OCEAN BASIN REVERBERATION FROM LARGE UNDERWATER EXPLOSIONS

PART II: COMPUTER MODEL FOR REVERBERATION

by

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ABSTRACT: Following detonation of an underwater explosion, sound reverberates from the ocean surface and bottom and from scatterers within the medium. In addition, the boundaries of the ocean basin and obstructions within it, such as sea mounts, reradiate the acoustic energy incident upon them. Our concern is with these latter signals.

This paper describes a computer reverberation model being developed to predict the sound level that will ensue following detonation of a large underwater explosion. We will also show comparisons with existing experimental data from high explosive tests and with theories concerning the reflection of sound in the ocean.

A simplistic model has proved adequate for matching available experimental measurements in the North Atlantic Basin. The parameters on which the model are based are applicable to any geometrical configuration and are not arbitrarily assigned according to the situation. Therefore, we have expectations that the methods used will be applicable to different ocean basins as well. The next phase of the work will include application to other basins for which we can obtain data for comparison.

I. INTRODUCTION

The sea contains many kinds of inhomogeneities, ranging in size from tiny dust particles to sea mounts and islands. These discontinuities in the medium intercept and reradiate a portion of the acoustic energy that impinges upon them. This reradiation of sound is known as scattering; the sum of contributions from all scatterers is called reverberation.

Following detonation of an underwater explosion, sound reverberates from the ocean surface and bottom and from scatterers in the medium itself. In addition, the boundaries of the ocean basin and obstructions within it, such as sea mounts and islands, reradiate the acoustic energy incident upon them. Our concern is with these latter signals.

Figure 1 shows two reverberation records, broadband playouts of a 10 ton and a 600 ton high explosive shot fired within 50 miles of each other in the North Atlantic. Both records are from a receiver located near Bermuda. The first high amplitude portion of each record is the direct arrival. For roughly 250 seconds beyond this we see only continuous reverberation from the ocean surface and bottom. The later clusters of larger signals are mostly returns from the continental shelf: the Cape Hatteras area, Blake Spur, North of the Bahamas, the Bahamas, Dominican Republic, Puerto Rico, the Virgin Islands. The two records look very similar, with the greatest differences between them being the amplitudes of the signals. It is these discrete reverberant returns from shelf and sea mounts that we have concentrated on as opposed to the continuous reverberation from the ocean surface and bottom that follows the direct arrival.

The ultimate reason for developing this reverberation model is to enable us to predict, for any given ocean basin of interest, the sound level that will ensue following detonation of a large underwater explosion. The computations are to include as many bounces off reflecting basin walls and interfering obstructions as are necessary to determine the time of arrival of significant reverberant returns.

As we have developed the model, we have, where possible, made comparisons with existing experimental data and with theories concerning the reflection of sound in the ocean in order to determine the relationship between the computer model and reality.

We shall describe briefly the development of the model to its present state and the results of the tests we have made on it thus far.

II. DEFINING THE PROBLEM

This problem comprises two main components. First, we must determine which of the reflected signals can actually reach the receiver and in what order they arrive. Second, we must know the durations and amplitudes of these individual arrivals and how they combine to make up the type of reverberation signal that we see here.

The first is essentially a problem in geography and spherical trigonometry. The second requires knowledge of the explosion source level, the effects of long range propagation on the initial source pulse, and the principles involved when a pressure wave interacts with a reflecting surface.

III. COMPUTING SIGNAL PATHS

In order to determine what arrivals can actually reach the receiver, we must first define the ocean basin of interest. The basin boundaries are defined by reading into the computer model geographical coordinates for a sufficient number of points at an appropriate depth along the continental shelf to define the major characteristics of the boundary. In like manner we read in coordinates for enough points on each island and sea mount to define its shape. In Figure 2 we see a diagram for a simple basin model. The circles indicate the points for which geographical coordinates are read into the program.

The method for determining what arrivals can reach the receiver is based on the computation of great circle paths. The assumption is made that each reflecting segment connecting two of these points on the continental shelf or on a sea mount is the arc of a great circle. (Gaps in the boundary are allowed for in the model as nonreflecting segments.) We now assume that over the long distances with which we are concerned the energy travels via the sound channel along a great circle from one point to another. Travel paths are calculated from the explosion source, indicated by an S, to the midpoint of each reflector and then to the receiver, marked with an R. For now we are concerned only with the direct and first bounce arrivals.

A great circle can be expressed analytically by a relatively simple equation; therefore, we can compute points of intersection and determine whether the path to a segment or to the receiver is blocked or obstructed. The diagram shows various types of paths from the omnidirectional source to the receiver. In this case the direct path to the receiver (1) is unobstructed, as is the other solid-line path (2), which does not intersect any reflector in the basin, and therefore does not return to the receiver.

In the program, each path is first tested for obstruction; that is, if the ray angle is such that the incident ray cannot fall on the reflecting face of the segment, the path is obstructed. The path marked (3) in Figure 2 cannot reach the interior, or reflecting, face of boundary segment A; therefore, there will be no arrival from this reflector. Tests are then made for the blocking of any path by any boundary or sea mount segment. The return portion of path (4), for example, is blocked by the sea mount. The dashed line marked (5) shows a simple source to reflector to receiver path.

Because there is available experimental data for the North Atlantic Basin, this is the region we have used in developing the model to its present state. As part of the Artemis project several ten-ton high explosive shots were detonated at various locations in the North Atlantic during 1959. Figure 3 shows source locations for these shots. (In addition to the Artemis shots, three CHASE shots, of from 400 to 700 tons yield, have been detonated at the indicated locations.) We have compared our model computations with 1/3 octave band analyses of broadband recordings from two different receiver locations.

In Figure 4 we see reverberation records from four different shots fired during the Artemis series. The first portion of each record is from the direct arrival; later we see first-bounce arrivals coming in from various segments of the continental shelf. At different times relative to the direct arrival we see a large group of arrivals coming in from the region near the Bahamas. The time differences, of course, are dependent on the different source-receiver geometries.

For comparison of this kind of data with our model, we have selected points by eye along the 1000 fathom line on bottom contour charts of the North Atlantic Basin. Figure 5 shows the basin as we have defined it in the model, with coordinates read in for 172 points along the continental shelf from the Leeward Islands to Nova Scotia. The length of an average shelf segment is about 15 nautical miles. The area to the east has been entered as a nonreflecting segment. The interior cross marks show locations of obstructions defined within the basin. With our model, we have been able to identify, for each experimental record, the parts of the shelf and the sea mounts responsible for each discrete portion of the reverberation.

IV. SIGNAL DURATION AND INTENSITY LEVEL

After we had convinced ourselves that the model geometry was giving us reasonable returns from the reflecting basin features, we began trying to determine what is important in the propagation and reflecting processes so that we might construct a final signal that would compare favorably with respect to arrival times and durations of signals and also in the intensity levels measured at a receiver.

The duration of the type of signal we are interested in depends on a combination of three effects. First, an explosion does not produce an instantaneous rise and fall of pressure, but a pulse that has finite duration. Then, as the pressure wave propagates over long distances, the signal is elongated by multipath propagation effects and becomes smeared out in time as it travels in range. In addition, as the wave travels along an extended reflecting surface, the signal is further distorted because of the differences in travel time to different parts of the reflector. It has been shown that the time spread resulting from long range propagation amounts to about one second per 100 n. miles of travel.[1] Relative to this, for the distances of interest here, the pulse duration at the source, which is of the order of a few milliseconds, is insignificant. As for the spreading due to the extension of the reflector, this could be of the order of a half second for a segment oriented nearly normal to the path of travel, to upwards of ten seconds for a more oblique angle. Since, for the cases we are presently dealing with, many of the reflectors are fairly normal to the propagation paths, we first considered in our model only the effect of the long distances traveled in time-spreading the individual signals before adding them up.

Let us look now at an experimental record (Figure 6) from one of the Artemis shots. Notice that some parts of this playout show very strong signals; others are relatively weak. Analysis performed on this type of data by others has generally led them to assign, arbitrarily, different target strengths to the reflectors from which the signals come. We have approached the problem a bit differently. In order to determine what is important in generating realistic intensity levels, we have been trying to learn something about the interaction between a pressure wave and the surface on which it impinges. Our aim is to develop a set of model parameters that will enable us to make reliable predictions for a completely different set of conditions.

The first approach was to assume spherical spreading of the energy from the source out to 10 nautical miles, cylindrical spreading to the reflector, and simple scattering from the reflecting surface. We then applied spherical and cylindrical spreading as before on the return path to the receiver. We made the assumption that the amount of energy returned after striking the reflector is proportional to the area from which it is scattered. We then would apply the same constant scattering strength factor to each individual signal in order to bring the general resultant level roughly in line with the experimental data.

Figure 7 shows the result of a 50 Hz, 1/3 octave band computation using a constant scattering strength of -20 dB.* The experimental analysis and the computations were performed using intensity averages over intervals of 10 seconds, which accounts for the "rectangular" appearance of the traces. The first 400 to 500 seconds of this record contain primarily continuous reverberation from surface and bottom, which we are not attempting to calculate. Beyond this we see that the model, on the average, seems to give reasonably good levels, but has highs and lows in some places that do not agree with the experimental data. For the most part we are calculating the correct arrivals, but they do not always add up properly.

While trying to decide what could be the most important factors in determining the signal strength from different pieces of the continental shelf, we noted a strong correlation between the shelf slope and the strength of the signal. Let us look again at the broadband reverberation record we saw earlier. In Figure 8 we have plotted the approximate slope from 500-1000 fathoms in depth (at the bottom); the slope from 1000-1500 fathoms is shown at the top of the figure. Note that when the slope at both depths is steep, we see a strong signal; when only one is steep, we receive a lesser level; if both are less than 200 feet per n. mile, the signal is lost in the ambient noise.

We decided to apply a slope correction, a simple taper that is a function of the slope of the reflector. If the shelf were vertical, the direction of the path of travel would be normal to the surface, and the computed signal level would be multiplied by one. The less vertical the reflecting surface, the smaller the multiplier and the less the amount of energy allowed to return to the receiver. The same sort of reasoning was applied to the aspect angle; i.e., the angle in the horizontal plane. Because the slope correction accounted

*In all comparisons, experimental data are indicated by the heavy trace, model computations by the fine trace.

for some difference in level, a smaller scattering coefficient than that used previously was necessary to bring the resultant level into agreement with the data.

Figure 9 shows results of scattering calculations with -10 dB scattering loss, made with slope modification only (top curve) and with aspect modification only (at the bottom). The slope seems to be much more important than the aspect angle. The top curve, which takes only reflector slope into consideration, shows a definite improvement in the shape of the curve when compared with the data trace, especially in the region from about 1050 to 1250 seconds. Therefore, we decided for the time being to apply the correction only to the angle in the vertical plane.

At this point in its development the model included the scattering calculation discussed earlier, along with a simple taper function applied to the slope of the reflector. Absorption losses and sea noise level were also added in. By applying the scattering loss of only -10 dB to each reflector in the basin, we were able to match quite well the peak level of the experimental curve for Artemis 2-2 (Receiver #1). This same factor of -10 dB gave good agreement not only with the remainder of the latter curve, but for all other Artemis data as well.

This model was run using the slope at 500-1000 fathoms, the slope at 1000-1500 fathoms, and for an average slope from 500-1500 fathoms. The deeper slope (1000-1500) gave the best comparison with experimental data. These results are shown in Figure 10 for two different receiver locations for Artemis 2-2. This finding is consistent with independent theoretical calculations that indicate that it is probably the deeper portions of the shelf that return the most energy.

V. FURTHER MODEL REFINEMENTS

When the reflecting segment is not normal to the travel path of the arriving signal, the reflected signal will be spread out in time because of arrival time differences to different portions of the reflector. This time spread must be added to that resulting from multipath effects to obtain the proper length for the individual signals arriving at the receiver before we add them to determine resultant signal characteristics.

In Figure 11 we see results from the model, with added time spread plus refinements in the basin topography, for Artemis 2-2 for both receiver locations. The general level and shape of the curves agree remarkably well with the experimental data obtained for this shot. Comparison with

50 Hz analyses for the other seven Artemis shots has not shown any inconsistencies in the model. A second set of results for a different source location is shown in Figure 12. Thus we have a set of model parameters that is not tied to a specific source-receiver geometry within the basin.

VI. SUMMARY, CONCLUSIONS, AND FUTURE WORK

Figure 13 summarizes the major components of the computer reverberation model as it stands today. The underlying assumption on which the model is based is that the complex interaction between the acoustic energy and the basin walls can be described by a single average scattering strength. This scattering coefficient is characteristic of the basin as a whole, but is modified for any given reflector by such factors as the segment slope. The generally good agreement between our calculations and the experimental data indicate that our simple model is an adequate first order representation of an obviously much more complicated process.

We have some 600 ton data with which to compare our calculations for the North Atlantic. We plan also to try some further refinements of the model to include such effects as aspect angle. In addition, we still must add the capability for computing paths with bounces off more than one reflector.

The next part of the task then will be to test the model for a different ocean basin, such as the Pacific, for which there are some data available. In addition, we hope to carry out some experiments that will provide tests for our prediction methods for an ocean basin with quite different characteristics.

When we first undertook this project, it seemed next to impossible to model such a complex situation in a simple manner and expect to produce results that could match experimental results at all. With a very simple model we have come remarkably close in the North Atlantic. The parameters on which the model is based are applicable to any geometrical configuration within the basin and are not arbitrarily assigned according to the situation or after the fact. For this reason we have expectations that the methods used will be applicable in different ocean basins as well.

ACKNOWLEDGEMENT

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REFERENCE

1. Ewing, M., and J. L. Worzel: Long Range Sound Transmission, Article in "Propagation of Sound in the Ocean," Geological Society of America Memoir 27, 1948.

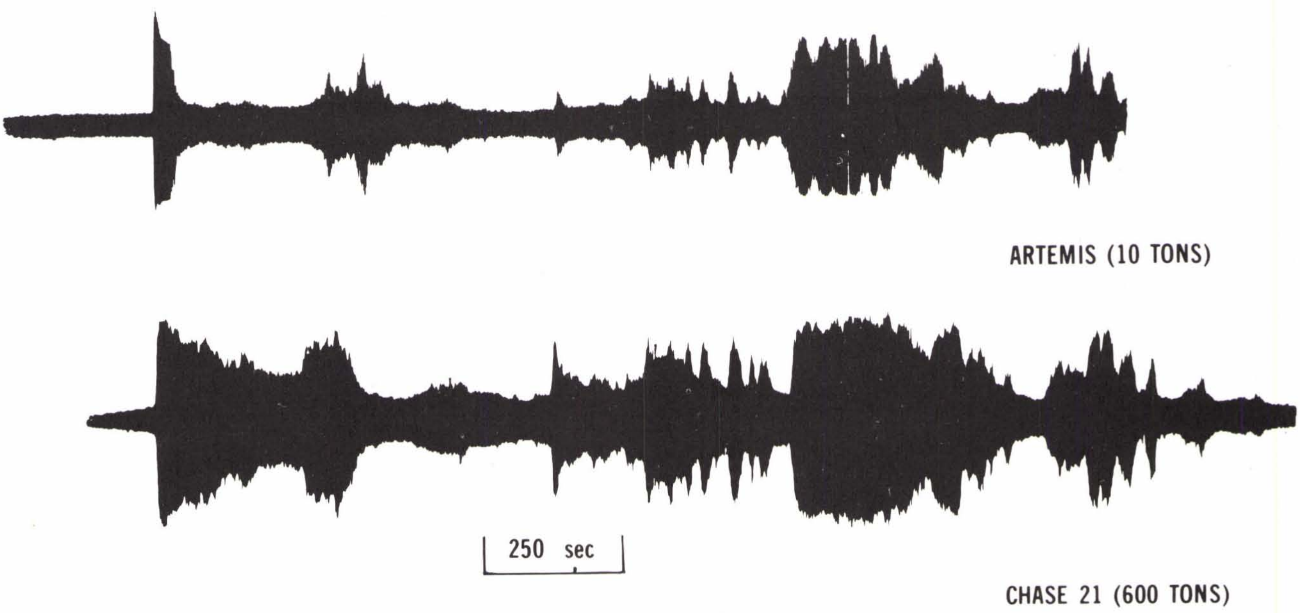

FIG. 1 ARTEMIS 1-2 (10 TONS) AND CHASE 21 (600 TONS) DETONATED IN THE NORTH ATLANTIC AND RECORDED AT BERMUDA

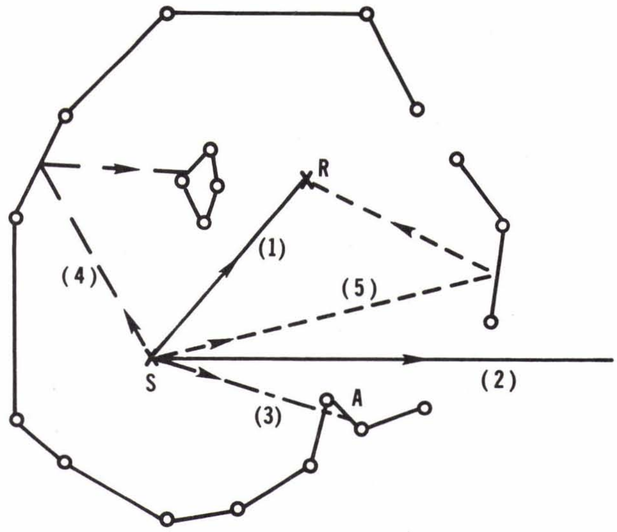

FIG. 2
SIMPLE BASIN MODEL SHOWING DIFFERENT TYPES OF PATHS FROM THE SOURCE

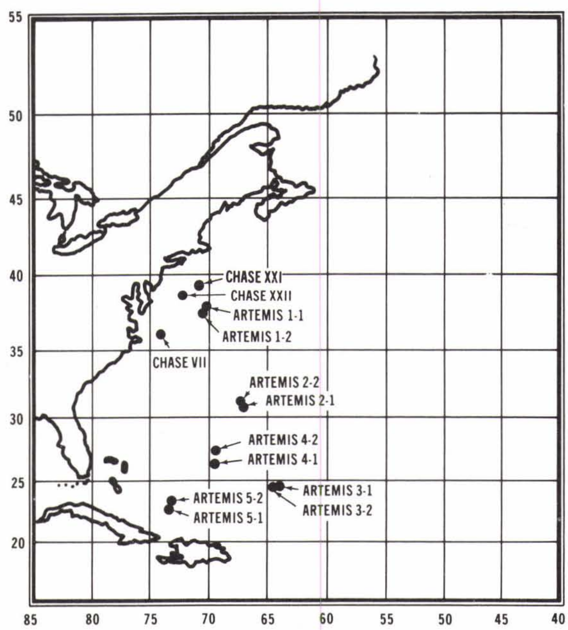

FIG. 3
SOURCE LOCATIONS FOR EXPERIMENTAL DATA : NORTH ATLANTIC BASIN

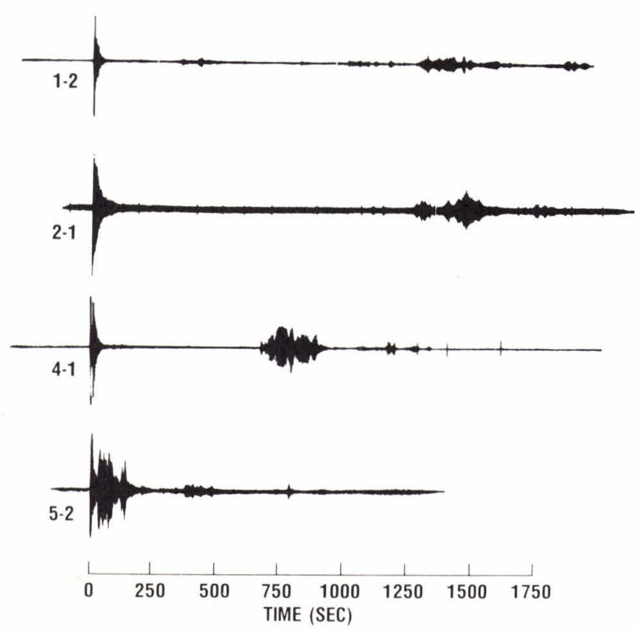

FIG. 4
ARTEMIS SHOTS DETONATED AT FOUR DIFFERENT SITES IN THE NORTH ATLANTIC AND RECORDED AT BERMUDA

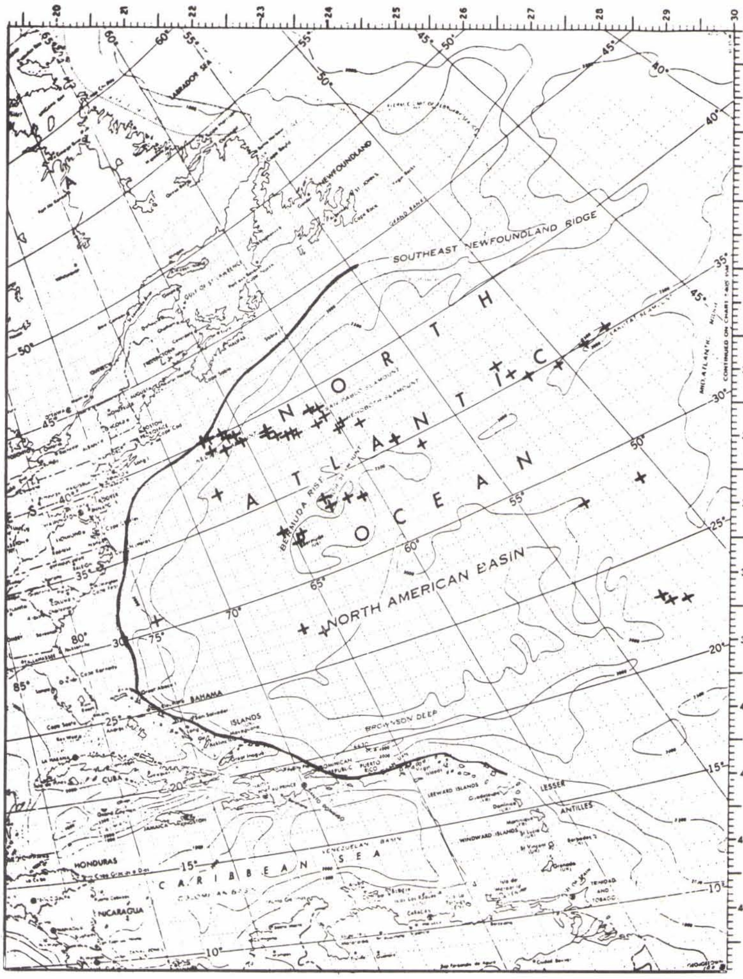

FIG. 5
BASIN DEFINITION

FIG. 6 ARTEMIS 1–2 : BROADBAND REVERBERATION RECORD (RECORDING TIME ~ 33 MINUTES)

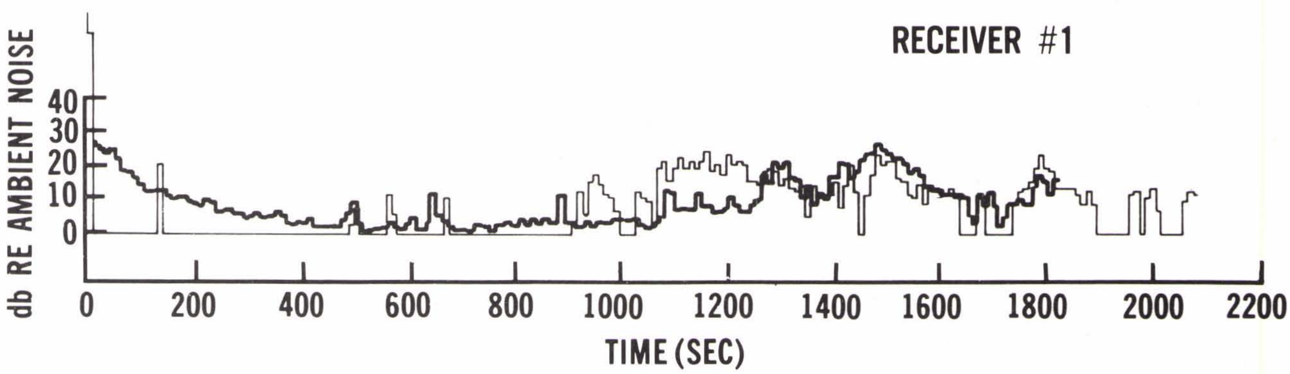

FIG. 7 ARTEMIS 2–2 : COMPARISON OF EXPERIMENTAL DATA AND SIMPLE SCATTERING CALCULATION (50 Hz, 1/3 OCTAVE BAND ANALYSIS)

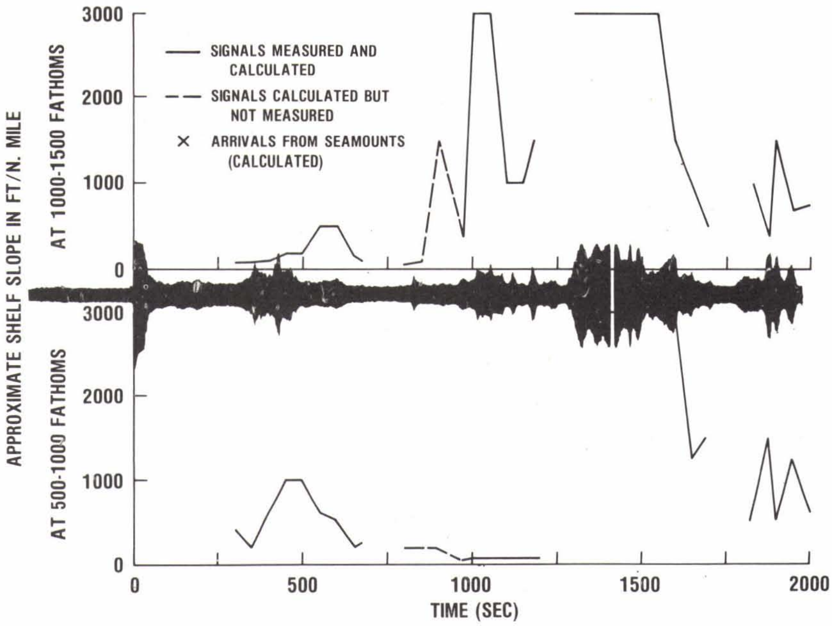

FIG. 8 EFFECT OF SHELF SLOPE ON RECEIVED SIGNALS

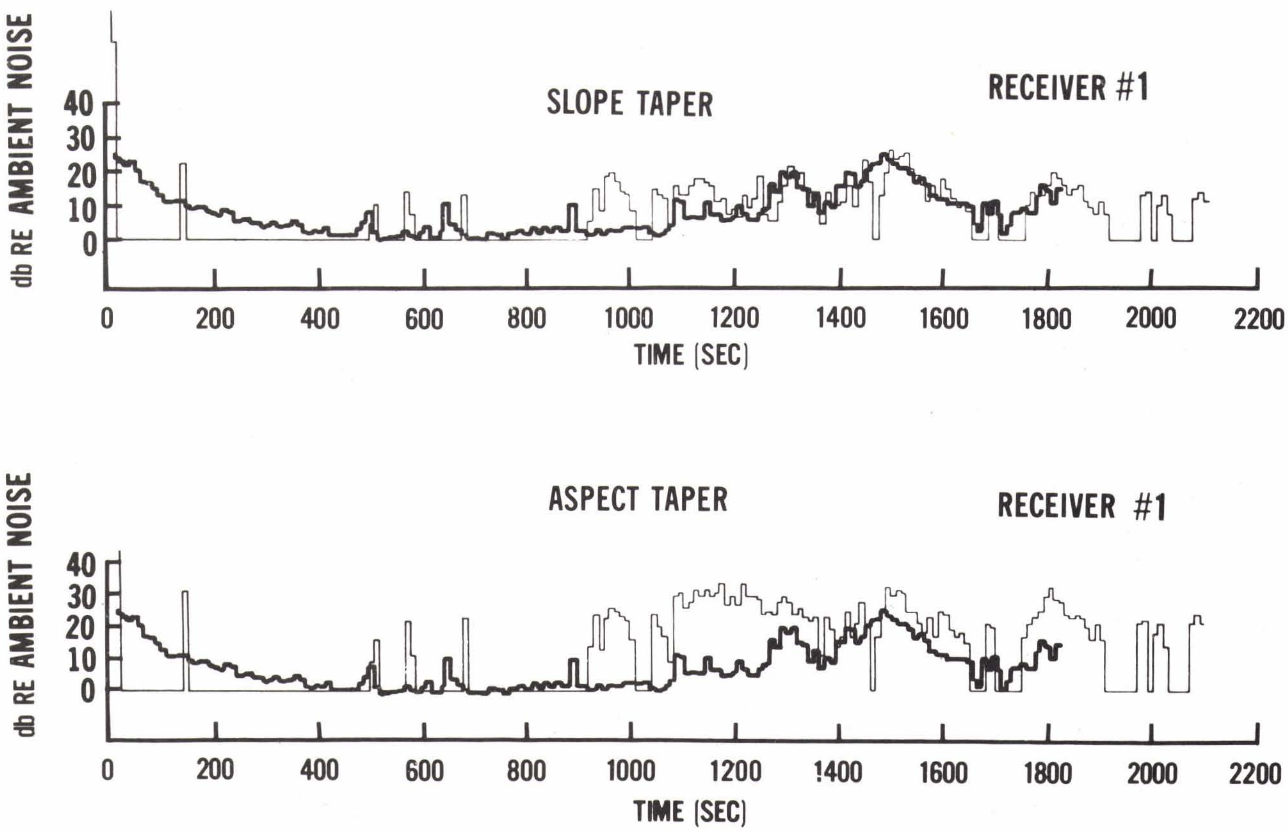

FIG. 9 ARTEMIS 2–2 : COMPARISON OF EXPERIMENTAL DATA WITH SIMPLE SCATTERING + ANGLE CORRECTION (50 Hz, 1/3 OCTAVE BAND ANALYSIS)

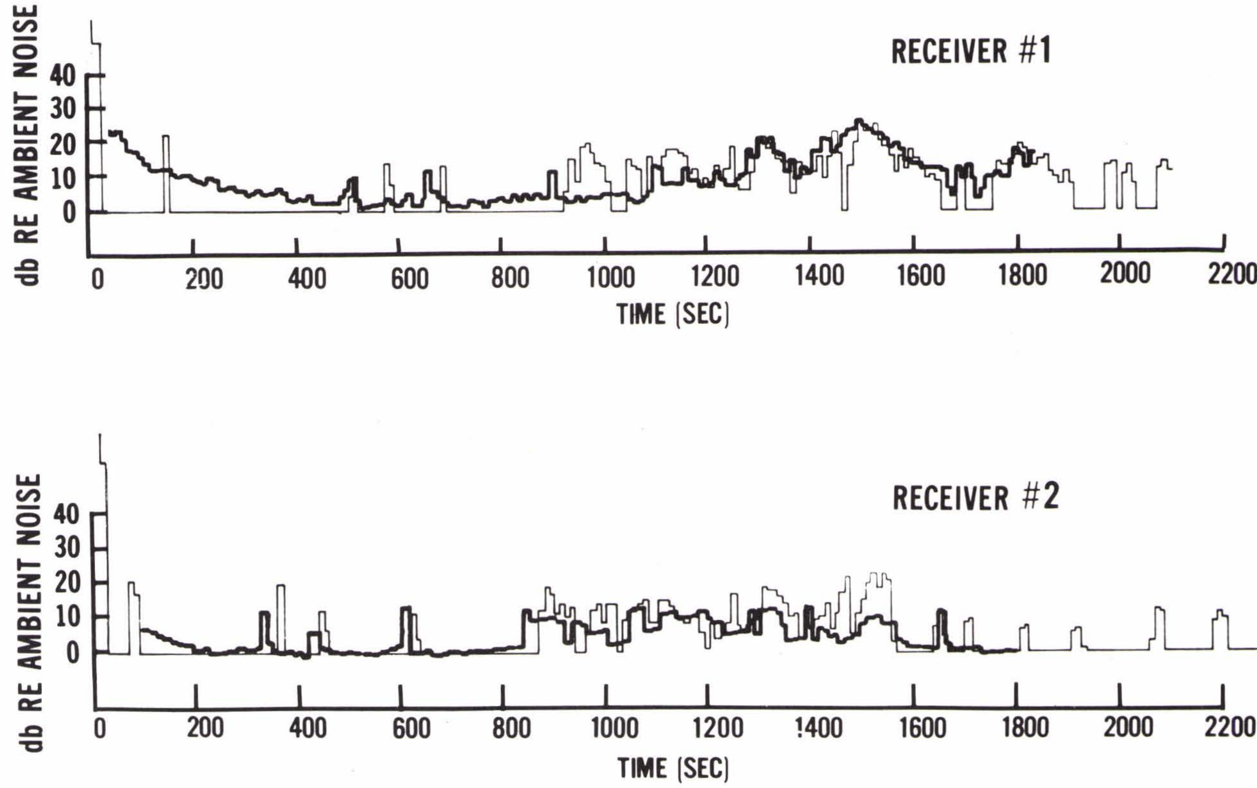

FIG. 10 ARTEMIS 2-2: COMPARISON OF EXPERIMENTAL DATA AND SIMPLE REFLECTION MODEL (50 Hz, 1/3 OCTAVE BAND ANALYSIS)

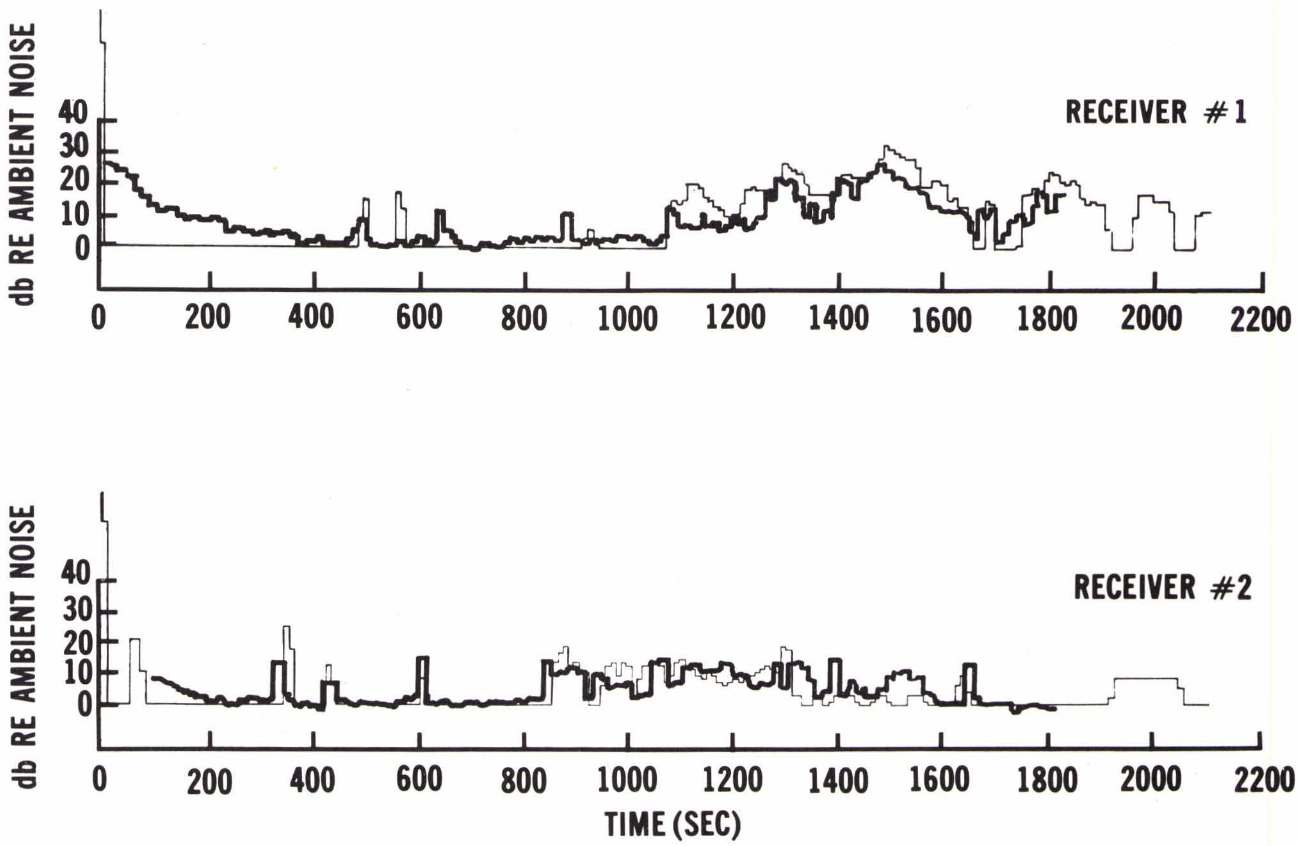

FIG. 11 ARTEMIS 2-2: COMPARISON OF EXPERIMENTAL DATA AND MODEL RESULTS (50 Hz, 1/3 OCTAVE BAND ANALYSIS)

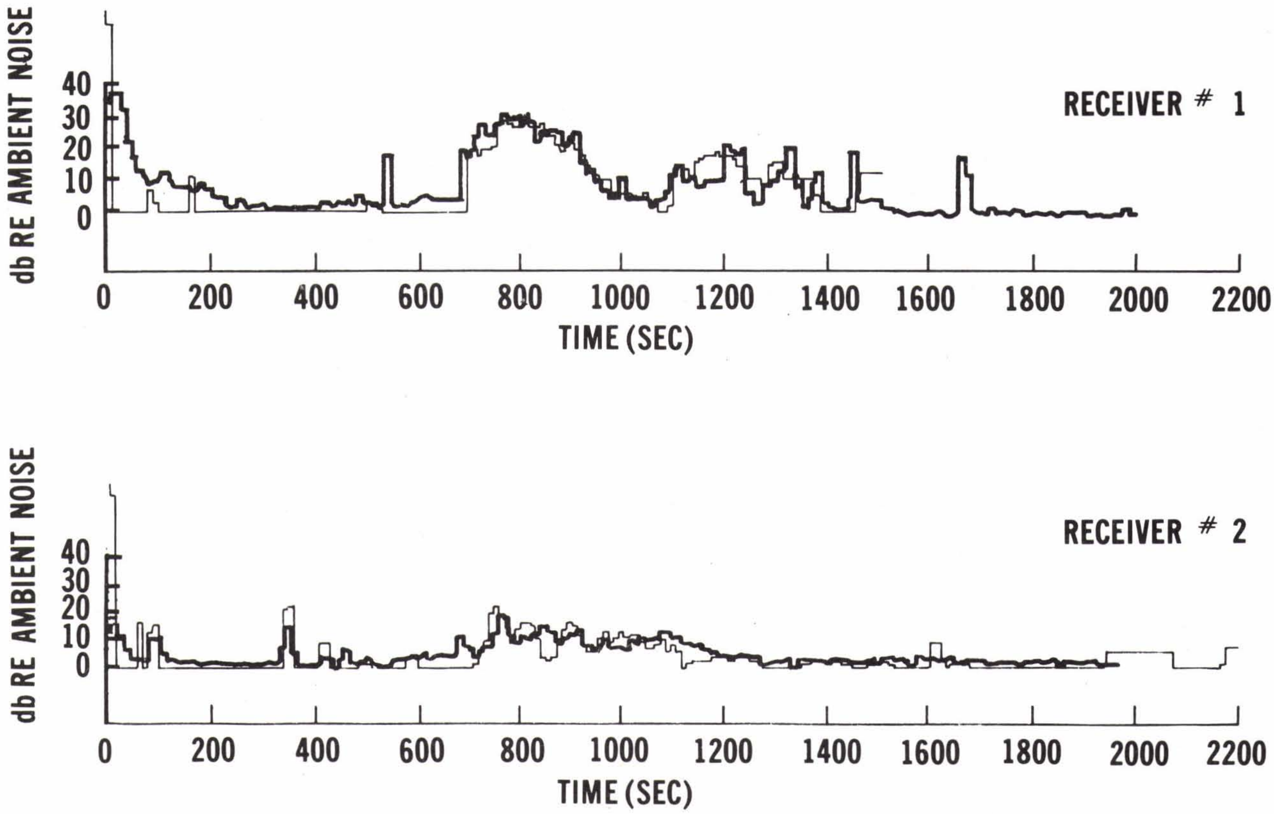

FIG. 12 ARTEMIS 4–1 : COMPARISON OF EXPERIMENTAL DATA AND MODEL RESULTS (50 Hz, 1/3 OCTAVE BAND ANALYSIS)

1. BASIN BOUNDARY AND INTERFERING OBSTRUCTIONS DEFINED
2. GREAT CIRCLE PATHS ASSUMED
3. INDIVIDUAL REFLECTORS IDENTIFIED
4. SPHERICAL SPREADING TO 10 MILES; CYLINDRICAL SPREADING BEYOND
5. ABSORPTION AND SEA NOISE INCLUDED
6. SCATTERING + TAPER FOR SLOPE ANGLE USED
7. INDIVIDUAL SIGNALS SPREAD FOR MULTIPATH EFFECTS AND FOR REFLECTOR EXTENSION
8. EXTRA 10 dB LOSS PER BOUNCE ADDED

FIG. 13 COMPUTER REVERBERATION MODEL (MAY 1975)