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ACOUSTIC OBSERVATIONS AT A SHALLOW WATER LOCATION OFF THE COAST OF FLORIDA

By
R. J. Urick

13 MAY 1969

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 69-90

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NOLTR 69-90

ACOUSTIC OBSERVATIONS AT A SHALLOW WATER LOCATION OFF THE COAST OF FLORIDA

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ABSTRACT

Measurements of acoustic transmission, reverberation level, reverberation coherence and bottom loss were made at a site off the West Coast of Florida in 200 feet of water. Standard Navy explosive sound signals were dropped by an aircraft and recorded aboard an anchored research vessel. The transmission results are found to have both some explainable and un-explainable features. The reverberation data have been interpreted in terms of a scattering strength consistent with deep water measurements, and a coherence angle describing the vertical distribution in angle of the reverberant return.

Physics Research Department
U. S. Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland

NOLTR 69-90 13 May 1969

This report deals with part of a program to determine the optimum acoustic parameters for shallow-water sonars and to improve our prediction capability for sonar operations in shallow water.

The field test and subsequent data analysis could not have been carried out without the willing participation of a sizeable number of individuals. Special acknowledgement is due to Messrs. T. Tulko, G. Lund, G. Colvin and D. Bradley of the Naval Ordnance Laboratory for their work in data collection and analysis; to Mr. D. Probert of the Naval Ordnance Unit, Key West Detachment of Naval Air Development Center for valuable logistic support, and to LT. R. Rudolph and others of Air Development Squadron One for their airborne services. To all these individuals, the writer is gratefully indebted.

The work was done under Airtask A37533/292/69F/08/121/702 assigned by the Air Systems Command.

E. F. SCHREITER
Captain, USN
Commander

Zaka I. Slawsky
Z. I. SLAWSKY
By direction

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FIGURES

INTRODUCTION

This report describes the results of a field trip made in October 1968 to investigate sound propagation and reverberation at a location in shallow water. During a period of a day and a half, the research vessel PAUL LANGEVIN remained at anchor at 26°00'N, 76°30'W, about 90 miles west of the West Coast of Florida. During the on-station period, standard explosive sound sources were dropped by an aircraft for propagation measurements and a number of other measurements were made by using explosive sources dropped from the vessel itself and from a small motor launch. Measurements of transmission loss, reverberation level, reverberation coherence and bottom loss were obtained. This report presents very briefly the results of the field work with only a minimum of discussion and with the intention of presenting some of the findings more fully in subsequent reports. The present report concludes with a few hypothetical, suggestive examples of how such data can be used by the design engineer and performance predictor interested in sonars to operate in shallow water.

SCENARIO

The measurement vessel was anchored at the intersecting arms of the cross shown in Fig. 1. The arms of the cross extended in directions parallel to, and perpendicular to, the bottom contours. During the aircraft phase of the work, a Navy P-3 type aircraft flew along, away, and back toward the vessel along the arms of the cross and dropped standard Navy Sound Signals Mk 61 at pre-assigned range intervals. The explosive signals were received by two Atlantic Research Type LC 57 hydrophones located at depths of 80 and 180 feet, and were tape-recorded on board the vessel for later analysis. Reverberation recordings were made using charges dropped "on top" the hydrophones by the aircraft and also, later on, with charges dropped over the side of a nearby motor-launch while underway. In addition, in the absence of the aircraft, two other types of measurements were made. One was the measurement of bottom reflection loss by means of small (1 oz. TNT equivalent) explosive signals Mk 64 dropped at distances out to 1000 yards from a recording hydrophone. The other was the recording of reverberation on individual hydrophones of a vertical string in order to determine the vertical coherence of shallow water reverberation.

BT's and a sound velocity profile taken aboard the vessel showed the presence of a mixed layer 120 feet thick overlying a thermocline extending down to the bottom 200 feet. Figure 2 shows a measured velocity profile taken with a velocimeter. Also, AN/SSQ-36 bathythermograph buoys were dropped by the aircraft at the ends of the arms of the cross. Figure 3 is a series of cross-sections showing the water depth, depths of hydrophones, depths and ranges of charges, and the velocity profiles at the ends of the aircraft runs.*

A bottom grab sample at the ship showed the bottom to be a mixture of coral, sand, mud, and shell. A bottom core was not taken. However, about 70 miles to the south near 24°50'N and 83°00'W, three cores, taken by Tracor, Inc. and analyzed by the Naval Oceanographic Office, showed the bottom to be unlayered, clayey silt with shells extending to the maximum core depth of 1 meter.

The wind was calm, with a glassy sea, during the 2-1/2 hour period of the aircraft runs. During the balance of the test period, the wind speed ranged from 0 to 7 knots with a sea state 0 to 1 and with a wave height estimated to be 1 foot or less.

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*Run C was aborted at 30 miles due to the weak shot signals received on this run.

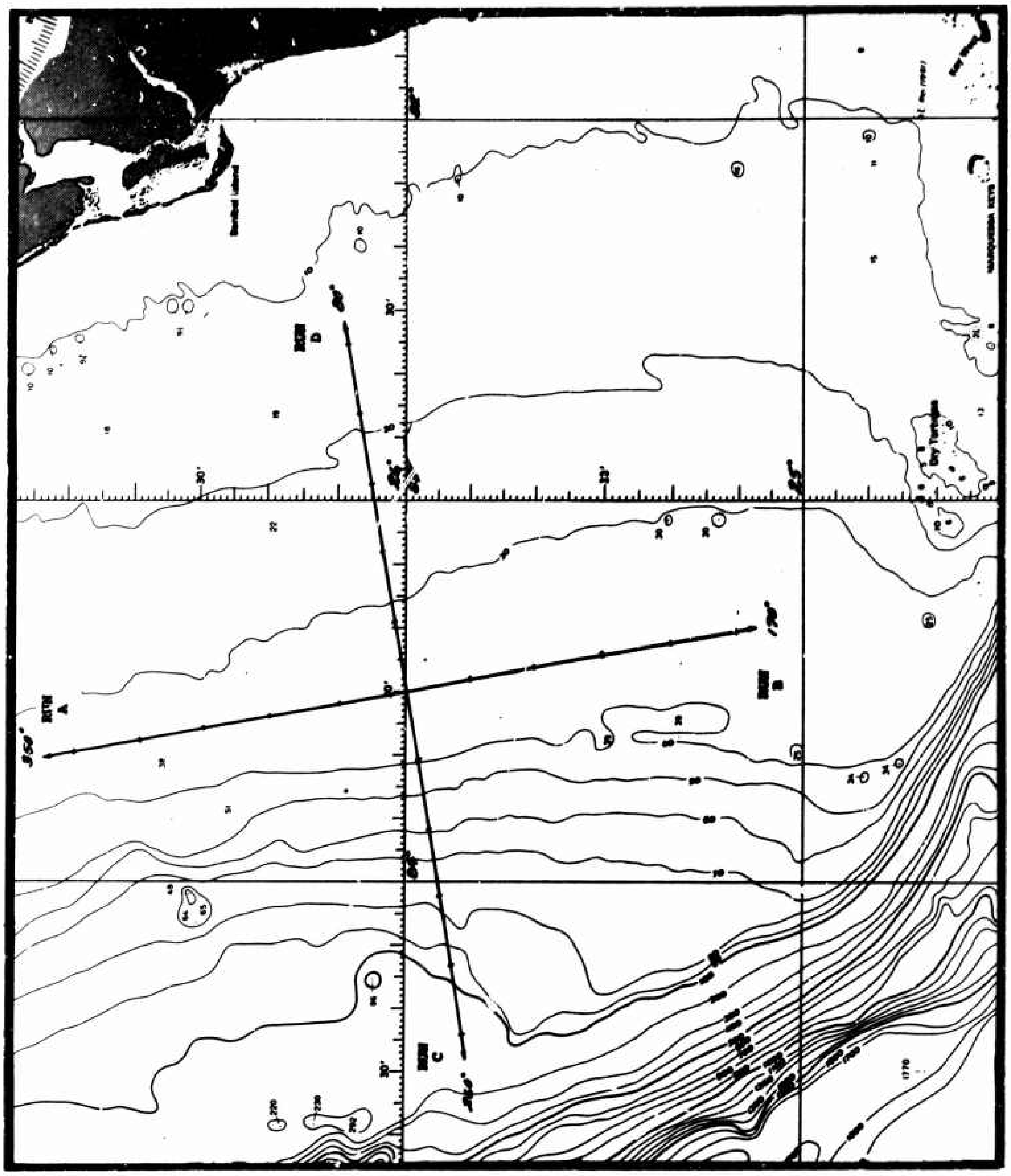

FIG. 1 LOCATION OF TEST SITE AND THE FOUR AIRCRAFT RUNS

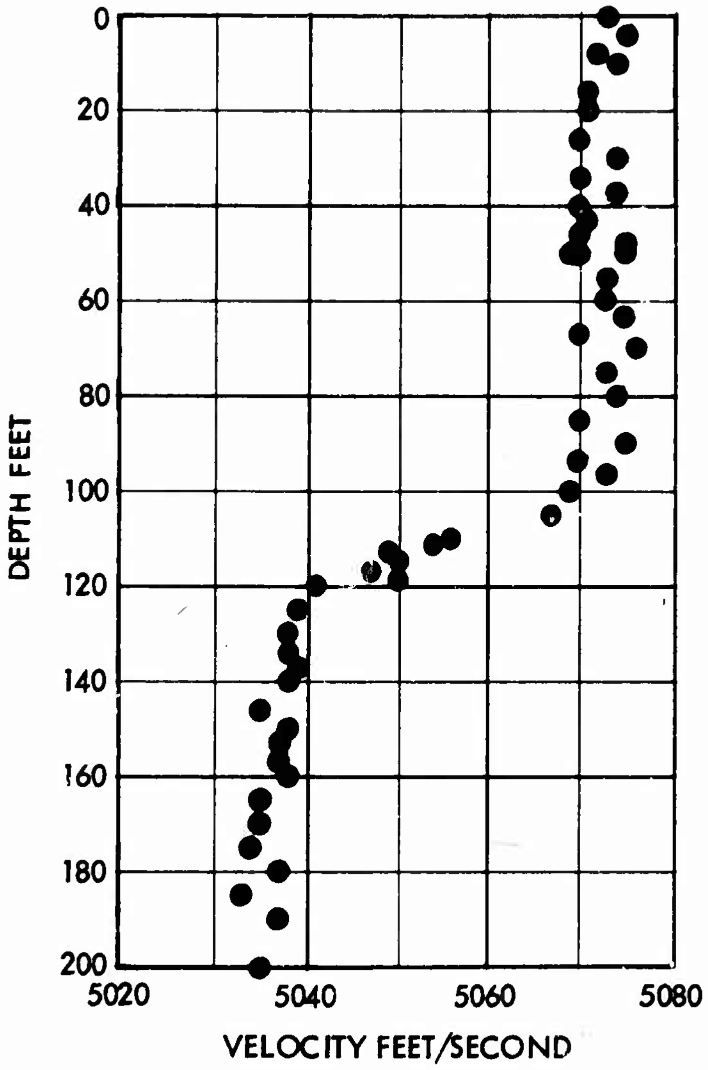

FIG. 2 VELOCIMETER PROFILE AT THE RESEARCH VESSEL

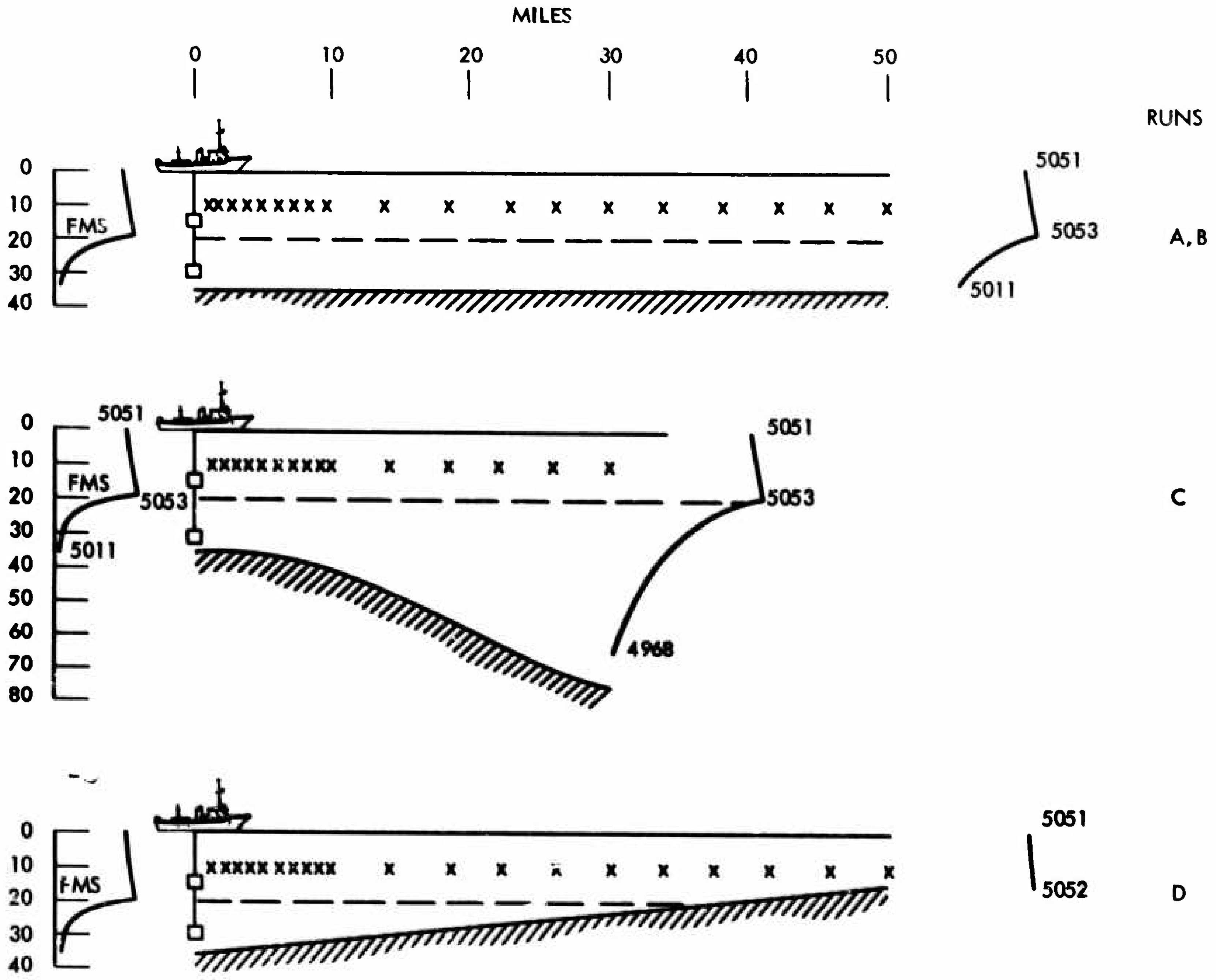

FIG. 3 CROSS-SECTIONS SHOWING WATER DEPTH, HYDROPHONE DEPTHS, SHOT DEPTHS AND DISTANCES, AND VELOCITY PROFILES COMPUTED FROM BT'S TAKEN AT THE VESSEL AND AT THE ENDS OF THE RUNS. THE BT-DERIVED VELOCITIES ARE SOME 40 FEET PER SECOND LOWER THAN THOSE FOUND BY USING THE VELOCIMETER (FIG. 2) THOUGH THE SHAPE OF THE PROFILES ARE SIMILAR

TRANSMISSION RESULTS

In the laboratory, the recorded signals from the aircraft-dropped charges were filtered in octave bands, squared and integrated, and then converted to transmission loss through the system calibration and the Weston (1) energy flux density spectrum levels of a 2 pound explosive charge.

The following octave-band levels computed from the Weston equations were used for this purpose: 25-50 Hz, 121 db; 50-100 Hz, 123 db; 100-200 Hz, 125 db; 200-400 Hz, 125-1/2 db; 400-800 Hz, 125 db; 800-1600 Hz, 123 db; 1600-3200 Hz, 121 db; 3200-6400 Hz, 118-1/2 db. These levels are relative to the energy flux density of a 1 dyne/cm^2 plane wave for an interval of 1 second. The eight figures 4a to 4h - one for each of 4 runs at 2 hydrophone depths - are plots of level versus range relative to the sloping solid lines of spherical or free-field spreading. The difference in db between a measured point and the sloping line is the <u>transmission anomaly</u>, equal to the transmission loss minus 20 log r. The crosses refer to shots dropped on outbound runs of the aircraft, the circles, to the inbound runs. The crosses generally fall along smooth curves within a db or two, so as to indicate a uniformity in the acoustic output of the source charges, as well as the smooth variation of transmission with range when octave frequency bands are employed. On Run A, the circles at low frequencies deviate widely from the crosses, suggesting an aircraft navigation error combined with a lateral variation of bottom structure in this direction.

The transmission plots 4a to 4h have the following noteworthy features:

(a) <u>Effect of Range</u>. The transmission tends to be better than spherical (that is, the transmission anomaly is negative) out to a range generally from 5 to 10 miles, followed by a rapid fall-off (when a logarithmic range scale is used).

This characteristic is typical of all range runs in shallow water, as indicated by a recent compilation (2), and is due to trapping at short ranges and the dominant effect of absorption at long ranges.

(b) <u>Effect of Frequency</u>. The transmission tends to be best in the 100-200 Hz or 200-400 Hz octaves, and poorer in octaves below and above. At lower frequencies, the transmission is worse because of a lower ratio of water depth to wavelength and a lesser number of trapped

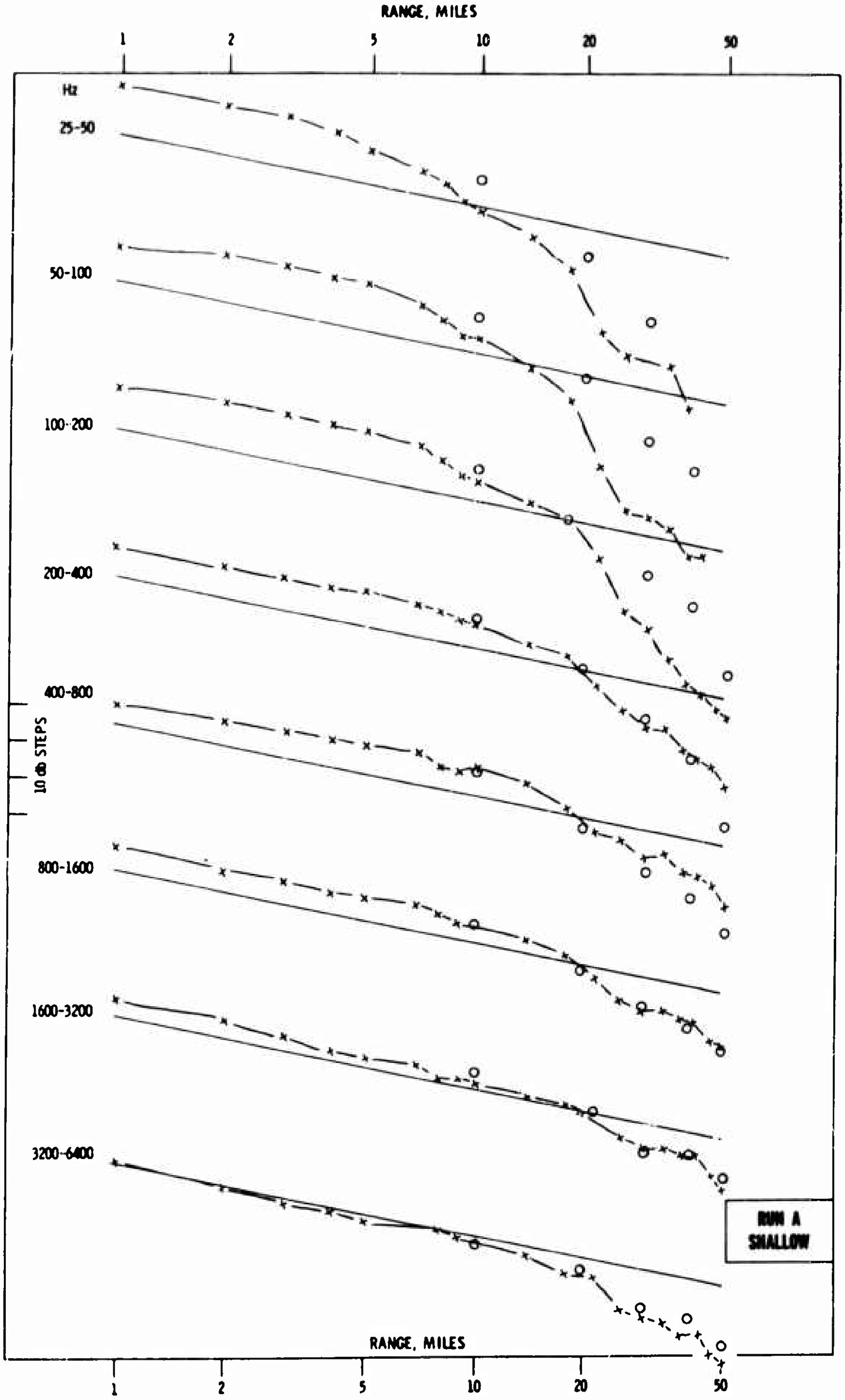
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
10 db STEPS
800-1600
1600-3200
3200-6400
RUN A
SHALLOW
RANGE, MILES
1
2
5
10
20
50

FIG. 4a

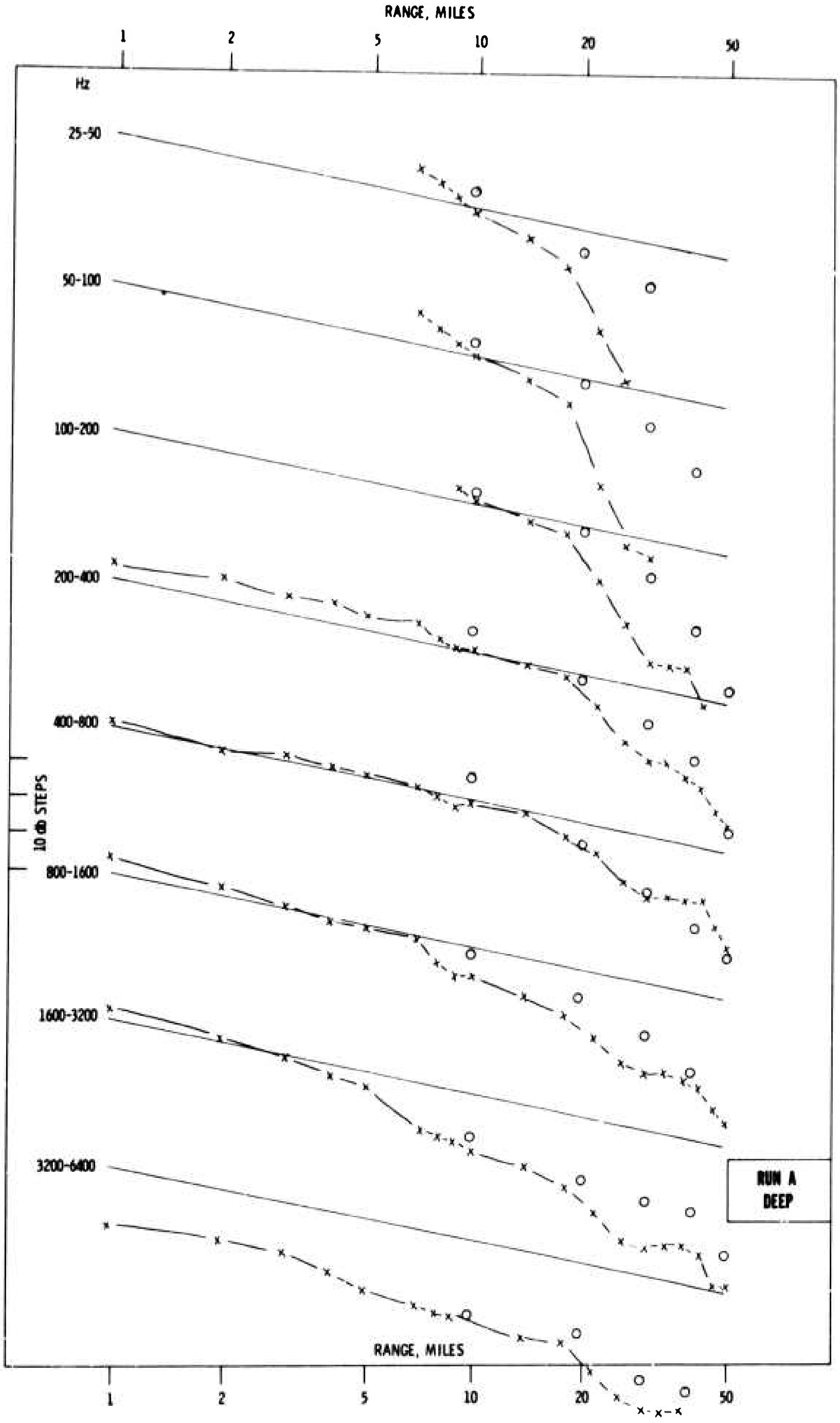
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
10 db STEPS
800-1600
1600-3200
3200-6400
RUN A
DEEP
RANGE, MILES
1
2
5
10
20
50

FIG. 4b

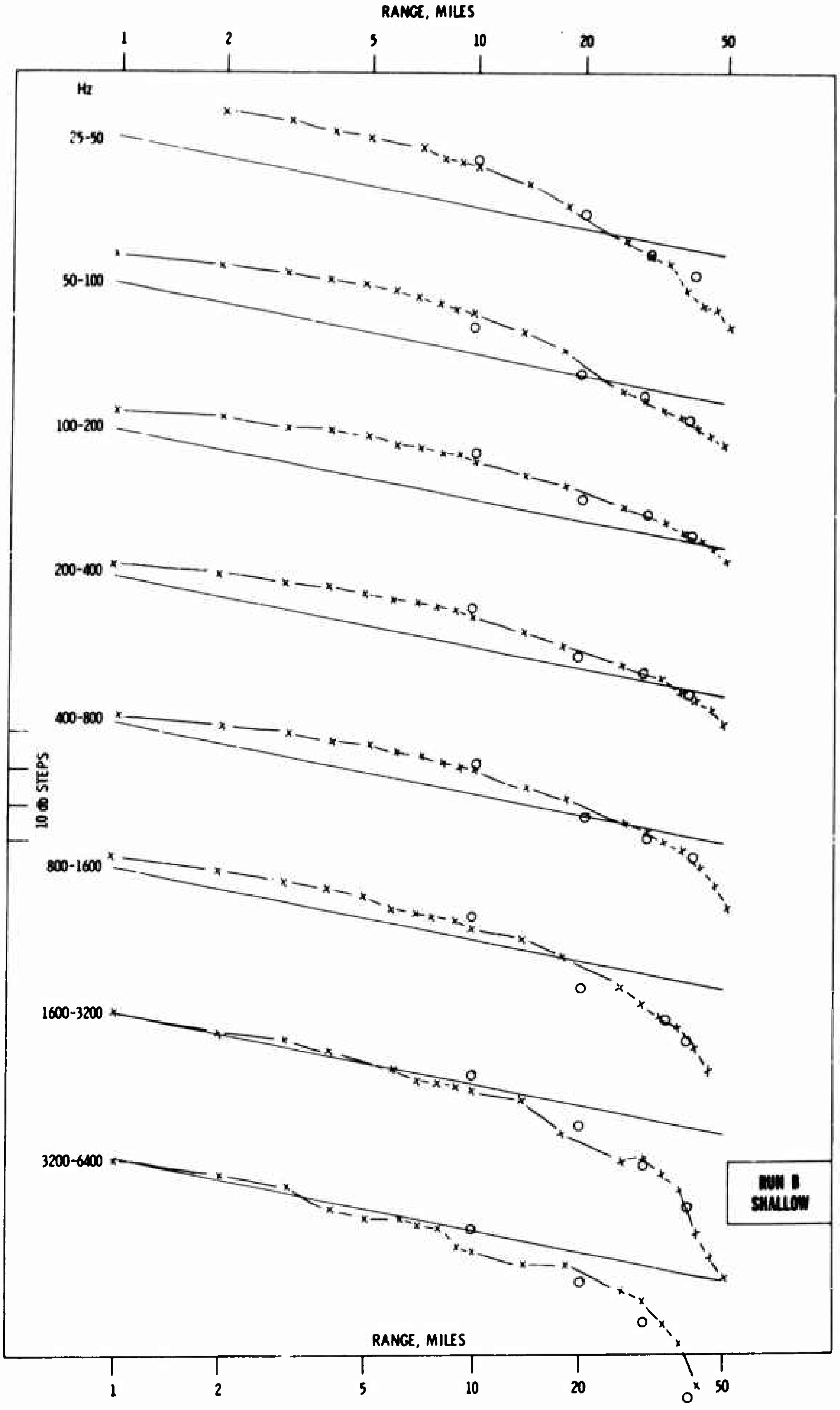
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
10 db STEPS
800-1600
1600-3200
3200-6400
RUN B
SHALLOW
RANGE, MILES
1
2
5
10
20
50

FIG. 4c

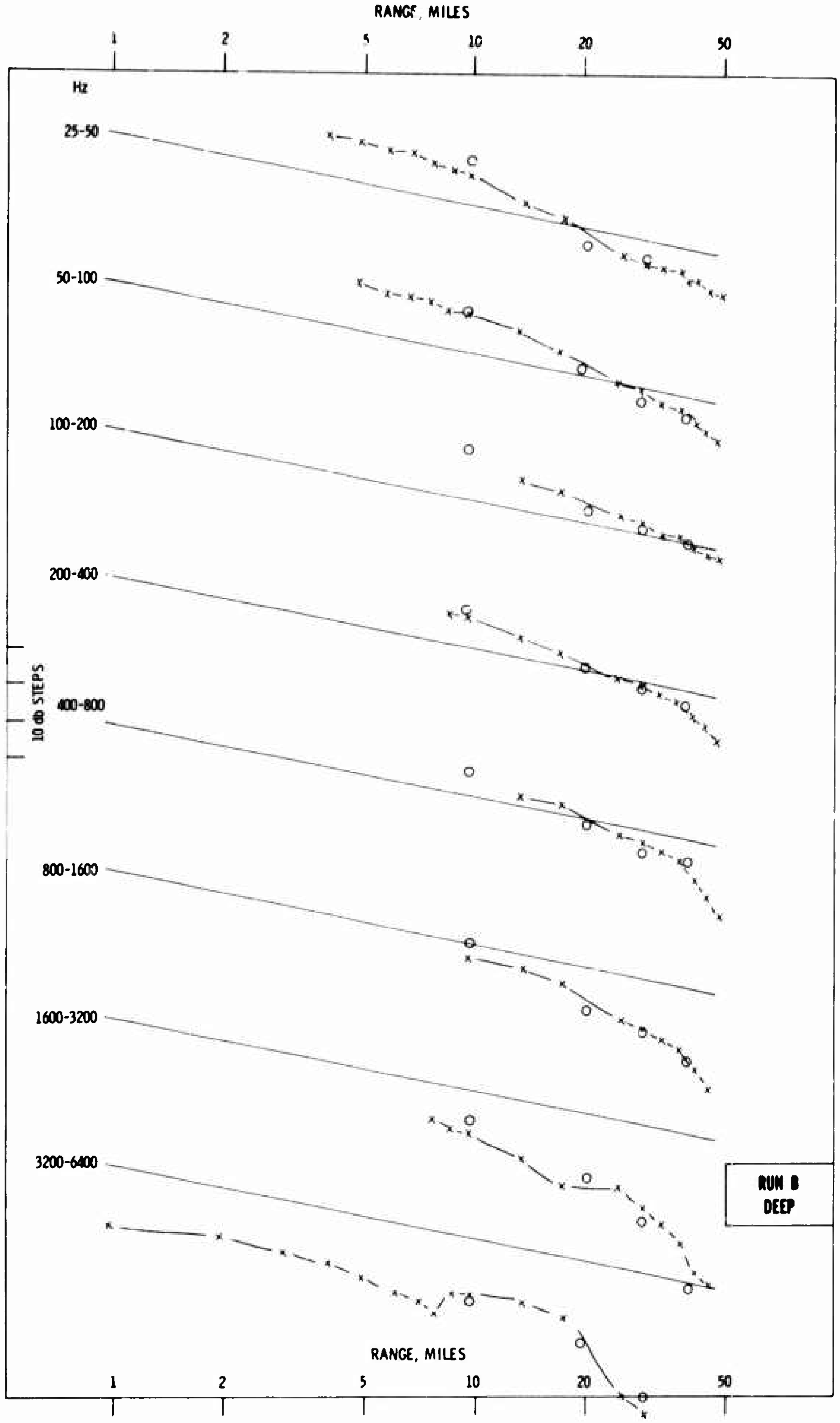
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
800-1600
1600-3200
3200-6400
10 db STEPS
RUN B
DEEP
RANGE, MILES
1
2
5
10
20
50

FIG. 4d

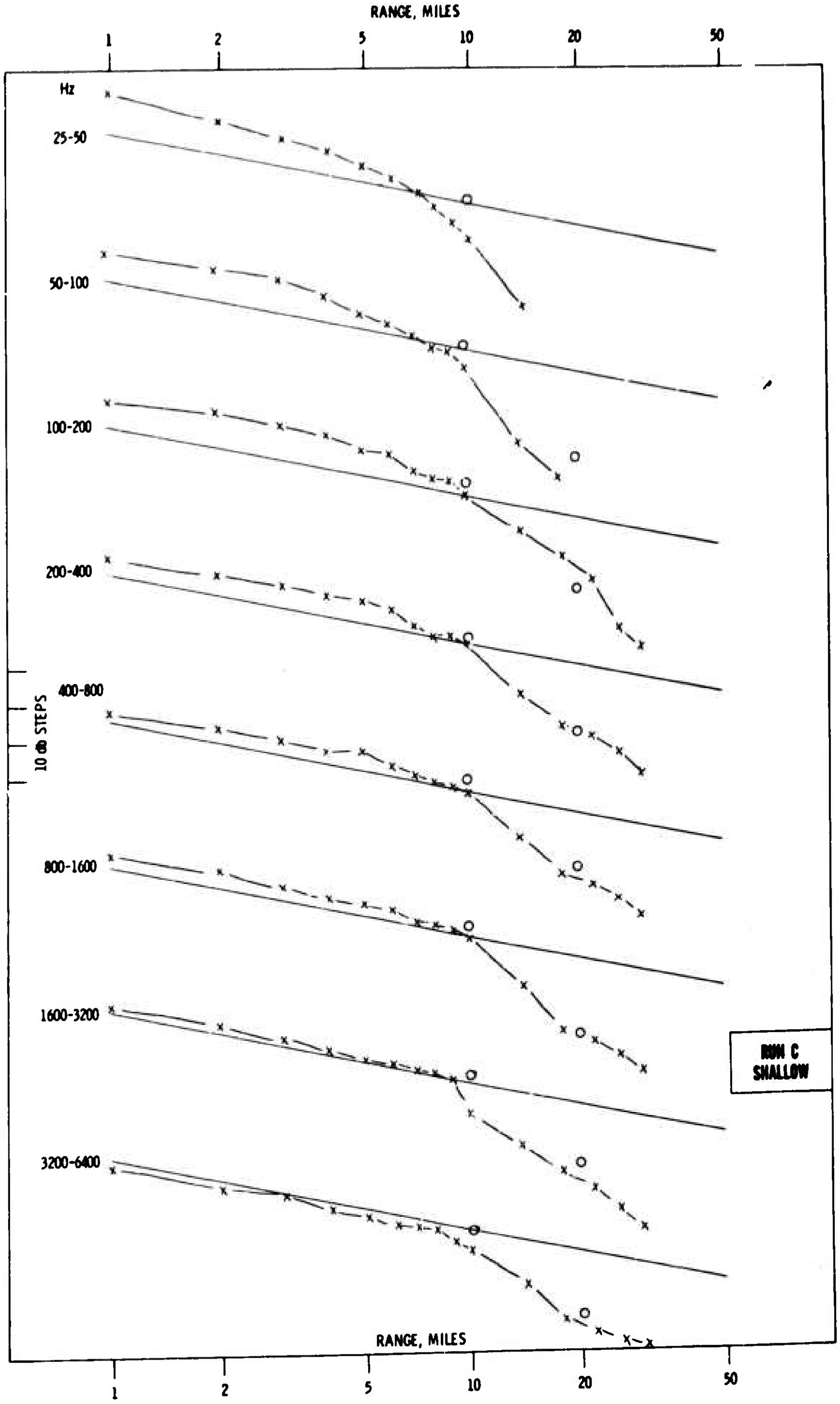
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
800-1600
1600-3200
3200-6400
10 db STEPS
RUN C
SHALLOW
RANGE, MILES
1
2
5
10
20
50

FIG. 4e

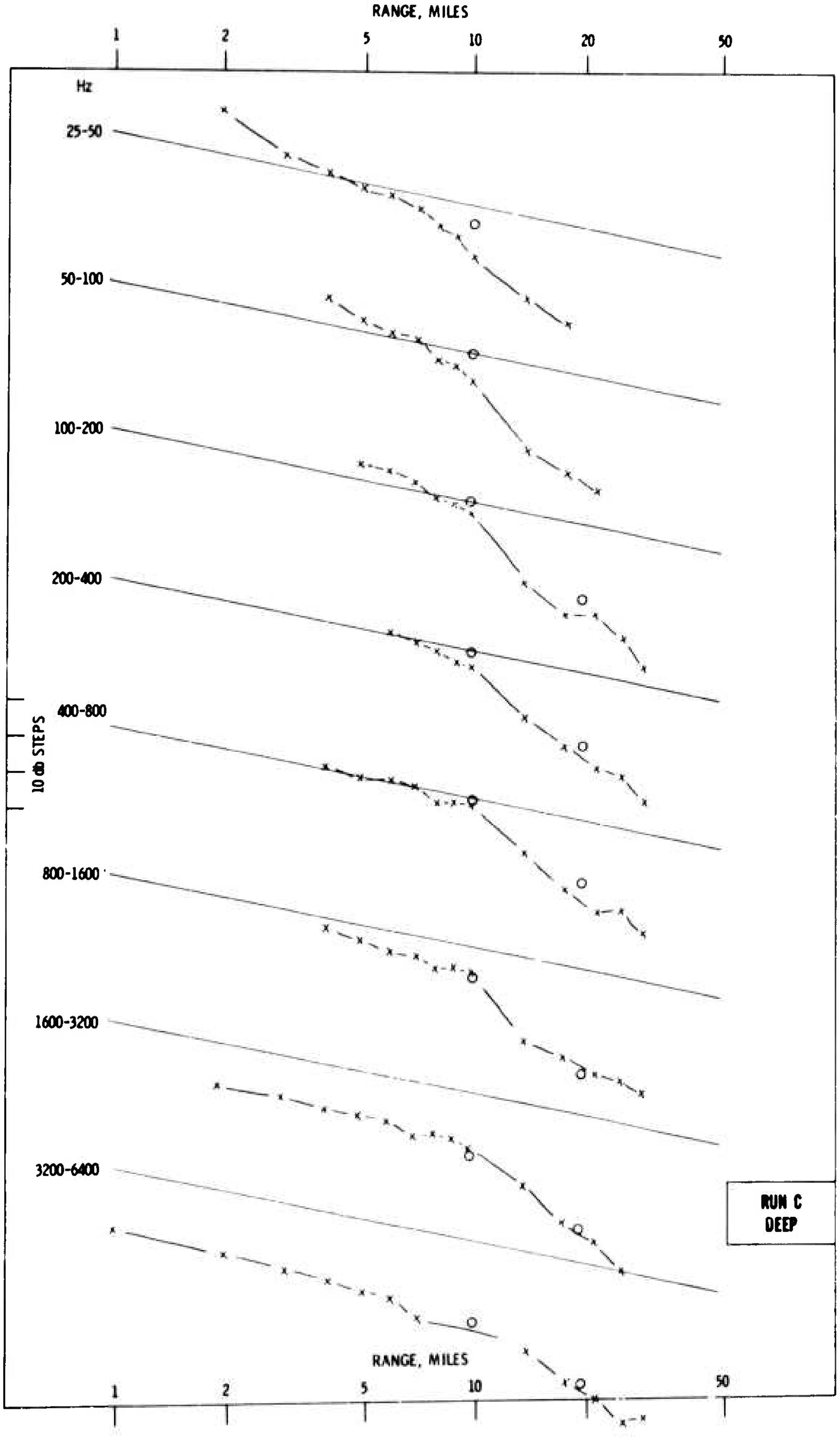
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
800-1600
1600-3200
3200-6400
10 db STEPS
RUN C
DEEP
RANGE, MILES
1
2
5
10
50

FIG. 4f

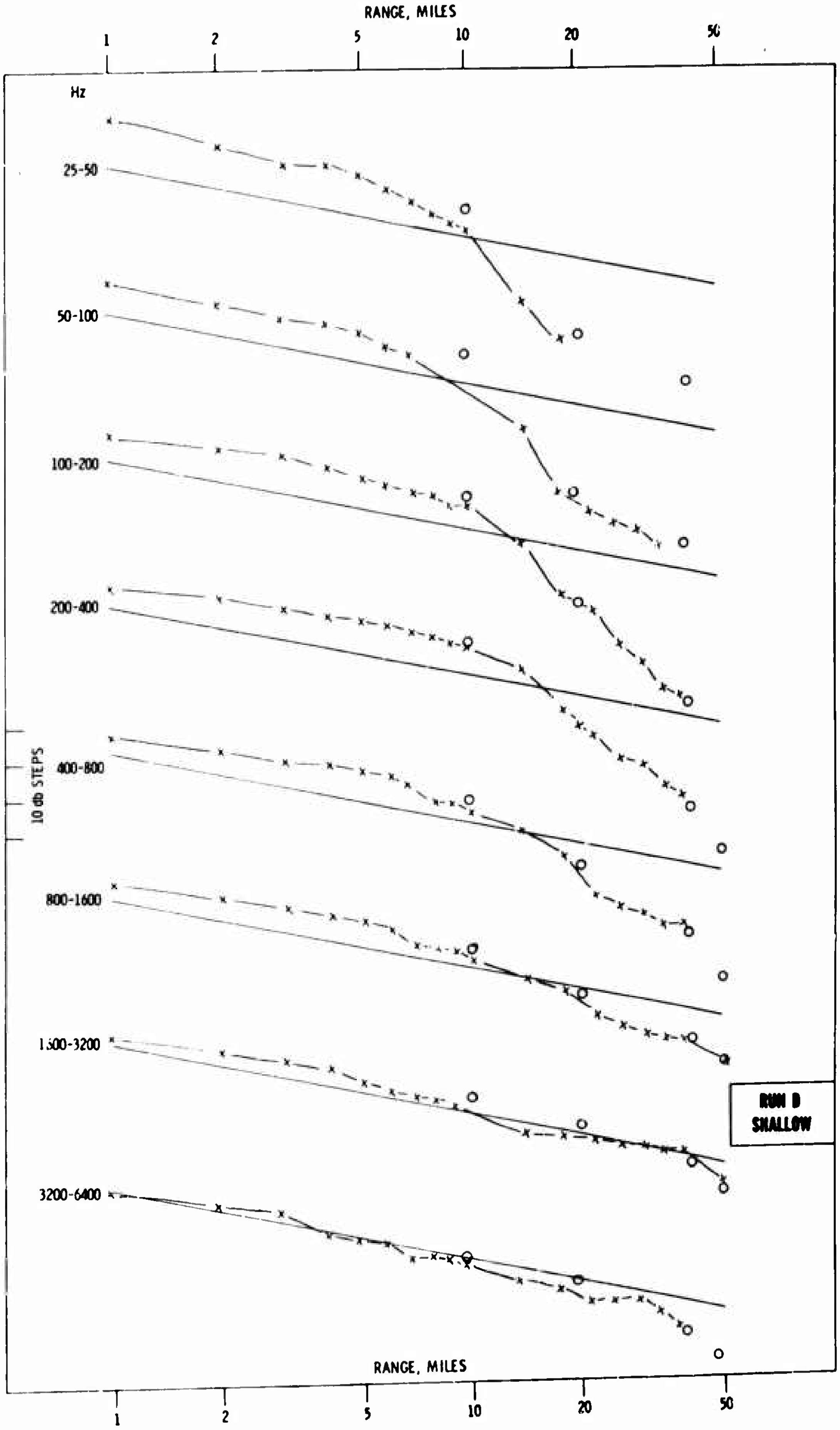
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
800-1600
1600-3200
3200-6400
10 db STEPS
RUN D
SHALLOW
RANGE, MILES
1
2
5
10
20
50

FIG. 4g

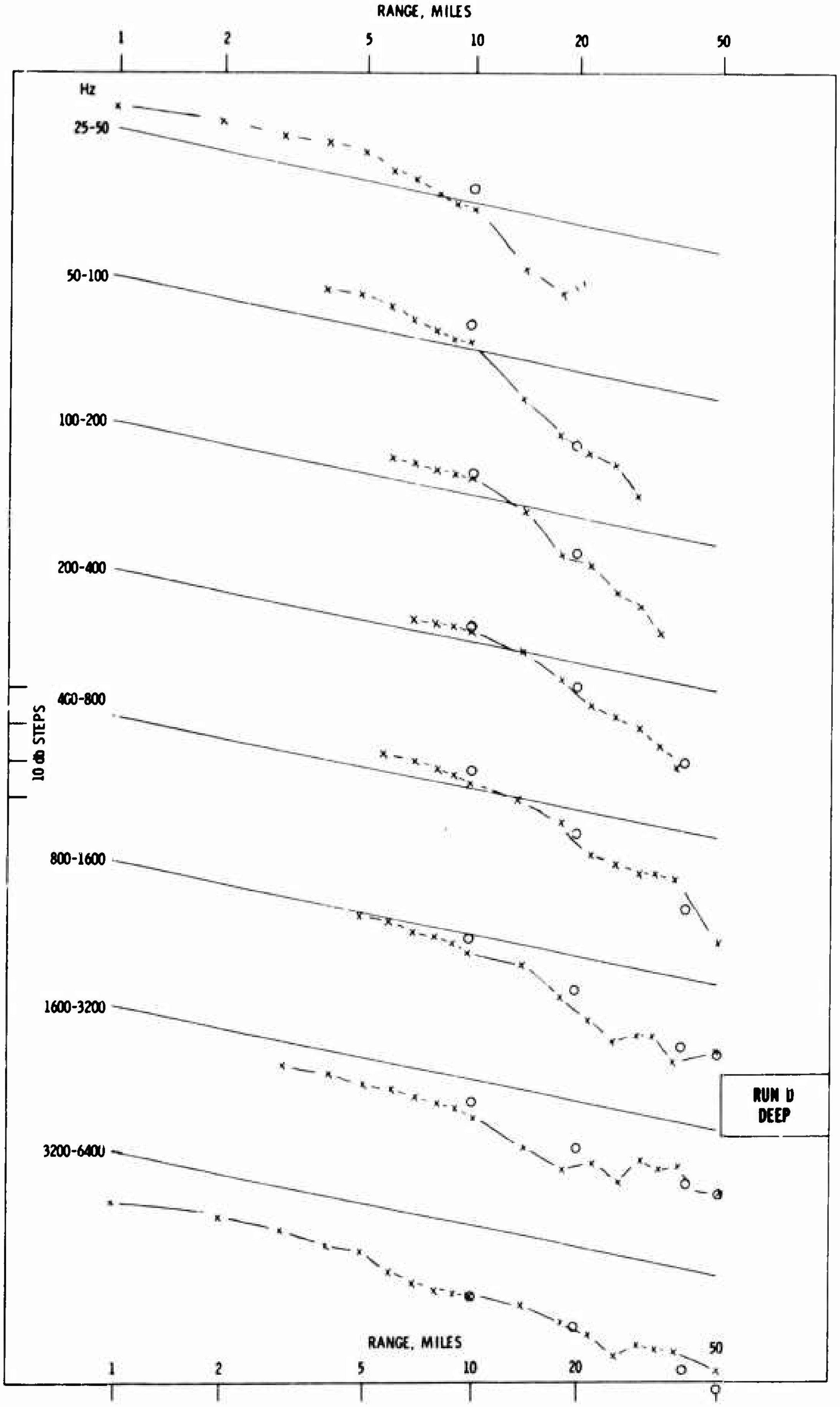
RANGE, MILES
1
2
5
10
20
50
Hz
25-50
50-100
100-200
200-400
400-800
800-1600
1600-3200
3200-6400
10 db STEPS
RUN D
DEEP
RANGE, MILES
1
2
5
10
20
50

FIG. 4h

modes and a greater attenuation; at higher frequencies, the transmission is worse because of a higher volume attenuation. The existence of an optimum frequency for these reasons is characteristic of all sound channels, of whatever type, in the sea.

(c) Effect of Hydrophone Depth. The transmission to the shallow (80 feet) hydrophone is better than to the deeper (180 feet) hydrophone at the higher frequencies, presumably because of trapping in the near-surface sound channel. At the lower frequencies, there is no great difference between the two hydrophone depths.

(d) Effect of Direction. In any one octave band the transmission out to a distance of about 10 miles is unaffected by the depth of the hydrophone or by the direction of the run. The transmission may therefore be said to be essentially isotropic about the receiving vessel out to 10 miles, and independent of hydrophone depth. But at longer ranges, there are great differences in transmission in the different directions. For example, and most notably, the transmission to the North (Run A) is poorer than to the South (Run B) at low frequencies where the bottom acoustic characteristics must play a dominant role, but not appreciably different at high frequencies where trapping in the near surface layer determines the transmission. This is shown by the sample Visicorder playouts of Figs. 5a and 5b for a low frequency band (50-100 Hz) and a high band (1.6-3.2 kHz). However, in the direction toward shore (Run D), the high frequencies are transmitted to the shallow hydrophone better than in other directions, possibly because of the enhancement of the mixed-layer trap by the shallow bottom at or just below its base in this direction. Contrarywise, in the reverse direction toward deep water (Run C) the transmission is the poorest of all at all frequencies, so much so, that Run C, when run, was aborted at 30 miles due to weak or absent recordable shot signals in this direction.

RUN A

RUN B

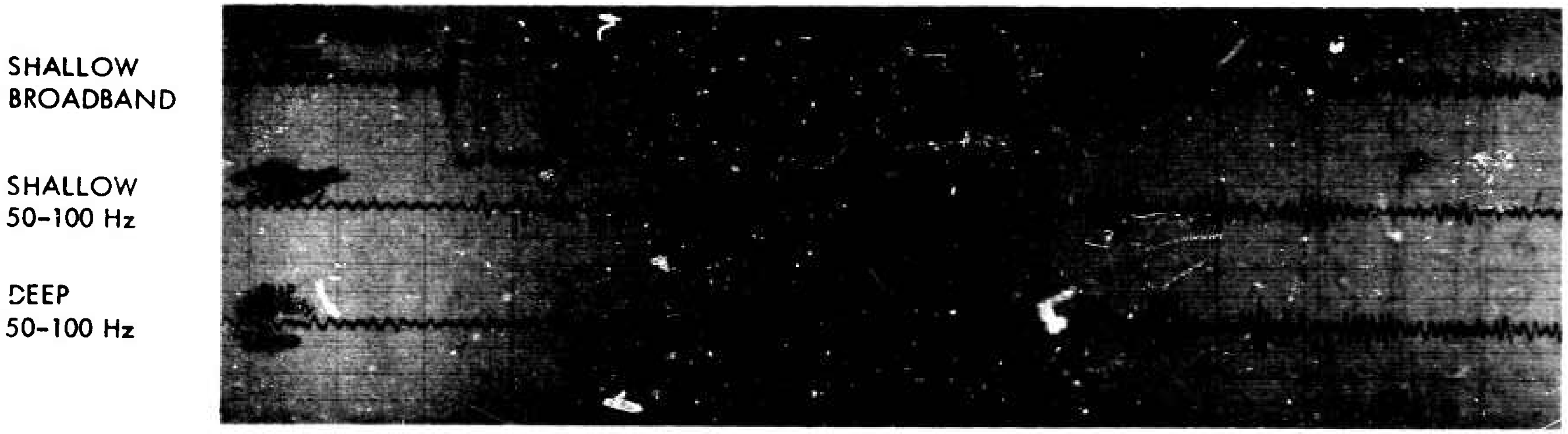

FIG. 5a VISICORDER PLAYOUTS OF 30 MILE SHOTS ON RUN A AND RUN B AS RECEIVED BY THE SHALLOW AND DEEP HYDROPHONES IN THE BAND 50-100 Hz

RUN A

RUN B

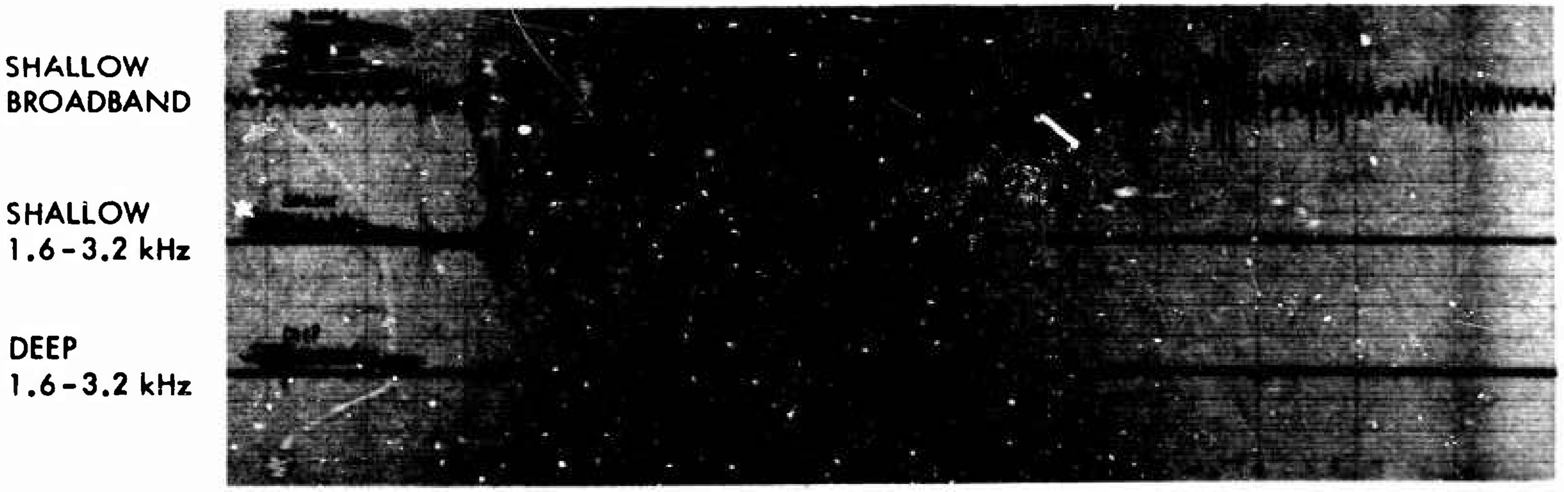

FIG. 5b VISICORDER PLAYOUTS OF 30 MILE SHOTS ON RUN A AND RUN B AS RECEIVED BY THE SHALLOW AND DEEP HYDROPHONES IN THE BAND 1.6-3.2 kHz

SIGNAL ELONGATION

The received shot signals have a time duration that increases with increasing range of the shot. Figure 6 shows the measured time interval from the start of the received pulses to an estimated point on their smooth envelope 10 db down from the maximum amplitude, as read from Sanborn playouts in a wide frequency band and in a 1/3 octave band. At short ranges the broad band signals have a duration about equal to the interval between the shock wave and the second bubble pulse of a 2 pound, 60 foot explosive charge. The signal duration in a broad frequency band increases with range at the rate of 1 second per 100 miles - a rate strangely the same as that of pulses travelling in the deep ocean sound channel. This time elongation is due to the well-known frequency dispersion associated with sound propagation in shallow water. In a narrow frequency band, such as a 1/3 octave band at 1 kHz, this dispersion is negligible and the elongation of a transmitted pulse is small or absent.

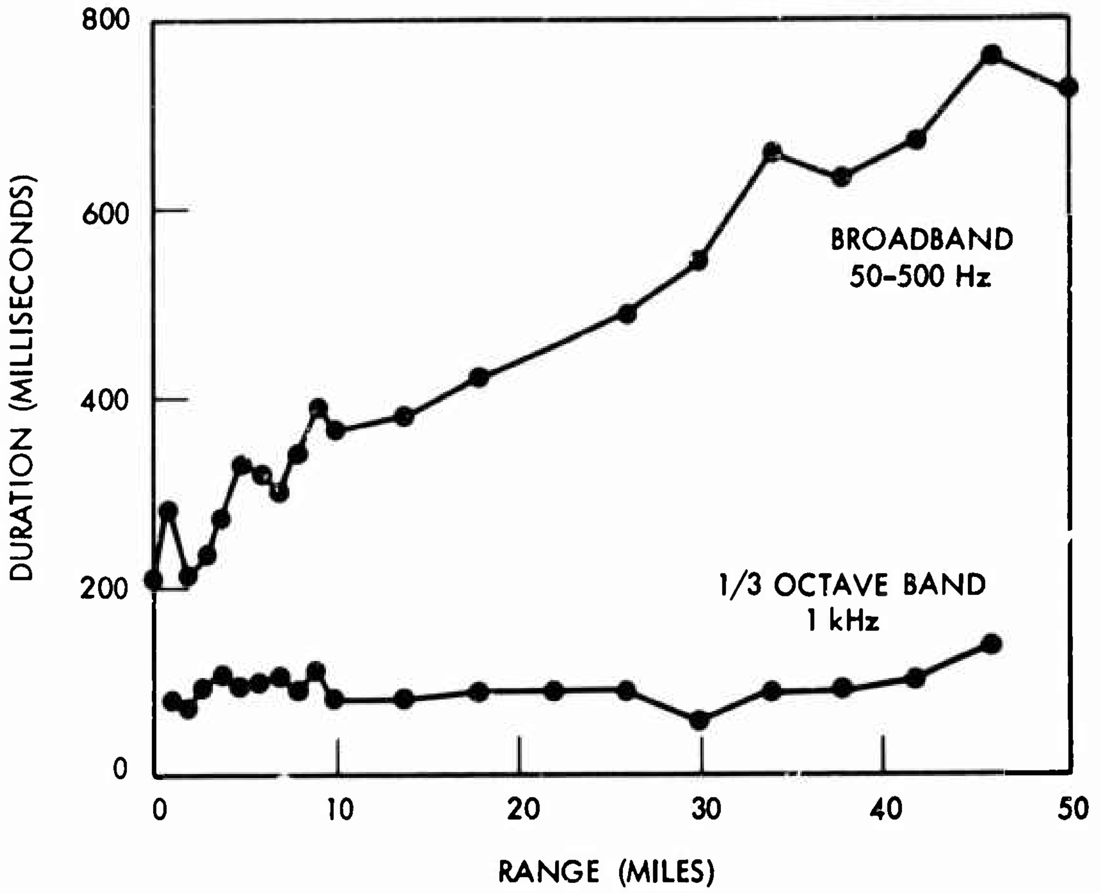

FIG. 6 TIME DURATION OF RECEIVED SHOT SIGNALS, FROM THE ONSET TO AN ENVELOPE POINT 10 db DOWN, AS A FUNCTION OF RANGE

BOTTOM LOSS

In order to provide some basis for an interpretation of the transmission data in terms of the available theories, the bottom reflection loss at the vessel was measured by a direct method. As depicted in Fig. 7, Mk 64 (1 oz.) explosive sound signals were dropped from a motor launch at various distances from the vessel. Shot signals travelling via various paths were recorded by a 50 foot hydrophone dangled from the vessel. Figure 8 shows oscilloscope photographs of the records obtained, unfiltered on the left, and filtered in the 1.6-3.2 kHz band on the right. The lower trace of the pair in each photograph shows the pulses arriving over the paths D, S, BS, SB, etc. as they appeared after squaring; the upper trace of the pair is the integrated trace of the lower at the output of an integrator. The ratio of the deflection of the integrated trace B to the deflection D or S (or sometimes $(D + S)/2$ where D and S were separately indistinguishable), was measured; 10 times the logarithm of this ratio is the energy-density reflection loss at the bottom. Figure 9 shows the measured reflection losses plotted against bottom grazing angle for individual shots in three frequency bands. It will be noted that the reflection loss lies between 0 and 7 db, and increases with grazing angle and frequency, as would be expected.

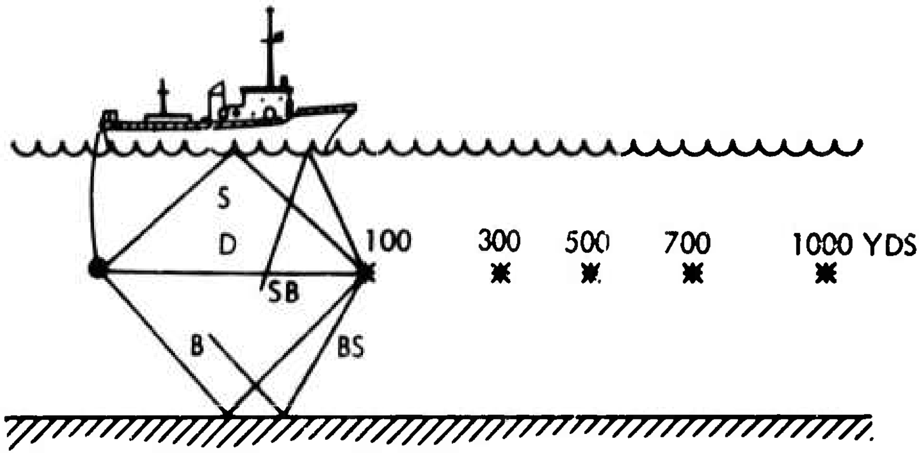

FIG. 7 GEOMETRY OF BOTTOM REFLECTION MEASUREMENTS

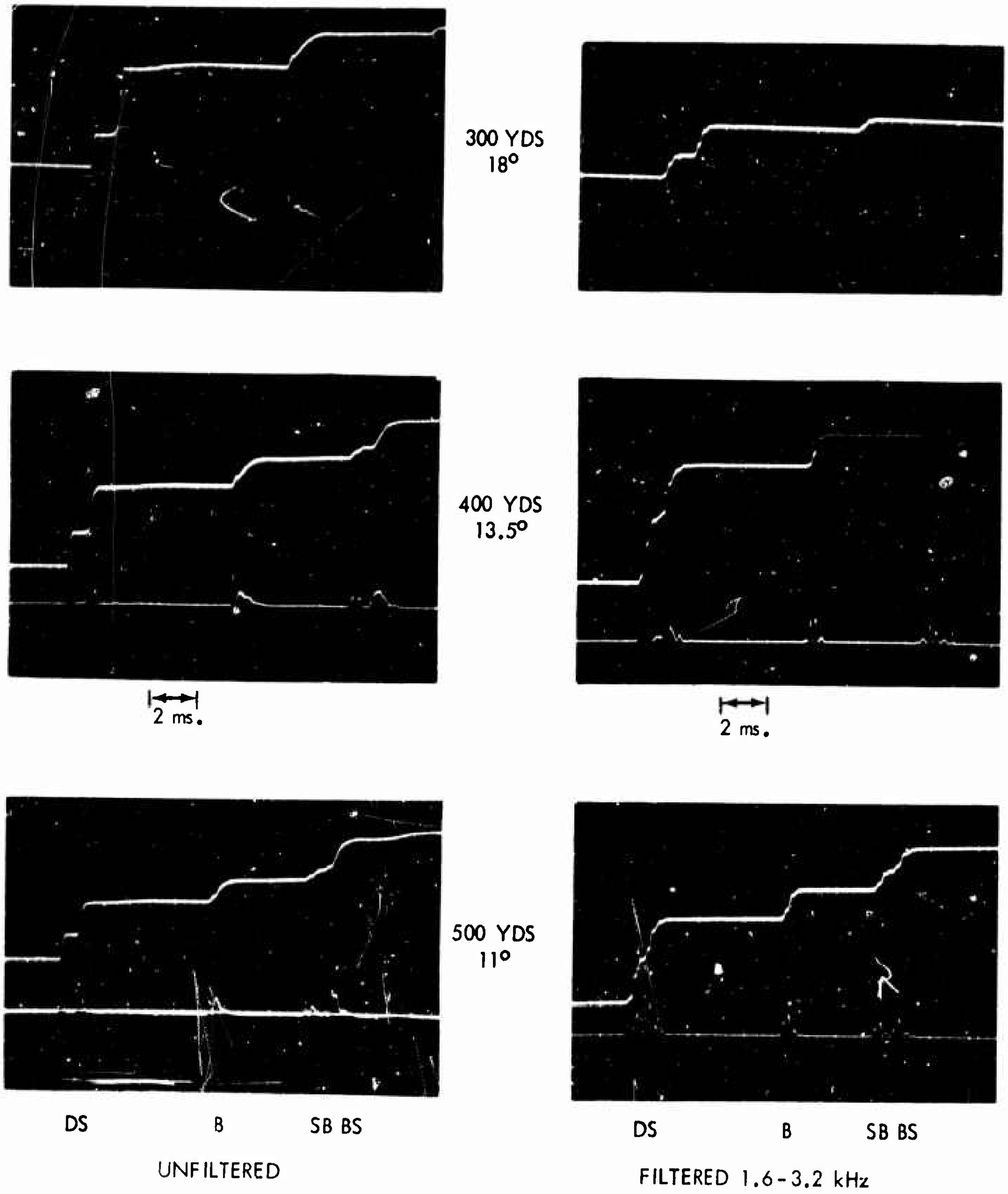

FIG. 8 OSCILLOSCOPE PHOTOGRAPHS OF DIRECT AND REFLECTED SHOT PULSES

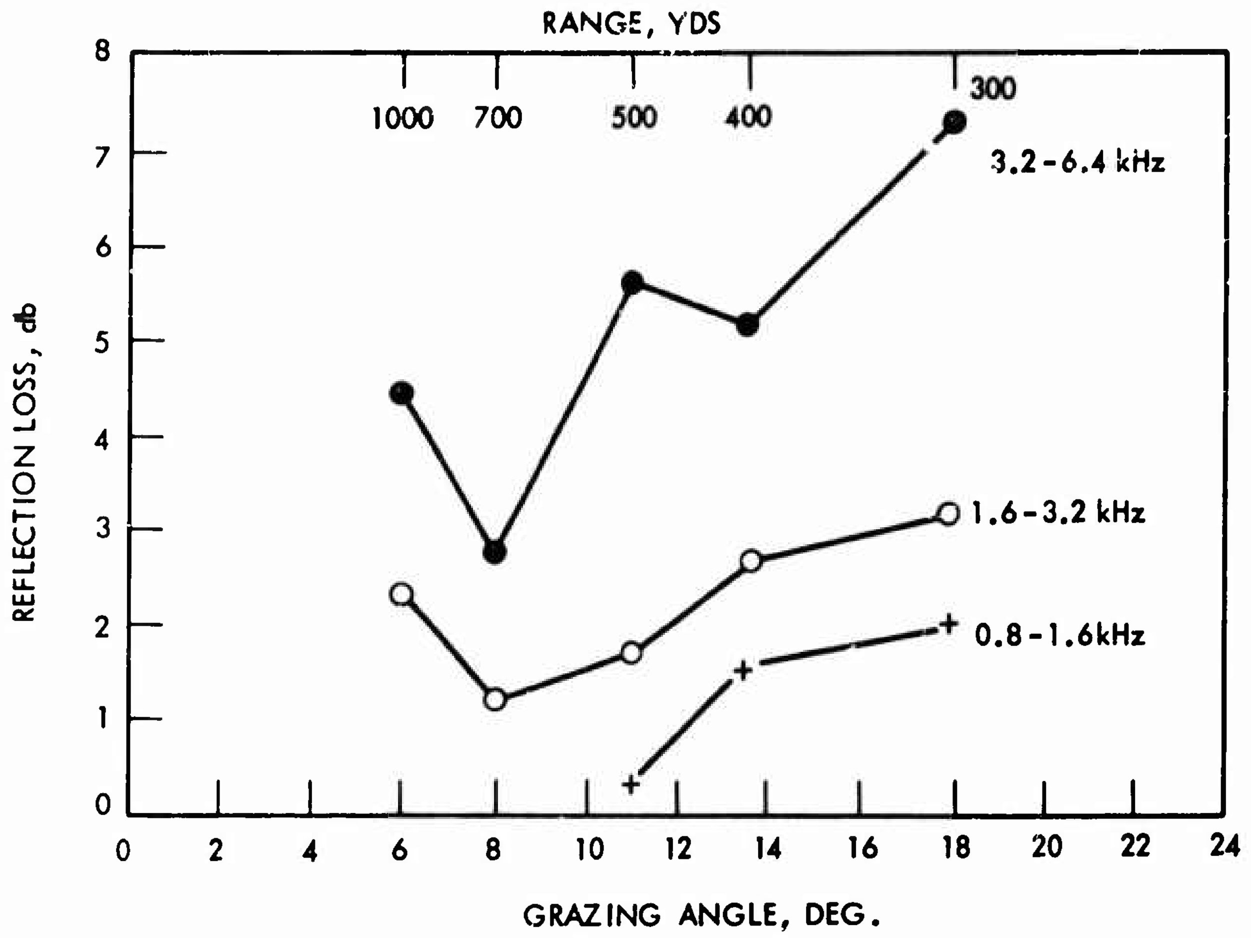

FIG. 9 MEASURED BOTTOM REFLECTION LOSS

REVERBERATION LEVEL

The reverberation level received on the shallow hydrophone from 2 pound explosive charges Mk 61, dropped both from the aircraft and from a motor launch within 100-200 yards of the hydrophones, is shown in Fig. 10, as traced from Sanborn recorder playouts of the tape recordings. No significant difference was found between the reverberation levels at the shallow and deep hydrophones. Figure 11 shows the transmission loss for the four runs at the shallow hydrophone, as read from Figs. 4a, 4c, 4e, and 4g out to limit of time (12 seconds) or range (5 miles) to which the reverberation recordings could be used. Combining the preceding two figures, and using the relation connecting scattering strength and reverberation level (3), we obtain Fig. 12 showing scattering strength as a function of frequency for times of 2, 4, and 8 seconds, corresponding to ranges of 1700, 3400, and 6800 yards. The scattering strength is found to decrease with time and to increase with frequency. The decrease with time is due to a decreasing grazing angle at which the scattering originates at the bottom with increasing time under the prevailing nearly smooth condition of the sea surface; the reverberation is no doubt the result of backscattering by the bottom. When associated with a particular value of angle, equal to one-half of the "coherence angle" mentioned below, the measured scattering strengths are entirely consistent with values of the scattering strength of the deep sea bottom at small grazing angles published in the literature (4)(5).

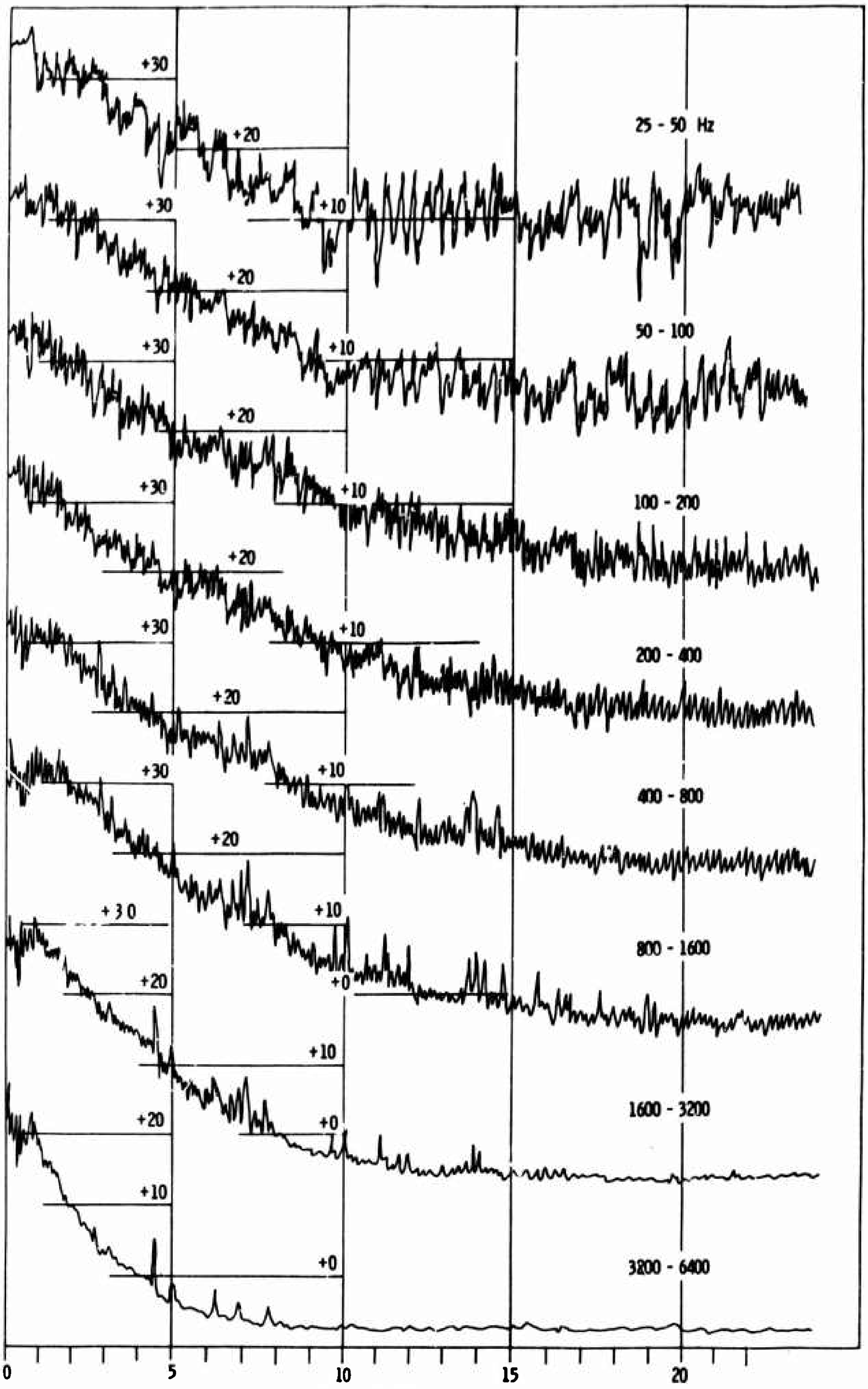

FIG. 10 REVERBERATION LEVEL IN VARIOUS OCTAVE BANDS VS TIME. LEVEL SCALE IS IN db RELATIVE TO 1 DYNE/CM^2.

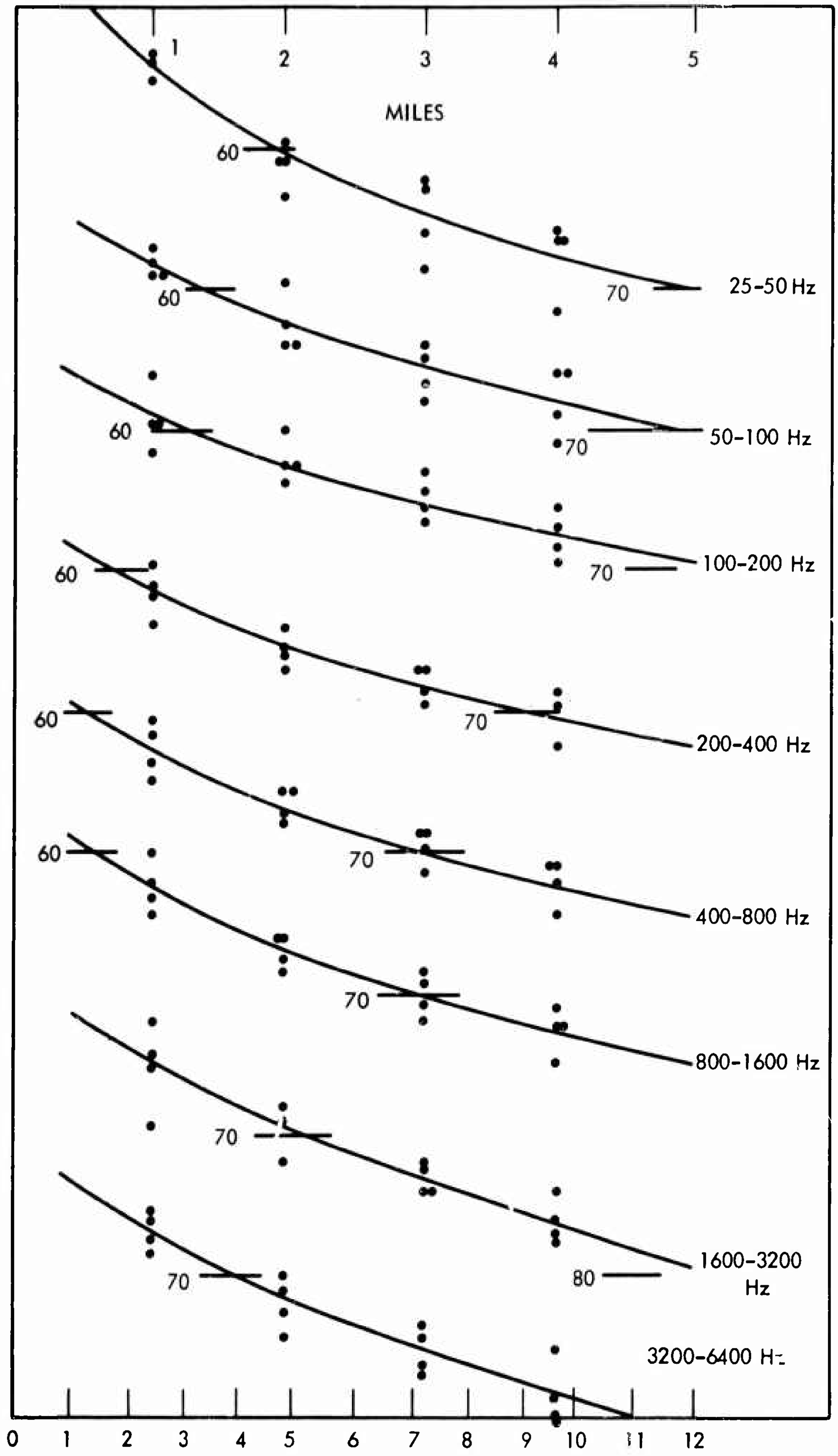

FIG. 11 TRANSMISSION LOSS TO THE SHALLOW HYDROPHONE FOR RANGES OF 1, 2, 3, AND 4 MILES. LOSS VALUES ARE IN DECIBELS.

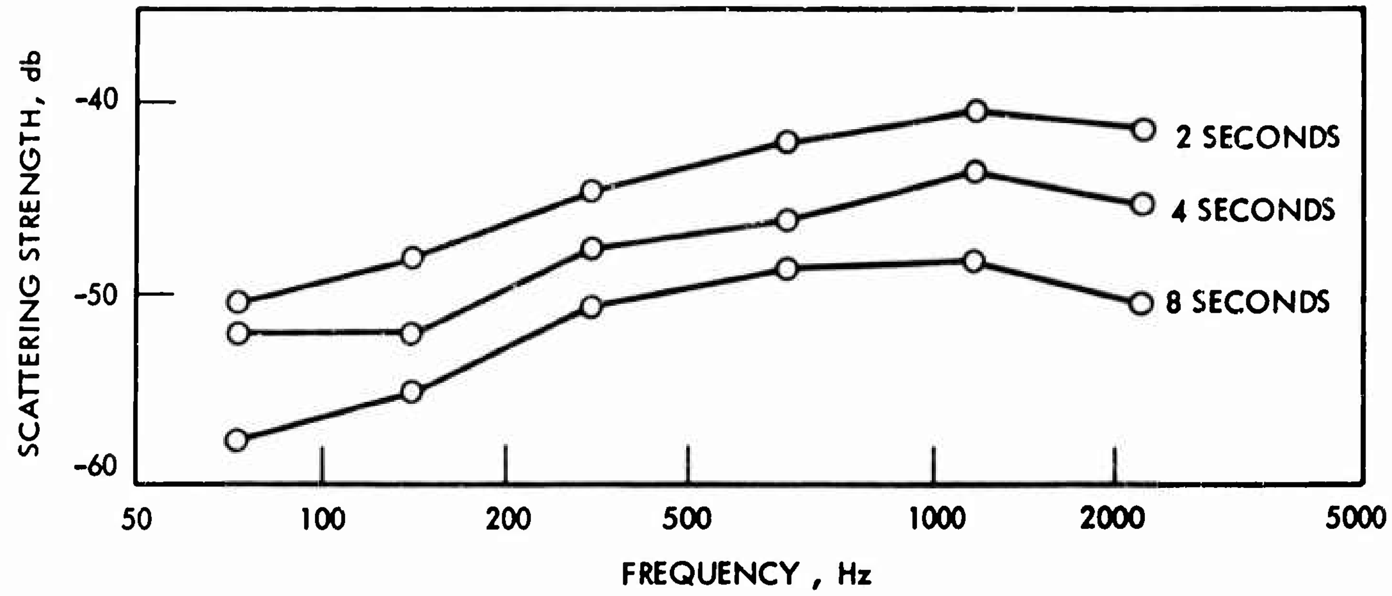

FIG. 12 SCATTERING STRENGTH VS FREQUENCY AT TIMES OF 2, 4, AND 8 SECONDS. THE POINTS ARE PLOTTED AT THE MID-FREQUENCY OF THE OCTAVE BANDS

REVERBERATION COHERENCE

In another experiment the reverberation from 60 foot Mk 61 charges was recorded on separate hydrophones of the vertical string shown in Fig. 13. The clipped tape-recordings were later fed into a DELTIC correlator, and peak values of the clipped (phase) correlation coefficient were read off in different frequency bands for different hydrophone spacings. After conversion to true correlation coefficient the results are shown in Fig. 14. The coefficient is seen to increase with time after the shot, no doubt because of the stripping-off of high angle reverberation paths with increasing time. That is to say, the reverberation may be interpreted as arriving within an increasingly narrow angle centered about the horizontal as time increases. Also, the reverberation coherence is observed to decrease with hydrophone spacing, as expected, and to decrease with increasing frequency at the same spacing.

For simplicity in analysis, the reverberation at a particular instant of time and at a particular frequency may be conceived to arrive at the receiver within a certain vertical angle above and below the horizontal, within which the intensity in a small vertical angle is constant, and beyond which the reverberation intensity is zero. At a particular time and frequency, the reverberation thus may be viewed as having an equivalent vertical beam width that determines its vertical coherence and the rate of decrease of its correlation coefficient with hydrophone spacing. The observed data show that the half-angle of this equivalent vertical beam - which may be called "coherence angle" of the reverberation - lies between 30° and 5°, and decreases with increasing time and frequency. Its value is so small that only an extremely long vertical array would be able to provide any discrimination against the shallow water reverberation observed in the present experiment.

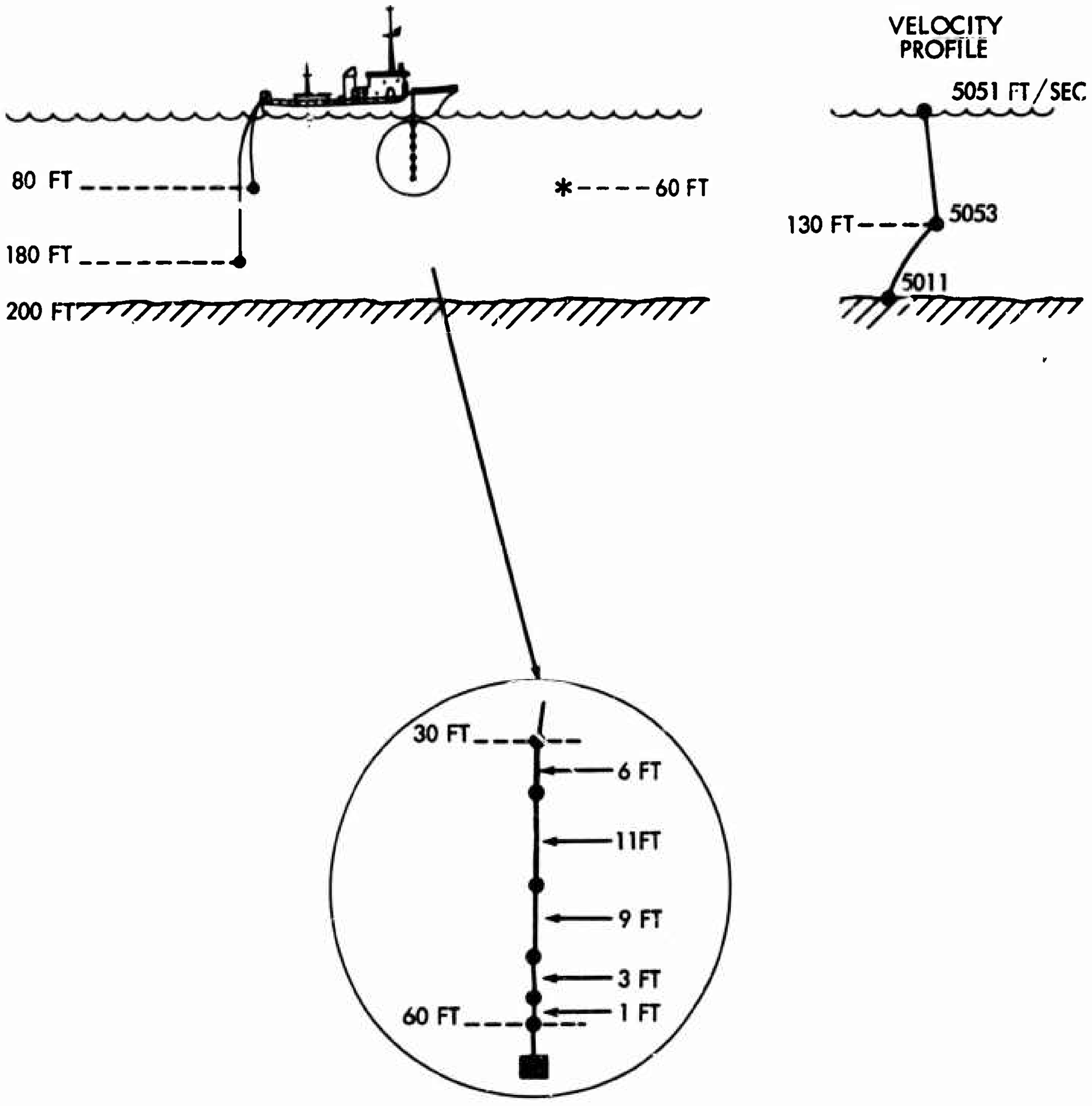

FIG. 13 EXPERIMENTAL GEOMETRY FOR VERTICAL COHERENCE MEASUREMENTS

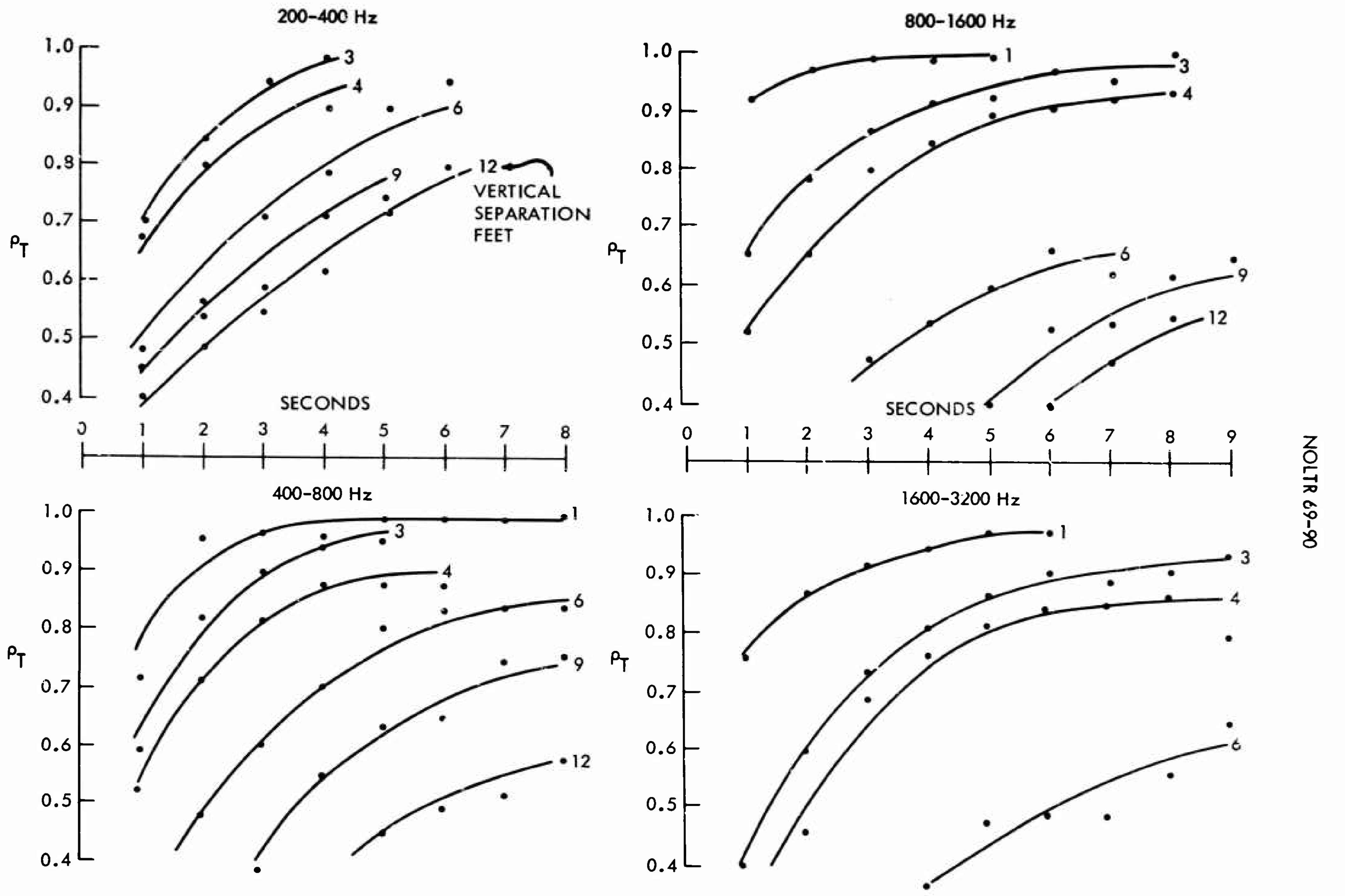

FIG. 14 TRUE REVERBERATION CORRELATION COEFFICIENTS ρ_T, IN DIFFERENT FREQUENCY BANDS, VERTICAL SEPARATIONS, AND TIMES AFTER THE SHOT

EXAMPLES OF DESIGN CURVES FOR SHALLOW WATER SONARS

For design considerations of sonars to operate in the shallow water of the test location, the data just presented can be utilized in a number of ways. The following are hypothetical examples illustrating some of these applications; others can be generated readily for particular purposes.

The last point mentioned in the preceding section is illustrated by Fig. 15. This shows the computed array gain of a vertical unshaded array having varying numbers of elements, against isotropic noise and against the observed shallow water reverberation, on the assumption of a perfectly coherent signal in both cases. Note that an array of 21 elements spaced 1 foot apart and therefore 20 feet long, would have an array gain of 9-1/2 db against isotropic noise, but only 1-1/2 db against the reverberation. Because of the confinement of reverberation to a narrow angle in the vertical, as compared to an essentially uniform distribution (under most circumstances) in the horizontal plane, it is far more practical to seek to reduce reverberation in shallow water by a horizontal rather than by a vertical array. This fact has been noted many times in the past by other investigators of shallow water acoustics.

Figure 16a shows curves of signal level from a passive 45 db target in the frequency band 100-200 Hz, assuming a 60 foot target depth and the shallow hydrophone depth, in an ambient shallow water background in a 1 Hz receiving bandwidth. The ambient noise levels shown were not observed in the present experiment, but were surmised from the (very scanty) literature on shallow water noise background. The level of the target signal would be surmised to fall off differently in different directions from the receiving hydrophone, because of the directional effects at the site location.

Figure 16b shows echo and reverberation levels computed for a hypothetical active sonar in the band 1.6-3.2 kHz, having a source level of 120 db and radiating non-directionally. The receiver is assumed to have an array gain of 10 db against reverberation, and the target to have a target strength of 10 db. We note that the echo level decreases in range at the same rate, or slightly slower, than the reverberation. This effect is brought about by the decreasing effective scattering strength with time (Fig. 12) and is brought about, in turn, by the narrowing vertical beamwidth of the reverberation. This anomalous effect - an increasing echo-to-reverberation

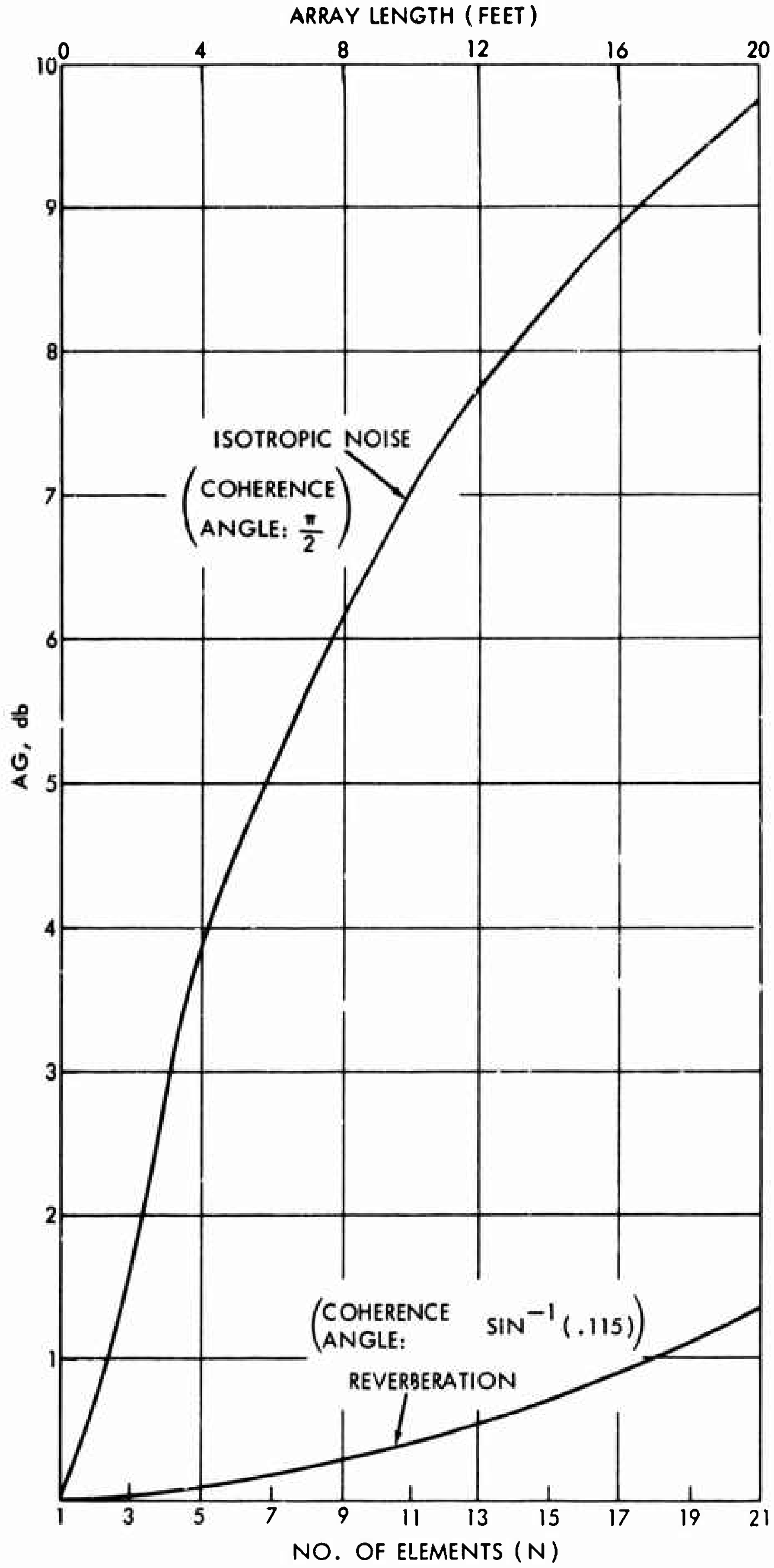

FIG. 15 ARRAY GAIN, AG, OF A VERTICAL UN-SHADED ARRAY OF N ELEMENTS ONE FOOT APART AGAINST ISOTROPIC NOISE AND REVERBERATION AT THE MID FREQUENCY (1120 Hz) OF THE 800-1200 Hz OCTAVE

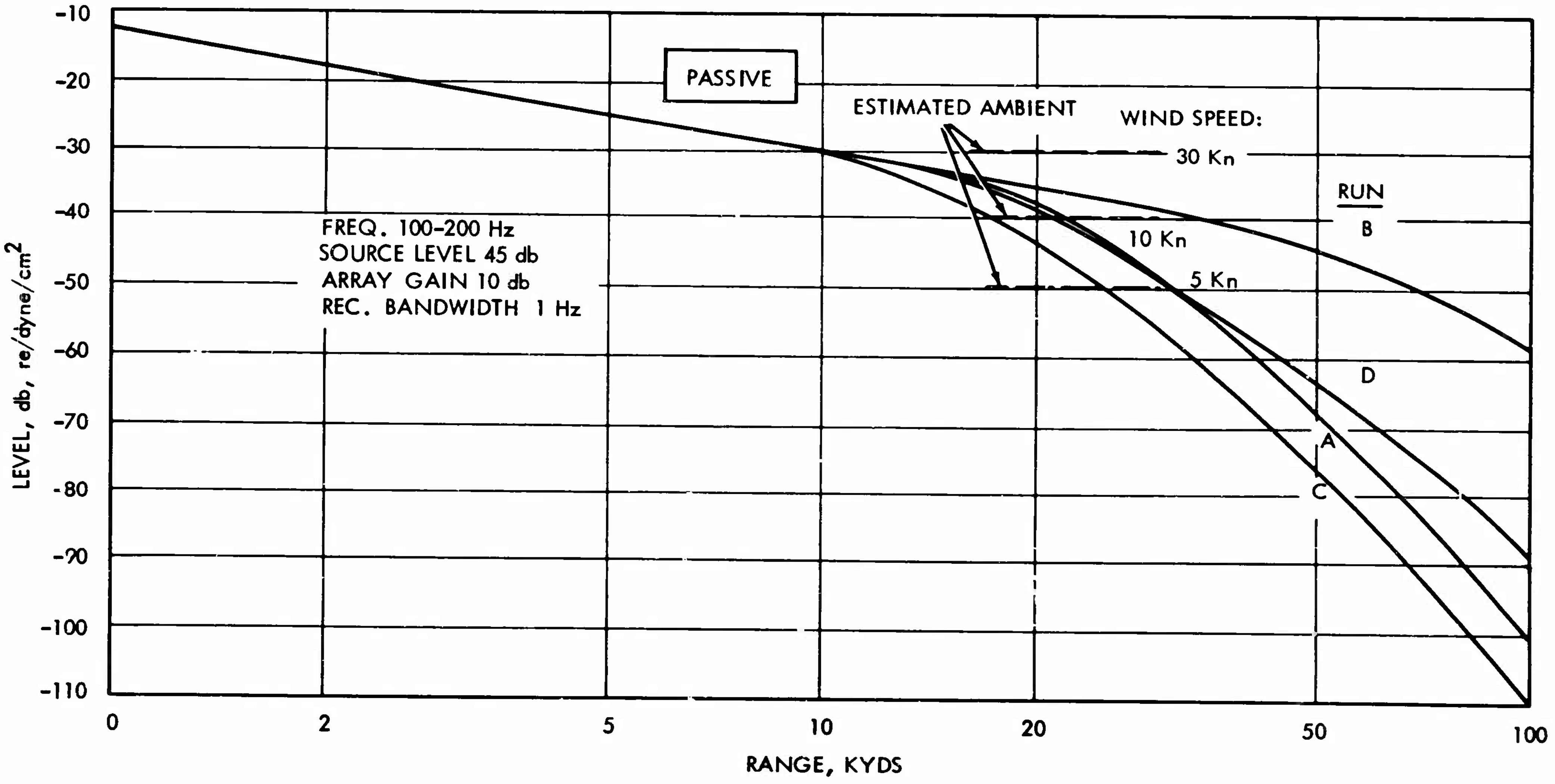

FIG. 16a SIGNAL LEVEL OF A HYPOTHETICAL +45 db TARGET AT THE TEST LOCATION.

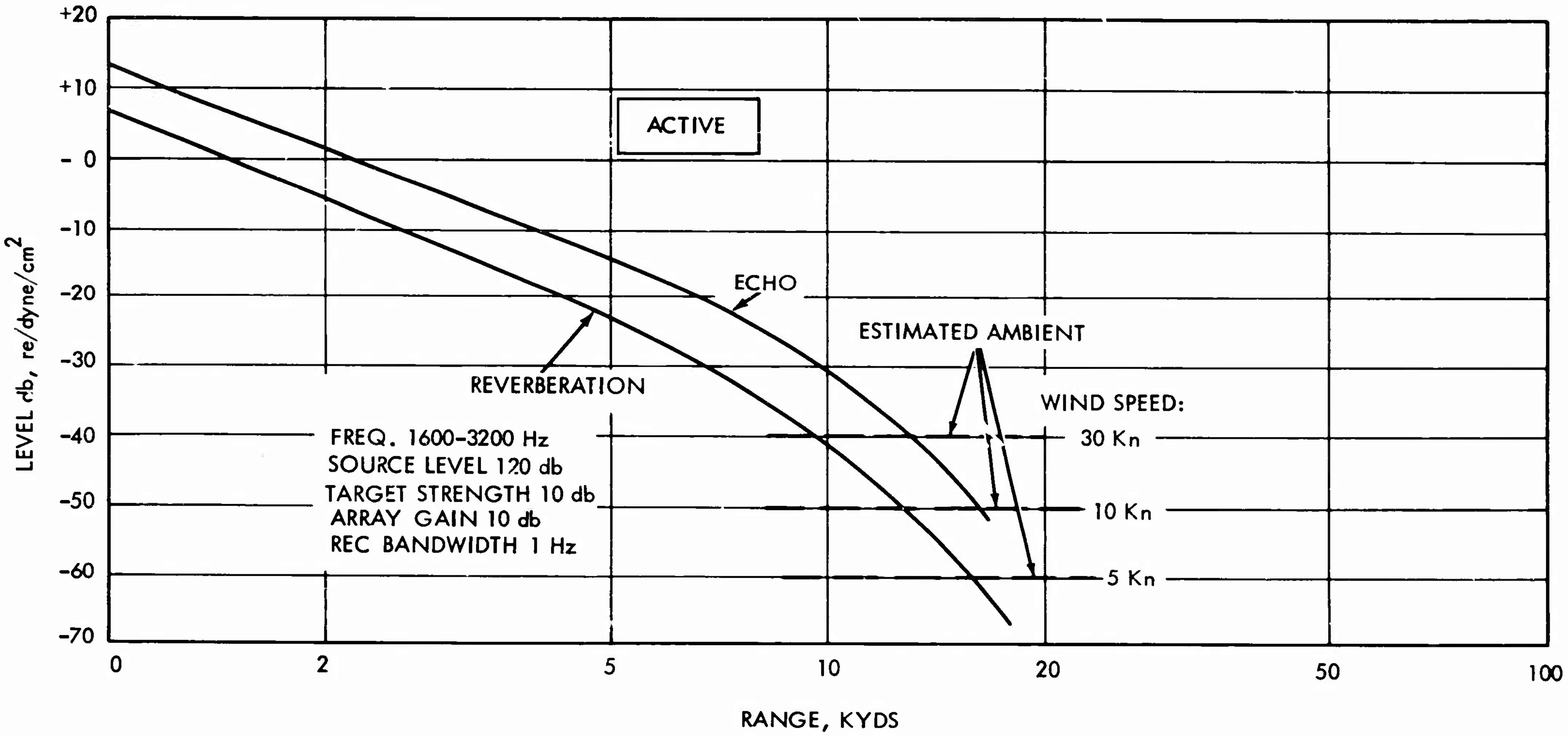

FIG. 16b ECHO AND REVERBERATION LEVELS OF A HYPOTHETICAL ACTIVE SONAR AT THE TEST LOCATION

ratio with range or time - in spite of an ever-increasing reverberating area - was noted long ago during shallow water explosive echo ranging trials by the Woods Hole Oceanographic Institution and by the Daystrom Co. (6).

CONCLUDING REMARKS

In a short field test, a variety of acoustic measurements were made at a location in 200 feet of water. Some of the transmission results (Figs. 4a to 4h) have a ready explanation, but others do not; neither is it easy to explain the transmission data by the available simple theories - even though a bottom loss measurement (Fig. 9) was made - because of complications introduced by the layered water column (Fig. 2) and by the sloping bottom in two of the four directions. Yet the measurements of reverberation level (Fig. 10) and reverberation coherence (Fig. 14) appear to be understandable in terms of a scattering strength and a coherence angle that vary with time and frequency in a reasonable way. Some examples have been given to illustrate how the explosive source data obtained in the present experiment may be used in some simple suggestive applications to shallow water sonars. More meaningful design and prediction uses await the gathering of quantitative data in additional shallow water areas.

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13. ABSTRACT

Measurements of acoustic transmission, reverberation level, reverberation coherence and bottom loss were made at a site off the West Coast of Florida in 200 feet of water. Standard Navy explosive sound signals were dropped by an aircraft and recorded aboard an anchored research vessel. The transmission results are found to have both some explainable and un-explainable features. The reverberation data have been interpreted in terms of a scattering strength consistent with deep water measurements, and a coherence angle describing the vertical distribution in angle of the reverberant return.

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