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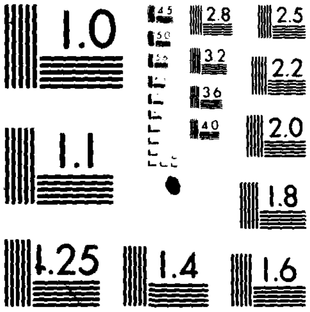

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NUSC Technical Report 6323

Eigenray Bundling Procedure for the TRIDENT Sonar Operational Trainer (TSOT) Ocean Data Base

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Surface Ship Sonar Department

14 October 1980

NUSC
Naval Underwater Systems Center
Newport, Rhode Island • New London, Connecticut

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Preface

This document was prepared under NUSC Project No. C18241. The principal investigator is Mr. John Barkley (Code 325). The sponsoring activity is the Naval Sea Systems Command (63X-4-7), R. Bova, Program Manager.

REVIEWED AND APPROVED: 14 October 1980

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR 6323	2. GOVT ACCESSION NO. AD A115 965	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EIGENRAY BUNDLING PROCEDURE FOR THE TRIDENT SONAR OPERATIONAL TRAINER (TSOT) OCEAN DATA BASE		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) H. Weinberg		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Underwater Systems Center New London Laboratory New London, CT 06320		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS C18241
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Underwater Systems Center New London Laboratory New London, CT 06320		12. REPORT DATE 14 October 1980 13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

TRIDENT Sonar Operational Trainer (TSOT)
Generic Sonar Model
Eigenray

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

This report describes the bundling procedure that was used to combine primary eigenrays for the TSOT Ocean Data Base. The primary eigenrays are computed by the Generic Sonar Model. Then a bundling procedure combines primary eigenrays into four types per range in each of two frequency bands. The resulting data base agrees with the primary model, makes optimum use of broadband displays, and reduces the number of discontinuities.

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EIGENRAY BUNDLING PROCEDURE FOR THE TRIDENT SONAR OPERATIONAL TRAINER (TSOT) OCEAN DATA BASE

INTRODUCTION

The TSOT simulates acoustic transmission loss in the ocean by interpolating in a data base. This data base contains the travel time, D/E angle, transmission loss, and phase change of four eigenrays (rays which connect own ship to target) for various ranges, depths, frequencies, and ocean environments.

The TSOT Ocean Data Base is created in three steps:

1. Compute primary eigenrays.
2. Bundle primary eigenrays.
3. Sort bundled eigenrays.

Primary eigenrays are computed by the Generic Sonar Model[1] and stored on magnetic tape. The model has several options available for this task. It was decided to use the Continuous Gradient Ray Tracing System (CONGRATS[2]) in conjunction with the Multipath Expansion eigenray routine.[3]

Since the Generic Sonar Model computes too many eigenrays for use by TSOT, it was necessary to develop a procedure that bundles the primary eigenrays into a suitable subset. Several constraints that were imposed on the bundling logic included the following:

1. The eigenrays were to be chosen using "best for training criteria."

2. The resulting data base would not require modification of existing IBM software.

3. The task was to be completed by January 1980.

After the eigenrays are bundled, they are sorted by an IBM Ocean Utility Routine, which, at the same time, adds header and reverberation data. The output of this final step constitutes the TSOT Ocean Data Base.

This report overviews the logic required to bundle primary eigenrays. Section 1 discusses the creation of primary eigenray tapes by the Generic Sonar Model. A detailed description of the computer program may be found in Weinberg.[1]

Section 2 discusses the MAIN program, which bundles the primary eigenrays, and a fade-in/fade-out algorithm for eigenrays whose D/E angle changes abruptly with range. The MAIN program controls own ship target-depth configurations, while subroutine CMPEIG sets the target range loop as explained in Section 3. Subroutine BUNDLE, described in Section 4, reduces the number of eigenrays at each range and frequency band to four. The choice depends on the weights set by subroutine WEIGHT in Section 5.

Finally, conclusions based on preliminary tests are presented in Conclusions. Although TSOT broadband displays are usually as good as can be expected, several areas of concern remain. So far, these problems have been traced to errors in TSOT.

1. PRIMARY EIGENRAYS

The initial step in producing the TSOT Ocean Data Base uses the Generic Sonar Model to create primary eigenray tapes. Each tape contains the travel time, D/E angle, transmission loss, and phase change of the most significant eigenrays for 200 ranges, three frequencies, seven own ship depths, seven target depths, and one ocean environment.

The ranges $\{1,2,3,\ldots,200 \text{ kyd}\}$ and frequencies $\{100,1000,10000 \text{ Hz}\}$ are identical for all ocean environments. However, the own ship and target depths are determined from a sensitivity study.[4]

As indicated by figure 1, pertinent environmental data are entered into the Generic Sonar Model. Aftet setting target and own ship depths, the CONGRATS-Multipath Expansion options are used to compute the most significant eigenrays at each range and frequency of interest. The eigenrays are reordered so that all eigenrays to a common range are grouped together and stored on the primary eigenray tape. This procedure is repeated for all own ship target-depth configurations.

2. MAIN PROGRAM

Primary eigenray tapes are processed by a computer program that, in turn, produces bundled eigenray tapes. The bundling program and primary Generic Sonar Model have similar structures so that numerous subroutines are interchangeable. The formats of the bundled eigenray tapes and the primary eigenray tapes are identical, allowing the Generic Sonar Model to print and plot bundled data versus range or frequency.

The bundling procedure is controlled by a MAIN program as indicated by figure 2. After reading the ocean sound speed, 49 cases corresponding to 49 own ship target-depth combinations are processed. This involves calling subroutines CMPEIG, SRTEIG, and OUTEIG.

Subroutine CMPEIG, discussed in the next section, computes the bundled eigenrays. SRTEIG sorts these eigenrays versus range at constant frequency, while OUTEIG outputs the eigenrays onto a bundled eigenray tape.

In general, SRTEIG and OUTEIG affect the order and storage device, but not the values of bundled eigenrays. However, in order to prevent abrupt

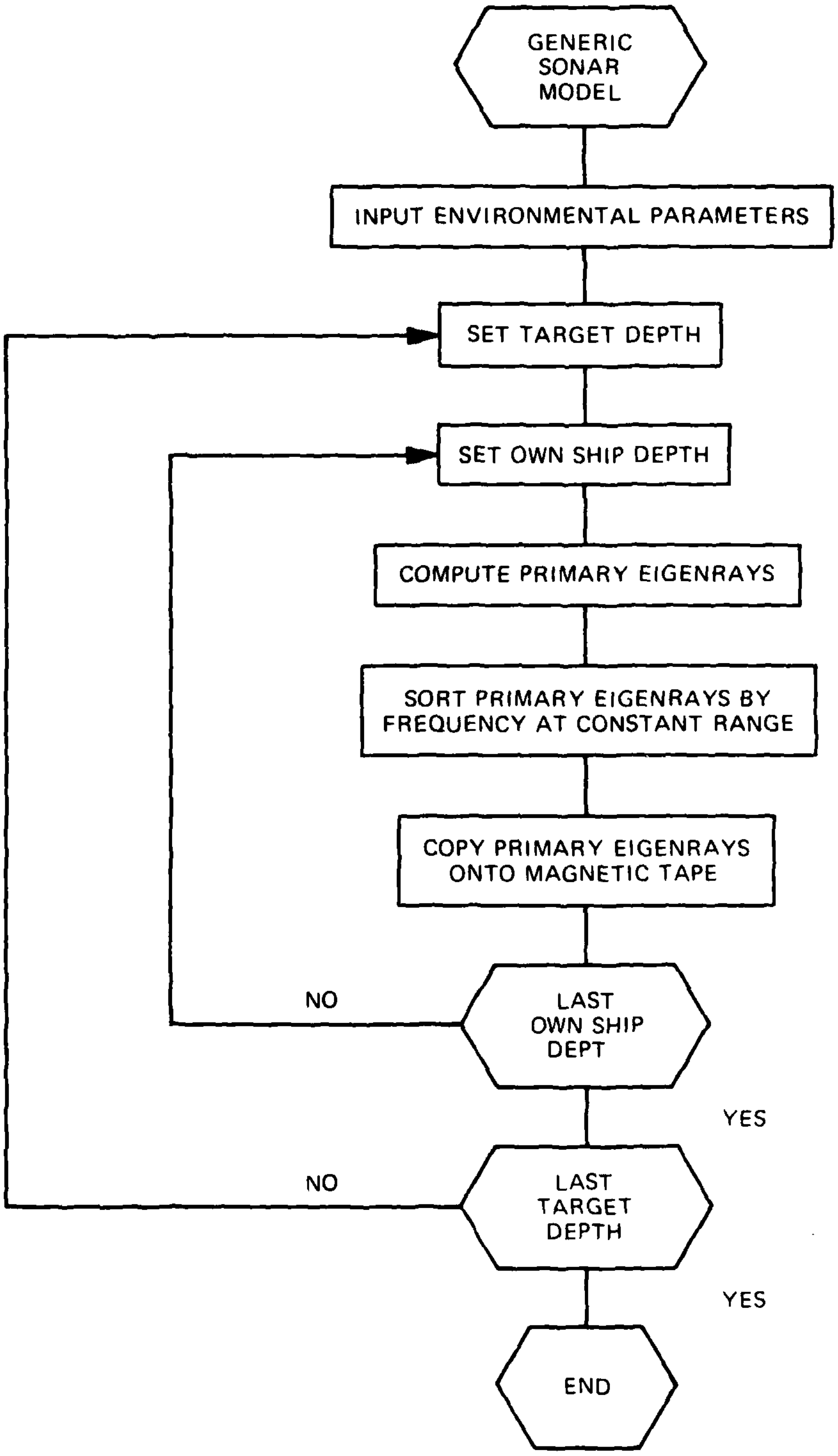

Figure 1. Flow Chart - Primary Eigenray Computation

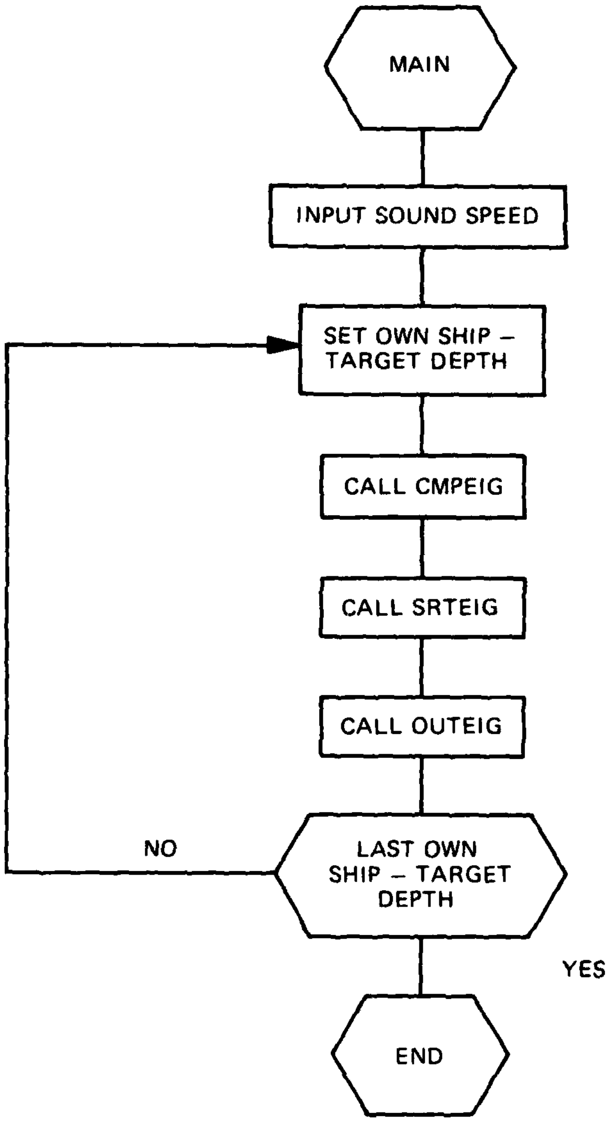

Figure 2. Flow Chart - MAIN Program

changes in D/E angle, the following fade-in/fade-out logic was added to SRTEIG.

When two adjacent ranges have broadband eigenrays (first two of four) of the same type whose difference in D/E angle exceeds 10 deg, the amplitudes of these eigenrays are reduced by 20 dB.

The total number of times that this fade-in/fade-out logic is invoked is printed at the end of each case. There have been at most a few per ocean area.

3. SUBROUTINE CMPEIG

As indicated in figure 3, subroutine CMPEIG controls the range loop for the bundling program. Primary eigenrays are read from tape by calling subroutine GNREIG. GNREIG also interpolates with respect to frequency, generating eigenrays at the nine octaves:

$$\{31.25,\ 62.5,\ 125,\ 250,\ 500,\ 1000,\ 2000,\ 4000,\ 8000\text{-Hz}\} \quad .$$

The interpolation algorithm is described in Weinberg.[1]

Surface duct eigenrays in the higher frequency band (1000, 2000, 4000, 8000-Hz) are converted to sea state 4 by adding surface loss, giving a total of 13 propagation loss values per eigenray type. The maximum number of eigenray types per range is 64. Subroutine BUNDLE, described in Section 4, reduces the number of eigenray types per frequency band at a range to four. The bundled eigenrays are stored on disk to be sorted by STREIG and output to tape by OUTEIG.

4. SUBROUTINE BUNDLE

Subroutine BUNDLE reduces the number of eigenray types in the two frequency bands (31.25,62.5,125,250,500-Hz and 1000,2000,4000,8000-Hz) to four. That is, the travel time, D/E angle, and ray type in a frequency band are independent of frequency. Transmission loss, of course, is not. In order to make optimum use of broadband displays, the ray types in the low frequency band will generally differ from that of the high frequency band.

For example, the towed array cannot distinguish between upward and downward directed paths. Hence, the first step in the bundling of low frequency eigenrays sets D/E angles positive (see figure 4). This step is omitted for the high frequency band.

Next the average power

$$\text{pwr(ieig)} = \sum_{\text{ifrq=mnfrq}}^{\text{mxfrq}} \text{eigpwr(ieig,ifrq)/(mxfrq-mnfrq+1)}$$

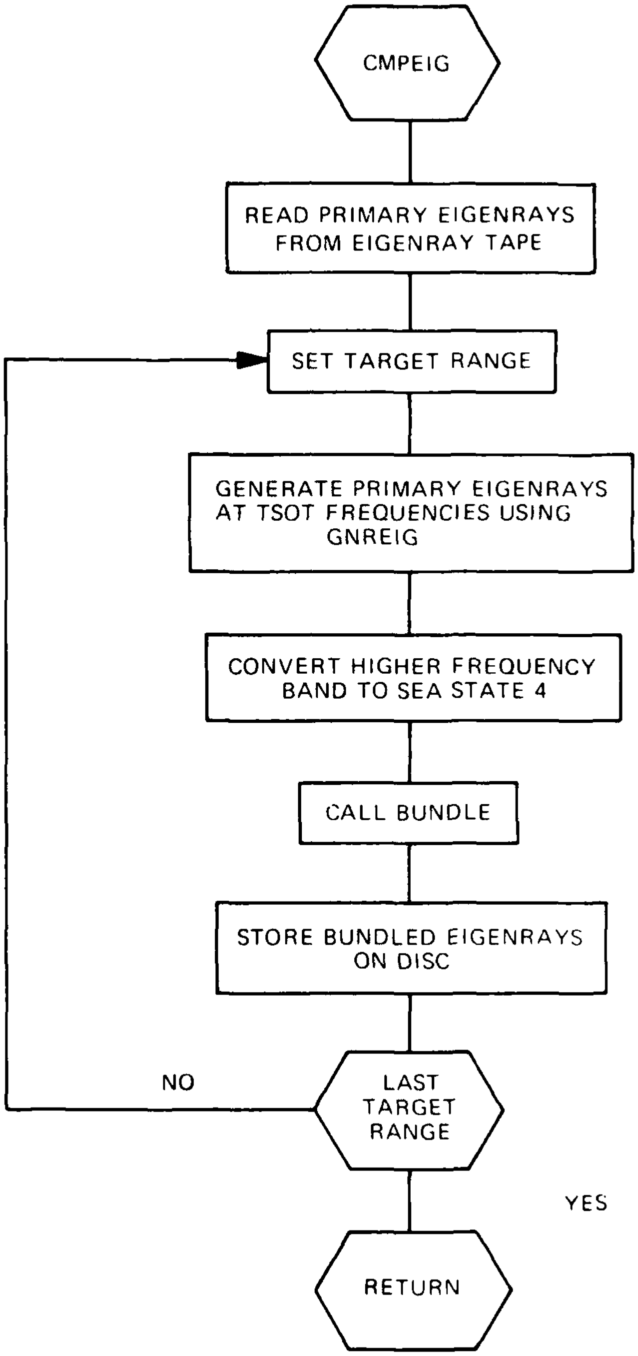

Figure 3. Flow Chart - Subroutine CMPEIG

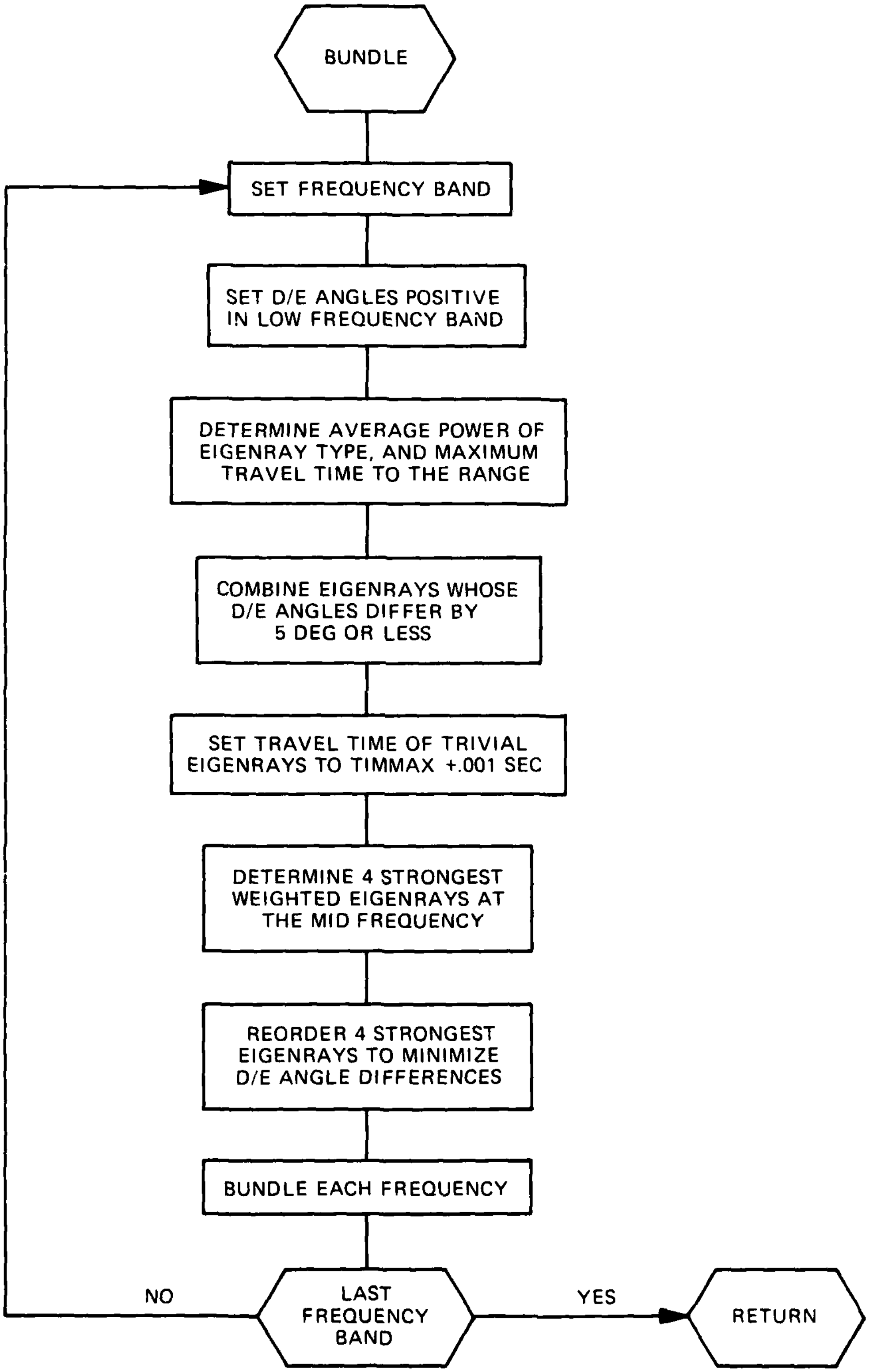

Figure 4. Flow Chart - Subroutine BUNDLE

and maximum travel time, timmax, to the range are found for each eigenray type (Note that pwr(ieig) is a temporary FORTRAN array with several definitions.) Here

mnfrq = 1 mxfrq = 5 for the low frequency band

mnfrq = 6 mxfrq = 9 for the high frequency band

eigpwr(ieig,ifrq) is the power of the ieig-th eigenray type at the ifrq-th octave frequency.

Eigenrays whose D/E angles differ by 1 deg or less are power summed, and the result is associated with the ray type having greater pwr(ieig). The weaker type is neglected from further considerations. This process is repeated for 2, 3, 4, and 5 deg, or until the number of eigenray types is reduced to four, two of which are nontrivial (a trivial eigenray has infinite loss). The travel times of trivial eigenrays are set to timmax+0.001 sec. This prevents their level from being used in active detection processes.

The surviving nontrivial eigenrays at the frequency band's midfrequency are assigned a weight by subroutine WEIGHT. The four for which

$$\text{pwr(ieig)} = \text{eigpwr(ieig,mdfrq)} * \text{WEIGHT(ieig)}$$

is greatest are selected to become bundled eigenray types. These types are reordered to minimize the weighted D/E angle difference:

$$\text{difang} = \sum_{j=1}^{4} \text{pwr(ieigj)}\ (\text{srcang(j,ibnd)} - \text{angsrc(leigj,mdfrq)})$$

between the current and previous range. In the summation above,

mdfrq = 4 ibnd = 1 for the low frequency band

mdfrq = 7 ibnd = 2 for the high frequency band

srcang(j,ibnd) is the D/E angle of the j-th eigenray in the ibnd-th frequency band at the previous range

angsrc(leigj,mdfrq) is the D/E angle of the leigj-th eigenray at the mdfrq-th octave frequency at the current range

leigj is the index of the primary eigenray which corresponds to the ieigh-th bundled eigenray

ieigj is a permutation of the integers {1,2,3,4} such as {2,3,1,4}, and such that

$$10*\min\{\text{pwr(ieig1)},\text{pwr(ieig2)}\} > \max\{\text{pwr(ieig3)},\text{pwr(ieig4)}\}.$$

In other words, the ray types are ordered to minimize D/E angle discontinuity between adjacent ranges.

At this point, the bundled eigenray types and their order have been chosen. Subroutine BUNDLE then adds the power of each eigenray to the nearest bundle. Thus the total power of primary eigenrays equals the total power of bundled eigenrays. However, the fade-in/fade-out algorithm, discussed in Section 2, will reduce the power when D/E angles change abruptly.

5. SUBROUTINE WEIGHT

The most crucial subroutine in the bundling procedure is subroutine WEIGHT. This element assigns weights that determine which of the primary eigenrays become bundled eigenrays.

As shown in figure 5, the weight is the product of four terms: wt1, wt2, wt3, and wt4 with values between zero and one. That is,

$$\mathrm{WEIGHT} = \mathrm{wt1} * \mathrm{wt2} * \mathrm{wt3} * \mathrm{wt4}.$$

The first term, wt1, given by

$$\mathrm{wt1} = \mathrm{avgpwr} / \{\mathrm{avgpwr} + \mathrm{eigpwr(ieig,mdfrq)}\} \quad ,$$

where

$$\mathrm{avgpwr} = \sum_{\mathrm{ifrq=mnfrq}}^{\mathrm{mxfrq}} \mathrm{eigpwr(ieig,ifrq)} / (\mathrm{mxfrq} - \mathrm{mnfrq} + 1)$$

prevents too much emphasis from being given to one frequency.

The second term, wt2, given by

$$\mathrm{wt2} = 0.25 \qquad \text{if delang} < 3 \text{ deg}$$

$$\mathrm{wt2} = \left(1 + \frac{\mathrm{delang}}{1 + \mathrm{absang}}\right)^{-1} \qquad \text{if delang} > 3 \text{ deg} \quad ,$$

where

$$\mathrm{delang} = \left| \mathrm{srcang(jeig,ibnd)} - \mathrm{angsrc(ieig,mdfrq)} \right|$$

$$\mathrm{absang} = \left| \mathrm{angsrc(ieig,mdfrq)} \right|$$

minimizes D/E discontinuities with range.

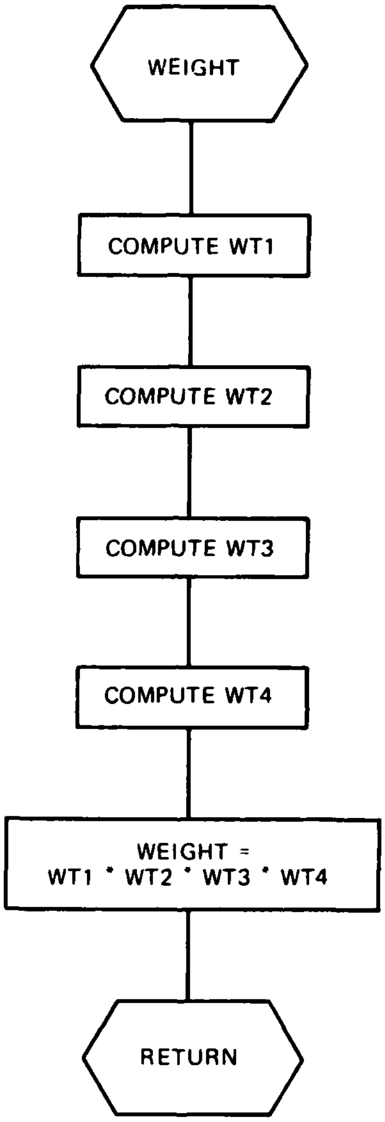

Figure 5. Flow Chart - Subroutine WEIGHT

The third term, wt3, given by

$wt3 = 1$ if the ray type was chosen at the previous range

$wt3 = 0.5$ if the ray type was not chosen at the previous range

minimizes ray type discontinuities with range.

Finally, the fourth term, wt4, given by

$$\mathrm{wt4} = \mathrm{sign(angrad)} \,/\, \mathrm{angrad} \quad ,$$

where

$$\mathrm{angdeg} = (180/\pi) * \mathrm{angsrc(ieig,mdfrq)}$$

$$\mathrm{angdif} = \begin{cases} -\mathrm{angdeg} - 11 & \mathrm{angdeg} < -11 \text{ deg} \\ 0.0 & \text{if} \quad -11 \text{ deg} < \mathrm{angdeg} < +53 \text{ deg} \\ +\mathrm{angdeg} - 53 & +53 \text{ deg} < \mathrm{angdeg} \end{cases}$$

$$\mathrm{angrad} = \min\{\, \pi,\ (79.7/5.5) * \mathrm{angdif} \,/\, (180/\pi) \,\} \quad ,$$

adds beam pattern considerations into the high frequency band. This concludes the description of the bundling procedure.

CONCLUSIONS

The eigenray bundling procedure described above was used to generate a TSOT Ocean Data Base for five ocean areas. At the time this report was written, only preliminary testing had been completed. The following conclusions are based on these tests.

Output of the bundling program gives reasonable propagation loss values at all points of interest except where the fade-in/fade-out algorithm has been applied. Only a few of these points occur in any depth combination.

Output of the bundling program can be processed by the IBM Ocean Utility Routine, and then loaded into TSOT.

Although actual TSOT broadband displays are generally as good as can be expected, several areas of concern remain. So far, these problems have been traced to TSOT broadband processing, as opposed to errors in the bundling procedure.

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