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A DESCRIPTIVE STUDY OF THE ACOUSTIC FADING OF MINE TARGETS

[UNCLASSIFIED TITLE]

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ABSTRACT

By the use of an unmodified AN/UQS-1 mine-hunting sonar set attached to a pier, the echoes from various bottomed and moored mine targets have been observed over a period of time. The echoes, together with the one-way transmission to a bottomed hydrophone nearby, were found to fluctuate in an irregular manner, with periods of fading lasting for fractions of an hour, during which their amplitudes were low. Attempts to correlate the fading with various measured oceanographic parameters proved unsuccessful, except that some evidence for relationship between the fading and surface roughness was found.

Some evidence is presented in favor of the view that much of the fading is caused by surface-reflection interference. On the other hand, other contemporary studies indicate that in different areas, differing explanations account for observed transmission phenomena.

From time to time during the study, a number of slowly moving echoes were observed on the PPI-Screen of the AN/UQS-1 equipment. Some of the characteristics of these mobile echoes, called "angels" in analogy with radar, were determined. From a small amount of indirect evidence it is believed that angels represent echoes from schools of fish, making it likely that angels are important forms of false targets in areas where fish are abundant.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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INTRODUCTION

The Navy's standard mine-hunting sonar is the AN/UQS-1 equipment, of which over a hundred are, or will be, installed on minesweepers. This sonar set operates at 100 kc with a ping length of 1 millisecond, and provides a PPI display of echoes and background. Its transducer beamwidth is relatively wide (10°) in the vertical plane; in the horizontal plane an effectively much sharper beam (1°) is produced by a complicated beam-scanning process.

This equipment had its origin during World War II, and has since demonstrated its ability to detect mine-like objects resting on the bottom under some conditions and in some areas; under other conditions its performance has apparently fallen short of what is desired from a mine-hunting sonar. The circumstances of these reported cases of peculiar behavior are such as to make one suspect that some unforeseen peculiarity of the acoustic medium, rather than any characteristic of the equipment, is responsible. For example, the Navy Mine Hunting Unit, Norfolk, Va., has made numerous operational tests of the AN/UQS-1 equipment and its predecessor, the UOL Mark IV, and encountered similar problems of erratic and generally unsatisfactory performance. These tests were the subject of a special study,[1] which suggested that the detection of bottomed mines could be correlated with the presence or absence of sound-velocity gradients, in analogy with the similar well-known effect in submarine detection.

The USN Mine Countermeasures Station, Panama City, Fla., has established the curve of detection probability versus lateral range of a bottomed target shown in Fig. 1 by means of runs of an AN/UQS-1-equipped ship through a known mine field.[2] The unfortunate characteristic of the curve is not so much the fact that the ranges are short, as it is the low detection probability at short ranges. Only five-tenths or six-tenths of the mines are found during a single passage of the mine-hunting ship, regardless of how close the searching vessel passes by, or over, the mine targets. Instead of rising to nearly unity at short ranges, as the corresponding curve for submarine detection is known to do, it falls short, and indicates that an appreciable fraction of mines remain undetected on a single run. This may be due in part to the search and plotting procedures employed AN/UQS-1 - equipped ships during mine-hunting runs.

But before placing the blame entirely on the equipment and the way it is used, let us inquire as to whether mine targets vary in their inherent detectability—or a more specifically, in signal-to-noise ratio—from time to time because of some fluctuating characteristic of the medium and its boundaries. Thus, if mine targets do "fade," they are likely to be more or less undetectable at certain times by any acoustic means, including an AN/UQS-1 - equipped ship. A fade of only 5 or 10 db, for instance, would suffice to bring a mine echo well into its background and make it nearly undetectable at any range. It is obviously a matter of pure necessity, if one is interested in the design of improved acoustic mine-locators, to determine the cause of this fading so that its effects may in part be overcome. Also, one would like to be able to uncover the oceanographic factors associated with target fluctuation in order to have some rational means for predicting its occurrence and prevalence.

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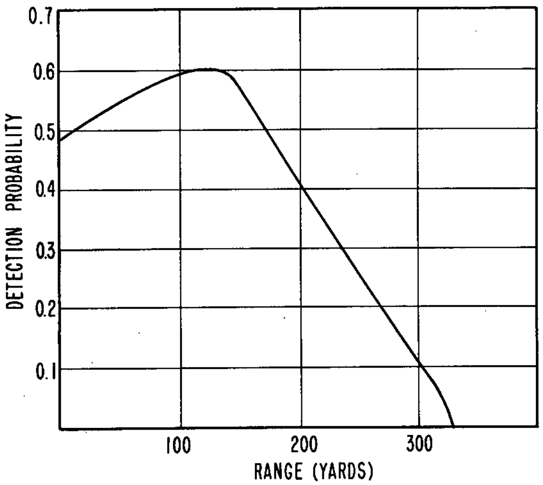

Fig. 1 - Probability of detection of bottomed mines versus lateral range during a single passage of an AN/UQS-1-equipped ship travelling at speeds from 1 to 10 knots (USNMCS, Panama City, plot copied from Ref. 2)

Before proceeding to the experiment that was set up for this study, it should be pointed out that the subject of mine echo fluctuation is essentially a part of the larger subject of sound propagation in the ocean. The transmission of underwater sound has had a long history dating back to the middle thirties,[3] when the first transmission tests were made in order to understand the vagaries of submarine detection that had been so baffling ever since the first World War. Since these first transmission measurements, many hundreds of essentially similar trials have been made, until today a comparatively voluminous literature based on the field data is in existence. But virtually all this work was concerned with what might be called the "average" transmission between two points in more or less continuous relative motion. Yet it is well known that the instantaneous level of a signal transmitted between two points in the ocean varies widely from instant to instant. The possible causes of this high-speed, short-period fluctuation having a period of a fraction of a second have been described[4,5,20] and studied theoretically.[6] Similar fluctuations in airborne sound have also received some attention.[21] On the other hand, long-period changes in transmission have tended to be overlooked, or dealt with as an unavoidable hindrance to precise measurements. In fact, the use of a nonstable platform, such as a ship at sea, itself introduces an artificial time variability because of a varying surface-reflection interference. In these measurements a rigidly fixed source and receiver has seldom been used, nor has the existence of fluctuation in transmission been accorded the dignity of recognition as an important problem of its own. As a result, the variability in the transmission of underwater sound is at the present time a virtually untouched problem.

THE FIELD EXPERIMENT

In order to tie this broad subject closely to acoustic mine-hunting, an AN/UQS-1 mine-hunting set was installed on a pier at the NOL Test Facility at Solomons, Maryland, at the mouth of the Patuxent River in Chesapeake Bay. Charts of the location of the test site, and a photograph of the installation on the pier are given in Figs. 2 and 3. As shown in Fig. 4, the UQS-1 transducer, adjustable in depth between 1 and 6 feet below the surface, was firmly mounted on a pier, and several three-foot-diameter more-or-less spherical Mark VI mine cases served as targets. One was located on the bottom at a distance of 100 yards, and two others were placed on the bottom along the same bearing at 285 and 302 yards, respectively. The water depth at these targets was 45 feet, and the bottom was a soft mud. In addition, a hydrophone with connecting cable to shore was located near the two three-hundred yard targets for the purpose of monitoring the signal received at the mines. During the latter part of the tests, an additional target (not shown in this figure) was employed. This was another three-foot mine case, similar to the bottomed objects, but moored halfway between surface and bottom at a point about 20 yards beyond the most distant mine. Also, during these more recent trials, the hydrophone and its tripod was moved so as to be halfway between the 285 and 302 yard mines.

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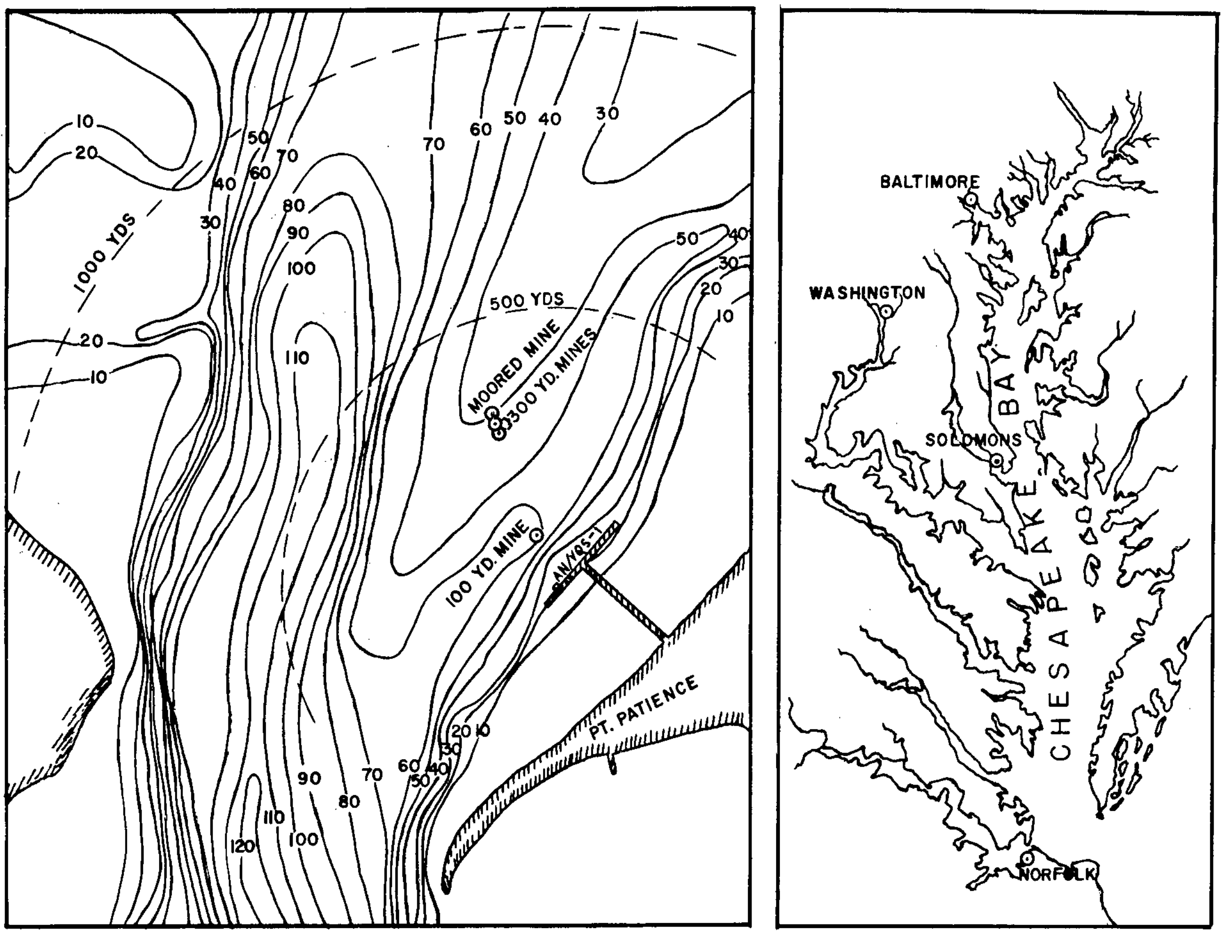

Fig. 2 - Bathymetric chart of test area at Solomons, Md., and location chart of Chesapeake Bay

By means of suitable instrumentation attached to the AN/UQS-1 console, the amplitudes of the mine echoes, as well as that of the received hydrophone signal, were recorded at intervals for comparitively long periods of time. Oceanographic observations of various sorts* were made by the Chesapeake Bay Institute, usually at points in the vicinity of the 300-yard group of targets.

ILLUSTRATIONS OF TARGET FLUCTUATION

It became at once evident that echo-level fluctuations did exist, not only in the mine echoes relative to the scattering background, but also, more surprisingly, in the echo levels of the two 300-yard mines (17 yards apart) relative to each other. Moreover, it was soon seen that there were periods of steadiness in the mine echoes, and other periods of more or less violent fluctuation.

The variability in the echoes may be best seen in a qualitative way by means of some records obtained with a specially-modified tactical range-recorder attached to the AN/UQS-1

*Under contract Nonr 248(30) with the Office of Naval Research

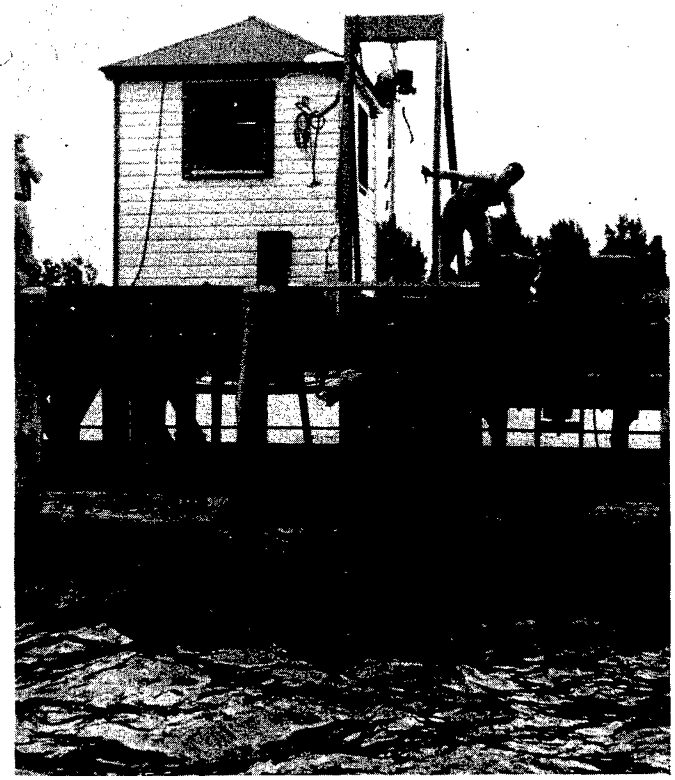

Fig. 3 - Photograph of AN/UQS-1 installation and instrument shack on pier at NOL Test Facility, Solomons, Md.

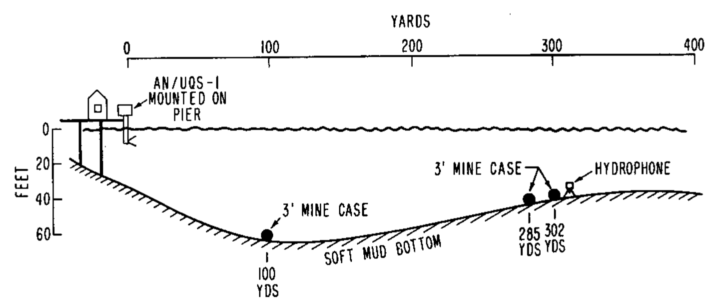

Fig. 4 - Schematic cross section of experimental setup at Solomons, Md.

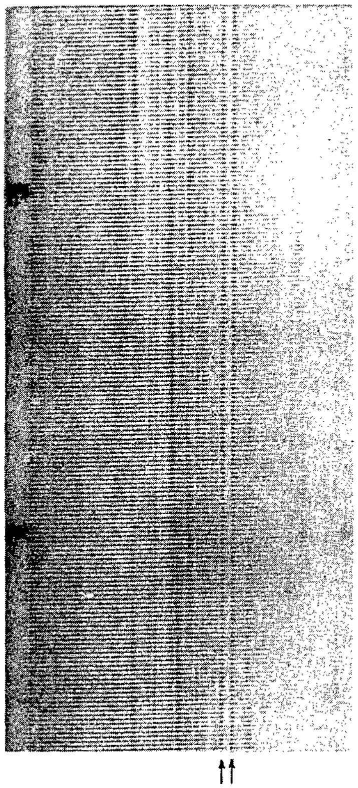

Fig. 5 - Two-minute portion of tactical range recorder trace obtained Nov. 4, 1954. Arrows indicate bottomed mines at about 300-yard range (measured from left to right).

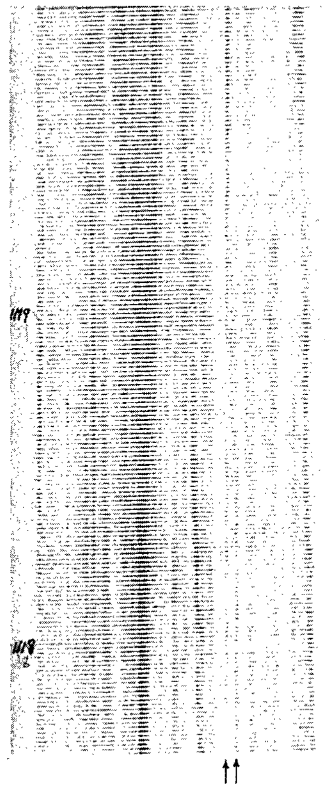

Fig. 6 - Two-minute portion of tactical range recorder trace, 48 minutes later than that of Fig. 5

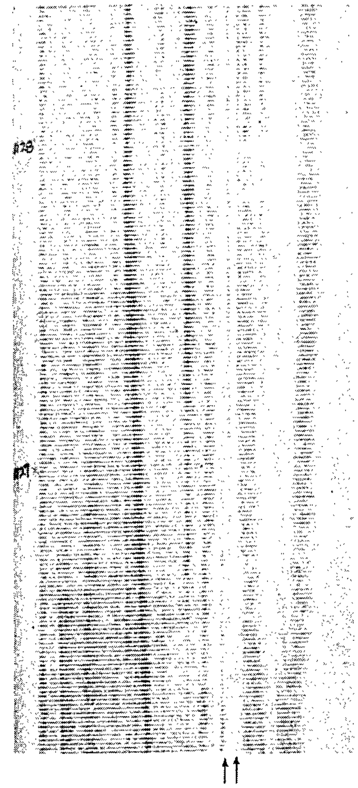

Fig. 7 - Two-minute portion of tactical range recorder trace, seven minutes later than that of Fig. 6

console. Figure 5 is a portion of recorder trace about two minutes long showing the two 300-yard mines, indicated by the two arrows. The range scale here is 500 yards. During this period, between times 1030-1/2 and 1031-1/2, the two mines stand out clearly and steadily. At a somewhat later time, between about 1118 and 1120, shown in Fig. 6, the mine echoes appear to be weak and variable, with frequent intervals when one or both of the targets are missing. From time to time on such records there appear apparent targets that seem to possess a motion of their own—that is, that seem to move in range and bearing relative to the pier on which the AN/UQS-1 equipment is mounted. A good example of one of these echoes is shown in Fig. 7 (times 1126-1/2 - 1128-1/2, same day). We have given the name of "angels" to these mobile objects, which will be described more fully in Appendix A. The variability of the mine echoes is also apparent in Fig. 7; during a period of more than a minute (on the lower half of the portion of record shown), the two mines appear to be absent from the record.

The essential features of the fluctuation are best demonstrated by some plots of the amplitudes of the various events as read from oscilloscope photographs. Figure 8 is a portion of data six hours long showing the level of the hydrophone signal, the two mine

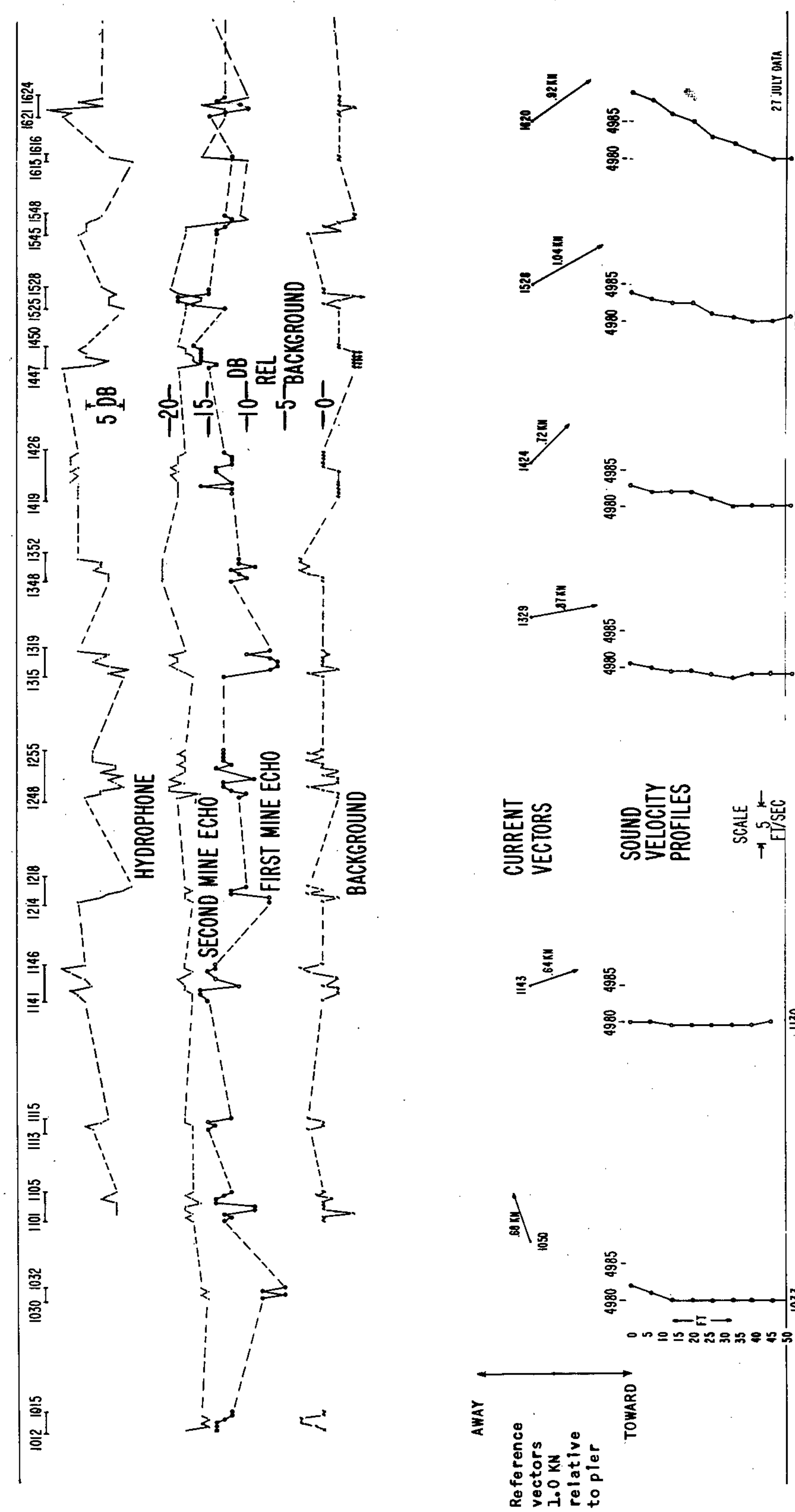

Fig. 8 - Portions of acoustic and oceanographic data of July 27, 1954

echoes (the "first" mine is the closer of the two, the "second" the more distant), and the mean peak level of the reverberation background in the vicinity of the mines. The interval between the plotted points, each of which shows the amplitude of the highest of three consecutive pings, was 30 seconds during the periods covered by the horizontal lines at the top of the figure. This data thus emphasizes the long-period changes rather than the ping-to-ping fluctuations, by means of samples taken at 30-second intervals.

Several interesting features of the fluctuation are immediately evident. The one-way transmission shows as much, or more, variability as the two-way transmission represented by the mine echoes. No evident correlation is seen between the level of the one-way transmission and the level of the echo on the same ping. What is even more remarkable is that there is little or no correlation between the echo amplitudes of the echoes from the two mines only 17 yards apart; in fact, one finds a mean difference in echo level of only 3 db during the 12-minute interval between 1012 and 1015, and a difference of about 10 db 15 minutes later (1030-1032). The 10-db difference observed between 1315 and 1319 had vanished by 1525 and beyond. Superposed on these long-period changes are faster variations (more evident in the figures to follow), which lead one to believe that a broad continuous spectrum of the variability exists. At the lower part of the figure are shown the vectors of current flow as measured at the bottom near the mines, and profiles of sound velocity—two of the oceanographic parameters that were measured in order to discover some oceanographic correlative of the fluctuation. No clue is apparent from this data that either of these slowly varying quantities is associated with the acoustic variability.

Figure 9 illustrates the lack of a strong correlation between the one-way transmission to a hydrophone and the two-way echo from a nearby target. Although a small positive correlation coefficient between hydrophone signal and echo amplitude may exist, the plot indicates that a hydrophone cannot be used to accurately monitor the echo from a nearby target.

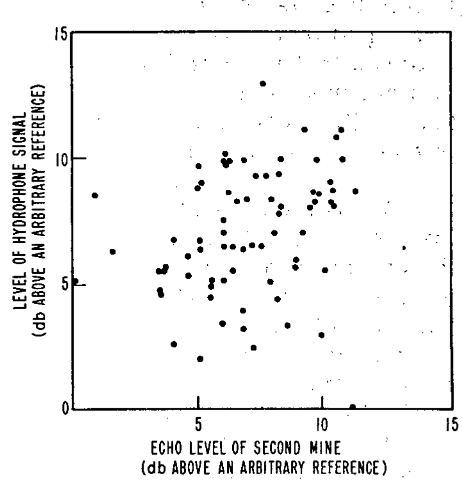

Fig. 9 - Relation between the one-way transmission to a bottomed hydrophone and the echo level from a nearby bottomed target

Figure 10 illustrates the echo variability, during a 15-minute period, of the 100-yard mine and its reverberation background. It shows merely that fluctuations of comparable magnitude exist at the shorter range. Unfortunately, no extensive data has been obtained on the range dependence of the fluctuation, because simultaneous observations of the 100- and 300-yard objects could not be made without adjusting the gain settings of the UQS-1 equipment.

Another illustration of mine echo fluctuation is given in Fig. 11, which shows a portion of data three hours long, taken during a period of continuous observation 22 hours in length, of certain acoustic and oceanographic variables measured at 30-second intervals. Reading from top to bottom, there are shown the amplitudes of the two mine echoes, the amplitude of the scattering background, optical transparency, temperature, electrical conductivity, and sound velocity. The latter four oceanographic parameters were measured with instruments mounted on a frame placed on the bottom alongside one of the mines. At the very bottom of the figure are shown profiles of temperature, conductivity, and current obtained once every hour. Turning to the acoustic data, one finds at the left a relatively steady period in the mine echoes, followed at 2100 by an interlude of weak and fluctuating echoes in which the upper or second mine suffered a gradual loss in level

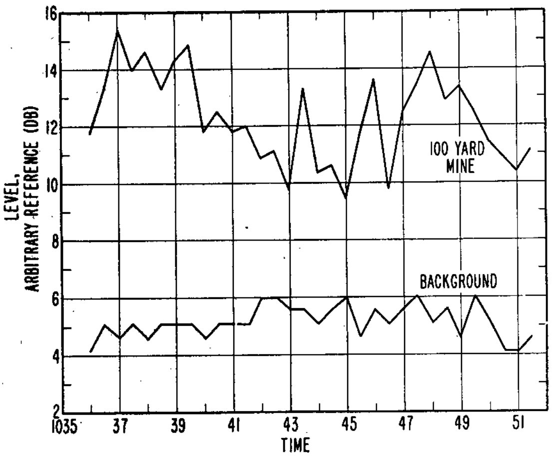

Fig. 10 - Echo variability during a 15-minute period of target at 100 yards

amounting to about 5 db. At the extreme right of the figure there is a return to the type of nonfluctuating, strong echoes with which the period began. Notice that the reverberation background is comparatively steady, as would be expected from the fact that it is created by numerous scatterers distributed over an appreciable area of bottom. Although the oceanographic parameters were measured with instruments of considerable sensitivity, none of them appears to vary in a manner similar to that of the acoustic data. One might imagine some correlations in the short portion of data given in the figure, but the whole 22-hour period of similar plotted data fails to to reveal a correlation between the fluctuations and any of the four measured properties of the medium.

In these tests, temperature and salinity were determined by means of a resistance thermometer and an H-type electrode for measuring specific conductance (from which salinity is computed) having sensitivities of a few hundredths °C and a few hundredths of a part per thousand, respectively.[7] Both measurements, however, involve a time lag of several seconds. Sound velocity was recorded directly to the nearest foot per second by means of a National Bureau of Standards "sing-around" type velocity meter having a negligible time lag.[8] The hydrophotometer used to measure light transmission is a newly developed instrument[9] whose accuracy and time constant are not well established. It is believed that its time lag is several seconds. Current measurements were made by means of a "current-cross"[10] whose readings are considered accurate to one or two tenths of a knot. However, the current readings are strictly time averages that may involve a period of one or two minutes.

A further illustration of the fluctuation is given on Fig. 12, which shows a period 15 minutes in length of observations taken every ten seconds. The five traces are (1) the the closer bottomed mine, (2) an echo believed to be from the hydrophone tripod which was here located between the pair of mines, (3) the second mine, (4) the moored mine located halfway between surface and bottom, and finally (5) the one-way hydrophone signal. The two new items of interest—the echoes from the hydrophone support and from the moored mine—give us some interesting information. There is less fluctuation in the hydrophone-support echo than in the other echoes, probably because of the fact that this echo is composed of scattered contributions by numerous scattering and reflecting structural members of the tripod and hydrophone. Another interesting point is that the echo from the moored mine is not steady, but fluctuates in somewhat the same way as the bottomed mine. This similarity points toward an explanation for the variability that does not require the target to rest on or in the bottom.

The data illustrated by Fig. 12 was obtained from oscilloscope photographs taken at 10-second intervals, and shows the more rapid fluctuations in echo level. Longer period changes are shown by smoothed data extending over a longer interval. Figure 13 gives some smoothed curves drawn by eye through a detailed plot similar to the preceding one, but extending over a three-hour period. One sees here fading in the bottomed-mine echoes lasting from several minutes up to nearly an hour and having a magnitude from 5 to 10 db

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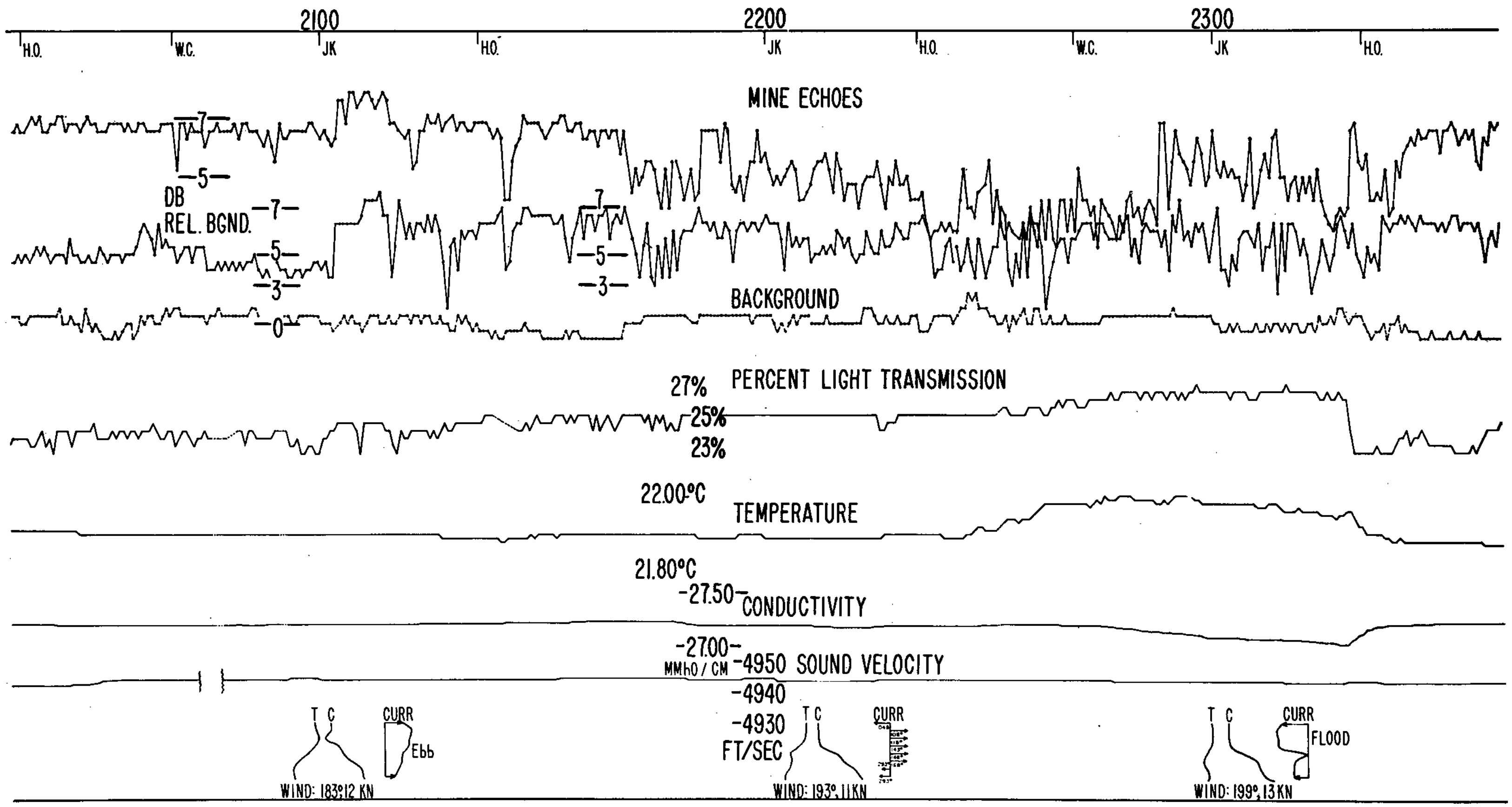

Fig. 11 - Three-hour portion of data 22 hours long, showing target echo and background levels and simultaneous measurements of a number of oceanographic parameters

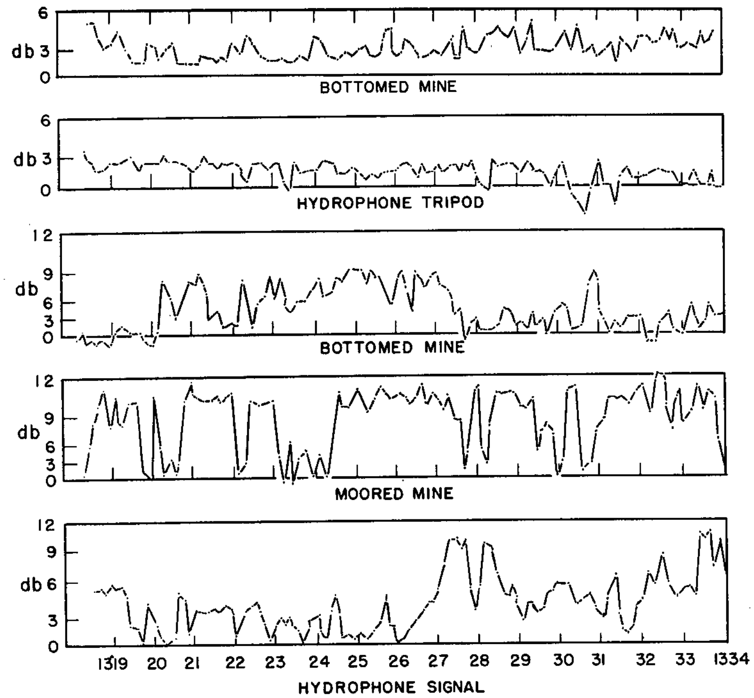

Fig. 12 - Echo levels from the two 300-yard mines, a moored mine, the hydrophone tripod, and the one-way signal level to the hydrophone. Data read from oscilloscope photographs taken at 10-second intervals.

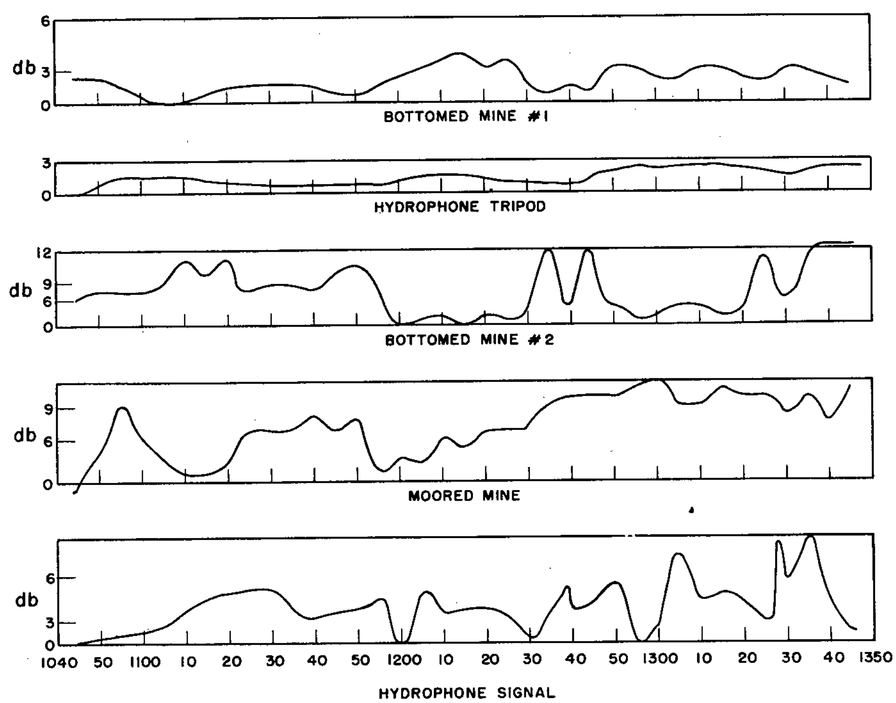

Fig. 13 - Eye-smoothed levels during a 3-hour period of the same events as in Fig. 12

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below the levels during the stronger intervals. But the fades apparently do not occur simultaneously for the various targets, all of which lie within a distance of 40 yards. In fact, a close inspection of the first and third traces shows a suggestion of a negative correlation, the No. 1 mine being strong when the No. 2 mine is weak, and vice versa.

SUMMARY OF TARGET FADING CHARACTERISTICS AT SOLOMONS, MD.

The principal descriptive features of the target fading as it has been observed at Solomons, Md. with the UQS-1 equipment may be summarized as follows:

1. There are both short-period and long-period variations in the echo from a bottomed target. The short period, or ping-to-ping changes, (which may be described as "twinkling") together with the long-period changes (or "fading") form a fluctuation spectrum extending from nearly instantaneous periods to periods lasting for minutes or for hours. By contrast, longer-period fades lasting for a number of hours or more have not been observed.

2. There is no strong correlation between the amplitudes of the echoes from the two mines 17 yards apart. In one day's data, however, with a particularly calm sea surface, there is suggestion of a negative correlation on a long-term basis, one mine being strong when the other is weak.

3. A moored mine, suspended above the bottom about halfway to the surface, fluctuates in much the same manner as a bottomed mine.

4. The amplitude of the one-way signal to a hydrophone on the bottom bears no clear relation to the amplitude of the echo from a mine target about 20 feet away from the hydrophone. However, no attempt to obtain a numerical value for the correlation coefficient, in this or in other cases, has been made.

5. No oceanographic correlative of the fluctuation (except surface roughness) has been discovered. The quantities measured at various times have been temperature, conductivity, turbidity, sound velocity, bubble content, and current. With the exception of the latter, these parameters have been measured at, or in the immediate neighborhood of, the bottomed targets.

6. There are periods, lasting from a few minutes to approximately an hour, when the echoes are strong and steady; there are similar periods of fading when the echoes are weak and variable. These periods are observed only when the sea is comparatively smooth. They exist in the echoes from both the moored and the bottomed targets, and occur at different times for the different targets. In this respect underwater sound transmission appears to be similar to radio propagation in the atmosphere.[11]

7. For rough seas, with wave heights greater than 5 to 10 inches crest to troughs, the ping-to-ping fluctuation is most violent, and the steady periods mentioned in the previous paragraph are obscured.

8. There is less fluctuation in the reverberation background than in the one-way transmission or in the echo from a single object.

SURFACE REFLECTION INTERFERENCE AS A CAUSE OF FADING

In searching for some explanation for the variability, based on these essentially negative observations, one is at once faced with two broad choices. On the one hand, it may be assumed that the fading is due to some sort of obscuration or occultation of the target, or more specifically, to some disturbance in their vicinity which hides them from the acoustic view of the AN/UQS-1 equipment. Here one readily thinks of clouds of bubbles or sediment which somehow envelop or obscure the bottomed mines, and which may even either partially or completely bury, and later uncover, the objects resting on the bottom. However, a visual inspection of one mine by SCUBA-equipped divers from the Chesapeake Bay Institute gave no indication of burial or of change of position on the bottom. Also, this hypothesis is not appealing in view of the failure to detect any oceanographic correlative—especially optical turbidity—of the acoustic fading. Moreover, if the fading is believed to be associated with the soft mud bottom, it is difficult to explain why a moored mine fades in the same manner as a bottomed mine, and why the fading occurs at different times for the two mines located 17 yards apart.

The other choice available is to explain the fading as an interference phenomenon between the different acoustic paths to a distant target. Here one finds a ready explanation for the "twinkling" of a target—that is, for the ping-to-ping, high-speed variability in echo level—on the basis of interference by reflection from a rough, constantly changing surface. But it is not obvious how surface reflection interference can produce the fades that last an appreciable fraction of an hour. If some way of producing long-period effects were available by means of an interference process, one might have a reasonable explanation for at least a portion of the fading.

Consider the paths available between a near-surface transducer and a target resting on the bottom, shown in Fig. 14a. In addition to the direct path and the single surface reflection indicated in the sketch, there are in theory a number of bottom-reflected paths whenever the transducer has a wide beam in the vertical plane. But these bottom reflections probably do not contribute appreciably to the received signal at the Solomons, Md. location—which has a soft mud bottom—because of the loss on reflection. Also, the single bottom-reflection strikes the bottom within a few inches of a target resting on it, and so is sensibly indistinguishable from the direct path. We may therefore in all likelihood ignore the bottom reflection, and consider merely the interference between the direct and the surface-reflected paths.

Let us make the key assumption that the three surface-reflected paths (there are two "mixed" paths involving surface reflection in one direction only) do not bear a completely random phase relative to the direct path, but that there is both a rapid and a slow variation in the vector representing the direct path. That is to say, in addition to the fast, random, phase variation caused by the irregular, constantly changing surface roughness, let us assume that the resultant of the surface-reflected paths exhibits a much slower fluctuation relative to the direct path vector. The surface reflection vector may thus be imagined to have a rapid random phase distribution of a certain standard deviation, about a mean vector which slowly wanders in phase relative to the reference direct-path vector. For simplicity (see Fig. 14b), the surface-reflected vector may be imagined to lie anywhere within the solid-shaded section at one instant of time, and at a later time to lie within the dashed-shaded sector. (Actually the amplitude of this vector will not be constant as implied in this figure, but will itself be a variable, Rayleigh-distributed quantity.) When the surface reflection lies in the right-hand sector, it reinforces the energy travelling via the direct path; when it lies in the left-hand sector partial cancellation, and fading, occur. When the sea is smooth, the random sector is small, giving deep fades when it is oriented 180° relative to the direct vector; when the sea is rough, the sector may occupy the entire circle, eliminating the fading and giving an increased high-speed fluctuation to the resultant. This sea-state effect is in qualitative agreement with the observations.

An alternative view of the phase relationships is to consider that the reflection may be resolved into a slowly, and a rapidly varying component as depicted in Fig. 14c. The slowly

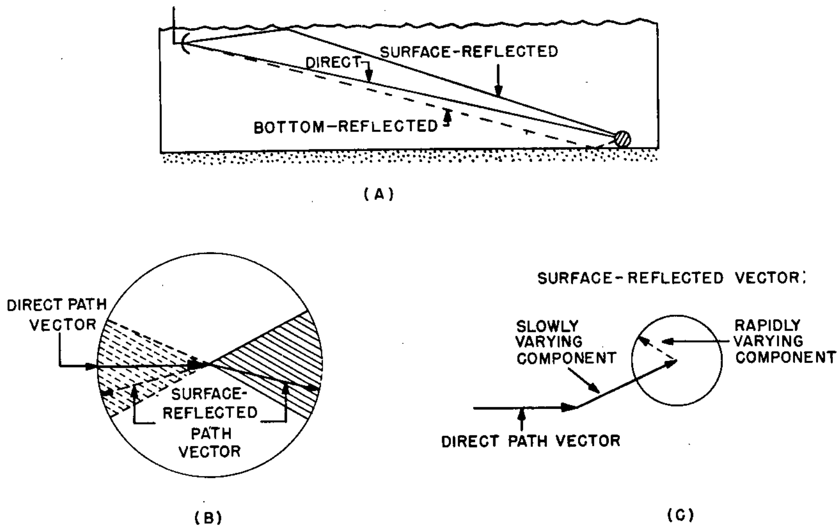

Fig. 14 - (a) Direct, surface-reflected, and bottom-reflected paths. (b,c) Vector phase relationships of the surface reflection.

varying component may be imagined to be of fixed amplitude and of slowly varying phase relative to the direct-path vector; the rapidly varying, or "noise" component, represents the effect of sea-surface roughness and thermal microstructure. When the surface is rough, the "noise" vector is large; when the surface is smooth, this vector tends to be small. Fading occurs when the slowly varying component is oriented so as to nearly cancel the direct path vector.

During the periods of reinforcement, the distribution of instantaneous echo amplitudes will be different from its distribution during the fading periods. A study of Figs. 14b and 14c will suggest that during the periods of reinforcement, the echo amplitudes will be relatively constant at a level near the maximum amplitude, and that during the fades the echo amplitudes will be more variable. The distribution of amplitudes becomes indentical to that of a signal in a noise background, the "signal" being small relative to noise during the fades. This problem has been analyzed mathematically.[12] An example of observed data on the distribution of echo amplitudes is given in Fig. 15, which shows two 16-minute portions of observed echo levels from one of the mine targets - the "A" portion from times 1233 to 1249 during a time of strong transmission, and the "B" portion between times 1204 and 1220 during a fade. The distribution of amplitudes for these two periods is shown below. The tendency for the echoes to remain steady and strong in the "A" portion is indicated by the peak near the maximum amplitude. The wide distribution of amplitude in "B" during a fade is also in agreement with theoretical expectations.

Another piece of evidence in favor of surface-reflection interference as an explanation of the fading is the fact that we have observed a faded echo to be restored on calm days by raising or lowering the AN/UQS-1 transducer by approximately the distance required to shift the surface reflection 180°. Surface-reflection interference also provides an explanation for the suggestion that the echo from one of the two mines 17 yards apart was strong when the other was weak, since the increased path difference for the more distant mine is roughly one-half wavelength.

We can resort only to conjecture if we seek an explanation for the slow phase fluctuation of the surface reflection. One explanation may be that the average sound velocity along the surface-reflected path changes slowly with time, relative to the average velocity

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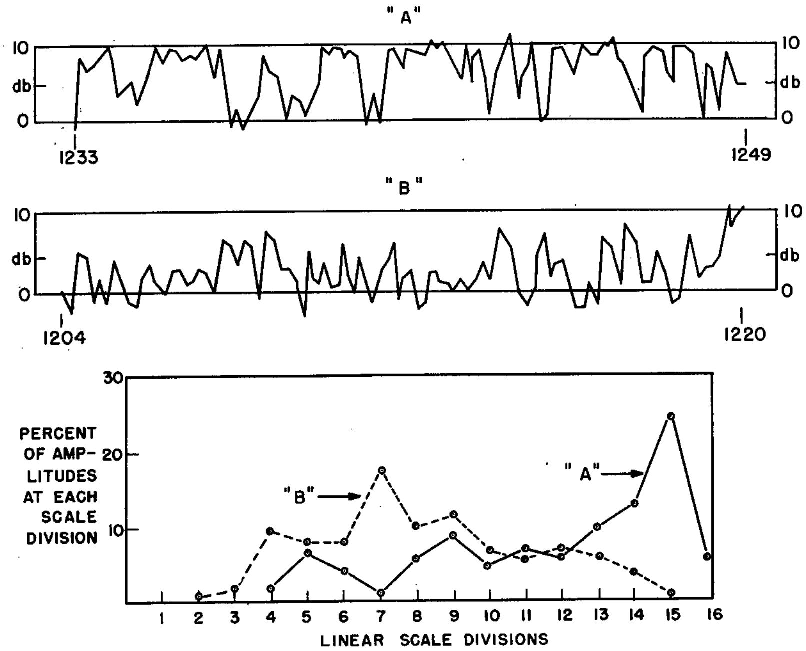

Fig. 15 - The distribution of amplitude of the echo from one of the bottomed mines during a period of good transmission "A" and during a fade "B"

of the direct path, as a result of vertical mixing, horizontal advection, and vertical current gradients. A differential change in average sound velocity between the two paths of only one part in 70,000 or 0.07 ft/sec is required for an 180° phase shift. This would correspond to an average change along the path of either 0.005°C in temperature (at 0°C) or 0.02 parts per thousand in salinity. With the transducer in our setup located about 6 feet below the surface, about one-third of the length of the specularly surface-reflected path to a target 300 yards distant will lie within the surface layer above the transducer. Consequently, changes in the average sound velocity in this surface layer of only 0.2 ft/sec would accomplish a 180° shift of phase. This figure is well below the magnitude of changes observed in the course of half-hourly velocity-meter lowerings in the vicinity of the 300-yard targets. Although the standard oceanographic instruments used are too insensitive to measure these small changes that could account for the varying interference pattern over very short time intervals, there is ample reason to believe in their existence. Good confirmation of such small scale variations was furnished by records of time variations of temperature at a point near the bottom obtained by means of a newly developed temperature-fluctuation instrument.* The records obtained showed periods of many minutes duration during which temperatures varied by several thousandths of a degree Centigrade with a period of about 10 seconds. In the open sea the existence of a thermal microstructure has been demonstrated by other observers.[20,22]

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*This instrument was designed and built by Mr. E. W. Schiemer of the Chesapeake Bay Institute, and consists of several thermistor beads with a time constant of 0.7 second. Each is balanced against a similar thermally insulated element having a time lag of about 5 minutes and located within inches of the rapid-response elements. Differences between the slow and fast elements are recorded on a continuous-strip chart at a maximum sensitivity of 0.1 inch per 0.001°C.

A more obvious source of a slow relative phase shift between the direct path and the surface reflection is a change in mean water level. With the sound source and target held fixed relative to the bottom, a change in mean level of only about four inches would result in a 180° phase shift in the (mixed) path. Such changes occur several times in the tidal cycle; in addition, small differences in water level could be produced by wind action. However, no attempt to correlate any differences in mean surface level with the acoustic data was made.

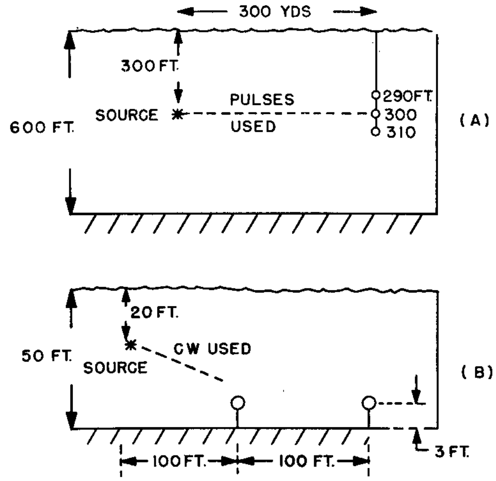

Fig. 16 - Sketches showing the transmission experiments performed by the Applied Physics Laboratory of the University of Washington (A) and by the Naval Ordnance Laboratory (B)

In practical mine-hunting, it is obvious that the most direct way of eliminating the troublesome reflection would be to provide greater directivity in the vertical plane, and to employ a small amount of downward tilt in order to place the surface reflection on a less favorable portion of the transducer beam pattern. On the other hand, this type of fading is probably not of primary importance to a mine-hunting vessel, since the forward travel of the ship together with its own roll and pitch will largely prevent a bottomed target from remaining faded out for any length of time—although the variability so induced into the target echo becomes an added hinderance to target detection because the number of pings available for detection is small. Thus, we arrive at the interesting conclusion that if the surface reflection is the principal cause of fading, it cannot account for the occurrences of target fading observed with shipboard AN/UQS-1 equipments. We must accordingly keep our minds open to the possibility that, in other areas, other mechanisms of echo fluctuation may be important.

RECENT OBSERVATIONS REPORTED BY OTHER LABORATORIES

In order to demonstrate that simple surface reflection is not the only cause of transmission variability, results of studies made within the last year by other laboratories may be mentioned. In Fig. 16 are shown diagrammatic sketches of recent transmission tests carried on by the Applied Physics Laboratory of the University of Washington[13] and by the Naval Ordnance Laboratory.[14] In the APL experiment conducted in Dabob Bay as part of the Bureau of Ordnance "Acoustics of the Medium" program, a nondirectional source and three nondirectional hydrophones spaced vertically 10 feet apart were used to study the transmission of short 60-kc pulses. The pulse length was short enough so that the surface reflection could be ignored and the direct transmission could be studied separately. In the NOL measurements, a much lower cw frequency (between 78 and 200 cps) was received at two bottomed hydrophones distant only 100 and 200 feet. In this case, the wavelength of the order of 40 feet, was of the same order of magnitude as the spatial geometry of the experiment.

An example of the APL results (Fig. 17) shows the measured transmission to the three hydrophones over an interval of an hour and a half. The remarkable feature here is that the transmission is so different from a common source to the three hydrophones placed 10 feet distant vertically. For example, it will be noted that the transmission to the middle hydrophone shows a slow rise of about six db over an appreciable part of an hour, while the transmission is simultaneously falling to a hydrophone 10 feet below. No explanation has as yet

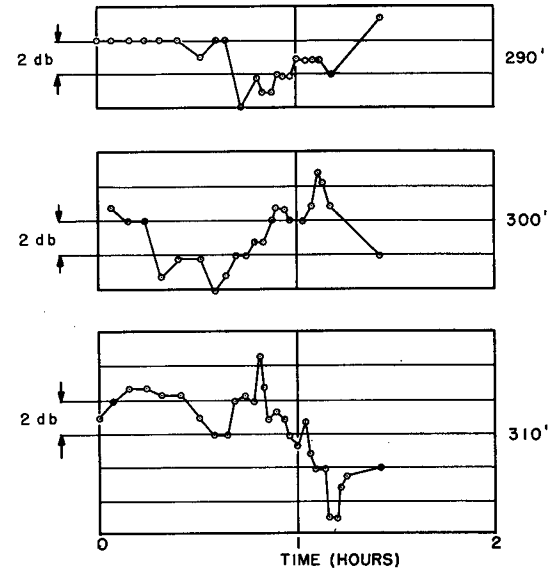

Fig. 17 - Transmission variability during a $1\frac{1}{2}$-hour period to three hydrophones 300 yards distant from a deep sound source (APL data, copied from Ref. 13)

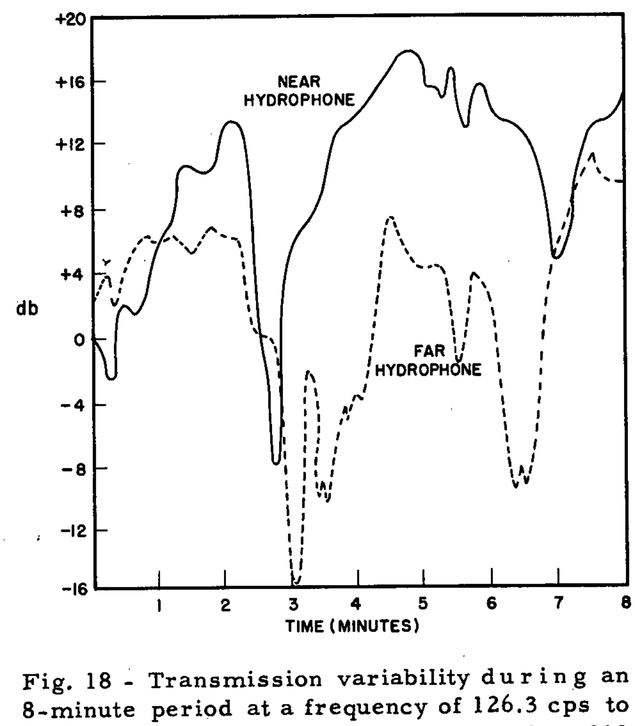

Fig. 18 - Transmission variability during an 8-minute period at a frequency of 126.3 cps to hydrophones located approximately 100 to 200 feet from the source (NOL data, from Ref. 14)

been forthcoming for these results in Dabob Bay, although it is believed that the fluctuation is somehow associated with a lenticular temperature microstructure existing in this deep fiord in Puget Sound.

A sample of the NOL results, obtained unexpectedly during another study, is shown in Fig. 18. Large fluctuations were found at the two hydrophones at a frequency of 126.3 cps. The fact that the fluctuations did not occur simultaneously at the two hydrophones effectively eliminates changes in the sound source from consideration. Any attempt to seek a hypothesis for the fluctuation as an interference phenomenon must in this case overcome the difficulty of providing a path difference of at least 20 feet. Since the wavelength involved is 40 feet, no interference process comes readily to mind.

According to a recent progress report of H. M. Underwater Detection Establishment,[15] the British have also been making studies of mine fading. Observations of bottomed mines over a period of time have been made from an anchored ship using equipments operating at 100 kc and at 300 kc, and both a short-period variation and a long-period fading have been found. During the fades, the echoes from a bottomed target and from one suspended above the bottom were found to decrease by 10 db or more while the level of the reverberation background remained steady. No correlation in fading existed between the two frequencies, nor was there any correlation between the fading of a spherical target resting on the bottom and one suspended six feet above it. These phenomena were observed in three areas having bottoms of sand and gravel, and appear to be similar to the fading observed at Solomons, Md., over a muddy bottom. British work on this problem is believed to be continuing.

From these examples of contemporary studies, it would appear that the fluctuation of sound transmission between two fixed points is not a problem having a single solution or explanation, but is more likely a phenomenon having a number of possible causes whose relative importance is different in different areas and for different experimental conditions. Much additional work in other areas with experimental acoustic equipment, and with new oceanographic instruments of considerable sensitivity and speed of response, is needed before it can be said that the subject is adequately understood.

ACKNOWLEDGMENTS

The willing assistance of Mr. E. W. Schiemer of CBI, and of Mr. J. J. Green of the NOL Test Facility, Solomons, Md., during this study is gratefully acknowledged. Mr. M. Pollak and other personnel of the Chesapeake Bay Institute made all oceanographic observations and provided invaluable cooperation during all phases of this study.

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APPENDIX A

"Angels" as a Type of False Contact in Acoustic Mine-Hunting

In the course of observing the mine echoes on the PPI screen of the AN/UQS-1 equipment, other echoes were observed to drift very slowly across the field of view. These echoes may be called "angels" in analogy with the radar echoes of the same name and similar characteristics first observed during World War II.[16] Some photographs of an angel are given in Fig. 19, which shows a series of PPI photographs, taken at the intervals shown, of an angel as it moved slowly in range and bearing relative to the pier on which the equipment was mounted. The fixed spot near the edge of each picture indicates a range of 185 yards, and serves as a reference point to show the travel in range of the moving angel. The mine targets are not present in these pictures. Another example of an angel is given in Fig. 20 where an angel is shown in outline as it moved across the screen during a period of 7-1/2 minutes. The diameter of this object was about 15 yards and its speed was about four-tenths of a knot.

Many other examples of angel motion, when considered along with the measured current velocity, show that although the angels tend to move along with the current, they possess a definite small "proper motion" of their own, and thus are unlikely to be echoes from inert objects drifting along with the current. An important practical point is that the angels

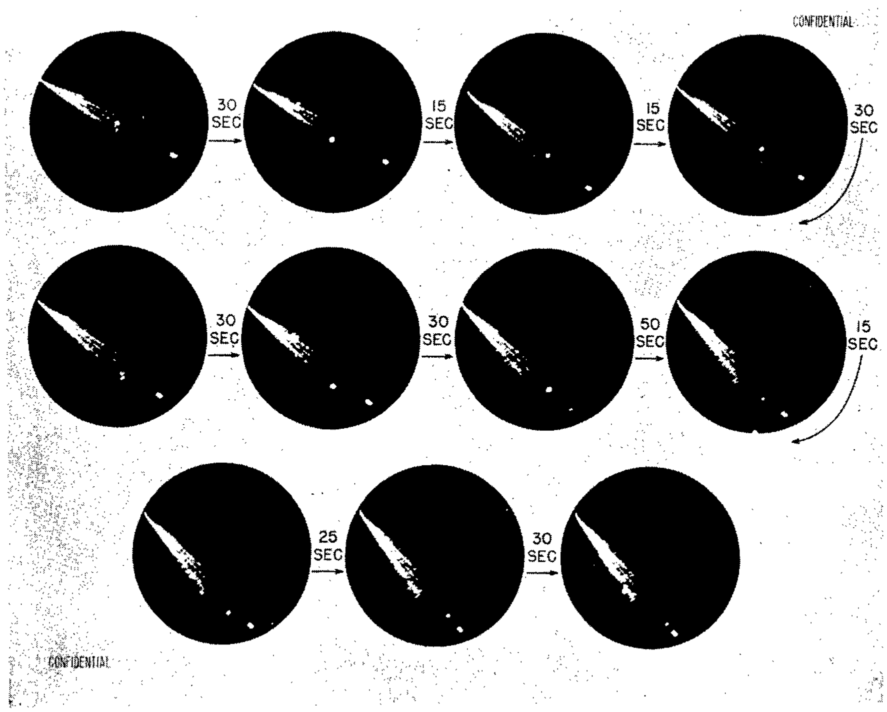

Fig. 19 - PPI photographs of an angel at intervals shown. Range scale to the beginning of the range-cursor spot is 185 yards.

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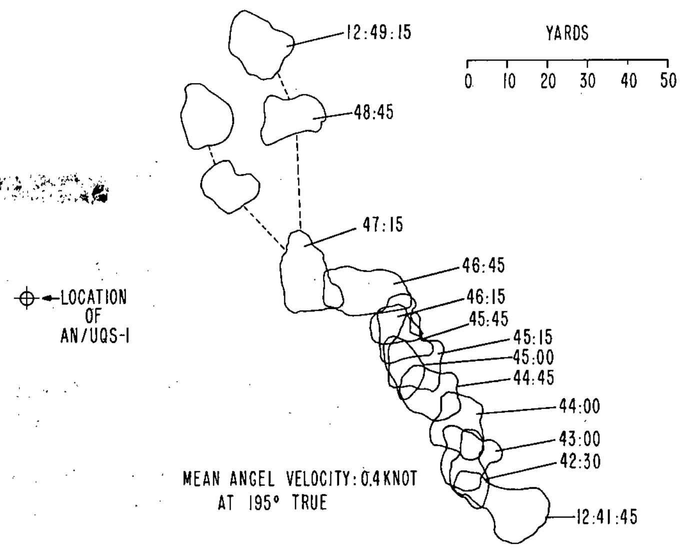

Fig. 20 - Outline of an angel during its motion past the pier carrying the AN/UQS-1 equipment. Figures indicate the times the photographs were taken.

have a target strength comparable with, and often exceeding, the mine targets. Figure 21 is a histogram giving the distribution in target strength of 31 angels as determined from a comparison of their echo amplitudes with those of the fluctuating mine echoes of approximately known target strength. The histogram is somewhat weighted toward the right, for many smaller angels had echoes whose amplitudes were buried in the reverberation background and could not be measured. In order to appreciate the significance of this plot one should bear in mind that a rough value for the target strength of a bottomed mine is -18 db.[17] Thus, many angels have a target strength approximately the same as that of a mine, and the smaller ones appear on the PPI screen to be indistinguishable from the echoes from a bottomed mine.

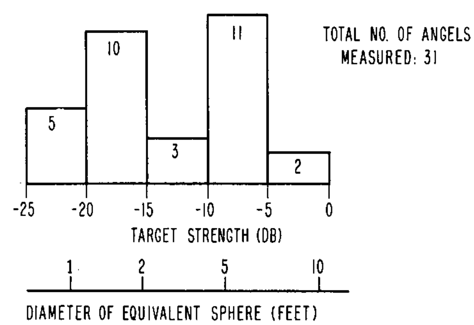

Fig. 21 - Histogram showing the distribution of the measured target strengths of 31 angels

The origin of angel echoes has not been firmly established, but it is likely from various bits and pieces of evidence that our angels are merely echoes of schools of fish. They cannot be echoes from individual fish, for the measured target strengths of single fish[18,19] lie in the range from -30 to -60 db depending upon size and orientation, and are thus much smaller than the target strengths indicated by the histogram of Fig. 21. If angels are fish-school echoes, it is possible that the data on angel motion collected during this study—which has not all been presented here—provides some of the most complete information so far obtained on the motion of fish schools in their natural habitat. If they indeed have this interpretation, it is apparent that they may be the source of troublesome false targets when using the AN/UQS-1 equipment in areas where fish are known to be abundant.

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