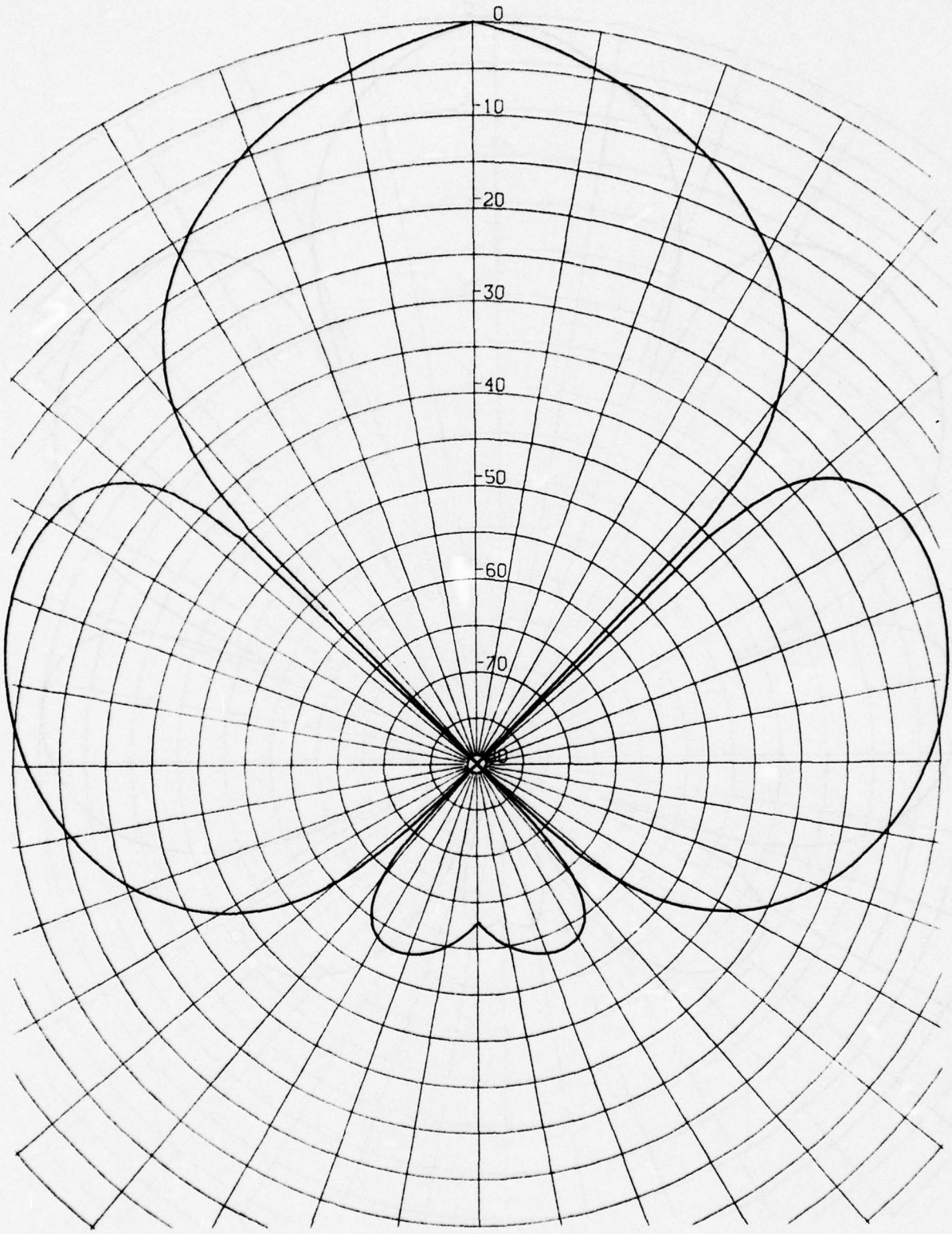


FIGURE G-2

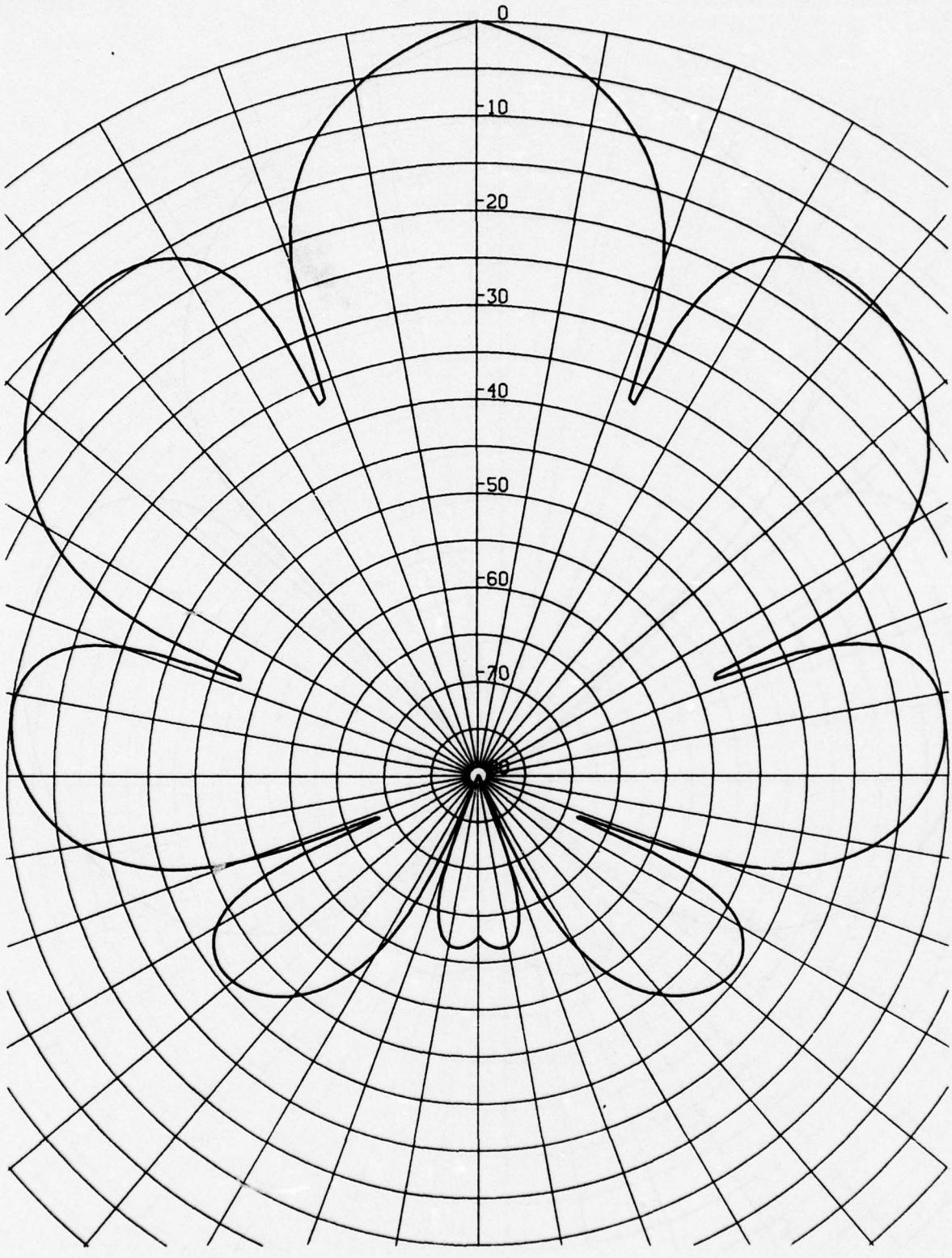
APPENDIX G



AXIAL COORDINATE PLANES

FIGURE G-2

HORIZONTAL RECEIVE



AXIAL COORDINATE PLANES

FIGURE G-1

APPENDIX G

PROCEDURES FOR DOP

```
      DCOMN1  PROC                                                          DCOMN 1
              COMMON /CBAND/  LMBAND,LMBND1,NBAND,MBAND,MNBND,FNBAND,VPTTRN DCOMN 2
      C                        800  , 801                                  DCOMN 3
      C                                                                     DCOMN 4
              COMMON /CBAND/  BAND(801),RRFS(800),FGAM(800),BNDOUT(801)     DCOMN 5
      C                       (LMBND1) ,(LMBAND) ,(LMBAND),(LMBND1)         DCOMN 6
      C                                                                     DCOMN 7
              COMMON /CCOUNT/ LMRB,LMTRS,LMKS,LMKS2,NSURF,NBTM,KT,KTT       DCOMN 8
      C                       9612, 17  , 400, 800                          DCOMN 9
      C                                                                     DCOMN10
              COMMON /CFCNST/ TRS(6),FPTS,TRS2(4),F1,TRS3(4),F2,F4,F10,F20  DCOMN11
      C                      (            LMTRS            )              DCOMN12
      C                                                                     DCOMN13
              COMMON /CFCNST/ FLOG10,INFNT,PI23,PI,TWOPI,DEGRAD,SHIFT,VDKT,F1E3 DCOMN14
              COMMON /CFCNST/ LOG4PI,F1MIN,F3,F90,F180                      DCOMN15
              COMMON /CHCNST/ HBAND(3),HUNIT(2),HSPRD(5),HSPRV(5),HFROR(2)  DCOMN16
              COMMON /CHCNST/ HEADS(41),HTOT1(4),HTOT2(3),HTOT3(3),HED(9)   DCOMN17
              COMMON /CINDAT/ OMEGA,DELT,CSKSI,SNKSI,KSID,DR,FCOVS,COKT     DCOMN18
              COMMON /CINDAT/ EXPS,FZSQ,FZ2,FC03,BWINT,LOGMVI               DCOMN19
      C                                                                     DCOMN20
              COMMON /CINDEF/ NNAMES,NAMDAT(40,3),NAMCNT(24)                DCOMN21
              COMMON /CINDEF/ CENTER,GO,END,FILTER,KTSBND,NOBTTM,NOPRNT     DCOMN22
              COMMON /CINDEF/ NOSURF,NOTAPE,NOVOLM,PLOT,SPREAD,TIMCMP,TOTALS,TVGDCOMN23
              COMMON /CINDEF/ RELBND                                        DCOMN24
      C                                                                     DCOMN25
              COMMON /CINPUT/ IDC,IDATE(2),IDV,DO                           DCOMN26
              COMMON /CINPUT/ CO,ALPHC,PING,DRTTM,LOGMV,S,KSI               DCOMN27
              COMMON /CINPUT/ VS,BWIDTH,DELT2,FZRO,NBEAM,OMEGAD,THTMAX      DCOMN28
              COMMON /CINPUT/ PULSE,IPEVRY                                  DCOMN29
              COMMON /CINPUT/ TIME(400),SPRED(150,3)                        DCOMN30
      C                         (LMTIM)     (LMSPRD)                      DCOMN31
      C                                                                     DCOMN32
              COMMON /CPRINT/ NTMIN,NTMAX,PAGE,NPAGE,NPSTRT                 DCOMN33
              COMMON /CSPRED/ NSPR1,NSPRH,NSPRH1                            DCOMN34
              COMMON /CTAPE/  AR1,BR1,INPT,IPRT,IPLT                        DCOMN35
              COMMON /CTBLKP/ DELIND,DELDEP,FACTOR,ITABLE                   DCOMN36
              COMMON /CXCNST/ K0,K1,K2,K3,K5,K6,K8,K10,K40                  DCOMN37
              DIMENSION       NBOUND(2)                                     DCOMN38
              DIMENSION       NOUTPT(14)                                    DCOMN39
              DIMENSION       IDATA(1)                                      DCOMN40
              DIMENSION       LFLAGS(16)                                    DCOMN41
      C                                                                     DCOMN42
              EQUIVALENCE     (K0,F0,RECV),(K1,XMIT),(K3,LMNT)              DCOMN43
              EQUIVALENCE     (NSURF,NBOUND)                                DCOMN44
              EQUIVALENCE     (IBLANK,HEADS(16)),(HUNIT,HOUTPT)             DCOMN45
              EQUIVALENCE     (IFZRO,FZRO),(IDC,IDATA)                      DCOMN46
              EQUIVALENCE     (LMTIM,NAMDAT(21,3)),(NTIME,NAMCNT(21))       DCOMN47
              EQUIVALENCE     (LMSPRD,NAMDAT(22,3)),(LFLAGS,CENTER)         DCOMN48
              EQUIVALENCE     (NSSPRD,NAMCNT(22)),(NBSPRD,NAMCNT(23))       DCOMN49
              EQUIVALENCE     (NVSPRD,NAMCNT(24))                           DCOMN50
      C                                                                     DCOMN51
              REAL            INFNT,KSI,KSID,LOGMV,LOG4PI,LOGMVI            DCOMN52
              INTEGER         AR1,BR1,PAGE                                  DCOMN53
              LOGICAL         CENTER,GO,END,FILTER,KTSBND,NOBTTM,NOPRNT     DCOMN54
              LOGICAL         NOSURF,NOTAPE,NOVOLM,PLOT,SPREAD,TIMCMP,TOTALS,TVGDCOMN55
              LOGICAL         RELBND,VPTTRN,LFLAGS                          DCOMN56
       END                                                                  DCOMN57
      DCOMN2  PROC                                                          DCOMN58
              COMMON          RVS(3,801),RVB(3,801),RVV(3,801),RVT(3,801)   DCOMN59
      C                      (              (LMNT,LMBND1)                 ) DCOMN60
              DIMENSION       REVERB(9612),RV(3,801,3)                      DCOMN61
      C                             (LMRB),(LMNT,LMBND1,3)                  DCOMN62
      C                                                                     DCOMN63
              EQUIVALENCE     (REVERB(1),RVS(1,1),RV(1,1,1))                DCOMN64
       END                                                                  DCOMN65
      DCOMN3  PROC                                                          DCOMN66
              COMMON          XMIN(400),TMIN(400)                           DCOMN67
              COMMON          RRX(400),RBT(400),RBTH(400),RBH(400)          DCOMN68
      C                 ( LMKS = MAX. NO. OF RAYS SORTED BY 'RAYSRT')       DCOMN69
       END                                                                  DCOMN70
```

```
  71    DCOMN4  PROC                                                    DCOMMN71
  72            COMMON          FCSGAM(801)                           DCOMMN72
  73    C                          (LMBND1)                           DCOMMN73
  74     END                                                           DCOMMN74
  75    DCOMN5  PROC                                                  DCOMMN75
  76            COMMON          X(800),Y(800),THA(800),THB(800),R(800),DOP(800)  DCOMMN76
  77            COMMON          COSTHA(800),COSTHB(800)               DCOMMN77
  78            COMMON          OMT(800),COSOMT(800),SINOMT(800)      DCOMMN78
  79    C                      (                    LMKS2             )  DCOMMN79
  80    C                                                             DCOMMN80
  81            COMMON          RBXA(400),RBTA(400),RBTHA(400),RBHA(400)  DCOMMN81
  82            DIMENSION       RBXB(400),RBTB(400),RBTHB(400),RBHB(400)  DCOMMN82
  83    C                      (                 (LMKS)               )  DCOMMN83
  84    C                                                             DCOMMN84
  85            EQUIVALENCE     (RBXB,DOP)                            DCOMMN85
  86            EQUIVALENCE     (RBTB,Y(400)),(RBTHB,THB(400)),(RBHB,R(400))  DCOMMN86
  87    C                      (                 (LMKS)               )  DCOMMN87
  88    C                                                             DCOMMN88
  89     END                                                          DCOMMN89
  90    DCOMN6  PROC                                                  DCOMMN90
  91            DATA            LMBAND/800/,LMBND1/801/,LMKS/400/,LMKS2/800/  DCOMMN91
  92            DATA            LMRB/9612/,LMTIM/400/,LMTRS/17/,LMSPRD/150/  DCOMMN92
  93    C                                                             DCOMMN93
  94    C                       LMRB = 4 * LMNT * LMBND1              DCOMMN94
  95    C                       LMBND1 = LMBAND + 1                   DCOMMN95
  96    C                       LMKS2 = LMKS * 2                      DCOMMN96
  97    C                       LMNT = 3                              DCOMMN97
  98     END                                                          DCOMMN98
```

APPENDIX G

I N D E X PAGE 3

PROCEDURES FOR DOP

SYMBOL	REFERENCES				
ALPHC -	27C0				
AR1 -	35C0	53IN			
BAND -	5C0				
BNDOUT -	5C0				
BR1 -	35C0	53IN			
BWIDTH -	28C0				
BWINT -	19C0				
CO -	27C0				
COKT -	18C0				
CBAND -	2CL	5CL			
CCOUNT -	8CL				
CENTER -	22C0	48EQ	54LG		
CFCNST -	11CL	14CL	15CL		
CHCNST -	16CL	17CL			
CINDAT -	18CL	19CL			
CINDEF -	21CL	22CL	23CL	24CL	
CINPUT -	26CL	27CL	28CL	29CL	30CL
COSORT -	78C0				
COSTNA -	77C0				
COSTND -	77C0				
CPRINT -	33CL				
CSKSI -	18C0				
CSPRED -	34CL				
CTAPE -	35CL				
CTBLKP -	36CL				
CXCNST -	37CL				
D0 -	26C0				
DBTTR -	27C0				
DCONN1 -	1				
DCONN2 -	58				
DCONN3 -	66				
DCONN4 -	71				
DCONN5 -	75				
DCONN6 -	90				
DEGRAD -	14C0				
DELDEP -	36C0				
DELIND -	36C0				
DELT -	18C0				
DELT2 -	28C0				
DOP -	76C0	85EQ			
DR -	18C0				
END -	22C0	54LG			
EXPS -	19C0				
F0 -	43EQ				
F1 -	11C0				
F10 -	11C0				
F180 -	15C0				
F1E3 -	14C0				
F1MIN -	15C0				
F2 -	11C0				
F20 -	11C0				
F3 -	15C0				
F4 -	11C0				
F90 -	15C0				
FACTOR -	36C0				
FC03 -	19C0				
FCOVS -	18C0				
FCSGAM -	72C0				
FGAM -	5C0				
FILTER -	22C0	54LG			
FLOG10 -	14C0				
FNBAND -	2C0				
FPTS -	11C0				
FZ2 -	19C0				
FZRO -	28C0	46EQ			
FZSQ -	19C0				
GO -	22C0	54LG			
HBAND -	16C0				

APPENDIX G

HEADS	-	17C0	45E0		
HED	-	17C0			
HFROP	-	16C0			
HOUTPT	-	39D1	45E0		
HSPRD	-	1600			
HSPRW	-	1600			
HTOT1	-	1700			
HTOT2	-	1700			
HTOT3	-	1700			
HUNIT	-	1600	45E0		
IBLANK	-	45E0			
IDATA	-	40D1	46E0		
IDATE	-	26C0			
IDC	-	26C0	46E0		
IDV	-	26C0			
IFZRO	-	46E0			
INFNT	-	14C0	52RL		
INPT	-	35C0			
IPEVRY	-	29C0			
IPLT	-	35C0			
IPRT	-	35C0			
ITABLE	-	36C0			
K0	-	37C0	43E0		
K1	-	37C0	43E0		
K10	-	37C0			
K2	-	37C0			
K3	-	37C0	43E0		
K40	-	37C0			
K5	-	37C0			
K6	-	37C0			
K8	-	37C0			
KSI	-	27C0	52RL		
KSID	-	18C0	52RL		
KT	-	8C0			
KTSBND	-	22C0	54L6		
KTT	-	8C0			
LFLAGS	-	41D1	48E0	56L6	
LMBAND	-	2C0	91DA		
LMBND1	-	2C0	91DA		
LMKS	-	8C0	91DA		
LMKS2	-	8C0	91DA		
LMNT	-	43E0			
LMRD	-	8C0	92DA		
LMSPRD	-	48E0	92DA		
LMTIM	-	47E0	92DA		
LMTRS	-	8C0	92DA		
LOG4PI	-	15C0	52RL		
LOGMV	-	27C0	52RL		
LOGMVI	-	19C0	52RL		
MBAND	-	2C0			
MNBND	-	2C0			
NAMCNT	-	21C0	47E0	49E0	50E0
NAMDAT	-	21C0	47E0	48E0	
NBAND	-	2C0			
NBEAM	-	28C0			
NBOUND	-	38D1	44E0		
NBSPRD	-	49E0			
NBTM	-	8C0			
NNAMES	-	21C0			
NOBTTM	-	22C0	54L6		
NOPRNT	-	22C0	54L6		
NOSURF	-	23C0	55L6		
NOTAPE	-	23C0	55L6		
NOVOLM	-	23C0	55L6		
NPAGE	-	33C0			
NPSTRT	-	33C0			
NSPR1	-	34C0			
NSPRM	-	34C0			
NSPRM1	-	34C0			
NSSPRD	-	49E0			

NSURF - 8C0 44E0
NTIME - 47E0
NTMAX - 33C0
NTMIN - 33C0
NVSPRD - 50E0
OMEGA - 18C0
OMEGAD - 28C0
OMT - 78C0
PAGE - 33C0 53IN
PI - 14C0
PI23 - 14C0
PING - 27C0
PLOT - 23C0 55L6
PULSE - 29C0
R - 76C0 86E0
RBN - 68C0
RBNA - 81C0
RBND - 82D1 86E0
RBT - 68C0
RBTA - 81C0
RBTB - 82D1 86E0
RBTN - 68C0
RBTNA - 81C0
RBTND - 82D1 86E0
RBX - 68C0
RBXA - 81C0
RBXD - 82D1 85E0
RECV - 43E0
RELBND - 24C0 56L6
REVERD - 61D1 64E0
RRFS - 5C0
RV - 61D1 64E0
RVB - 59C0
RVS - 59C0 64E0
RVT - 59C0
RVV - 59C0
S - 27CC
SHIFT - 14C0
SINOMT - 78C0
SNKSI - 18C0
SPREAD - 23C0 55L6
SPRED - 30C0
T - 76C0 86E0
TNA - 76C0
TND - 76C0 86E0
TNTMAX - 28C0
TIMCMP - 23C0 55L6
TIME - 30C0
TMIN - 67C0
TOTALS - 23C0 55L6
TRS - 11C0
TRS2 - 11C0
TRS3 - 11C0
TVG - 23C0 55L6
TWOPI - 14C0
VPTTRN - 2C0 56L6
VS - 28C0
X - 76C0
XMIN - 67C0
XMIT - 43E0
YDRT - 14C0

PROGRAM DOP

```
      1           INCLUDE DCOMN1                                          DOP    1
      2           INCLUDE DCOMN2                                          DOP    2
      3     C                                                             DOP    3
      4     C        READ AND PROCESS INPUT, CARDS AND TAPE.              DOP    4
      5     C                                                             DOP    5
      6      9000 CALL IDENT                                              DOP    6
      7           IF (END) GO TO 20000                                    DOP    7
      8     C                                                             DOP    8
      9     C        SET UP BAND LIMITS.                                  DOP    9
     10     C                                                             DOP   10
     11           CALL BCOMP                                              DOP   11
     12     C                                                             DOP   12
     13     C        EXTRACT SURFACE AND/OR BOTTOM DATA FROM INPUT TAPE, AND  DOP  13
     14     C        ARRANGE PROPERLY FOR DOP.  WRITE ON TEMPORARY FILE.  DOP   14
     15     C                                                             DOP   15
     16           CALL RBSORT                                             DOP   16
     17     C                                                             DOP   17
     18     C        PROCESS TABLE OF REVERBERATION TIMES AS NECESSARY.   DOP   18
     19     C                                                             DOP   19
     20           CALL TCOMP                                              DOP   20
     21     C                                                             DOP   21
     22           NTMAX = 0                                               DOP   22
     23     C                                                             DOP   23
     24     C        COMPUTE REVERBERATION FOR EACH TIME IN TABLE.        DOP   24
     25     C                                                             DOP   25
     26     10000 NTMIN = NTMAX + K1                                      DOP   26
     27           NTMAX = MIND(NTMAX + LMNT, NTIME)                       DOP   27
     28           IF (SPREAD) NTMAX = NTMIN                               DOP   28
     29     C                                                             DOP   29
     30     C        ZERO OUT REVERBERATION TABLE.                        DOP   30
     31     C                                                             DOP   31
     32           DO 10010 KT = 1, LMRB                                   DOP   32
     33           REVERB(KT) = 0.                                         DOP   33
     34     10010 CONTINUE                                                DOP   34
     35     C                                                             DOP   35
     36     C        COMPUTE A PAGE FULL--THREE TIMES OR ONE TIME WITH SPREADING.  DOP  36
     37     C                                                             DOP   37
     38           DO 15000 KT = NTMIN, NTMAX                              DOP   38
     39           KTT = KT + K1 - NTMIN                                   DOP   39
     40     C                                                             DOP   40
     41     C        COMPUTE BOUNDARY AND VOLUME REVERB. AND SPREAD AS REQUIRED.  DOP  41
     42     C        COMPUTE TOTALS.                                      DOP   42
     43     C                                                             DOP   43
     44           IF (.NOT. NOTAPE) CALL RBCOMP                           DOP   44
     45           IF (.NOT. NOVOLM) CALL RVCOMP                           DOP   45
     46           IF (SPREAD) CALL RVSPRD                                 DOP   46
     47           CALL RTCOMP                                             DOP   47
     48     15000 CONTINUE                                                DOP   48
     49     C                                                             DOP   49
     50     C        PRINT REVERBERATION DATA.                            DOP   50
     51           CALL RVPRNT                                             DOP   51
     52     C                                                             DOP   52
     53     C                                                             DOP   53
     54           IF (NTMAX .LT. NTIME) GO TO 10000                       DOP   54
     55           GO TO 9000                                              DOP   55
     56     C                                                             DOP   56
     57     C        REWIND TAPES AS REQUIRED, AND EXIT.                  DOP   57
     58     C                                                             DOP   58
     59     20000 IF (NOTAPE) GO TO 20010                                 DOP   59
     60           REWIND AR1                                              DOP   60
     61           REWIND BR1                                              DOP   61
     62     20010 IF (PLOT) REWIND IPLT                                   DOP   62
     63     30000 STOP                                                    DOP   63
     64           END                                                     DOP   64
```

I N D E X

PROGRAM DOP

SYMBOL		REFERENCES					
9000	-	6*	55				
10000	-	26*	54				
10010	-	32	34*				
15000	-	38	48*				
20000	-	7	59*				
20010	-	59	62*				
30000	-	63*					
AR1	-	60					
BCOMP	-	11					
BR1	-	61					
BCONN1	-	1					
BCONN2	-	2					
END	-	7					
IDENT	-	6					
IPLT	-	62					
K1	-	26	39				
KT	-	32=	33	38=	39		
KTT	-	39=					
LANT	-	27					
LARB	-	32					
MINO	-	27					
NOTAPE	-	44	59				
NOVOLM	-	45					
NTIME	-	27	54				
NTMAX	-	22=	26	27=	28=	38	54
NTMIN	-	26=	28	38	39		
PLOT	-	62					
RBCOMP	-	44					
RBSORT	-	16					
REVERB	-	33=					
RTCOMP	-	47					
RVCOMP	-	45					
RVPRNT	-	51					
RVSPRD	-	46					
SPREAD	-	28	46				
STOP	-	63					
TCOMP	-	2U					
1MAIN	-	0					

```
      1          SUBROUTINE IDENT                                          IDENT  1
      2     C                                                              IDENT  2
      3          INCLUDE DCOMN1                                            IDENT  3
      4          COMMON ID(12),I,J,K,L,M                                   IDENT  4
      5          LOGICAL OUTFLG                                            IDENT  5
      6          DATA INPFLG/0/,OUTFLG/.TRUE./                             IDENT  6
      7     C                                                              IDENT  7
      8     C         WRITE HEADING ON INPUT DATA PAGE.                    IDENT  8
      9     C                                                              IDENT  9
     10          WRITE (IPRT,501) HED                                      IDENT 10
     11        501 FORMAT (8A6,A4,16H-- INPUT DATA --/)                    IDENT 11
     12     C                                                              IDENT 12
     13     C         READ NEXT VARIABLE NAME AND RELATED DATA FROM DATA CARD(S).  IDENT 13
     14     C                                                              IDENT 14
     15        600 CALL INPUT(NNAMES,IDC,INPFLG,OUTFLG)                    IDENT 15
     16          IF (GO) GO TO 700                                         IDENT 16
     17          IF (END) GO TO 900                                        IDENT 17
     18          IF (INPFLG .GT. 1) END = .TRUE.                           IDENT 18
     19          GO TO 600                                                 IDENT 19
     20        700 GO = .FALSE.                                            IDENT 20
     21          IF (NOTAPE) GO TO 2000                                    IDENT 21
     22     C                                                              IDENT 22
     23     C         READ FIRST HEADER RECORD FROM INPUT TAPE.            IDENT 23
     24     C                                                              IDENT 24
     25          READ (AR1) (ID(I), I = 1, 6)                              IDENT 25
     26          IF (ID(6) .NE. 0) GO TO 1000                              IDENT 26
     27     C                                                              IDENT 27
     28          END = .TRUE.                                              IDENT 28
     29        900 WRITE (IPRT,901)                                        IDENT 29
     30        901 FORMAT (69X,18H*** END OF RUN ***)                      IDENT 30
     31          GO TO 30000                                               IDENT 31
     32     C                                                              IDENT 32
     33     C         READ SECOND HEADER RECORD.  PRESERVE ANY DATA FROM INPUT  IDENT 33
     34     C         TAPE WHICH HAS NOT BEEN READ IN FROM CARDS.          IDENT 34
     35     C                                                              IDENT 35
     36       1000 READ (AR1) (ID(I), I = 6, 12)                           IDENT 36
     37          DO 1500 I = 1, 12                                         IDENT 37
     38          J = I                                                     IDENT 38
     39          IF (J .GT. K2) J = J - K1                                 IDENT 39
     40          IF (NAMCNT(J) .EQ. 0) GO TO 1200                          IDENT 40
     41          IF (J .NE. 11) GO TO 1500                                 IDENT 41
     42          KSI = KSI * DEGRAD                                        IDENT 42
     43          GO TO 1500                                                IDENT 43
     44       1200 IDATA(I) = ID(I)                                        IDENT 44
     45       1500 CONTINUE                                                IDENT 45
     46     C                                                              IDENT 46
     47     C         SCALE INPUT DATA AND PRECOMPUTE RELATED QUANTITIES.  IDENT 47
     48     C                                                              IDENT 48
     49       2000 OMEGA = OMEGAD * DEGRAD                                 IDENT 49
     50          DELT = DELT2/F2                                           IDENT 50
     51          KSID = KSI/DEGRAD                                         IDENT 51
     52          BWINT = BWIDTH                                            IDENT 52
     53          IF (.NOT. KTSBND) BWINT = BWINT/F1E3                      IDENT 53
     54          LOGRVI = LOGRV - LOG4PI                                   IDENT 54
     55          CSKSI = COS(KSI)                                          IDENT 55
     56          SNKSI = SIN(KSI)                                          IDENT 56
     57          DR = DELT2 * CO/F4                                        IDENT 57
     58          COKT = CO * VDKT                                          IDENT 58
     59          FCOVS = COKT/VS                                           IDENT 59
     60          FCO3 = CO**3 * TWOPI                                      IDENT 60
     61          IF (FZRO .LE. 0.) FZRO = F1                               IDENT 61
     62          FZSQ = FZRO**2                                            IDENT 62
     63          FZ2 = FZRO * F2                                           IDENT 63
     64          EXPS = EXP(S/F10 * FLOG10)                                IDENT 64
     65          IF (THTMAX .EQ. 0.) THTMAX = F90                          IDENT 65
     66          IF (THTMAX .GT. F180) THTMAX = F180                       IDENT 66
     67     C                                                              IDENT 67
     68          NSPRM1 = K1                                               IDENT 68
     69          SPREAD = SPREAD .OR. (NSSPRD.NE.0) .OR. (NBSPRD.NE.0) .OR.  IDENT 69
     70         1    (NVSPRD.NE.0)                                         IDENT 70
```

SUBROUTINE IDENT

```
                IF (.NOT. SPREAD) GO TO 5010                                    IDENT 71
C                                                                               IDENT 72
C                  GENERATE ANY REQUIRED MISSING SPREADING TABLES.              IDENT 73
C                                                                               IDENT 74
                IF ((NSSPRD .EQ. 0) .OR. (NBSPRD .EQ.0) .OR. (NVSPRD .EQ. 0))   IDENT 75
               1    CALL SPRCMP                                                 IDENT 76
                NSPRM1 = MAX0(NSSPRD,NBSPRD,NVSPRD)                             IDENT 77
C                                                                               IDENT 78
 5010           NSPRM = NSPRM1 - K1                                             IDENT 79
                NSPR1 = NSPRM + NSPRM1                                          IDENT 80
                IF (NOPRNT) GO TO 7010                                          IDENT 81
C                                                                               IDENT 82
C                  SET UP APPROPRIATE PAGE HEADINGS.                            IDENT 83
C                                                                               IDENT 84
                K = 0                                                           IDENT 85
                J = K5                                                          IDENT 86
                IF (.NOT.SPREAD) GO TO 6020                                     IDENT 87
                J = 0                                                           IDENT 88
                IF (TVG) K = K10                                                IDENT 89
                IF (FILTER) K = K + K5                                          IDENT 90
 6020           M = K1                                                          IDENT 91
                L = K1                                                          IDENT 92
                IF (KTSBND) L = 0                                               IDENT 93
                IF (.NOT. TOTALS) GO TO 6030                                    IDENT 94
                NTOT3(1) = HEADS(L+36)                                          IDENT 95
                L = K3                                                          IDENT 96
                M = K3                                                          IDENT 97
C                                                                               IDENT 98
 6030           L = L + K5                                                      IDENT 99
                DO 6040 I = K1, K5                                              IDENT100
                L = L + K1                                                      IDENT101
                NBAND(I) = HEADS(L)                                             IDENT102
                J = J + K1                                                      IDENT103
                NSPRD(I) = HEADS(J+10)                                          IDENT104
                K = K + K1                                                      IDENT105
                NSPRV(I) = HEADS(K+15)                                          IDENT106
 6040           CONTINUE                                                        IDENT107
                NFROM(1) = HEADS(M+37)                                          IDENT108
                NFROM(2) = HEADS(M+38)                                          IDENT109
 7010           IF (.NOT. NOTAPE) REWIND BR1                                    IDENT110
30000           RETURN                                                          IDENT111
                END                                                             IDENT112
```

APPENDIX G

I N D E X SUBROUTINE IDENT

SYMBOL REFERENCES

501 - 10WR 11*
600 - 15* 19
700 - 16 20*
900 - 17 29*
901 - 29WR 30*
1000 - 26 36*
1200 - 40 44*
1500 - 37 41 43 45*
2000 - 21 49*
5010 - 71 79*
6020 - 87 91*
6030 - 94 99*
6040 - 100 107*
7010 - 81 110*
30000 - 31 111*
AR1 - 25RD 36RD
BR1 - 110
BWIDTH - 52
BWINT - 52= 53=
CO - 57 58 60
COKT - 58= 59
COS - 55
CSKS1 - 55=
DCOMN1 - 3
DEGRAD - 42 49 51
DELT - 50=
DELT2 - 50 57
DR - 57=
END - 17 18= 28=
EXP - 64
EXPS - 64=
F1 - 61
F10 - 64
F180 - 66
F1E3 - 53
F2 - 50 63
F4 - 57
F90 - 65
FCO3 - 60=
FCOVS - 59=
FILTER - 90
FLOG10 - 64
FZ2 - 63=
FZRO - 61= 62 63
FZSQ - 62=
GO - 16 20=
HBAND - 102=
HEADS - 95 102 104 106 108 109
HED - 10WR
HFROM - 108= 109=
HSPRD - 104=
HSPRW - 106=
HTOT3 - 95=
I - 4CO 25RD 36RD 37= 38 44 100= 102 104 106
ID - 4CO 25RD 26 36RD 44
IDATA - 44=
IDC - 15A6
IDENT - 1
INPFLG - 6DA 15A6 18
INPUT - 15
IPRT - 10WR 29WR
J - 4CO 38= 39= 40 41 86= 88= 103= 104
K - 4CO 85= 89= 90= 105= 106
K1 - 39 68 79 91 92 100 101 103 105
K10 - 89
K2 - 39
K3 - 96 97
K5 - 86 90 99 100

KSI	-	42=	51	55	56				
KSID	-	51=							
KTSBND	-	53	93						
L	-	400	92=	93=	95	96=	99=	101=	102
LOG4PI	-	54							
LOGRV	-	54							
LOGRVI	-	54=							
R	-	400	91=	97=	108	109			
RATIO	-	77							
RARCNT	-	40							
RBSPRD	-	69	75	77					
RNARES	-	15A6							
ROPRNT	-	81							
ROTAPE	-	21	110						
RSPR1	-	80=							
RSPRN	-	79=	80						
RSPRN1	-	68=	77=	79	80				
RSSPRD	-	69	75	77					
RVSPRD	-	70	75	77					
OMEGA	-	49=							
OMEGAD	-	49							
OUTFLG	-	5L6	6DA	15A6					
RETURN	-	111							
S	-	64							
SIN	-	56							
SNKSI	-	56=							
SPRCMP	-	76							
SPREAD	-	69=	71	87					
TNTMAX	-	65=	66=						
TOTALS	-	94							
TVG	-	89							
TWOPI	-	60							
VS	-	59							
VSKT	-	58							

I N D E X PAGE 12

```
      1          SUBROUTINE BCOMP                                                    BCOMP  1
      2      C                                                                       BCOMP  2
      3          INCLUDE BCOMN1                                                      BCOMP  3
      4          COMMON B,BND(3),CNT(3),D,E,F,I,L,Q,                                 BCOMP  4
      5      C                                                                       BCOMP  5
      6          BND(3) = COS(TNTMAX * DEGRAD) * VS                                  BCOMP  6
      7          IF (TNTMAX .EQ. F90) BND(3) = 0.                                    BCOMP  7
      8          IF (TNTMAX .EQ. F180) BND(3) = -VS                                  BCOMP  8
      9          IF (KTSBND) GO TO 1000                                              BCOMP  9
     10      C                                                                       BCOMP 10
     11      C        OUTPUT BAND LIMITS IN KILOHERZ.                                BCOMP 11
     12      C                                                                       BCOMP 12
     13          Q = (COKT + VS)/(COKT - VS)                                         BCOMP 13
     14          BND(1) = FZRO * Q - FZRO                                            BCOMP 14
     15          B = FZRO                                                            BCOMP 15
     16          BND(2) = FZRO - FZRO/Q                                              BCOMP 16
     17          D = FZRO                                                            BCOMP 17
     18          BND(3) = (COKT + BND(3))/(COKT - BND(3)) * FZRO - FZRO              BCOMP 18
     19          GO TO 2000                                                          BCOMP 19
     20      C                                                                       BCOMP 20
     21      C        OUTPUT BAND LIMITS IN KNOTS OF DOPPLER.                        BCOMP 21
     22      C                                                                       BCOMP 22
     23     1000 BND(1) = VS                                                         BCOMP 23
     24          B = 0.                                                              BCOMP 24
     25          BND(2) = VS                                                         BCOMP 25
     26          D = VS                                                              BCOMP 26
     27      C                                                                       BCOMP 27
     28     2000 E = 0.                                                              BCOMP 28
     29          IF (CENTER) E = BWINT * FPT5                                        BCOMP 29
     30          B = B + E                                                           BCOMP 30
     31          IF (.NOT. RELBND) B = 0.                                            BCOMP 31
     32      C                                                                       BCOMP 32
     33      C        COMPUTE NO. OF BANDS WITH POSITIVE AND NEGATIVE DOPPLER,       BCOMP 33
     34      C        ALSO BAND LIMIT DUE TO THETA MAX.                              BCOMP 34
     35      C                                                                       BCOMP 35
     36          DO 2500 I = 1, 3                                                    BCOMP 36
     37          CNT(I) = ABS(AINT(BND(I)/BWINT))                                    BCOMP 37
     38          IF (CNT(I) * BWINT + E .LT. ABS(BND(I))) CNT(I) = CNT(I) + F1       BCOMP 38
     39          IF (CENTER) CNT(I) = CNT(I) + FPT5                                  BCOMP 39
     40     2500 CONTINUE                                                            BCOMP 40
     41          CNT(3) = SIGN(CNT(3),BND(3))                                        BCOMP 41
     42          IF (BND(3) .GT. 0.) CNT(3) = CNT(3) - F1                            BCOMP 42
     43      C                                                                       BCOMP 43
     44      C        NBAND = THEORETICAL NUMBER OF UNSPREAD BANDS.                  BCOMP 44
     45      C        NBAND - NSPRN = NO. OF UNSPREAD BANDS TO BE COMPUTED.          BCOMP 45
     46      C        NNBAND = NO. OF BANDS TO BE OUTPUT, INCLUDING SPREADING.       BCOMP 46
     47      C        NPSTRT = FIRST BAND TO BE PRINTED.                             BCOMP 47
     48      C                                                                       BCOMP 48
     49          FNBAND = CNT(1) + CNT(2)                                            BCOMP 49
     50          NBAND = FNBAND                                                      BCOMP 50
     51          NBAND = MIN0(LMBAND,NBAND + NSPRN,IFIX(CNT(1) - CNT(3)) + NSPRN)    BCOMP 51
     52          NNBND = MIN0(LMBAND, NBAND + NSPRN)                                 BCOMP 52
     53          L = IFIX(CNT(1)) + NSPRN                                            BCOMP 53
     54          F = L                                                               BCOMP 54
     55          IF (.NOT. CENTER) L = L - K1                                        BCOMP 55
     56          NPSTRT = MOD(L, IPEVRY) + K1                                        BCOMP 56
     57      C                                                                       BCOMP 57
     58      C        COMPUTE VALUES OF BAND LIMITS FOR COMPUTATION AND OUTPUT.      BCOMP 58
     59      C                                                                       BCOMP 59
     60          L = NNBND + K1                                                      BCOMP 60
     61          DO 3000 I = 1, L                                                    BCOMP 61
     62          BAND(I) = BWINT * F + B                                             BCOMP 62
     63          BNDOUT(I) = BAND(I) - D                                             BCOMP 63
     64          IF (KTSBND) BAND(I) = FZRO * (COKT + BAND(I))/                      BCOMP 64
     65         1                             (COKT - BAND(I))                       BCOMP 65
     66          IF (FILTER) RRFS(I-1) = RRF((BAND(I-1)+BAND(I))*FPT5)               BCOMP 66
     67          F = F - F1                                                          BCOMP 67
     68     3000 CONTINUE                                                            BCOMP 68
     69      C                                                                       BCOMP 69
     70      C        RESET FLAG FOR VOLUME REVERB. PATTERN COMP. (NON-TURNING).     BCOMP 70
```

INDEX

SUBROUTINE BCOMP

```
      C
            VPTTRN = .FALSE.
      C
            RETURN
            END
```

BCOMP 71
BCOMP 72
BCOMP 73
BCOMP 74
BCOMP 75

SUBROUTINE DCOMP

SYMBOL - REFERENCES

1000	-	9	23*								
2000	-	19	28*								
2500	-	36	40*								
3000	-	61	68*								
ABS	-	37	38								
AINT	-	37									
B	-	4C0	15=	24=	30=	62					
BAND	-	62=	63	64=	65	66					
BCOMP	-	1									
BND	-	4C0	6=	7=	8=	14=	16=	18=	23=	25=	37
		38	41	42							
BNDOUT	-	63=									
BWINT	-	29	37	38	62						
CONT	-	13	18	64	65						
CENTER	-	29	39	55							
CNT	-	4C0	37=	38=	39=	41=	42=	49	51	53	
COS	-	6									
D	-	4C0	17=	26=	31=	63					
DCOMN1	-	3									
DEGRAD	-	6									
E	-	4C0	28=	29=	30	38					
F	-	4C0	54=	62	67=						
F1	-	38	42	67							
F180	-	8									
F90	-	7									
FILTER	-	66									
FNBAND	-	49=	50								
FPTS	-	29	39	66							
FZRO	-	14	15	16	17	18	64				
I	-	4C0	36=	37	38	39	61=	62	63	64	65
		66									
IFIX	-	51	53								
IPEVRY	-	56									
K1	-	55	56	60							
KTSBND	-	9	64								
L	-	4C0	53=	54	55=	56	60=	61			
LMBAND	-	51	52								
MBAND	-	50=	51								
MIND	-	51	52								
MNBND	-	52=	60								
MOD	-	56									
NBAND	-	51=	52								
NPSTRT	-	56=									
NSPAN	-	51	52	53							
Q	-	4C0	13=	14	16						
RELBND	-	31									
RETURN	-	74									
RRF	-	66									
RRFS	-	66=									
SIGN	-	41									
TNTMAX	-	6	7	8							
VPTTRN	-	72=									
VS	-	6	8	13	23	25	26				

```
                      SUBROUTINE  RBSORT                                        RBSORT 1
                C                                                               RBSORT 2
                      INCLUDE DCOMN1                                            RBSORT 3
                      INCLUDE DCOMN3                                            RBSORT 4
                      COMMON I,J,K,L,M,N,NA,NB,NC,ND,A,D,TEST,WRFLG             RBSORT 5
                      LOGICAL WRFLG                                             RBSORT 6
                C                                                               RBSORT 7
                      NSURF = 0                                                 RBSORT 8
                      NBTM = 0                                                  RBSORT 9
                      IF (NOTAPE) GO TO 16                                      RBSORT10
                C                                                               RBSORT11
                      TEST = DBTTM + SHIFT                                      RBSORT12
                      L = 0                                                     RBSORT13
                C                                                               RBSORT14
                C        READ DEPTH ID. RECORD AND TEST FOR SURFACE.            RBSORT15
                C                                                               RBSORT16
                    1 WRFLG = .FALSE.                                           RBSORT17
                      READ (AR1) I, D, N                                        RBSORT18
                      IF (I .EQ. 0) GO TO 15                                    RBSORT19
                      IF (D .NE. 0.) GO TO 2                                    RBSORT20
                      IF (NOSURF) GO TO 7                                       RBSORT21
                      NSURF = N                                                 RBSORT22
                      GO TO 5                                                   RBSORT23
                C                                                               RBSORT24
                C        TEST FOR BOTTOM DEPTH.                                 RBSORT25
                C                                                               RBSORT26
                    2 IF (ABS(D - DBTTM) .GT. TEST) GO TO 7                     RBSORT27
                      IF (NOBTTM) GO TO 7                                       RBSORT28
                      NBTM = N                                                  RBSORT29
                C                                                               RBSORT30
                C        READ DATA FOR NEXT PATH.  SKIP PATHS NOT AT (DESIRED) SURFACE  RBSORT31
                C        OR BOTTOM.                                             RBSORT32
                C                                                               RBSORT33
                    5 WRFLG = .TRUE.                                            RBSORT34
                    7 DO 14 I = 1, N                                            RBSORT35
                      READ (AR1) J,(RBTM(K),RBX(K),RBM(K),RBT(K), K = 1, J)     RBSORT36
                      IF (.NOT. WRFLG) GO TO 14                                 RBSORT37
                      DO 9 K = 1, J                                             RBSORT38
                      RBM(K) = RBM(K) - S                                       RBSORT39
                    9 CONTINUE                                                  RBSORT40
                C                                                               RBSORT41
                C        PUT DATA IN ASCENDING ORDER OF X, IF NECESSARY.        RBSORT42
                C                                                               RBSORT43
                      IF (RBX(2) .GT. RBX(1)) GO TO 12                          RBSORT44
                      NA = J/2                                                  RBSORT45
                      NB = -LMKS                                                RBSORT46
                      DO 11 K = 1, 4                                            RBSORT47
                      NB = NB + LMKS                                            RBSORT48
                      NC = NB + J                                               RBSORT49
                      DO 10 M = 1, NA                                           RBSORT50
                      ND = NB + M                                               RBSORT51
                      A = RBX(ND)                                               RBSORT52
                      RBX(ND) = RBX(NC)                                         RBSORT53
                      RBX(NC) = A                                               RBSORT54
                      NC = NC - 1                                               RBSORT55
                   10 CONTINUE                                                  RBSORT56
                   11 CONTINUE                                                  RBSORT57
                C                                                               RBSORT58
                C        SAVE MINIMUM X AND T FOR EACH PATH, IF TIMCMP OPTION.  RBSORT59
                C                                                               RBSORT60
                      IF (.NOT. TIMCMP) GO TO 13                                RBSORT61
                   12 L = L + 1                                                 RBSORT62
                      XMIN(L) = RBX(1)                                          RBSORT63
                      TMIN(L) = RBT(1)                                          RBSORT64
                C                                                               RBSORT65
                C        WRITE DATA ON INTERMEDIATE TAPE.                       RBSORT66
                C                                                               RBSORT67
                   13 WRITE (BR1) J,(RBX(K),RBT(K),RBTM(K),RBM(K), K = 1, J)    RBSORT68
                   14 CONTINUE                                                  RBSORT69
                      GO TO 1                                                   RBSORT70
```

```
   71      C                                                        RBSORT71
   72            15 REWIND BR1                                      RBSORT72
   73            16 RETURN                                          RBSORT73
   74               END                                             RBSORT74
```

SUBROUTINE RBSORT

SYMBOL	REFERENCES
1	17* 70
2	20 27*
5	23 34*
7	21 27 28 35*
9	38 40*
10	50 56*
11	47 57*
12	44 62*
13	61 68*
14	35 37 69*
15	19 72*
16	10 73*
A	5C0 52= 54
ABS	27
AR1	18RD 36RD
BR1	68WR 72
B	5C0 18RD 20 27
BBTTR	12 27
BCOMN1	3
BCOMN3	4
I	5C0 18RD 19 35=
J	5C0 36RD 38 45 49 68WR
K	5C0 36RD 38= 39 47= 68WR
L	5C0 13= 62= 63 64
LMKS	46 48
M	5C0 50= 51
N	5C0 18RD 22 29 35
NA	5C0 45= 50
NB	5C0 46= 48= 49 51
NBTR	9= 29=
NC	5C0 49= 53 54 55=
ND	5C0 51= 52 53
NOBTTR	28
NOSURF	21
NOTAPE	10
NSURF	8= 22=
RBN	36RD 39= 68WR
RBSORT	1
RBT	36RD 64 68WR
RBTN	36RD 68WR
RBX	36RD 44 52 53= 54= 63 68WR
RETURN	73
S	39
SHIFT	12
TEST	5C0 12= 27
TIMCMP	61
TMIN	64=
WRFLG	5C0 6L6 17= 34= 37
XMIN	63=

```
      SUBROUTINE  TCOMP                                                  TCOMP  1
C                                                                        TCOMP  2
      INCLUDE DCOMN1                                                     TCOMP  3
      INCLUDE DCOMN3                                                     TCOMP  4
      COMMON I,J,K,M,IBOUND,NMIN,NMAX,NTBL                               TCOMP  5
C                                                                        TCOMP  6
      IF (.NOT. TIMCMP) GO TO 10                                         TCOMP  7
C                                                                        TCOMP  8
C        TIME COMPUTATION IS DESIRED.  NOTE THAT CONSTANT CHECKING IS    TCOMP  9
C        DONE TO ENSURE THAT ALL ADDED TIMES LIE BETWEEN 1/2 DELTA T     TCOMP 10
C        AND PING INTERVAL. NO SUCH CHECK IS MADE ON INPUT TIMES.        TCOMP 11
C        ALSO LENGTH OF THE TIME ARRAY IS CHECKED TO AVOID OVER-FILLING. TCOMP 12
C                                                                        TCOMP 13
      IF (NTIME .EQ. LMTIM) GO TO 10                                     TCOMP 14
      NTIME = NTIME + K1                                                 TCOMP 15
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 16
      TIME(NTIME) = DELT                                                 TCOMP 17
      NTIME = NTIME + K1                                                 TCOMP 18
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 19
      IF (NOTAPE) GO TO  6                                               TCOMP 20
C                                                                        TCOMP 21
C        COMPUTE TIMES ASSOCIATED WITH WAVE-FRONT ARRIVAL OVER EACH      TCOMP 22
C        COMBINATION OF TWO-WAY PATHS.                                   TCOMP 23
C                                                                        TCOMP 24
      NMAX = 0                                                           TCOMP 25
      DO 4 IBOUND = K1, K2                                               TCOMP 26
      IF (NBOUND(IBOUND) .EQ. 0) GO TO 4                                 TCOMP 27
      NMIN = NMAX + K1                                                   TCOMP 28
      NMAX = NMAX + NBOUND(IBOUND)                                       TCOMP 29
      DO 3 I = NMIN, NMAX                                                TCOMP 30
      READ (BR1) NTBL,(RBX(K),RBT(K),RBTH(K),RBN(K), K = 1, NTBL)        TCOMP 31
C                                                                        TCOMP 32
      DO 2 J = 1, NMAX                                                   TCOMP 33
      TIME(NTIME) = (TMIN(J) + TABLKP(XMIN(J),RBX,RBT,1,NTBL)) * FPT5    TCOMP 34
      IF (ITABLE .EQ. 0) GO TO 2                                         TCOMP 35
      IF (TIME(NTIME) .GE. PING) GO TO 2                                 TCOMP 36
      M = NTIME                                                          TCOMP 37
      IF (TIME(NTIME) .LE. DELT) GO TO  1                                TCOMP 38
      NTIME = NTIME + K1                                                 TCOMP 39
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 40
      TIME(NTIME) = TIME(M) - DELT                                       TCOMP 41
      IF (TIME(NTIME) .GT. DELT) NTIME = NTIME + K1                      TCOMP 42
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 43
    1 TIME(NTIME) = TIME(M) + DELT                                       TCOMP 44
      IF (TIME(NTIME) .LT. PING) NTIME = NTIME + K1                      TCOMP 45
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 46
    2 CONTINUE                                                           TCOMP 47
    3 CONTINUE                                                           TCOMP 48
    4 CONTINUE                                                           TCOMP 49
      REWIND BR1                                                         TCOMP 50
C                                                                        TCOMP 51
C        ADD PRESET TABLE OF TIMES.                                      TCOMP 52
C                                                                        TCOMP 53
    6 DO 7 I = K1, LMTRS                                                 TCOMP 54
      IF (TRS(I) .GE. PING) GO TO 9                                      TCOMP 55
      TIME(NTIME) = TRS(I)                                               TCOMP 56
      IF (TIME(NTIME) .GT. DELT) NTIME = NTIME + K1                      TCOMP 57
      IF (NTIME .EQ. LMTIM) GO TO 9                                      TCOMP 58
    7 CONTINUE                                                           TCOMP 59
C                                                                        TCOMP 60
C        CONTINUE WITH EVERY 1/2 SECOND TO PING.  ADD PING INTERVAL.     TCOMP 61
C                                                                        TCOMP 62
    8 TIME(NTIME) = TIME(NTIME-1) + FPT5                                 TCOMP 63
      IF (TIME(NTIME) .GE. PING) GO TO 9                                 TCOMP 64
      NTIME = NTIME + K1                                                 TCOMP 65
      IF (NTIME .NE. LMTIM) GO TO 8                                      TCOMP 66
C                                                                        TCOMP 67
    9 TIME(NTIME) = PING                                                 TCOMP 68
C                                                                        TCOMP 69
C        SORT TIME ARRAY INTO ASCENDING ORDER, ELIMINATING DUPLICATES.   TCOMP 70
```

I N D E X

SUBROUTINE TCOMP


```
      C                                                                 TCOMP 71
   10 CALL SORT(TIME,NTIME)                                             TCOMP 72
      C                                                                 TCOMP 73
      C        INITIATE PAGE COUNTER AND COMPUTE TOTAL NUMBER OF PAGES OF TCOMP 74
      C        OUTPUT FOR THIS FILE OF INPUT DATA.                      TCOMP 75
      C                                                                 TCOMP 76
           PAGE = 0                                                     TCOMP 77
           NMAX = (NTIME - K1)/K3 + K1                                  TCOMP 78
           IF (SPREAD) NMAX = NTIME                                     TCOMP 79
           NPAGE = (((MNBND - NPSTRT)/IPEVRY)/K40 + K1) * NMAX          TCOMP 80
           IF (TOTALS) NPAGE = (NTIME - K1)/K40 + K1                    TCOMP 81
      C                                                                 TCOMP 82
           RETURN                                                       TCOMP 83
           END                                                          TCOMP 84
```

SUBROUTINE TCOMP

SYMBOL = = = = = = = = = = = = = = REFERENCES = = = = = = = = = = = = = =

1	-	38	44*								
2	-	33	35	36	47*						
3	-	30	48*								
4	-	26	27	49*							
6	-	20	54*								
7	-	54	59*								
8	-	63*	66								
9	-	16	19	40	43	46	55	58	64	68*	
10	-	7	14	72*							
BR1	-	31RD	50								
DCORN1	-	3									
DCORN3	-	4									
DELT	-	17	38	41	42	44	57				
FPTS	-	34	63								
I	-	5CO	30=	33	54=	55	56				
IBOUND	-	5CO	26=	27	29						
IPEVRY	-	80									
ITABLE	-	35									
J	-	5CO	33=	34							
K	-	5CO	31RD								
K1	-	15	18	26	28	39	42	45	54	57	65
		78	80	81							
K2	-	26									
K3	-	78									
K40	-	80	81								
LMTIM	-	14	16	19	40	43	46	58	66		
LMTRS	-	54									
M	-	5CO	37=	41	44						
MNBND	-	80									
NPOUND	-	27	29								
NMAX	-	5CO	25=	28	29=	30	33	78=	79=	80	
NMIN	-	5CO	28=	30							
NOTAPE	-	20									
NPAGE	-	80=	81=								
NPSTRT	-	80									
NTBL	-	5CO	31RD	34							
NTIME	-	14	15=	16	17	18=	19	34	36	37	38
		39=	40	41	42=	43	44	45=	46	56	57=
		58	63	64	65=	66	68	72AG	78	79	81
PAGE	-	77=									
PING	-	36	45	55	64	68					
RPH	-	31RD									
RPT	-	31RD	34								
RPTH	-	31RD									
RPX	-	31RD	34								
RETURN	-	83									
SORT	-	72									
SPREAD	-	79									
TABLKP	-	34									
TCOMP	-	1									
TIMCMP	-	7									
TIME	-	17=	34=	36	38	41=	42	44=	45	56=	57
		63=	64	68=	72AG						
TMIN	-	34									
TOTALS	-	81									
TRS	-	55	56								
XMIN	-	34									

```
      1            SUBROUTINE RBCOMP                                          RBCOMP 1
      2      C                                                                RBCOMP 2
      3            INCLUDE DCOMN1                                             RBCOMP 3
      4            INCLUDE DCOMN2                                             RBCOMP 4
      5            INCLUDE DCOMN5                                             RBCOMP 5
      6            COMMON DD(2),XD(2),TD(2),THAD(2),THBD(2),RD(2)             RBCOMP 6
      7            COMMON CSTHAD(2),CSTHBD(2),OMTD(2),CSOMTD(2),SNOMTD(2)     RBCOMP 7
      8            COMMON XTMU,OMTTMU,COMTMU,SOMTMU,CTHTMU(2)                 RBCOMP 8
      9            COMMON RT(2),THAT(2),THBT(2)                               RBCOMP 9
     10            COMMON ARG,FA,QA,QB,QC,QAB,QAC,QBC,QABC,QAABC,QBABC        RBCOMP10
     11            COMMON CSALFA,CSALFB,CSBETA,CSBETB,CSGAMA,CSGAMB           RBCOMP11
     12            COMMON CALFAP,CALFBP,CGAMAP,CGAMBP,COSA,COSB               RBCOMP12
     13            COMMON PHI,PHMOMT,DELR,TWMAX,TWMIN,TTMAX,A,DOPSKP          RBCOMP13
     14            COMMON X1(2),X2(2),X3(2),X4(2),Y1(2),Y2(2),Y3(2),Y4(2)     RBCOMP14
     15            COMMON I,II,IJ,JA,JB,JBOUND,JC,JD,JDD,JDELT,JDMAX,JDMIN,JE RBCOMP15
     16            COMMON JMAX,JUMP,KBAND,KTIM,L,LEAP,LL,MLMU(2),MM,MN,MX,NA,NB,NEXT RBCOMP16
     17            EQUIVALENCE (MLMU(1),ML),(MLMU(2),MU),(DOP,IDOP),(MNMX,MN) RBCOMP17
     18            EQUIVALENCE (QCOS,QAABC),(QSIN,QBABC),(QCOSM,QAB)          RBCOMP18
     19            DIMENSION IDOP(1),MNMX(2)                                  RBCOMP19
     20            LOGICAL TTMAX,DOPSKP                                       RBCOMP20
     21      C                                                                RBCOMP21
     22      C        BOUNDARY LOOP--                                         RBCOMP22
     23      C        ONCE THROUGH EACH FOR SURFACE AND BOTTOM                RBCOMP23
     24      C                                                                RBCOMP24
     25            DO 9010 JBOUND = 1, 2                                      RBCOMP25
     26            JMAX = NBOUND(JBOUND)                                      RBCOMP26
     27            IF (JMAX .EQ. 0) GO TO 9010                                RBCOMP27
     28      C                                                                RBCOMP28
     29      C        PATH LOOP--                                             RBCOMP29
     30      C        ONCE THROUGH FOR EACH SURFACE REFLECTED PATH AND EACH BOTTOM RBCOMP30
     31      C        REFLECTED PATH ON THE INTERMEDIATE TAPE.  (PATH A)      RBCOMP31
     32      C                                                                RBCOMP32
     33            DO 8010 JA = 1, JMAX                                       RBCOMP33
     34      C                                                                RBCOMP34
     35      C        POSITION TAPE AT JA'TH RECORD.                          RBCOMP35
     36      C                                                                RBCOMP36
     37            IF (JA .EQ. 1) GO TO 1020                                  RBCOMP37
     38            DO 1010 I = JA,JMAX                                        RBCOMP38
     39            BACKSPACE BR1                                              RBCOMP39
     40       1010 CONTINUE                                                   RBCOMP40
     41      C                                                                RBCOMP41
     42       1020 READ (BR1) NA,(RBXA(I),RBTA(I),RBTHA(I),RBHA(I), I = 1, NA) RBCOMP42
     43            BACKSPACE BR1                                              RBCOMP43
     44      C                                                                RBCOMP44
     45      C        PATH COMBINATION LOOP--                                 RBCOMP45
     46      C        ONCE THROUGH FOR EACH COMBINATION OF PATHS TO SURFACE   RBCOMP46
     47      C        OR TO BOTTOM.  (PATH B)                                 RBCOMP47
     48      C                                                                RBCOMP48
     49            DO 7080 JB = JA, JMAX                                      RBCOMP49
     50            READ (BR1) NB,(RBXB(I),RBTB(I),RBTHB(I),RBHB(I), I = 1, NB) RBCOMP50
     51      C                                                                RBCOMP51
     52      C        DEFINE THE AREA COMMON TO THE TWO PATHS AND ALSO TO THE RBCOMP52
     53      C        CURRENT TIME INTERVAL, IF ANY SUCH AREA EXISTS.         RBCOMP53
     54      C                                                                RBCOMP54
     55            TWMIN = AMAX1(TIME(KT)-DELT,RBTA(1),RBTB(1))               RBCOMP55
     56            TWMAX = AMIN1(TIME(KT)+DELT,RBTA(NA),RBTB(NB))             RBCOMP56
     57            IF (TWMAX .LE. TWMIN) GO TO 7080                           RBCOMP57
     58      C                                                                RBCOMP58
     59            DO 1030 JC = 1, NA                                         RBCOMP59
     60            X(JC) = RBXA(JC)                                           RBCOMP60
     61       1030 CONTINUE                                                   RBCOMP61
     62            JC = NA                                                    RBCOMP62
     63      C                                                                RBCOMP63
     64            DO 1040 I = 1, NA                                          RBCOMP64
     65            JC = JC + K1                                               RBCOMP65
     66            X(JC) = RBXB(I)                                            RBCOMP66
     67       1040 CONTINUE                                                   RBCOMP67
     68            CALL SORT(X, JC)                                           RBCOMP68
     69      C                                                                RBCOMP69
     70      C        EVALUATE TABLES FOR OVERLAPPED AREA.                    RBCOMP70
```

```
      C                                                                 RBCOMP71
            JD = 0                                                      RBCOMP72
            II = K1                                                     RBCOMP73
            IJ = K1                                                     RBCOMP74
            DO 1050 I = 1, JC                                           RBCOMP75
            T(JD+1) = TABLKP(X(I),RBXA,RBTA,II,NA)                      RBCOMP76
            IF (ITABLE .EQ. 0) GO TO 1050                               RBCOMP77
            II = ITABLE                                                 RBCOMP78
            T(JD+1) = (T(JD+1) + TABLKP(X(I),RBXB,RBTB,IJ,NB)) * FPT5   RBCOMP79
            IF (ITABLE .EQ. 0) GO TO 1050                               RBCOMP80
            IJ = ITABLE                                                 RBCOMP81
            JD = JD + K1                                                RBCOMP82
            X(JD) = X(I)                                                RBCOMP83
            THB(JD) = AINTRP(RBTHB) * DEGRAD                            RBCOMP84
            R(JD) = AINTRP(RBHB)                                        RBCOMP85
            THA(JD) = TABLKP(X(I),RBXA,RBTHA,II,NA) * DEGRAD            RBCOMP86
            R(JD) = EXP(FLOG10 * (AINTRP(RBHA) + R(JD))/F20)            RBCOMP87
            COSTHA(JD) = COS(THA(JD))                                   RBCOMP88
            COSTHB(JD) = COS(THB(JD))                                   RBCOMP89
            ORT(JD) = AMOD(OMEGA * T(JD), TWOPI)                        RBCOMP90
            IF (ABS(ORT(JD)) .GT. PI) ORT(JD) = ORT(JD) - SIGN(TWOPI, ORT(JD))RBCOMP91
            COSORT(JD) = COS(ORT(JD))                                   RBCOMP92
            SINORT(JD) = SIGN(SQRT(F1-COSORT(JD)**2),ORT(JD))           RBCOMP93
       1050 CONTINUE                                                    RBCOMP94
      C                                                                 RBCOMP95
      C        TRANSMIT-RECEIVE LOOP--                                  RBCOMP96
      C        JC = 1, TRANSMIT PATH A, RECEIVE PATH B                  RBCOMP97
      C        JC = 2, TRANSMIT PATH B, RECEIVE PATH A                  RBCOMP98
      C                                                                 RBCOMP99
            DO 7070 JC = 1,2                                            RBCOM100
      C                                                                 RBCOM101
      C        FORE - AFT LOOP--                                        RBCOM102
      C        JE = 1, FORWARD HEMISPHERE, OR RECEIVE FREQUENCY GREATER RBCOM103
      C        THAN TRANSMIT FREQUENCY.                                 RBCOM104
      C        JE = 2, AFTER HEMISPHERE, OR RECEIVE FREQ. LESS THAN XMIT FREQ.RBCOM105
      C                                                                 RBCOM106
            DO 7050 JE = 1, 2                                           RBCOM107
            LL = (JC - K1) * LMKS2                                      RBCOM108
            MM = LMKS2 - LL                                             RBCOM109
            FA = K3 - JE * K2                                           RBCOM110
            QCOS = FA                                                   RBCOM111
            QCOSM = FA                                                  RBCOM112
            DO 2020 I = 1, JD                                           RBCOM113
            ML = LL + I                                                 RBCOM114
            MU = MM + I                                                 RBCOM115
            IF (OMEGA .EQ. F0) GO TO 2010                               RBCOM116
            QA = COSTHA(MU) * COSORT(I) + COSTHA(ML)                    RBCOM117
            QB = COSTHA(MU) * SINORT(I)                                 RBCOM118
            QC = QB * COSTHA(ML)/FCOVS                                  RBCOM119
            QAB = QA**2 + QB**2                                         RBCOM120
            QCOS = (QB * QC + FA * QA * SQRT(QAB - QC**2))/QAB          RBCOM121
            QSIN = (QB * QCOS - QC)/QA                                  RBCOM122
            QCOSM = (QCOS * COSORT(I) + QSIN * SINORT(I))               RBCOM123
       2010 DOP(I) = FZRO * (COKT + VS * COSTHA(MU) * QCOSM)            RBCOM124
           1                  /(COKT - VS * COSTHA(ML) * QCOS)         RBCOM125
       2020 CONTINUE                                                    RBCOM126
            MM = K1                                                     RBCOM127
            DOPSKP = .FALSE.                                            RBCOM128
            SORTMU = 0.                                                 RBCOM129
      C                                                                 RBCOM130
      C        LOOP TO PROCESS CONSECUTIVE STRINGS OF DATA WHICH ARE    RBCOM131
      C        MONOTONIC IN "DOP"                                       RBCOM132
      C                                                                 RBCOM133
       3010 JDELT = ISIGN(1,IDOP(MM) - IDOP(MM+1))                      RBCOM134
            ML = K1 + (JDELT + K1)/K2                                   RBCOM135
            MU = K3 - ML                                                RBCOM136
            IJ = JD - K1                                                RBCOM137
            DO 3020 I = MM, IJ                                          RBCOM138
            IF (JDELT .NE. ISIGN(1, IDOP(I) - IDOP(I+1))) GO TO 3030    RBCOM139
       3020 CONTINUE                                                    RBCOM140
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```
      I = JD                                                            RBCOM141
C                                                                       RBCOM142
 3030 MX = I                                                            RBCOM143
      JDMIN = MNMX(ML)                                                  RBCOM144
      JDMAX = MNMX(MU)                                                  RBCOM145
C                                                                       RBCOM146
      DD(1) = DOP(JDMAX)                                                RBCOM147
      IF (JE .EQ. K2) DD(1) = FZRO                                      RBCOM148
      JDD = JDMAX                                                       RBCOM149
      ASSIGN 3050 TO NEXT                                               RBCOM150
      DO 3040 KBAND = NSPRM1, NBAND                                     RBCOM151
      IF (DD(1) .GT. BAND(KBAND+1)) GO TO (3070, 3090), JE              RBCOM152
 3040 CONTINUE                                                          RBCOM153
      GO TO 7030                                                        RBCOM154
C                                                                       RBCOM155
C        LOOP FOR ALL DESIRED BANDS AND FOR ALL DATA AT CONSTANT DOPPLERRBCOM156
C        WITHIN A BAND. IF BANDWIDTH IS GREATER THAN DATA SPACING.      RBCOM157
C        IN THE FOLLOWING TABLES, THE SUBSCRIPTS 1 AND 2 REFER TO      RBCOM158
C        DATA POINTS OF THE LOWEST AND HIGHEST FREQUENCY--SUBSCRIPTS   RBCOM159
C        ML AND MU REFER TO POINTS OF THE LOWEST AND HIGHEST TIMES.     RBCOM160
C                                                                       RBCOM161
 3050 ASSIGN 4020 TO NEXT                                               RBCOM162
C                                                                       RBCOM163
 3060 DD(2) = DD(1)                                                     RBCOM164
      XD(2) = XD(1)                                                     RBCOM165
      TD(2) = TD(1)                                                     RBCOM166
      THAD(2) = THAD(1)                                                 RBCOM167
      THBD(2) = THBD(1)                                                 RBCOM168
      RD(2) = RD(1)                                                     RBCOM169
      CSTHAD(2) = CSTHAD(1)                                             RBCOM170
      CSTHBD(2) = CSTHBD(1)                                             RBCOM171
      OMTD(2) = OMTD(1)                                                 RBCOM172
      CSOMTD(2) = CSOMTD(1)                                             RBCOM173
      SNOMTD(2) = SNOMTD(1)                                             RBCOM174
C                                                                       RBCOM175
      JDD = JDD + JDELT                                                 RBCOM176
      IF (DOP(JDD) .LT. BAND(KBAND+1)) GO TO 3080                       RBCOM177
      DD(1) = DOP(JDD)                                                  RBCOM178
 3070 XD(1) = X(JDD)                                                    RBCOM179
      TD(1) = T(JDD)                                                    RBCOM180
      THAD(1) = THA(JDD)                                                RBCOM181
      THBD(1) = THB(JDD)                                                RBCOM182
      RD(1) = R(JDD)                                                    RBCOM183
      CSTHAD(1) = COSTHA(JDD)                                           RBCOM184
      CSTHBD(1) = COSTHB(JDD)                                           RBCOM185
      OMTD(1) = OMT(JDD)                                                RBCOM186
      CSOMTD(1) = COSOMT(JDD)                                           RBCOM187
      SNOMTD(1) = SINOMT(JDD)                                           RBCOM188
      GO TO 4010                                                        RBCOM189
C                                                                       RBCOM190
 3080 JDD = JDD - JDELT                                                 RBCOM191
      DD(1) = BAND(KBAND+1)                                             RBCOM192
 3090 XD(1) = TABLKP(DD(1),DOP,X,MN,MX)                                 RBCOP193
      DOPSKP = ITABLE .EQ. 0                                            RBCOM194
      IF (DOPSKP) GO TO NEXT                                            RBCOM195
      TD(1)=  AINTRP(T)                                                 RBCOM196
      THAD(1) = AINTRP(THA)                                             RBCOM197
      THBD(1) = AINTRP(THB)                                             RBCOM198
      RD(1) = AINTRP(R)                                                 RBCOM199
      CSTHAD(1) = AINTRP(COSTHA)                                        RBCOM200
      CSTHBD(1) = AINTRP(COSTHB)                                        RBCOM201
      OMTD(1) = AINTRP(OMT)                                             RBCOM202
      CSOMTD(1) = AINTRP(COSOMT)                                        RBCOM203
      SNOMTD(1) = AINTRP(SINOMT)                                        RBCOM204
C                                                                       RBCOM205
 4010 GO TO NEXT                                                        RBCOM206
C                                                                       RBCOM207
 4020 ASSIGN 6010 TO LEAP                                               RBCOM208
      KTIM = K1                                                         RBCOM209
      TTMAX = .FALSE.                                                   RBCOM210
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      C                                                                 RBCOR211
            IF (BOPSKP) GO TO 4040                                      RBCOR212
            IF (MLMU(JE) .EQ. K1) GO TO 4030                            RBCOR213
            IF (TWMIN .LT. TB(MU)) GO TO 4040                           RBCOR214
            GO TO 7020                                                  RBCOR215
      C                                                                 RBCOR216
       4030 IF (TWMAX .LT. TB(ML)) GO TO 7020                           RBCOR217
            IF (TWMIN .LT. TB(ML)) GO TO 4080                           RBCOR218
       4040 ARG = TWMIN                                                 RBCOR219
            GO TO 4120                                                  RBCOR220
      C                                                                 RBCOR221
      C        LOOP FOR ALL TIMES AT CONSTANT DOPPLER                   RBCOR222
      C                                                                 RBCOR223
       4050 IF (X(KTIM) .LE. XTMU) GO TO 7010                           RBCOR224
            RT(ML) = RT(MU)                                             RBCOR225
            THAT(ML) = THAT(MU)                                         RBCOR226
            THBT(ML) = THBT(MU)                                         RBCOR227
      C                                                                 RBCOR228
            ARG = AMIN1(T(KTIM), TWMAX)                                 RBCOR229
            ASSIGN 4110 TO JUMP                                         RBCOR230
            IF (ARG .LT. TWMAX) ASSIGN 4100 TO JUMP                     RBCOR231
            IF (BOPSKP) GO TO JUMP                                      RBCOR232
            IF (MLMU(JE) .EQ. K2) GO TO 4070                            RBCOR233
            IF (XTMU .GE. XB(MU)) GO TO JUMP                            RBCOR234
       4060 IF (ARG .LT. TB(MU)) GO TO JUMP                             RBCOR235
            MM = MU                                                     RBCOR236
            GO TO 4090                                                  RBCOR237
      C                                                                 RBCOR238
       4070 IF (ARG .LT. TB(ML)) GO TO JUMP                             RBCOR239
            IF (XTMU .LT. XB(ML)) GO TO 4080                            RBCOR240
            IF (ARG .GE. TB(MU)) TTMAX = .TRUE.                         RBCOR241
            GO TO 4060                                                  RBCOR242
       4080 MM = ML                                                     RBCOR243
      C                                                                 RBCOR244
       4090 XTMU = XB(MM)                                               RBCOR245
            RT(MU) = RB(MM)                                             RBCOR246
            THAT(MU) = THAB(MM)                                         RBCOR247
            THBT(MU) = THBB(MM)                                         RBCOR248
            CTHTMU(1) = CSTHAB(MM)                                      RBCOR249
            CTHTMU(2) = CSTHBB(MM)                                      RBCOR250
            ORTTMU = ORTB(MM)                                           RBCOR251
            CORTMU = CSORTB(MM)                                         RBCOR252
            SORTMU = SNORTB(MM)                                         RBCOR253
            KTIM = KTIM - K1                                            RBCOR254
            GO TO 4130                                                  RBCOR255
      C                                                                 RBCOR256
       4100 XTMU = X(KTIM)                                              RBCOR257
            RT(MU) = R(KTIM)                                            RBCOR258
            THAT(MU) = THA(KTIM)                                        RBCOR259
            THBT(MU) = THB(KTIM)                                        RBCOR260
            CTHTMU(1) = COSTHA(KTIM)                                    RBCOR261
            CTHTMU(2) = COSTHB(KTIM)                                    RBCOR262
            ORTTMU = ORT(KTIM)                                          RBCOR263
            CORTMU = COSORT(KTIM)                                       RBCOR264
            SORTMU = SINORT(KTIM)                                       RBCOR265
            GO TO 4130                                                  RBCOR266
      C                                                                 RBCOR267
       4110 TTMAX = .TRUE.                                              RBCOR268
       4120 XTMU = TABLKP(ARG,T,X,KTIM,JD)                              RBCOR269
            RT(MU) = AINTRP(R)                                          RBCOR270
            THAT(MU) = AINTRP(THA)                                      RBCOR271
            THBT(MU) = AINTRP(THB)                                      RBCOR272
            CTHTMU(1) = AINTRP(COSTHA)                                  RBCOR273
            CTHTMU(2) = AINTRP(COSTHB)                                  RBCOR274
            ORTTMU = AINTRP(ORT)                                        RBCOR275
            CORTMU = AINTRP(COSORT)                                     RBCOR276
            SORTMU = AINTRP(SINORT)                                     RBCOR277
      C                                                                 RBCOR278
       4130 LL = K3 - JC                                                RBCOR279
      C                                                                 RBCOR280
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      C        LOOP FOR POINTS 3 AND 4--                                    RBCOM281
      C        I = 1, COMPUTE FOR POINTS 1 AND 3                            RBCOM282
      C        I = 2, COMPUTE FOR POINTS 2 AND 4                            RBCOM283
      C                                                                     RBCOM284
            DO 5020 I = 1, 2                                                RBCOM285
            L = K3 - I                                                      RBCOM286
            FA = FZRO * CTHTMU(LL)                                          RBCOM287
            QA = DD(L) * CTHTMU(JC) + FA * COMTMU                           RBCOM288
            QB = FA * SOMTMU                                                RBCOM289
            QC = FCOVS * (DD(L) - FZRO)                                     RBCOM290
            QAB = QA**2 + QB**2                                             RBCOM291
            QAC = QA * QC                                                   RBCOM292
            QBC = QB * QC                                                   RBCOM293
            QABC = SQRT(AMAX1(F0, QAB - QC**2))                             RBCOM294
            QAABC = QA * QABC                                               RBCOM295
            QBABC = QB * QABC                                               RBCOM296
            II = K2 * (I - K1)                                              RBCOM297
      C                                                                     RBCOM298
      C        PORT - STARBOARD LOOP--                                      RBCOM299
      C        L = 1, AREA IN FIRST QUADRANT (OMEGA = 0)                    RBCOM300
      C        L = 2, AREA IN FOURTH QUADRANT (OMEGA = 0)                   RBCOM301
      C                                                                     RBCOM302
            DO 5010 L = 1, 2                                                RBCOM303
            IJ = L + II                                                     RBCOM304
            A = K3 - L * K2                                                 RBCOM305
            FA = XTMU/QAB                                                   RBCOM306
      C                                                                     RBCOM307
            X1(IJ) = X3(IJ)                                                 RBCOM308
            X3(IJ) = FA * (QAC - A * QBABC)                                 RBCOM309
            Y1(IJ) = Y3(IJ)                                                 RBCOM310
            Y3(IJ) = FA * (QBC + A * QAABC)                                 RBCOM311
       5010 CONTINUE                                                        RBCOM312
       5020 CONTINUE                                                        RBCOM313
      C                                                                     RBCOM314
            GO TO LEAP                                                      RBCOM315
       6010 ASSIGN 6020 TO LEAP                                             RBCOM316
            GO TO 7010                                                      RBCOM317
      C                                                                     RBCOM318
       6020 CSGAMA = SIN((THAT(MU) + THAT(ML))/F2)                          RBCOM319
            CSGAMB = SIN((THBT(MU) + THBT(ML))/F2)                          RBCOM320
            COSA = SQRT(F1 - CSGAMA**2)                                     RBCOM321
            COSB = SQRT(F1 - CSGAMB**2)                                     RBCOM322
      C                                                                     RBCOM323
      C        PORT - STARBOARD LOOP--                                      RBCOM324
      C        L = 1, AREA IN FIRST QUADRANT (OMEGA = 0)                    RBCOM325
      C        L = 2, AREA IN FOURTH QUADRANT (OMEGA = 0)                   RBCOM326
      C                                                                     RBCOM327
            DO 6030 L = 1,2                                                 RBCOM328
            A = ((X4(L)*Y2(L) + X3(L)*Y4(L) + X2(L)*Y1(L) + X1(L)*Y3(L)) -  RBCOM329
           1     (X2(L)*Y4(L) + X4(L)*Y3(L) + X1(L)*Y2(L) + X3(L)*Y1(L)))   RBCOM330
            A = ABS(A/(RT(MU) + RT(ML)))                                    RBCOM331
      C                                                                     RBCOM332
            PHI = ATAN2(Y1(L) + Y2(L) + Y3(L) + Y4(L),                      RBCOM333
           1            X1(L) + X2(L) + X3(L) + X4(L))                      RBCOM334
            PHMORT = PHI - ORTTMU                                           RBCOM335
      C                                                                     RBCOM336
            CSALFA = COSA * COS(PHI)                                        RBCOM337
            CSBETA = COSA * SIN(PHI)                                        RBCOM338
            CSALFB = COSB * COS(PHMORT)                                     RBCOM339
            CSBETB = COSB * SIN(PHMORT)                                     RBCOM340
      C                                                                     RBCOM341
            CALFAP = CSALFA * CSKSI + CSGAMA * SNKSI                        RBCOM342
            CGAMAP = CSGAMA * CSKSI - CSALFA * SNKSI                        RBCOM343
            CALFBP = CSALFB * CSKSI + CSGAMB * SNKSI                        RBCOM344
            CGAMBP = CSGAMB * CSKSI - CSALFB * SNKSI                        RBCOM345
      C                                                                     RBCOM346
            DELR = A * OXL(XMIT,CALFAP,CSBETA,CGAMAP) *                     RBCOM347
           1 OXL(RECV,CALFBP,CSBETB,CGAMBP)                                 RBCOM348
      C                                                                     RBCOM349
            RV(KTT,KBAND,JBOUND) = RV(KTT,KBAND,JBOUND) + DELR              RBCOM350
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```
 6030 CONTINUE                                                          RBCOM351
C                                                                       RBCOM352
 7010 IF (TTMAX) GO TO 7020                                             RBCOM353
      KTIM = KTIM + K1                                                  RBCOM354
      IF (KTIM .LE. JD) GO TO 4050                                      RBCOM355
 7020 IF (DD(1) .LE. BAND(KBAND+1)) KBAND = KBAND + K1                  RBCOM356
      IF (KBAND .GT. NBAND) GO TO 7030                                  RBCOM357
      IF (JDD .NE. JDMIN) GO TO 3060                                    RBCOM358
      IF (DD(1) .LE. FZRO) GO TO 7030                                   RBCOM359
      DOPSKP = .TRUE.                                                   RBCOM360
      DD(2) = DD(1)                                                     RBCOM361
      DD(1) = AMAX1(BAND(KBAND+1), FZRO)                                RBCOM362
      GO TO 4020                                                        RBCOM363
C                                                                       RBCOM364
 7030 IF (MX .EQ. JD) GO TO 7040                                        RBCOM365
      MN = MX                                                           RBCOM366
      GO TO 3010                                                        RBCOM367
C                                                                       RBCOM368
 7040 MN = K1                                                           RBCOM369
      IF (TMTMAX .LE. F90) GO TO 7060                                   RBCOM370
 7050 CONTINUE                                                          RBCOM371
 7060 IF (JA .EQ. JB) GO TO 7080                                        RBCOM372
 7070 CONTINUE                                                          RBCOM373
C                                                                       RBCOM374
 7080 CONTINUE                                                          RBCOM375
 8010 CONTINUE                                                          RBCOM376
 9010 CONTINUE                                                          RBCOM377
C                                                                       RBCOM378
      REWIND BR1                                                        RBCOM379
      RETURN                                                            RBCOM380
      END                                                               RBCOM381
```

SUBROUTINE RBCOMP

SYMBOL - REFERENCES

1010	-	38	40*								
1020	-	37	42*								
1030	-	59	61*								
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7050	-	107	371*								
7060	-	370	372*								
7070	-	100	373*								
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COSORT	-	92=	93	117	123	187	203	264	276		
COSTHA	-	88=	117	118	119	124	125	184	200	261	273
COSTHB	-	89=	185	201	262	274					
CSALFA	-	1100	337=	342	343						

CSALFB - 11C0 339= 344 345
CSBETA - 11C0 338= 347
CSBETB - 11C0 340= 348
CSGAMA - 11C0 319= 321 342 343
CSGAMB - 11C0 320= 322 344 345
CSKSI - 342 343 344 345
CSQRTB - 7C0 173= 187= 203= 252
CSTHAB - 7C0 170= 184= 200= 249
CSTHBB - 7C0 171= 185= 201= 250
CTNTRU - 8C0 249= 250= 261= 262= 273= 274= 287 288
DCONN1 - 3
DCONN2 - 4
DCONN5 - 5
DD - 6C0 147= 148= 152 164= 178= 192= 193 288 290
356 359 361= 362=
DEGRAD - 84 86
DELR - 13C0 347= 350
DELT - 55 56
DOP - 17E0 124= 147 177 178 193
DOPSKP - 13C0 20L6 128= 194= 195 212 232 360=
EXP - 87
F0 - 116 294
F1 - 93 321 322
F2 - 319 320
F20 - 87
F90 - 370
FA - 10C0 110= 111 112 121 287= 288 289 306= 309
311
FCOVS - 119 290
FLOG10 - 87
FPTS - 79
FZRO - 124 148 287 290 359 362
I - 15C0 38= 42RD 50RD 64= 66 75= 76 79 83
86 113= 114 115 117 118 123 124 138= 139
141= 143 285= 286 297
IDOP - 17E0 19D1 134 139
II - 15C0 73= 76 78= 86 297= 304
IJ - 15C0 74= 79 81= 137= 138 304= 308 309 310
311
ISIGN - 134 139
ITABLE - 77 78 80 81 194
JA - 15C0 33= 37 38 49 372
JB - 15C0 49= 372
JBOUND - 15C0 25= 26 350
JC - 15C0 59= 60 62= 65= 66 68A6 75 100= 108
279 288
JD - 15C0 72= 76 79 82= 83 84 85 86 87
88 89 90 91 92 93 113 137 141 269
355 365
JDD - 15C0 149= 176= 177 178 179 180 181 182 183
184 185 186 187 188 191= 358
JDELT - 15C0 134= 135 139 176 191
JDMAX - 15C0 145= 147 149
JDMIN - 15C0 144= 368
JE - 15C0 107= 110 148 152 213 233
JMAX - 16C0 26= 27 33 38 49
JUMP - 16C0 230= 231= 232 234 235 239
K1 - 65 73 74 82 108 127 135 137 209 213
254 297 354 356 369
K2 - 110 135 148 233 297 305
K3 - 110 136 279 286 305
KBAND - 16C0 151= 162 177 192 350 356= 357 362
KT - 55 56
KTIM - 16C0 209= 224 229 254= 257 258 259 260 261
262 263 264 265 269 354= 355
KTT - 350
L - 16C0 286= 288 290 303= 304 305 328= 329 330
333 334
LEAP - 16C0 208= 315 316=
LL - 16C0 108= 109 114 279= 287

LMKS2 - 108 109
ML - 17E@ 114= 117 119 125 135= 136 144 217 218
225 226 227 239 240 243 319 320 331
MLMU - 16C0 17E@ 213 233
MM - 16C0 109= 115 236= 243= 245 246 247 248 249
250 251 252 253
MN - 16C0 17E@ 127= 134 138 193 366= 369=
MNMX - 17E@ 19D1 144 145
MU - 17E@ 115= 117 118 124 136= 145 214 225 226
227 234 235 236 241 246 247 248 258 259
260 270 271 272 319 320 331
MX - 16C0 143= 193 365 366
NA - 16C0 42RD 56 59 62 64 76 86
NB - 16C0 50RD 56 79
NBAND - 151 357
NBOUND - 26
NEXT - 16C0 150= 162= 195 206
NSPRM1 - 151
OMEGA - 90 116
OMT - 90= 91= 92 93 186 202 263 275
OMTD - 7C0 172= 186= 202= 251
OMTTMU - 8C0 251= 263= 275= 335
SAL - 347 348
PHI - 13C0 333= 335 337 338
PHMOMT - 13C0 335= 339 340
PI - 91
QA - 10C0 117= 120 121 122 288= 291 292 295
QAABC - 10C0 18E@ 295= 311
QAB - 10C0 18E@ 120= 121 291= 294 306
QABC - 10C0 294= 295 296
QAC - 10C0 292= 309
QB - 10C0 118= 119 120 121 122 289= 291 293 296
QBABC - 10C0 18E@ 296= 309
QBC - 10C0 293= 311
QC - 10C0 119= 121 122 290= 292 293 294
QCOS - 18E@ 111= 121= 122 123 125
QCOSM - 18E@ 112= 123= 124
QSIN - 18E@ 122= 123
R - 85= 87= 183 199 258 270
RBCOMP - 1
RBHA - 42RD 87
RBHB - 50RD 85
RBTA - 42RD 55 56 76
RBTB - 50RD 55 56 79
RBTMA - 42RD 86
RBTMB - 50RD 84
RBXA - 42RD 60 76 86
RBXB - 50RD 66 79
RD - 6C0 169= 183= 199= 246
RECV - 348
RETURN - 380
RT - 9C0 225= 246= 258= 270= 331
RV - 350=
SIGN - 91 93
SIN - 319 320 338 340
SINOMT - 93= 118 123 188 204 265 277
SNKSI - 342 343 344 345
SNOMTD - 7C0 174= 188= 204= 253
SOMTMU - 8C0 129= 253= 265= 277= 289
SORT - 68
SQRT - 93 121 294 321 322
T - 76= 79= 90 180 196 229 269
TABLKP - 76 79 86 193 269
TD - 6C0 166= 180= 196= 214 217 218 235 239 241
THA - 86= 88 181 197 259 271
THAD - 6C0 167= 181= 197= 247
THAT - 9C0 226= 247= 259= 271= 319
THB - 84= 89 182 198 260 272
THBD - 6C0 168= 182= 198= 248
THBT - 9C0 227= 248= 260= 272= 320

THTMAX	-	370									
TIME	-	55	56								
TTMAX	-	13C0	20L6	210=	241=	268=	353				
TWMAX	-	13C0	56=	57	217	229	231				
TWMIN	-	13C0	55=	57	214	218	219				
TWOPI	-	90	91								
VS	-	124	125								
X	-	60=	66=	68A6	76	79	83=	86	179	193	224
		257	269								
X1	-	14C0	308=	329	330	334					
X2	-	14C0	329	330	334						
X3	-	14C0	308	309=	329	330	334				
X4	-	14C0	329	330	334						
XD	-	6C0	165=	179=	193=	234	240	245			
XMIT	-	347									
XTMU	-	8C0	224	234	240	245=	257=	269=	306		
Y1	-	14C0	310=	329	330	333					
Y2	-	14C0	329	330	333						
Y3	-	14C0	310	311=	329	330	333				
Y4	-	14C0	329	330	333						

```
      1          SUBROUTINE RVCOMP                                              RVCOMP 1
      2    C                                                                    RVCOMP 2
      3          INCLUDE DCOMN1                                                 RVCOMP 3
      4          INCLUDE DCOMN2                                                 RVCOMP 4
      5          INCLUDE DCOMN4                                                 RVCOMP 5
      6          COMMON I,J,K,NN,OMT,CSOMTF,SNOMTF,FR,FRSQ,FXSQ,FX,CSA,SNA,PN,B,G RVCOMP 6
      7          COMMON SNPHI(2),CSPHI(2),X(2),Y(2),Z(2),D,DD,R,FRV             RVCOMP 7
      8          COMMON T1,T2,A1,A2,VOL1,T3                                     RVCOMP 8
      9    C                                                                    RVCOMP 9
     10    C        COMPUTE ONE-WAY RANGE TO MIDPOINT OF TRANSMITTED PULSE.     RVCOMP10
     11    C        PRE-COMPUTE RELATED VALUES FOR VOLUME AND FOR RANGE LOSSES. RVCOMP11
     12    C                                                                    RVCOMP12
     13          R = TIME(KT) * CO * FPT5                                       RVCOMP13
     14          FRV = EXP((LOGMVI - ALPHC * TIME(KT))/F10 * FLOG10)/R**4       RVCOMP14
     15          IF (OMEGA .EQ. 0.) FRV = FRV *                                 RVCOMP15
     16         1      ((R + DR)**3 - AMAX1(R - DR, F0)**3) * PI23              RVCOMP16
     17          IF (VPTTRN) GO TO 9000                                         RVCOMP17
     18    C                                                                    RVCOMP18
     19    C        PATTERN LOSSES MUST BE COMPUTED.                            RVCOMP19
     20    C                                                                    RVCOMP20
     21          OMT = AMOD(OMEGA * TIME(KT), TWOPI)                            RVCOMP21
     22          IF (ABS(OMT) .GT. PI) OMT = OMT - SIGN(TWOPI, OMT)             RVCOMP22
     23          CSOMTF = COS(OMT)                                              RVCOMP23
     24          SNOMTF = SIGN(SQRT(F1-CSOMTF**2),OMT) * FZRO                   RVCOMP24
     25          CSOMTF = CSOMTF * FZ2                                          RVCOMP25
     26          FCSGAM(NSPRM1) = 0.                                            RVCOMP26
     27          IF (OMEGA .EQ. 0.) FCSGAM(NSPRM1) = F1                         RVCOMP27
     28          T1 = AMAX1(TIME(KT) - DELT, F0) * FPT5                         RVCOMP28
     29          T2 = ((TIME(KT) + DELT) * FPT5 - T1)/F10                       RVCOMP29
     30    C                                                                    RVCOMP30
     31    C        COMPUTE AVERAGE PATTERN LOSSES FOR EACH BAND.               RVCOMP31
     32    C                                                                    RVCOMP32
     33          DO 8000 I = NSPRM1, NBAND                                      RVCOMP33
     34          FGAM(I) = 0.                                                   RVCOMP34
     35          FR = (BAND(I) + BAND(I+1)) * FPT5                              RVCOMP35
     36          FRSQ = FR**2                                                   RVCOMP36
     37          FXSQ = FZSQ + FRSQ + FR * CSOMTF                               RVCOMP37
     38          FX = SQRT(FXSQ)                                                RVCOMP38
     39          A1 = FCOVS * (FR - FZRO)                                       RVCOMP39
     40          CSA = A1/FX                                                    RVCOMP40
     41          IF (ABS(CSA) .GT. F1) CSA = SIGN(F1, CSA)                      RVCOMP41
     42          SNA = SQRT(F1 - CSA**2)                                        RVCOMP42
     43          NN = MINO(K2 * IFIX(FNBAND * SNA) + K1, 360)                   RVCOMP43
     44          PN = NN                                                        RVCOMP44
     45          DD = TWOPI/PN                                                  RVCOMP45
     46          D = 0.                                                         RVCOMP46
     47          SNPHI(1) = SNOMTF/FX                                           RVCOMP47
     48          SNPHI(2) = -SNPHI(1) * FR/FZRO                                 RVCOMP48
     49          CSPHI(1) = SQRT(F1 - SNPHI(1)**2)                              RVCOMP49
     50          CSPHI(2) = SQRT(F1 - SNPHI(2)**2)                              RVCOMP50
     51          IF (ABS(FZSQ - FRSQ) .LE. FXSQ) GO TO 2000                     RVCOMP51
     52          CSPHI(1) = SIGN(CSPHI(1), CSA)                                 RVCOMP52
     53          CSPHI(2) = -SIGN(CSPHI(1), CSA)                                RVCOMP53
     54   2000   DO 4000 J = 1,NN                                               RVCOMP54
     55          D = D + DD                                                     RVCOMP55
     56          B = SNA * SIN(D)                                               RVCOMP56
     57          G = SNA * COS(D)                                               RVCOMP57
     58    C                                                                    RVCOMP58
     59          DO 3000 K = 1, 2                                               RVCOMP59
     60          X(K) = CSA * CSPHI(K) - B * SNPHI(K)                           RVCOMP60
     61          Y(K) = B * CSPHI(K) + CSA * SNPHI(K)                           RVCOMP61
     62          X(K) = X(K) * CSKSI + G * SNKSI                                RVCOMP62
     63          Z(K) = G * CSKSI - X(K) * SNKSI                                RVCOMP63
     64   3000   CONTINUE                                                       RVCOMP64
     65          FGAM(I) = FGAM(I) + OXL(XMIT,X(1),Y(1),Z(1))                   RVCOMP65
     66         1                  * OXL(RECV,X(2),Y(2),Z(2))                   RVCOMP66
     67   4000   CONTINUE                                                       RVCOMP67
     68          FGAM(I) = FGAM(I)/PN * EXPS                                    RVCOMP68
     69          IF (OMEGA .EQ. 0.) GO TO 8000                                  RVCOMP69
     70          T3 = T1                                                        RVCOMP70
```

SUBROUTINE RVCOMP

```
      A2 = FI2 * FR                                                    RVCOMP71
      A1 = A1/SQRT(A2)                                                 RVCOMP72
      A2 = (FRSQ + FZSQ)/A2                                            RVCOMP73
      VOL1 = 0.                                                        RVCOMP74
C                                                                      RVCOMP75
      DO 5000 J = 1, 10                                                RVCOMP76
      T3 = T3 + T2                                                     RVCOMP77
      VOL1 = VOL1 - T3**2 * AMAX1(F1 - A1/SQRT(A2 + COS(OMEGA * T3)),F0)RVCOMP78
 5000 CONTINUE                                                         RVCOMP79
      FCSGAM(I+1) = VOL1 * T2 * FC03                                   RVCOMP80
      GOTO 7000                                                        RVCOMP81
 6000 FCSGAM(I+1) =  FCOVS * (BAND(I+1) - FZRO)/(BAND(I+1) + FZRO)     RVCOMP82
 7000 FGAM(I) = FGAM(I) * (FCSGAM(I) - FCSGAM(I+1))                    RVCOMP83
      RVV(KTT,I) = FRV * FGAM(I)                                       RVCOMP84
 8000 CONTINUE                                                         RVCOMP85
C                                                                      RVCOMP86
C        FOR STRAIGHT-RUNNING CASE, PATTERN LOSSES FOR ANY BAND WILL   RVCOMP87
C        BE THE SAME AT ALL TIMES.                                     RVCOMP88
C                                                                      RVCOMP89
      IF (OMEGA .EQ. 0.) VPTTRN = .TRUE.                               RVCOMP90
      GO TO 30000                                                      RVCOMP91
 9000 DO 10000 I = NSPRH1, NBAND                                       RVCOMP92
      RVV(KTT,I) = FRV * FGAM(I)                                       RVCOMP93
10000 CONTINUE                                                         RVCOMP94
30000 RETURN                                                           RVCOMP95
      END                                                              RVCOMP96
```

SUBROUTINE RVCOMP

SYMBOL		REFERENCES									
2000	-	51	54*								
3000	-	59	64*								
4000	-	54	67*								
5000	-	76	79*								
6000	-	69	82*								
7000	-	81	83*								
8000	-	33	85*								
9000	-	17	92*								
10000	-	92	94*								
30000	-	91	95*								
A1	-	8C0	39=	40	72=	78					
A2	-	8C0	71=	72	73=	78					
ABS	-	22	41	51							
ALPHC	-	14									
AMAX1	-	16	28	78							
AMOD	-	21									
B	-	6C0	56=	60	61						
BAND	-	35	82								
C0	-	13									
COS	-	23	57	78							
CSA	-	6C0	40=	41=	42	52	53	60	61		
CSKSI	-	62	63								
CSQRTF	-	6C0	23=	24	25=	37					
CSPHI	-	7C0	49=	50=	52=	53=	60	61			
D	-	7C0	46=	55=	56	57					
DCOMN1	-	3									
DCOMN2	-	4									
DCOMN4	-	5									
DD	-	7C0	45=	55							
DELT	-	28	29								
DR	-	16									
EXP	-	14									
EXPS	-	68									
F0	-	16	28	78							
F1	-	24	27	41	42	49	50	78			
F1C	-	14	29								
FCD3	-	80									
FCOVS	-	39	82								
FCSGAM	-	26=	27=	80=	82=	83					
FGAM	-	34=	65=	68=	83=	84	93				
FLOG10	-	14									
FNBAND	-	43									
FPI5	-	13	28	29	35						
FR	-	6C0	35=	36	37	39	48	71			
FRSQ	-	6C0	36=	37	51	73					
FRV	-	7C0	14=	15=	84	93					
FX	-	6C0	38=	40	47						
FXSQ	-	6C0	37=	38	51						
FZ2	-	25	71								
FZRO	-	24	39	48	82						
FZSQ	-	37	51	73							
G	-	6C0	57=	62	63						
I	-	6C0	33=	34	35	65	68	80	82	83	84
		92=	93								
IFIX	-	43									
J	-	6C0	54=	76=							
K	-	6C0	59=	60	61	62	63				
K1	-	43									
K2	-	43									
KT	-	13	14	21	28	29					
KTT	-	84	93								
LOGRVI	-	14									
MINO	-	43									
NBAND	-	33	92								
NN	-	6C0	43=	44	54						
NSPRN1	-	26	27	33	92						
OMEGA	-	15	21	27	69	78	90				
OMT	-	6C0	21=	22=	23	24					

OXL	-	65	66					
PI	-	22						
PI23	-	16						
PN	-	6C0	44=	45	68			
R	-	7C0	13=	14	16			
RECV	-	66						
RETURN	-	95						
RVCOMP	-	1						
RVV	-	84=	93=					
SIGN	-	22	24	41	52	53		
SIN	-	56						
SNA	-	6C0	42=	43	56	57		
SNKSI	-	62	63					
SNORTF	-	6C0	24=	47				
SNPHI	-	7C0	47=	48=	49	50	60	61
SQRT	-	24	38	42	49	50	72	78
T1	-	8C0	28=	29	70			
T2	-	8C0	29=	77	80			
T3	-	8C0	70=	77=	78			
TIME	-	13	14	21	28	29		
TWOPI	-	21	22	45				
VOL1	-	8C0	74=	78=	80			
VPTTRN	-	17	90=					
X	-	7C0	60=	62=	63	65	66	
XMIT	-	65						
Y	-	7C0	61=	65	66			
Z	-	7C0	63=	65	66			

I N D E X PAGE 35

```
    1          SUBROUTINE RVSPRD                                    RVSPRD 1
    2     C                                                         RVSPRD 2
    3          INCLUDE DCOMN1                                       RVSPRD 3
    4          INCLUDE DCOMN2                                       RVSPRD 4
    5          COMMON IMAX,I,II,J,K,KK                              RVSPRD 5
    6     C                                                         RVSPRD 6
    7          DO 13 J = K1, K3                                     RVSPRD 7
    8          DO 11 I = NSPRH1, NBAND                              RVSPRD 8
    9          II = I-NSPRH                                         RVSPRD 9
   10          DO 10 K = K1, NSPR1                                  RVSPRD10
   11          KK = ABS(K-NSPRH1) + K1                              RVSPRD11
   12          RV(2,II,J) = RV(2,II,J) + RV(1,I,J) * SPRED(KK,J)    RVSPRD12
   13          II = II + 1                                          RVSPRD13
   14           IF (II .GT. LMBAND) GO TO 11                        RVSPRD14
   15       10 CONTINUE                                             RVSPRD15
   16       11 CONTINUE                                             RVSPRD16
   17       13 CONTINUE                                             RVSPRD17
   18          RETURN                                               RVSPRD18
   19          END                                                  RVSPRD19
```

APPENDIX G

SUBROUTINE RVSPRD

SYMBOL	REFERENCES
10	10 15*
11	8 14 16*
13	7 17*
ABS	11
DCONN1	3
DCONN2	4
I	5CO 8= 9 12
II	5CO 9= 12 13= 14
IMAX	5CO
J	5CO 7= 12
K	5CO 10= 11
K1	7 10 11
K3	7
KK	5CO 11= 12
LMBAND	14
NBAND	8
NSPR1	10
NSPRN	9
NSPRN1	8 11
RETURN	18
RV	12=
RVSPRD	1
SPRED	12

```
      1          SUBROUTINE RTCOMP                                          RTCOMP 1
      2      C                                                              RTCOMP 2
      3          INCLUDE DCOMN1                                             RTCOMP 3
      4          INCLUDE DCOMN2                                             RTCOMP 4
      5          COMMON IMAX,I,J,T,TR                                       RTCOMP 5
      6      C                                                              RTCOMP 6
      7          IMAX = KTT                                                 RTCOMP 7
      8          IF (.NOT. SPREAD) GO TO 2                                  RTCOMP 8
      9          IMAX = K2                                                  RTCOMP 9
     10          IF (.NOT. (FILTER .OR. TVG)) GO TO 2                       RTCOMP10
     11          IMAX = K3                                                  RTCOMP11
     12          T = F1                                                     RTCOMP12
     13          IF (TVG) T = TVGF(TIME(KT))                                RTCOMP13
     14          DO 1 I = 1, RNBND                                          RTCOMP14
     15          TR = T                                                     RTCOMP15
     16          IF (FILTER) TR = T * RRFS(I)                               RTCOMP16
     17          RVS(3,I) = RVS(2,I) * TR                                   RTCOMP17
     18          RVB(3,I) = RVB(2,I) * TR                                   RTCOMP18
     19          RVV(3,I) = RVV(2,I) * TR                                   RTCOMP19
     20        1 CONTINUE                                                   RTCOMP20
     21      C                                                              RTCOMP21
     22        2 DO 5 I = KTT, IMAX                                         RTCOMP22
     23          J = 0                                                      RTCOMP23
     24      C                                                              RTCOMP24
     25        3 J = J + K1                                                 RTCOMP25
     26          RVS(I,LMBND1) = RVS(I,LMBND1) + RVS(I,J)                   RTCOMP26
     27          RVB(I,LMBND1) = RVB(I,LMBND1) + RVB(I,J)                   RTCOMP27
     28          RVV(I,LMBND1) = RVV(I,LMBND1) + RVV(I,J)                   RTCOMP28
     29      C                                                              RTCOMP29
     30        4 RVT(I,J) = RVS(I,J) + RVB(I,J) + RVV(I,J)                  RTCOMP30
     31          IF (RVS(I,J) .NE. 0.) RVS(I,J) = F10 * ALOG10(RVS(I,J))    RTCOMP31
     32          IF (RVB(I,J) .NE. 0.) RVB(I,J) = F10 * ALOG10(RVB(I,J))    RTCOMP32
     33          IF (RVV(I,J) .NE. 0.) RVV(I,J) = F10 * ALOG10(RVV(I,J))    RTCOMP33
     34          IF (RVT(I,J) .NE. 0.) RVT(I,J) = F10 * ALOG10(RVT(I,J))    RTCOMP34
     35      C                                                              RTCOMP35
     36          IF (J .LT. RNBND) GO TO 3                                  RTCOMP36
     37          IF (J .EQ. LMBND1) GO TO 5                                 RTCOMP37
     38          J = LMBND1                                                 RTCOMP38
     39          GO TO 4                                                    RTCOMP39
     40      C                                                              RTCOMP40
     41        5 CONTINUE                                                   RTCOMP41
     42          RETURN                                                     RTCOMP42
     43          END                                                        RTCOMP43
```

SUBROUTINE RTCOMP

SYMBOL		REFERENCES									
1	-	14	20*								
2	-	8	10	22*							
3	-	25*	36								
4	-	30*	39								
5	-	22	37	41*							
ALOG10	-	31	32	33	34						
DCOMN1	-	3									
DCOMN2	-	4									
F1	-	12									
F10	-	31	32	33	34						
FILTER	-	10	16								
I	-	5C0	14=	16	17	18	19	22=	26	27	28
		30	31	32	33	34					
IMAX	-	5C0	7=	9=	11=	22					
J	-	5C0	23=	25=	26	27	28	30	31	32	33
		34	36	37	38=						
K1	-	25									
K2	-	9									
K3	-	11									
KT	-	13									
KTT	-	7	22								
LMBND1	-	26	27	28	37	38					
MNBND	-	14	36								
RETURN	-	42									
RRFS	-	16									
RTCOMP	-	1									
RVB	-	16=	27=	30	32=						
RVS	-	17=	26=	30	31=						
RVT	-	30=	34=								
RVV	-	19=	28=	30	33=						
SPREAD	-	6									
T	-	5C0	12=	13=	15	16					
TIME	-	13									
TR	-	5C0	15=	16=	17	18	19				
TVG	-	10	13								
TVGF	-	13									

```
      SUBROUTINE RVPRNT                                                 RVPRNT 1
C                                                                       RVPRNT 2
      INCLUDE DCOMN1                                                    RVPRNT 3
      INCLUDE DCOMN2                                                    RVPRNT 4
      COMMON I,J,K,L,II                                                 RVPRNT 5
      DIMENSION HRVB(6)                                                 RVPRNT 6
      DATA HTIME/6HTIME =/,(HRVB(I), I = 1,6)                           RVPRNT 7
     1  /6H    SUR, 6HFACE  , 6HBOTTOM, 6H    VOL, 6HUME    , 6H TOTAL/  RVPRNT 8
      DATA ITOTAL/1/                                                    RVPRNT 9
C                                                                       RVPRNT10
      IF (PLOT) WRITE (IPLT) TIME(NTMIN),MNBND,(BNDOUT(K),BNDOUT(K+1),  RVPRNT11
     1          RVS(2,K),RVB(2,K),RVV(2,K),RVT(2,K), K = 1, MNBND)      RVPRNT12
      IF (NOPRNT) GO TO 30000                                           RVPRNT13
      IF (TOTALS) GO TO 2000                                            RVPRNT14
      J = NPSTRT                                                        RVPRNT15
    1 PAGE = PAGE + K1                                                  RVPRNT16
      WRITE (IPRT,10) HED,IDC,IDV,IDATE,PAGE,NPAGE,                     RVPRNT17
     1                VS,CO,FZRO,DO,S,KSID,OMEGAD,PING,DELT2,DBTTM     RVPRNT18
      IF (TOTALS) GO TO 2020                                            RVPRNT19
C                                                                       RVPRNT20
      IF (SPREAD) GO TO 5                                               RVPRNT21
      WRITE (IPRT,11) HBAND,(HTIME,TIME(K), K = NTMIN, NTMAX)           RVPRNT22
      GO TO 6                                                           RVPRNT23
C                                                                       RVPRNT24
    5 WRITE (IPRT,11) HBAND,(HTIME,TIME(NTMIN), K = 1, I)               RVPRNT25
C                                                                       RVPRNT26
    6 WRITE (IPRT,12) HOUTPT, (HRVB, K = 1, I)                          RVPRNT27
      IF (TOTALS) GO TO 2100                                            RVPRNT28
      DO 3 K = K1, K8                                                   RVPRNT29
      WRITE (IPRT,20)                                                   RVPRNT30
C                                                                       RVPRNT31
      DO 2 L = K1, K5                                                   RVPRNT32
      WRITE (IPRT, 20) BNDOUT(J), BNDOUT(J+1),                          RVPRNT33
     1     (RVS(II,J), RVB(II,J), RVV(II,J), RVT(II,J), II = 1, I)      RVPRNT34
      J = J + IPEVRY                                                    RVPRNT35
      IF (J .GT. MNBND) GO TO 4                                         RVPRNT36
C                                                                       RVPRNT37
    2 CONTINUE                                                          RVPRNT38
    3 CONTINUE                                                          RVPRNT39
      GO TO 1                                                           RVPRNT40
C                                                                       RVPRNT41
    4 WRITE (IPRT,30) HTOT1, (RVS(II,LMBND1),RVB(II,LMBND1),            RVPRNT42
     1                        RVV(II,LMBND1),RVT(II,LMBND1), II = 1, I) RVPRNT43
      GO TO 30000                                                       RVPRNT44
C                                                                       RVPRNT45
 2000 IF (.NOT. SPREAD) I = K1                                          RVPRNT46
      J = K1                                                            RVPRNT47
      II = NTMIN                                                        RVPRNT48
 2010 ITOTAL = ITOTAL - K1                                              RVPRNT49
      IF (ITOTAL .NE. 0) GO TO 2100                                     RVPRNT50
      ITOTAL = K40                                                      RVPRNT51
      GO TO 1                                                           RVPRNT52
C                                                                       RVPRNT53
 2020 WRITE (IPRT,13) HTOT1,MNBND,HTOT2,BWIDTH,HTOT3                    RVPRNT54
      GO TO 6                                                           RVPRNT55
C                                                                       RVPRNT56
 2100 IF (MOD(ITOTAL,K5) .EQ. 0) WRITE (IPRT,20)                        RVPRNT57
      WRITE (IPRT,21) TIME(II), (RVS(K,LMBND1),RVB(K,LMBND1),           RVPRNT58
     1                           RVV(K,LMBND1),RVT(K,LMBND1), K = J, I) RVPRNT59
      I = I + K1                                                        RVPRNT60
      J = J + K1                                                        RVPRNT61
      II = II + K1                                                      RVPRNT62
      IF (II .LE. NTMAX) GO TO 2010                                     RVPRNT63
C                                                                       RVPRNT64
30000 RETURN                                                            RVPRNT65
C                                                                       RVPRNT66
   10 FORMAT (8A6,A4,9H   IDC   ,A6,6X,6HIDV   , A6,7X,4HDATE,2A6,7X,  RVPRNT67
     1 4HPAGE,I5,3H OF,I5/                                              RVPRNT68
     2132HGV.S, KTS.   C.D, YDS./SEC.   F.O, KHZ.   D.O, FT.   S, DB.  RVPRNT69
     3XI, DEG.   OMEGA, DEG./SEC.   P.I., SEC.   DEL. T, SEC.   D. BTM.,RVPRNT70
```

APPENDIX G

```
   71          4 FT./ F8.2,F15.2,F15.4,F13.4,F9.2,F10.3,F15.3,F16.4,F13.4,F17.4)  RVPRNT71
   72      C                                                                      RVPRNT72
   73         11 FORMAT (1HO, 2A6, A4, 3(13X,A6,F12.8,7X))                        RVPRNT73
   74      C                                                                      RVPRNT74
   75         12 FORMAT (5X,2A6,17X,2A6,23X,3A6,13X,5A6/3X,2A6,3X,3(2X,6A6))      RVPRNT75
   76      C                                                                      RVPRNT76
   77         13 FORMAT (1HO,30X,4A6,14,2A6,A3,F6.3,3A6)                          RVPRNT77
   78      C                                                                      RVPRNT78
   79         20 FORMAT (1X,F8.4,F9.4,3(2X,4F9.2))                                RVPRNT79
   80      C                                                                      RVPRNT80
   81         21 FORMAT (F17.8,1X,3(2X,4F9.2))                                    RVPRNT81
   82      C                                                                      RVPRNT82
   83         30 FORMAT (1HO,3A6,A1,4F9.2,2(2X,4F9.2))                            RVPRNT83
   84            END                                                             RVPRNT84
```

SUBROUTINE RVPRNT

SYMBOL	REFERENCES									
1	16*	40	52							
2	32	38*								
3	29	39*								
4	36	42*								
5	21	25*								
6	23	27*	55							
10	17#R	67*								
11	22#R	25#R	73*							
12	27#R	75*								
13	54#R	77*								
20	30#R	33#R	57#R	79*						
21	58#R	81*								
30	42#R	83*								
2000	14	46*								
2010	49*	63								
2020	19	54*								
2100	28	50	57*							
30000	13	44	65*							
BNDOUT	11#R	33#R								
BW10TH	54#R									
CO	18#R									
DO	18#R									
DBTTH	18#R									
DCONN1	3									
DCONN2	4									
DELT2	18#R									
FZRO	18#R									
HBAND	22#R	25#R								
HED	17#R									
HOUTPT	27#R									
HRVD	6DI	7DA	27#R							
HTIME	7DA	22#R	25#R							
HTOT1	42#R	54#R								
HTOT2	54#R									
HTOT3	54#R									
I	5CO	7DA	25#R	27#R	34#R	43#R	46=	59#R	60=	
IDATE	17#R									
IDC	17#R									
IDV	17#R									
II	5CO	34#R	42#R	43#R	48=	58#R	62=	63		
IPEVRY	35									
IPLT	11#R									
IPRT	17#R	22#R	25#R	27#R	30#R	33#R	42#R	54#R	57#R	58#R
ITOTAL	9DA	49=	50	51=	57					
J	5CO	15=	33#R	34#R	35=	36	47=	59#R	61=	
K	5CO	11#R	12#R	22#R	25#R	27#R	29=	58#R	59#R	
K1	16	29	32	46	47	49	60	61	62	
K40	51									
K5	32	57								
K8	29									
KSID	18#R									
L	5CO	32=								
LMBND1	42#R	43#R	58#R	59#R						
MNBND	11#R	12#R	36	54#R						
MOD	57									
NOPRNT	13									
NPAGE	17#R									
NPSTRT	15									
NTMAX	22#R	63								
NTMIN	11#R	22#R	25#R	48						
OMEGAD	18#R									
PAGE	16=	17#R								
PING	18#R									
PLOT	11									
RETURN	65									
RVD	12#R	34#R	42#R	58#R						
RVPRNT	1									
RVS	12#R	34#R	42#R	58#R						

I N D E X

SUBROUTINE RVPRNT

RVT	-	12WR	34WR	43WR	59WR
RVV	-	12WR	34WR	43WR	59WR
S	-	18WR			
SPREAD	-	21	46		
TIME	-	11WR	22WR	25WR	58WR
TOTALS	-	14	19	28	
VS	-	18WR			

BLOCK DATA FOR DOP

```
      BLOCK DATA                                                                BLOCK  1
C                                                                               BLOCK  2
      INCLUDE DCOMN1                                                            BLOCK  3
      INCLUDE DCOMN6                                                            BLOCK  4
C                                                                               BLOCK  5
      DATA  K0/0/,K1/1/,K2/2/,K3/3/,K5/5/,K6/6/,K8/8/,K10/10/,K40/40/           BLOCK  6
      DATA  (TRS(I), I = 1,6)/.01,.05,.1,.2,.3,.4/,FPT5/.5/,                    BLOCK  7
     1  (TRS2(I), I = 1,4)/.6,.7,.8,.9/,F1/1./,                                BLOCK  8
     2  (TRS3(I), I = 1,4)/1.2,1.4,1.6,1.8/,F2/2./,F4/4./,F10/10./,            BLOCK  9
     3  F20/20./,FLOG10/2.302585509/,INFNT/1.E38/                              BLOCK 10
     4 PI23/2.094395510/,P1/3.14159265/,TWOPI/6.28318531/,                      BLOCK 11
     5  DEGRAD/.01745329251/,SHIFT/01504000000000/,VOKT/1.77625736/,           BLOCK 12
     6 F1E3/1000./,LOG4P1/10.9920986/,F1MIN/02007777777777/,F3/3./,             BLOCK 13
     7 F90/90./,F180/180./                                                      BLOCK 14
      DATA AR1/22/,BR1/28/,INPT/5/,IPRT/6/,IPLT/15/                             BLOCK 15
      DATA HED/52H1PROGRAM B00003 -- DOPPLER CONTENT OF REVERBERATION /         BLOCK 16
      DATA (HEADS(I), I = 1, 41)/30H  DOPPLER BAND,     KNOTS      ,            BLOCK 17
     1                           30H FREQUENCY BAND,  KILOHERTZ   ,            BLOCK 18
     2                           30H PURE TONE   AFTER SPREADING  ,            BLOCK 19
     3                           30H                              ,            BLOCK 20
     4                           30H       SPREAD WITH FILTER     ,            BLOCK 21
     5                           30H         SPREAD WITH TVG      ,            BLOCK 22
     6                           30H  SPREAD WITH FILTER AND TVG  ,            BLOCK 23
     7                      36H KNOTS HERTZFROM-    TO-       TIME /           BLOCK 24
      DATA (NTOT1(I), I = 1, 4)/24HTOTAL REVERBERATION FROM/                    BLOCK 25
      DATA (NTOT2(I), I = 1, 3)/18H BANDS, EACH OF   /                          BLOCK 26
      DATA (NTOT3(I), I = 1, 3)/18H       BANDWIDTH  /                          BLOCK 27
      DATA ITADMM/1/,IPEVRY/1/                                                  BLOCK 28
C                                                                               BLOCK 29
      DATA          NNAMES/40/,NAMCNT/24 * 0/,LFLAGS/16 * .FALSE./              BLOCK 30
      DATA          ((NAMBAT(I,J), J = 1, 3), I = 1, 40)/                       BLOCK 31
     A              6H1DC   ,   0, 4,6HDATE  ,   1, 2,6H1DV   ,  3, 1,BLOCK 32
     B              6HDO    ,   4, 1,6HCO    ,   5, 1,6HALPHC  ,  6, 1,BLOCK 33
     C              6HPING  ,   7, 1,6HDBTTM ,   8, 1,6HLOGRV  ,  9, 1,BLOCK 34
     D              6HS     ,  10, 1,6HXI    ,  11, 1,6HVS     , 12, 1,BLOCK 35
     E              6HBWIDTH,  13, 1,6HDELT  ,  14, 1,6HFO     , 15, 1,BLOCK 36
     F              6HNBEAM ,  16, 1,6HOMEGA ,  17, 1,6HTNTMAX, 18, 1,BLOCK 37
     G              6HPULSE , 19, 1,6HPRINTE,  20,  1,                BLOCK 38
     H              6HTIME  ,21,400,6HSSPRED,421,150,6HDSPRED,571,150,BLOCK 39
     I              6HVSPRED,721,150,                                  BLOCK 40
     J              6HCENTER,   0, 1,6HGO    ,   0, 1,6HEND    ,  0,1,BLOCK 41
     K              6HFILTER,   0, 1,6HKNOTS ,   0, 1,6HNOBOTT,  0,1,BLOCK 42
     L              6HNOPRIN,   0, 1,6HNOSURF,   0, 1,6HNOTAPE,  0,1,BLOCK 43
     M              6HNOVOLU,   0, 1,6HPLOT  ,   0, 1,6HSPREAD,  0,1,BLOCK 44
     N              6HTIMECO,   0, 1,6HTOTALS,   0, 1,6HTVG   ,  0,1,BLOCK 45
     O              6HRELATI,   0, 1/                                  BLOCK 46
      END                                                               BLOCK 47
```

APPENDIX G

SYMBOL		REFERENCES
AR1	-	15DA
BR1	-	15DA
DCORN1	-	3
DCORN6	-	4
DEGRAD	-	12DA
F1	-	8DA
F10	-	9DA
F180	-	14DA
F1E3	-	13DA
F1MIN	-	13DA
F2	-	9DA
F20	-	10DA
F3	-	13DA
F4	-	9DA
F90	-	14DA
FLOG10	-	10DA
FPT5	-	7DA
HEADS	-	17DA
HED	-	16DA
HTOT1	-	25DA
HTOT2	-	26DA
HTOT3	-	27DA
I	-	7DA 8DA 9DA 17DA 25DA 26DA 27DA 31DA
INFNT	-	10DA
INPT	-	15DA
IPEVRY	-	28DA
IPLT	-	15DA
IPRT	-	15DA
ITABNN	-	28DA
J	-	31DA
K0	-	6DA
K1	-	6DA
K10	-	6DA
K2	-	6DA
K3	-	6DA
K40	-	6DA
K5	-	6DA
K6	-	6DA
K8	-	6DA
LFLAGS	-	30DA
LOG4PI	-	13DA
NAMCNT	-	30DA
NAMDAT	-	31DA
NNAMES	-	30DA
PI	-	11DA
PI23	-	11DA
SHIFT	-	12DA
TRS	-	7DA
TRS2	-	8DA
TRS3	-	9DA
TWOPI	-	11DA
YDKT	-	12DA
1BLCK	-	1

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```
      1          FUNCTION FNCNS(ARG)                                    FNCNS  1
      2      C                                                          FNCNS  2
      3          ENTRY OXL (IFLAG,COSA,COSB,COSC)                       FNCNS  3
      4      C                                                          FNCNS  4
      5      C       NBEAM = 0 FOR NARROW BEAM                          FNCNS  5
      6      C             = 1 FOR BROAD BEAM                           FNCNS  6
      7      C       IFLAG = 0 FOR RECEIVE                              FNCNS  7
      8      C             = 1 FOR TRANSMIT                             FNCNS  8
      9      C                                                          FNCNS  9
     10          COMMON /CINPUT/ X(16), NBEAM                           FNCNS 10
     11      C                                                          FNCNS 11
     12          A = ACOS(COSA)                                         FNCNS 12
     13          FCNS = 10**(-2.*A)                                     FNCNS 13
     14          IF (IFLAG .EQ. 0) GO TO 1                              FNCNS 14
     15          FCNS = FCNS * COS(A*2.0)**2                            FNCNS 15
     16          IF (NBEAM .NE. 0) RETURN                               FNCNS 16
     17          FCNS = FCNS * ABS(COSA)                                FNCNS 17
     18        1 FCNS = FCNS * COS(A*4.0)**2                            FNCNS 18
     19          RETURN                                                 FNCNS 19
     20      C                                                          FNCNS 20
     21          ENTRY RRF(FREQ)                                        FNCNS 21
     22      C                                                          FNCNS 22
     23          FNCNS = 1. - (FREQ/31.4159)**4                         FNCNS 23
     24          RETURN                                                 FNCNS 24
     25      C                                                          FNCNS 25
     26          ENTRY TVGF(TIME)                                       FNCNS 26
     27      C                                                          FNCNS 27
     28          FNCNS = 0.1 + .9 * TIME/2.                             FNCNS 28
     29          RETURN                                                 FNCNS 29
     30          END                                                    FNCNS 30
```

APPENDIX G

FUNCTION FNCNS(ARG)

SYMBOL		REFERENCES				
1	-	14	18*			
A	-	12=	13	15	18	
ABS	-	17				
ACOS	-	12				
ARG	-	1A6				
CINPUT	-	10CL				
COS	-	15	18			
COSA	-	3	12	17		
COSB	-	3				
COSC	-	3				
FCNS	-	13=	15=	17=	18=	
FNCNS	-	1	23=	28=		
FREQ	-	21	23			
IFLAG	-	3	14			
NBEAR	-	10C0	16			
OXL	-	3				
RETURN	-	16	19	24	29	
RRF	-	21				
TIME	-	26	28			
TVGF	-	26				
X	-	10C0				

```
  1            SUBROUTINE SORT(ARRAY,LENGTH)                                  SORT   1
  2            DIMENSION ARRAY(1)                                             SORT   2
  3      C                                                                    SORT   3
  4      C         SORT IN ASCENDING ORDER (SIMPLE REPLACEMENT SORT)           SORT   4
  5      C                                                                    SORT   5
  6            IF (LENGTH .LE.1) GO TO 4                                      SORT   6
  7            DO 2 J = 2,LENGTH                                              SORT   7
  8            IF (ARRAY(J) .GE. ARRAY(J-1)) GO TO 2                          SORT   8
  9            TEMP = ARRAY(J)                                                SORT   9
 10            I = J                                                          SORT  10
 11      C                                                                    SORT  11
 12          1 ARRAY(I) = ARRAY(I-1)                                          SORT  12
 13            I = I - 1                                                      SORT  13
 14            IF ((I .GT. 1) .AND. (TEMP .LT. ARRAY(I-1))) GO TO 1           SORT  14
 15            ARRAY(I) = TEMP                                                SORT  15
 16          2 CONTINUE                                                       SORT  16
 17      C                                                                    SORT  17
 18      C         REMOVE DUPLICATE ENTRIES                                   SORT  18
 19      C                                                                    SORT  19
 20            DO 3 I = 2, LENGTH                                             SORT  20
 21            IF (ARRAY(I) .EQ. ARRAY(I-1)) GO TO 5                          SORT  21
 22          3 CONTINUE                                                       SORT  22
 23          4 RETURN                                                         SORT  23
 24      C                                                                    SORT  24
 25          5 J = LENGTH                                                     SORT  25
 26            LENGTH = I - 1                                                 SORT  26
 27          6 IF (I .GE. J) GO TO 4                                          SORT  27
 28            I = I + 1                                                      SORT  28
 29            IF (ARRAY(I) .EQ. ARRAY(I-1)) GO TO 6                          SORT  29
 30            LENGTH = LENGTH + 1                                            SORT  30
 31            ARRAY(LENGTH) = ARRAY(I)                                       SORT  31
 32            GO TO 6                                                        SORT  32
 33      C                                                                    SORT  33
 34            END                                                            SORT  34
```

APPENDIX G

I N D E X

SUBROUTINE SORT(ARRAY,LENGTH)

SYMBOL		REFERENCES									
1	-	12*	14								
2	-	7	8	16*							
3	-	20	22*								
4	-	6	23*	27							
5	-	21	25*								
6	-	27*	29	32							
ARRAY	-	1A6	2B1	8	9	12=	14	15=	21	29	31=
I	-	10=	12	13=	14	15	20=	21	26	27	28=
		29	31								
J	-	7=	8	9	10	25=	27				
LENGTH	-	1A6	6	7	20	25	26=	30=	31		
RETURN	-	23									
SORT	-	1									
TEMP	-	9=	14	15							

```
      1            FUNCTION TABLKP(ARG,INDEP,DEPND,ITABMN,ITABMX)          TABLKP  1
      2      C                                                             TABLKP  2
      3            COMMON /CTBLKP/ DELIND,DELDEP,FACTOR,ITABLE             TABLKP  3
      4            DIMENSION INDEP(1),DEPND(1)                             TABLKP  4
      5            REAL INDEP                                              TABLKP  5
      6      C                                                             TABLKP  6
      7            DELIND = INDEP(2) - INDEP (1)                           TABLKP  7
      8            DO 3 ITABLE = ITABMN, ITABMX                            TABLKP  8
      9            FACTOR = ARG - INDEP(ITABLE)                            TABLKP  9
     10            IF (FACTOR * DELIND) 5, 6, 3                            TABLKP10
     11          3 CONTINUE                                                TABLKP11
     12          4 ITABLE = 0                                              TABLKP12
     13            GO TO 7                                                 TABLKP13
     14      C                                                             TABLKP14
     15          5 IF (ITABLE .EQ. 1) GO TO 4                              TABLKP15
     16            DELIND = INDEP(ITABLE) - INDEP(ITABLE-1)                TABLKP16
     17            FACTOR = FACTOR/DELIND                                  TABLKP17
     18      C                                                             TABLKP18
     19          6 TABLKP = AINTRP(DEPND)                                  TABLKP19
     20          7 RETURN                                                  TABLKP20
     21            END                                                     TABLKP21
```

APPENDIX G

I N D E X PAGE 50

FUNCTION TABLKP(ARG,INDEP,DEPND,ITABNN,ITABNX)

SYMBOL		REFERENCES					
3	-	8	10	11*			
4	-	12*	15				
5	-	10	15*				
6	-	10	19*				
7	-	13	20*				
AINTRP	-	19					
ARG	-	1A6	9				
CTBLKP	-	3CL					
DELDEP	-	3C0					
DELIND	-	3C0	7=	10	16=	17	
DEPND	-	1A6	4DI	19			
FACTOR	-	3C0	9=	10	17=		
INDEP	-	1A6	4DI	5RL	7	9	16
ITABLE	-	3C0	8=	9	12=	15	16
ITABNN	-	1A6	8				
ITABNX	-	1A6	8				
RETURN	-	20					
TABLKP	-	1	19=				

I N D E X


```
      1            FUNCTION AINTRP(DEPND)                                  AINTRP 1
      2      C                                                             AINTRP 2
      3            COMMON /CTBLKP/ DELIND,DELDEP,FACTOR,ITABLE             AINTRP 3
      4            DIMENSION DEPND(1)                                      AINTRP 4
      5      C                                                             AINTRP 5
      6            IF (FACTOR .NE. 0.) GO TO 1                             AINTRP 6
      7            AINTRP = DEPND(ITABLE)                                  AINTRP 7
      8            GO TO 2                                                 AINTRP 8
      9      C                                                             AINTRP 9
     10          1 DELDEP = DEPND(ITABLE) - DEPND(ITABLE-1)                AINTRP10
     11            AINTRP = DEPND(ITABLE) + DELDEP * FACTOR                AINTRP11
     12          2 RETURN                                                  AINTRP12
     13            END                                                     AINTRP13
```

FUNCTION AINTRP(DEPND)

SYMBOL		REFERENCES				
1	-	6	10*			
2	-	8	12*			
AINTRP	-	1	7=	11=		
CTBLKP	-	3CL				
DELDEP	-	3CO	10=	11		
DELIND	-	3CO				
DEPND	-	1A6	4DI	7	10	11
FACTOR	-	3CO	6	11		
ITABLE	-	3CO	7	10	11	
RETURN	-	12				

```
I N D E X                                                                    PAGE  53

      1            SUBROUTINE INPUT(NAMTAB,DATA,INPFLG,OUTFLG)                    INPUT  1
      2      C                                                                    INPUT  2
      3            COMMON /CINCOD/ INAP,IIMAGE,IPAGE(80),IBLANK,NUMBER(21)        INPUT  3
      4            EQUIVALENCE (IQUOTE,NUMBER(17)),(ICOMMA,NUMBER(20))            INPUT  4
      5            EQUIVALENCE (IEQUAL,NUMBER(21))                                INPUT  5
      6            COMMON /CMACHN/ NWORD,NCHAR,MAXCOL                             INPUT  6
      7      C                                                                    INPUT  7
      8            LOGICAL BCDFLG,DECPT,EXPNT,CXBOTH,OUTFLG,LVALUE,LTRUE          INPUT  8
      9            DOUBLE PRECISION  VALUE,D10                                    INPUT  9
     10            DIMENSION NAMTAB(1),DATA(1),AVALUE(1)                          INPUT 10
     11            EQUIVALENCE (VALUE,AVALUE,IVALUE,LVALUE,NAME),(I,IIMAGE),      INPUT 11
     12           1    (NTRUE,LTRUE)                                              INPUT 12
     13            DATA ITYPE/0/,J/3/,ITRUE/5HTRUE./,D10/1.D1/,FRMAT1/6H(80A1)/,  INPUT 13
     14           1    LTRUE/.TRUE./                                              INPUT 14
     15      C                                                                    INPUT 15
     16      C          ITYPE = 1, INTEGER (NO DECIMAL POINT)                     INPUT 16
     17      C          ITYPE = 2, REAL (WITH OR WITHOUT EXPONENT)                INPUT 17
     18      C          ITYPE = 3, DOUBLE PRECISION (D-TYPE EXPONENT)             INPUT 18
     19      C          ITYPE = 4, COMPLEX (TWO REAL NUMBERS IN PARENTHESES)      INPUT 19
     20      C          ITYPE = 5, LOGICAL (.TRUE. OR .FALSE. ONLY)               INPUT 20
     21      C          ITYPE = 6, ALPHAMERIC (ENCLOSED IN APOSTROPHES, THUS 'ABC')INPUT 21
     22      C                                                                    INPUT 22
     23            GO TO (1260, 1600, 1030, 2000), J                              INPUT 23
     24       1030 READ FRMAT1, IMAGE                                             INPUT 24
     25            IF (OUTFLG) PRINT 2001, IMAGE                                  INPUT 25
     26            I = 0                                                          INPUT 26
     27            GO TO 1600                                                     INPUT 27
     28       1100 I = I + 1                                                      INPUT 28
     29            IF (ITYPE .EQ. 6) GO TO 1160                                   INPUT 29
     30            IF (IMAGE(I) .EQ. IBLANK) GO TO 1900                           INPUT 30
     31            IF (IMAGE(I) .NE. ICOMMA) GO TO (1130, 1110), J                INPUT 31
     32       1105 GO TO (1200, 1400), J                                          INPUT 32
     33       1110 DO 1120 K = 1, 19                                              INPUT 33
     34            IF (IMAGE(I) .NE. NUMBER(K)) GO TO 1120                        INPUT 34
     35            IF (K .LT. 18) GO TO 1300                                      INPUT 35
     36            IF (DECPT) GO TO 1300                                          INPUT 36
     37       1120 CONTINUE                                                       INPUT 37
     38            IF (L + NAME .NE. 0) GO TO 1995                                INPUT 38
     39            J = 1                                                          INPUT 39
     40            IF (DECPT) ITYPE = 5                                           INPUT 40
     41       1130 IF (IMAGE(I) .EQ. IEQUAL) GO TO 1200                           INPUT 41
     42       1140 IF (L .LT. NWORD) GO TO 1150                                   INPUT 42
     43            IF (ITYPE .NE. 6) GO TO (1900, 1210), J                        INPUT 43
     44            IF (BCDFLG) I = I - 1                                          INPUT 44
     45            GO TO (1500, 1210), J                                          INPUT 45
     46       1150 FLD(L,NCHAR,NAME) = FLD(0,NCHAR,IMAGE(I))                      INPUT 46
     47            L = L + NCHAR                                                  INPUT 47
     48            GO TO (1900, 1140), J                                          INPUT 48
     49       1160 IF (BCDFLG) GO TO 1170                                         INPUT 49
     50            IF (IMAGE(I) .EQ. ICOMMA) GO TO 1200                           INPUT 50
     51            GO TO 1900                                                     INPUT 51
     52       1170 IF (IMAGE(I) .NE. IQUOTE) GO TO 1140                           INPUT 52
     53            NQT = 1 - NQT                                                  INPUT 53
     54            IF (NQT .EQ. 0) GO TO 1140                                     INPUT 54
     55            IF (IMAGE(I+1) .NE. IQUOTE) BCDFLG = .FALSE.                   INPUT 55
     56            GO TO 1900                                                     INPUT 56
     57       1200 J = 2                                                          INPUT 57
     58            K = I                                                          INPUT 58
     59            I = 81                                                         INPUT 59
     60            GO TO 1140                                                     INPUT 60
     61       1210 I = K                                                          INPUT 61
     62            IF (ITYPE .GE. 5) GO TO 1500                                   INPUT 62
     63            NNAMES = NAMTAB(1)                                             INPUT 63
     64            INPFLG = 0                                                     INPUT 64
     65            NAMSAV = NAME                                                  INPUT 65
     66            DO 1220 K = 1, NNAMES                                          INPUT 66
     67            IF (NAME .NE. NAMTAB(K+1)) GO TO 1220                          INPUT 67
     68            IF (ITYPE .EQ. 0) GO TO 1260                                   INPUT 68
     69            J = 1                                                          INPUT 69
     70            GO TO 1999                                                     INPUT 70
```

SUBROUTINE INPUT(NAMTAB,DATA,INPFLG,OUTFLG)

```
 71      1220 CONTINUE                                                          INPUT 71
 72           GO TO 1996                                                        INPUT 72
 73      1260 NL = NNAMES + K + 1                                               INPUT 73
 74           NM = NNAMES + NL                                                  INPUT 74
 75           NC = NNAMES + NM                                                  INPUT 75
 76           NAMTAB(NC) = 0                                                    INPUT 76
 77           IF (IMAGE(1) .EQ. IEQUAL) GO TO 1600                              INPUT 77
 78           J = 2                                                             INPUT 78
 79           NAMTAB(NC) = NTRUE                                                INPUT 79
 80           GO TO 1998                                                        INPUT 80
 81      1300 IF (K .GT. 10) GO TO 1320                                         INPUT 81
 82           IF (.NOT. EXPNT) GO TO 1310                                       INPUT 82
 83           IEXP = IEXP * 10 + SIGN(K - 1, IESIGN)                            INPUT 83
 84           GO TO 1900                                                        INPUT 84
 85      1310 IF (DECPT) L = L + 1                                              INPUT 85
 86           VALUE = VALUE * D10 + DBLE(FLOAT(SIGN(K - 1, IVSIGN)))            INPUT 86
 87           GO TO 1900                                                        INPUT 87
 88      1320 K = K - 10                                                        INPUT 88
 89           GO TO (1330, 1330, 1350, 1360, 1380, 1900, 1390, 1325, 1335),K    INPUT 89
 90      1325 ITYPE = 3                                                         INPUT 90
 91      1330 IF (.NOT. DECPT) GO TO 1340                                       INPUT 91
 92           IF (K .EQ. 2) IESIGN = - 1                                        INPUT 92
 93      1335 EXPNT = .TRUE.                                                    INPUT 93
 94           GO TO 1900                                                        INPUT 94
 95      1340 IF (K .EQ. 2) IVSIGN = - 1                                        INPUT 95
 96           GO TO 1900                                                        INPUT 96
 97      1350 DECPT = .TRUE.                                                    INPUT 97
 98           ITYPE = 2                                                         INPUT 98
 99           GO TO 1900                                                        INPUT 99
100      1360 IREPT = VALUE                                                     INPUT100
101           GO TO 1620                                                        INPUT101
102      1380 ITYPE = 4                                                         INPUT102
103           GO TO 1900                                                        INPUT103
104      1390 ITYPE = 6                                                         INPUT104
105           BCDFLG = .TRUE.                                                   INPUT105
106           J = 1                                                             INPUT106
107           NBT = 0                                                           INPUT107
108           GO TO 1900                                                        INPUT108
109      1400 IF (INPFLG .NE. 0) GO TO 1600                                     INPUT109
110           L = IEXP - L                                                      INPUT110
111           IEXP = ABS(L)                                                     INPUT111
112           DO 1430 K = 1, IEXP                                               INPUT112
113           IF (L) 1410, 1440, 1420                                           INPUT113
114      1410 VALUE = VALUE/D10                                                 INPUT114
115           GO TO 1430                                                        INPUT115
116      1420 VALUE = VALUE * D10                                               INPUT116
117      1430 CONTINUE                                                          INPUT117
118      1440 IF (ITYPE .NE. 4) GO TO 1500                                      INPUT118
119           IF (CXBOTH) GO TO 1500                                            INPUT119
120           CXVAL = VALUE                                                     INPUT120
121           CXBOTH = .TRUE.                                                   INPUT121
122           GO TO 1610                                                        INPUT122
123      1500 IF (INPFLG .NE. 0) GO TO 1600                                     INPUT123
124           DO  1590 K = 1, IREPT                                             INPUT124
125      1505 INDEX = NAMTAB(NC) + 1                                            INPUT125
126           IF (INDEX .GT. NAMTAB(NM)) GO TO 1997                             INPUT126
127           NAMTAB(NC) = INDEX                                                INPUT127
128           INDEX = INDEX + NAMTAB(NL)                                        INPUT128
129           GO TO (1520, 1530, 1540, 1540, 1560, 1580, 1570), ITYPE           INPUT129
130      1520 IVALUE = VALUE                                                    INPUT130
131      1525 DATA(INDEX) = AVALUE(1)                                           INPUT131
132           GO TO 1590                                                        INPUT132
133      1530 DATA(INDEX) = VALUE                                               INPUT133
134           GO TO 1590                                                        INPUT134
135      1540 INDEX = INDEX + NAMTAB(NC) - 1                                    INPUT135
136           IF (ITYPE .EQ. 4) GO TO 1550                                      INPUT136
137           DATA(INDEX+1) = AVALUE(2)                                         INPUT137
138           GO TO 1525                                                        INPUT138
139      1550 DATA(INDEX) = CXVAL                                               INPUT139
140           DATA(INDEX+1) = VALUE                                             INPUT140
```

APPENDIX G

```
141          GO TO 1590                                                INPUT141
142     1560 LVALUE = .FALSE.                                          INPUT142
143          IF (NAME .EQ. ITRUE) LVALUE = .TRUE.                      INPUT143
144          GO TO 1525                                                INPUT144
145     1570 M = INDEX - IEXP                                          INPUT145
146          DATA(INDEX) = DATA(M)                                     INPUT146
147          IF (M .EQ. L) GO TO 1585                                  INPUT147
148          GO TO 1505                                                INPUT148
149     1580 DATA(INDEX) = AVALUE(1)                                   INPUT149
150          IEXP = IEXP + 1                                           INPUT150
151          IF (BCDFLG) GO TO 1610                                    INPUT151
152          ITYPE = 7                                                 INPUT152
153     1585 L = INDEX                                                 INPUT153
154     1590 CONTINUE                                                  INPUT154
155     1600 CXBOTH = .FALSE.                                          INPUT155
156          IREPT = 1                                                 INPUT156
157          J = 2                                                     INPUT157
158          K = 0                                                     INPUT158
159          ITYPE = 1                                                 INPUT159
160     1610 L = 0                                                     INPUT160
161          IEXP = 0                                                  INPUT161
162          IESIGN = 0                                                INPUT162
163          IVSIGN = 0                                                INPUT163
164          DECPT = .FALSE.                                           INPUT164
165          EXPNT = .FALSE.                                           INPUT165
166     1620 VALUE  =  0.                                              INPUT166
167     1900 IF (I .LT. MAXCOL) GO TO 1100                             INPUT167
168          IF (K .NE. 0) GO TO 1105                                  INPUT168
169          GO TO 1030                                                INPUT169
170     1995 IF (INPFLG .NE. 0) GO TO 1900                             INPUT170
171          INPFLG = 1                                                INPUT171
172     1996 INPFLG = 1 + INPFLG                                       INPUT172
173     1997 INPFLG = 1 + INPFLG                                       INPUT173
174          J = 4                                                     INPUT174
175     1998 ITYPE = 0                                                 INPUT175
176     1999 RETURN                                                    INPUT176
177     2000 IF (INPFLG .EQ. 0) GO TO 1600                             INPUT177
178          IF (.NOT. OUTFLG) PRINT 2001, IMAGE                       INPUT178
179     2001 FORMAT (20X,80A1)                                         INPUT179
180          DO 2010 J = 1, 90                                         INPUT180
181          IMAGE(J) = IBLANK                                         INPUT181
182     2010 CONTINUE                                                  INPUT182
183          IMAGE(IIMAGE) = NUMBER(14)                                INPUT183
184          PRINT 2001, IMAGE                                         INPUT184
185          J = 2                                                     INPUT185
186          GO TO (2020, 2030, 2040), INPFLG                          INPUT186
187     2020 PRINT 2021, NAMSAV                                        INPUT187
188     2021 FORMAT (20X, 17HTOO MUCH DATA IN , A6/)                   INPUT188
189          GO TO 1999                                                INPUT189
190     2030 PRINT 2031, NAMSAV                                        INPUT190
191     2031 FORMAT (20X, A6, 17H NOT IN NAME LIST/)                   INPUT191
192          GO TO 1999                                                INPUT192
193     2040 PRINT 2041                                                INPUT193
194     2041 FORMAT (20X, 33HSYNTAX ERROR OR ILLEGAL CHARACTER/)       INPUT194
195          GO TO 1999                                                INPUT195
196          END                                                       INPUT196
```

SYMBOL		REFERENCES									
1030	-	23	24*	169							
1100	-	28*	167								
1105	-	32*	168								
1110	-	31	33*								
1120	-	33	34	37*							
1130	-	31	41*								
1140	-	42*	48	52	54	60					
1150	-	42	46*								
1160	-	29	49*								
1170	-	49	52*								
1200	-	32	41	50	57*						
1210	-	43	45	61*							
1220	-	66	67	71*							
1260	-	23	68	73*							
1300	-	35	36	81*							
1310	-	82	85*								
1320	-	81	88*								
1325	-	89	90*								
1330	-	89	91*								
1335	-	89	93*								
1340	-	91	95*								
1350	-	89	97*								
1360	-	89	100*								
1380	-	89	102*								
1390	-	89	104*								
1400	-	32	109*								
1410	-	113	114*								
1420	-	113	116*								
1430	-	112	115	117*							
1440	-	113	118*								
1500	-	45	62	118	119	123*					
1505	-	125*	148								
1520	-	129	130*								
1525	-	131*	138	144							
1530	-	129	133*								
1540	-	129	135*								
1550	-	136	139*								
1560	-	129	142*								
1570	-	129	145*								
1580	-	129	149*								
1585	-	147	153*								
1590	-	124	132	134	141	154*					
1600	-	23	27	77	109	123	155*	177			
1610	-	122	151	160*							
1620	-	101	166*								
1900	-	30	43	48	51	56	84	87	89	94	96
		99	103	108	167*	170					
1995	-	38	170*								
1996	-	72	172*								
1997	-	126	173*								
1998	-	80	175*								
1999	-	70	176*	189	192	195					
2000	-	23	177*								
2001	-	25PR	178PR	179*	184PR						
2010	-	180	182*								
2020	-	186	187*								
2021	-	187PR	188*								
2030	-	186	190*								
2031	-	190PR	191*								
2040	-	186	193*								
2041	-	193PR	194*								
ABS	-	111									
AVALUE	-	100I	11E0	131	137	149					
BCDFLG	-	8L6	44	49	55=	105=	151				
CINCOD	-	3CL									
CMACHN	-	6CL									
CXBOTH	-	8L6	119	121=	155=						
CXVAL	-	120=	139								

D10 - 9DB 13DA 86 114 116
DATA - 1AG 10DI 131= 133= 137= 139= 140= 146= 149=
DBLE - 86
DECPT - 8LG 36 40 85 91 97= 164=
EXPNT - 8LG 82 93= 165=
FLD - 46=
FLOAT - 86
FRMAT1 - 13DA 24RD
I - 11EQ 26= 28= 30 31 34 41 44= 50 52
55 58 59= 61= 77 167
IBLANK - 3CO 30 181
ICOMMA - 4EQ 31 50
IEQUAL - 5EQ 41 77
IESIGN - 83 92= 162=
IEXP - 83= 110 111= 112 145 150= 161=
IIMAGE - 3CO 11EQ 183
IMAGE - 3CO 24RD 25PR 30 31 34 41 50 52 55
77 178PR 181= 183= 184PR
INAM - 3CO
INDEX - 125= 126 127 128= 131 133 135= 137 139 140
145 146 149 153
INPFLG - 1AG 64= 109 123 170 171= 172= 173= 177 186
INPUT - 1
IQUOTE - 4EQ 52 55
IREPT - 100= 124 156=
ITRUE - 13DA 143
ITYPE - 13DA 29 40= 43 62 68 90= 98= 102= 104=
118 129 136 152= 159= 175=
IVALUE - 11EQ 130=
IVSIGN - 86 95= 163=
J - 13DA 23 31 32 39= 43 45 48 57= 69=
73= 106= 157= 174= 180= 181 185=
K - 33= 34 35 58= 61 66= 67 73 81 83
86 88= 89 92 95 112= 124= 158= 168
L - 38 42 46 47= 85= 110= 111 113 147 153=
160=
LTRUE - 8LG 12EQ 14DA
LVALUE - 3LG 11EQ 142= 143=
M - 145= 146 147
MAXCOL - 6CO 167
NAME - 11EQ 38 46 65 67 143
NAMSAV - 65= 187PR 190PR
NAMTAB - 1AG 10DI 63 67 76= 79= 125 126 127= 128
135
NC - 75= 76 79 125 127 135
NCHAR - 6CO 46 47
NL - 73= 74 128
NM - 74= 75 126
NNAMES - 63= 66 73 74 75
NOT - 53= 54 107=
NTRUE - 12EQ 79
NUMBER - 3CO 4EQ 5EQ 34 183
NWORD - 6CO 42
OUTFLG - 1AG 8LG 25 178
RETURN - 176
SIGN - 83 86
VALUE - 9DB 11EQ 86= 100 114= 116= 120 130 133 140
166=

BLOCK DATA FOR INPUT SUBROUTINE

```
      1          BLOCK DATA                                                        BLOCK  1
      2          COMMON /CINCOD/ INAM,IIMAGE,IMAGE(80),IBLANK,NUMBER(21)           BLOCK  2
      3          DATA IBLANK/1H /                                                  BLOCK  3
      4          DATA (NUMBER(I),I=1,21)/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,  BLOCK  4
      5         1                       1H+,1H-,1H.,1H*,1H(,1H),1H',1H$,1HE,1H,,1H=/ BLOCK  5
      6     C                                                                     BLOCK  6
      7     C         NOTE THAT THE FOLLOWING DATA IS MACHINE DEPENDENT.           BLOCK  7
      8     C         NWORD = NO.OF BITS IN MACHINE WORD.                         BLOCK  8
      9     C         NCHAR = NO.OF BITS IN ALPHA-NUMERIC CHARACTER.              BLOCK  9
     10     C         MAXCOL = NO.OF COLUMNS TO BE READ FROM CARDS.               BLOCK 10
     11     C                                                                     BLOCK 11
     12          COMMON /CMACHN/ NWORD,NCHAR,MAXCOL                               BLOCK 12
     13          DATA NWORD/36/,NCHAR/6/,MAXCOL/80/                               BLOCK 13
     14          END                                                              BLOCK 14
```

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BLOCK DATA FOR INPUT SUBROUTINE

SYMBOL	REFERENCES		
CINCOD	-	2CL	
CMACHN	-	12CL	
I	-	4DA	
IBLANK	-	2CO	36A
IIMAGE	-	2CO	
IPAGE	-	2CO	
INAM	-	2CO	
MAXCOL	-	12CO	13DA
NCHAR	-	12CO	13DA
NUMBER	-	2CO	4DA
NWORD	-	12CO	13DA
IBLCKO	-	1	

APPENDIX G

********** SUPER INDEX **********

SYMBOL	ROUTINES IN WHICH THE SYMBOL IS USED						
A	FNCNS	RBCOMP	RBSORT				
A1	RVCOMP						
A2	RVCOMP						
ABS	BCOMP	FNCNS	INPUT	RBCOMP	RBSORT	RVCOMP	RVSPRD
ACOS	FNCNS						
AINT	BCOMP						
AINTRP	RBCOMP	TABLKP					
ALOG10	RTCOMP						
ALPHC	DCOMN1	RVCOMP					
AMAX1	RBCOMP	RVCOMP					
AMIN1	RBCOMP						
AMOD	RBCOMP	RVCOMP					
AR1	DCOMN1	IDENT	RBSORT	1BLCK	1MAIN		
AR6	FNCNS	RBCOMP	TABLKP				
ARRAY	SORT						
ATAN2	RBCOMP						
AVALUE	INPUT						
B	BCOMP	RVCOMP					
BAND	BCOMP	DCOMN1	RBCOMP	RVCOMP			
BCDFLG	INPUT						
BCOMP	1MAIN						
BND	BCOMP						
BNDOUT	BCOMP	DCOMN1	RVPRNT				
BR1	DCOMN1	IDENT	RBCOMP	RBSORT	TCOMP	1BLCK	1MAIN
BWIDTH	DCOMN1	IDENT	RVPRNT				
BWINT	BCOMP	DCOMN1	IDENT				
C0	DCOMN1	IDENT	RVCOMP	RVPRNT			
CORT	BCOMP	DCOMN1	IDENT	RBCOMP			
CALFAP	RBCOMP						
CALFBP	RBCOMP						
CBAND	DCOMN1						
CCOUNT	DCOMN1						
CENTER	BCOMP	DCOMN1					
CFCNST	DCOMN1						
CGAMAP	RBCOMP						
CGAMBP	RBCOMP						
CHCNST	DCOMN1						
CINCOD	INPUT	1BLCK0					
CINDAT	DCOMN1						
CINDEF	DCOMN1						
CINPUT	DCOMN1	FNCNS					
CMACHN	INPUT	1BLCK0					
CNT	BCOMP						
CONTNU	RBCOMP						
COS	BCOMP	FNCNS	IDENT	RBCOMP	RVCOMP		
COSA	FNCNS	RBCOMP					
COSB	FNCNS	RBCOMP					
COSC	FNCNS						
COSORT	DCOMN5	RBCOMP					
COSTHA	DCOMN5	RBCOMP					
COSTHB	DCOMN5	RBCOMP					
CPRINT	DCOMN1						
CSA	RVCOMP						
CSALFA	RBCOMP						
CSALFB	RBCOMP						
CSBETA	RBCOMP						
CSBETB	RBCOMP						
CSGAMA	RBCOMP						
CSGAMB	RBCOMP						
CSKSI	DCOMN1	IDENT	RBCOMP	RVCOMP			
CSOPTB	RBCOMP						
CSORTF	RVCOMP						
CSPHI	RVCOMP						
CSPRED	DCOMN1						
CSTHAB	RBCOMP						
CSTHBB	RBCOMP						
CTAPE	DCOMN1						
CTBLKP	AINTRP	DCOMN1	TABLKP				

CTHTMP - RBCOMP
CXBOTH - INPUT
CXCNST - DCOMN1
CXVAL - INPUT
D - BCOMP RESORT RVCOMP
D0 - DCOMN1 RVPRNT
D10 - INPUT
DATA - INPUT
DBLE - INPUT
DBTTP - DCOMN1 RESORT RVPRNT
DCOMN1 - BCOMP IDENT RBCOMP RBSORT RTCOMP RVCOMP RVPRNT RVSPRD
TCOMP 1BLCK 1MAIN
DCOMN2 - RBCOMP RTCOMP RVCOMP RVPRNT RVSPRD 1MAIN
DCOMN3 - RBSORT TCOMP
DCOMN4 - RVCOMP
DCOMN5 - RBCOMP
DCOMN6 - 1BLCK
DD - RBCOMP RVCOMP
DECPT - INPUT
DEGRAD - BCOMP DCOMN1 IDENT RBCOMP 1BLCK
DELDEP - AINTRP DCOMN1
DELIND - DCOMN1 TABLKP
DELR - RBCOMP
DELT - DCOMN1 IDENT RBCOMP RVCOMP TCOMP
DELT2 - DCOMN1 IDENT RVPRNT
DEPND - AINTRP TABLKP
DOP - DCOMN5 RBCOMP
DOPSKP - RBCOMP
DR - DCOMN1 IDENT RVCOMP
E - BCOMP
END - DCOMN1 IDENT 1MAIN
EXP - IDENT RBCOMP RVCOMP
EXPNT - INPUT
EXPS - DCOMN1 IDENT RVCOMP
F - BCOMP
F0 - DCOMN1 RBCOMP RVCOMP
F1 - BCOMP DCOMN1 IDENT RBCOMP RTCOMP RVCOMP 1BLCK
F10 - DCOMN1 IDENT RTCOMP RVCOMP 1BLCK
F180 - BCOMP DCOMN1 IDENT 1BLCK
F1E3 - DCOMN1 IDENT 1BLCK
F1MIN - DCOMN1 1BLCK
F2 - DCOMN1 IDENT RBCOMP 1BLCK
F20 - DCOMN1 RBCOMP 1BLCK
F3 - DCOMN1 1BLCK
F4 - DCOMN1 IDENT 1BLCK
F90 - BCOMP DCOMN1 IDENT RBCOMP 1BLCK
FA - RBCOMP
FACTOR - AINTRP DCOMN1 TABLKP
FCC3 - DCOMN1 IDENT RVCOMP
FCCVS - DCOMN1 IDENT RBCOMP RVCOMP
FCNS - FNCNS
FCSGAM - DCOMN4 RVCOMP
FGAM - DCOMN1 RVCOMP
FILTER - BCOMP DCOMN1 IDENT RTCOMP
FLD - INPUT
FLOAT - INPUT
FLO610 - DCOMN1 IDENT RBCOMP RVCOMP 1BLCK
FNBAND - BCOMP DCOMN1 RVCOMP
FPTS - BCOMP DCOMN1 RBCOMP RVCOMP TCOMP 1BLCK
FR - RVCOMP
FREQ - FNCNS
FRMAT1 - INPUT
FRSQ - RVCOMP
FRV - RVCOMP
FX - RVCOMP
FXSQ - RVCOMP
FZ2 - DCOMN1 IDENT RVCOMP
FZRO - ECOMP DCOMN1 IDENT RBCOMP RVCOMP RVPRNT
FZSQ - DCOMN1 IDENT RVCOMP
G - RVCOMP

********** SUPER INDEX **********

GO - DCOMN1 IDENT
HBAND - DCOMN1 IDENT RVPRNT
HEADS - DCOMN1 IDENT 1BLCK
HED - DCOMN1 IDENT RVPRNT 1BLCK
HFROM - DCOMN1 IDENT
HOUTPT - DCOMN1 RVPRNT
HRVB - RVPRNT
HSPRD - DCOMN1 IDENT
HSPRV - DCOMN1 IDENT
HTIME - RVPRNT
HTOT1 - DCOMN1 RVPRNT 1BLCK
HTOT2 - DCOMN1 RVPRNT 1BLCK
HTOT3 - DCOMN1 IDENT RVPRNT 1BLCK
HUNIT - DCOMN1
I - BCOMP IDENT INPUT RBCOMP RBSORT RTCOMP RVCOMP RVPRNT
RVSPRD SORT TCOMP 1BLCK 1BLCK0
IBLANK - DCOMN1 INPUT 1BLCK0
IBOUND - TCOMP
ICOMMA - INPUT
ID - IDENT
IDATA - DCOMN1 IDENT
IDATE - DCOMN1 RVPRNT
IDC - DCOMN1 IDENT RVPRNT
IDENT - 1MAIN
IDOP - RBCOMP
IDV - DCOMN1 RVPRNT
IEQUAL - INPUT
IESIGN - INPUT
IEXP - INPUT
IFIX - BCOMP RVCOMP
IFLAG - FNCNS
IFZRO - DCOMN1
II - RBCOMP RVPRNT RVSPRD
IIMAGE - INPUT
IJ - RBCOMP
IMAGE - INPUT
IMAX - RTCOMP
INDEP - TABLKP
INDEX - INPUT
INFNT - DCOMN1 1BLCK
INPFLG - IDENT INPUT
INPT - DCOMN1 1BLCK
INPUT - IDENT
IPEVRY - BCOMP DCOMN1 RVPRNT TCOMP 1BLCK
IPLT - DCOMN1 RVPRNT 1BLCK 1MAIN
IPRT - DCOMN1 IDENT RVPRNT 1BLCK
IQUOTE - INPUT
IREPT - INPUT
ISIGN - RBCOMP
ITABLE - AINTRP DCOMN1 RBCOMP TABLKP TCOMP
ITABMN - TABLKP 1BLCK
ITABMX - TABLKP
ITOTAL - RVPRNT
ITRUE - INPUT
ITYPE - INPUT
IVALUE - INPUT
IVSIGN - INPUT
J - IDENT INPUT RBSORT RTCOMP RVCOMP RVPRNT RVSPRD SORT
TCOMP 1BLCK
JA - RBCOMP
JB - RBCOMP
JBOUND - RBCOMP
JC - RBCOMP
JD - RBCOMP
JDD - RBCOMP
JDELT - RBCOMP
JDMAX - RBCOMP
JDMIN - RBCOMP
JE - RBCOMP
JMAX - RBCOMP

JUMP - RBCOMP
K - IDENT INPUT RBSORT RVCOMP RVPRNT RVSPRD TCOMP
K0 - DCOMN1 1BLCK
K1 - BCOMP DCOMN1 IDENT RBCOMP RTCOMP RVCOMP RVPRNT RVSPRD
TCOMP 1BLCK ;MAIN
K10 - DCOMN1 IDENT 1BLCK
K2 - DCOMN1 IDENT RBCOMP RTCOMP RVCOMP TCOMP 1BLCK
K3 - DCOMN1 IDENT RBCOMP RTCOMP RVSPRD TCOMP 1BLCK
K40 - DCOMN1 RVPRNT TCOMP 1BLCK
K5 - DCOMN1 IDENT RVPRNT 1BLCK
K6 - DCOMN1 1BLCK
K8 - DCOMN1 RVPRNT 1BLCK
KBAND - RBCOMP
KK - RVSPRD
KSI - DCOMN1 IDENT
KSID - DCOMN1 IDENT RVPRNT
KT - DCOMN1 RBCOMP RTCOMP RVCOMP 1MAIN
KTIM - RBCOMP
KTSBND - BCOMP DCOMN1 IDENT
KTT - DCOMN1 RBCOMP RTCOMP RVCOMP 1MAIN
L - BCOMP IDENT INPUT RBCOMP RBSORT RVPRNT
LEAP - RBCOMP
LENGTH - SORT
LFLAGS - DCOMN1 1BLCK
LL - RBCOMP
LMBAND - BCOMP DCOMN1 DCOMN6 RVSPRD
LMBND1 - DCOMN1 DCOMN6 RTCOMP RVPRNT
LMKS - DCOMN1 DCOMN6 RBSORT
LMKS2 - DCOMN1 DCOMN6 RBCOMP
LMNT - DCOMN1 1MAIN
LMRB - DCOMN1 DCOMN6 1MAIN
LMSPRD - DCOMN1 DCOMN6
LMTIM - DCOMN1 DCOMN6 TCOMP
LMTRS - DCOMN1 DCOMN6 TCOMP
LOG4PI - DCOMN1 IDENT 1BLCK
LOGMV - DCOMN1 IDENT
LOGMVI - DCOMN1 IDENT RVCOMP
LTRUE - INPUT
LVALUE - INPUT
M - IDENT INPUT RBSORT TCOMP
MAX0 - IDENT
MAXCOL - INPUT 1BLCK0
MBAND - BCOMP DCOMN1
MIN0 - BCOMP RVCOMP 1MAIN
ML - RBCOMP
MLMU - RBCOMP
MM - RBCOMP
MN - RBCOMP
MNBND - BCOMP DCOMN1 RTCOMP RVPRNT TCOMP
MNMX - RBCOMP
MOD - BCOMP RVPRNT
MU - RBCOMP
MX - RBCOMP
N - RBSORT
NA - RBCOMP RBSORT
NAMCNT - DCOMN1 IDENT 1BLCK
NAMDAT - DCOMN1 1BLCK
NAME - INPUT
NAMSAV - INPUT
NAMTAB - INPUT
NB - RBCOMP RBSORT
NBAND - BCOMP DCOMN1 RBCOMP RVCOMP RVSPRD
NBEAR - DCOMN1 FNCNS
NBOUND - DCOMN1 RBCOMP TCOMP
NBSPRD - DCOMN1 IDENT
NBTM - DCOMN1 RBSORT
NC - INPUT RBSORT
NCHAR - INPUT 1BLCK0
ND - RBSORT
NEXT - RBCOMP

NL - INPUT
NM - INPUT
NMAX - TCOMP
NMIN - TCOMP
NN - RVCOMP
NNAMES - DCOMN1 IDENT INPUT 1BLCK
NOBTTM - DCOMN1 RBSORT
NOPRNT - DCOMN1 IDENT RVPRNT
NOSURF - DCOMN1 RVSORT
NOTAPE - DCOMN1 IDENT RBSORT TCOMP 1MAIN
NOVOLM - DCOMN1 1MAIN
NPAGE - DCOMN1 RVPRNT TCOMP
NPSTRT - BCOMP DCOMN1 RVPRNT TCOMP
NQT - INPUT
NSPR1 - DCOMN1 IDENT RVSPRD
NSPRN - BCOMP DCOMN1 IDENT RVSPRD
NSPRN1 - DCOMN1 IDENT RBCOMP RVCOMP RVSPRD
NSSPRD - DCOMN1 IDENT
NSURF - DCOMN1 RBSORT
NTBL - TCOMP
NTIME - DCOMN1 TCOMP 1MAIN
NTMAX - DCOMN1 RVPRNT 1MAIN
NTMIN - DCOMN1 RVPRNT 1MAIN
NTRUE - INPUT
NUMBER - INPUT 1BLCKD
NVSPRD - DCOMN1 IDENT
NWORD - INPUT 1BLCKD
OMEGA - DCOMN1 IDENT RBCOMP RVCOMP
OMEGAD - DCOMN1 IDENT RVPRNT
OMT - DCOMN5 RBCOMP RVCOMP
OPTD - RBCOMP
OMTTMU - RBCOMP
OUTFLG - IDENT INPUT
OXL - FNCNS RBCOMP RVCOMP
PAGE - DCOMN1 RVPRNT TCOMP
PHI - RBCOMP
PHMOMT - RBCOMP
PI - DCOMN1 RBCOMP RVCOMP 1BLCK
PI23 - DCOMN1 RVCOMP 1BLCK
PING - DCOMN1 RVPRNT TCOMP
PLOT - DCOMN1 RVPRNT 1MAIN
PN - RVCOMP
PULSE - DCOMN1
Q - BCOMP
QA - RBCOMP
QAABC - RBCOMP
QAB - RBCOMP
QABC - RBCOMP
QAC - RBCOMP
QB - RBCOMP
QBABC - RBCOMP
QBC - RBCOMP
QC - RBCOMP
QCOS - RBCOMP
QCOSM - RBCOMP
QSIN - RBCOMP
R - DCOMN5 RBCOMP RVCOMP
RBCOMP - 1MAIN
RBH - DCOMN3 RBSORT TCOMP
RBHA - DCOMN5 RBCOMP
RBHB - DCOMN5 RBCOMP
RBSORT - 1MAIN
RBT - DCOMN3 RBSORT TCOMP
RBTA - DCOMN5 RBCOMP
RBTB - DCOMN5 RBCOMP
RBTH - DCOMN3 RBSORT TCOMP
RBTHA - DCOMN5 RBCOMP
RBTHB - DCOMN5 RBCOMP
RBZ - DCOMN3 RBSORT TCOMP
RBZA - DCOMN5 RBCOMP

RBIB - BCOMN5 RBCOMP
RD - RBCOMP
RECV - BCOMN1 RBCOMP RVCOMP
RELBRD - BCOMP BCOMN1
RETURN - AINTRP BCOMP FNCNS IDENT INPUT RBCOMP RBSORT RTCOMP
RVCOMP RVPRNT RVSPRD SORT TABLKP TCOMP
REVERB - BCOMN2 1MAIN
RRF - BCOMP FNCNS
RRFS - BCOMP BCOMN1 RTCOMP
RT - RBCOMP
RTCOMP - 1MAIN
RV - BCOMN2 RBCOMP RVSPRD
RVB - BCOMN2 RTCOMP RVPRNT
RVCOMP - 1MAIN
RVPRNT - 1MAIN
RVS - BCOMN2 RTCOMP RVPRNT
RVSPRD - 1MAIN
RVT - BCOMN2 RTCOMP RVPRNT
RVV - BCOMN2 RTCOMP RVCOMP RVPRNT
S - BCOMN1 IDENT RBSORT RVPRNT
SHIFT - BCOMN1 RBSORT 1BLCK
SIGN - BCOMP INPUT RBCOMP RVCOMP
SIN - IDENT RBCOMP RVCOMP
SINOMT - BCOMN5 RBCOMP
SNA - RVCOMP
SNKSI - BCOMN1 IDENT RBCOMP RVCOMP
SNOMTB - RBCOMP
SNOMTF - RVCOMP
SNPHI - RVCOMP
SONTRU - RBCOMP
SORT - RBCOMP TCOMP
SPRCMP - IDENT
SPREAD - BCOMN1 IDENT RTCOMP RVPRNT TCOMP 1MAIN
SPRED - BCOMN1 RVSPRD
SQRT - RBCOMP RVCOMP
STOP - 1MAIN
T - BCOMN5 RBCOMP RTCOMP
T1 - RVCOMP
T2 - RVCOMP
T3 - RVCOMP
TABLKP - RBCOMP TCOMP
TCOMP - 1MAIN
TD - RBCOMP
TEMP - SORT
TEST - RBSORT
TNA - BCOMN5 RBCOMP
TNAB - RBCOMP
TNAT - RBCOMP
TNB - BCOMN5 RBCOMP
TNBB - RBCOMP
TNBT - RBCOMP
TNTMAX - BCOMP BCOMN1 IDENT RBCOMP
TIMCMP - BCOMN1 RBSORT TCOMP
TIME - BCOMN1 FNCNS RBCOMP RTCOMP RVCOMP RVPRNT TCOMP
TRIN - BCOMN3 RBSORT TCOMP
TOTALS - BCOMN1 IDENT RVPRNT TCOMP
TR - RTCOMP
TRS - BCOMN1 TCOMP 1BLCK
TRS2 - BCOMN1 1BLCK
TRS3 - BCOMN1 1BLCK
TTMAX - RBCOMP
TV6 - BCOMN1 IDENT RTCOMP
TV6F - FNCNS RTCOMP
TWMAX - RBCOMP
TWMIN - RBCOMP
TWOPI - BCOMN1 IDENT RBCOMP RVCOMP 1BLCK
VALUE - INPUT
VOL1 - RVCOMP
\PTTRN - BCOMP BCOMN1 RVCOMP
VS - BCOMP BCOMN1 IDENT RBCOMP RVPRNT

********** SUPER INDEX **********

WRFLG	-	RBSORT		
X	-	BCOMN5	RBCOMP	RVCOMP
X1	-	RBCOMP		
X2	-	RBCOMP		
X3	-	RBCOMP		
X4	-	RBCOMP		
XD	-	RBCOMP		
XMIN	-	BCOMN3	RBSORT	TCOMP
XMIT	-	BCOMN1	RBCOMP	RVCOMP
XTMU	-	RBCOMP		
Y	-	RVCOMP		
Y1	-	RBCOMP		
Y2	-	RBCOMP		
Y3	-	RBCOMP		
Y4	-	RBCOMP		
YDKT	-	BCOMN1	IDENT	1BLCK
Z	-	RVCOMP		

****

I N D E X
END OF COMPUTATION,
6 APRIL 1976 VERSION.
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