MOST Project -3

TRACOR Document
T72-AU-9508-U

ADA045661

IR & D REPORT

TARGET STRENGTH PREDICTION

by

B. M. Brown, J. J. Lobdill,
and W. McKemie

23 February 1972

TRACOR

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53 p.

Approved:

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PREFACE

The study described in this report was conducted for the purpose of improving our submarine target-strength prediction model. In the study computer programs were expanded to treat a greater variety of elementary shapes such as cones and hemispheres in order that hull forms can be represented more realistically. Additionally the relationship of surface reflections of pulses to jitter parameters was assessed for the purpose of gaining some physical insight in the echo forming process.

The study was sponsored by TRACOR, Inc., in the Sciences and Systems Group, under the direction of Dr. Bob Brown. Jerry Lobdill conducted the analysis of surface reflections and William McKemie conducted the revision and improvement of the computer programs with assistance from Clifford Kite.

Letter on file.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TRACOR 6500 TRACOR LANE, AUSTIN, TEXAS 78721

I. THE TARGET STRENGTH MODEL

by

B. M. Brown

INTRODUCTION AND SUMMARY

The TRACOR target strength work began in 1964 with support of NAVSHIPS exploratory development funds. This program resulted in calculation of target strengths for four hull types which, in three out of four cases, were in agreement with target strengths measured by Leiss.* In these studies it was found that target strengths similar to those measured could be computed if slight (less than 0.1 period) random deviations from ideal two-way travel time from the sonar to points on the target hull were introduced. As this travel time "jitter" was increased the computed target strength was reduced to a nearly constant value which is in good agreement with measured target strengths.

While the technique provided good estimates of target strength, based upon hull structure, the arbitrary introduction of arrival time jitter into the process without a physical basis is an inadequate foundation for understanding the mechanism of echo formation.

The class of hull structures which were used at TRACOR prior to the present work consisted of a combination of ellipsoids, plates, and hemicylinders. Some structures on submarine hulls are not well represented by these three geometries.

The work on computation of target strength carried out under this project had two specific aims:

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*W. J. Leiss, "Submarine Target Strength Summary," University of Pennsylvania, Ordnance Research Laboratory, 1964.

1. Describe a specific physical process for the jitter phenomenon which would allow selection of the jitter parameters from environmental parameters.

2. Upgrade the target strength program to include structures such as hemispheres and truncated cones.

Progress has been made in accomplishing both these goals. A physical basis for selecting jitter parameters may have been found. The waveform which results from reflections off the sea surface has an arrival structure similar to that which has been employed in the program in the past. In addition, the arrival delay distribution depends upon the environmental sea state, wind speed, and velocity profile. The work on the description of the arrival delay distribution has also shown that arrival delay is correlated along the target hull, the correlation being characterized by a vertical correlation distance and a horizontal correlation distance. These two parameters are also dependent upon sea state, wind speed, and velocity profile.

A detailed description of the root-mean-square delay "jitter" and its correlation distances along the target hull has been prepared by J. J. Lobdill.* This document is included as one of three parts of this report.

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*J. J. Lobdill, "Surface Reflections: Their Effects on Real or Simulated Echoes in Target Strength Determinations," Section II of this document.

The description of the TRACOR target strength programs as upgraded is also included as a part of this report. It was prepared by William McKemie.* The programs described are modifications of the original target strength programs developed by C. L. Kite.**

The remainder of this part of the report provides some examples of typical echo forms obtained for a few values of the jitter parameters, using a typical hull form. It also contains target strength distributions obtained with the program.

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*William McKemie, "Target Strength Programs," Section III of this document.

**C. L. Kite, "Computation of Target Strength (U)," Summary Report, TRACOR Document 66-487-C, 17 November 1966, CONDIFENTIAL.

GENERAL PROGRAM DESCRIPTION

The target strength program is based upon rigid body scattering theory. The hull is divided by planes which are parallel to an incident wavefront and which are separated by a fraction of one wavelength. The separations are set significantly below the $\lambda/4$ value which would provide an elementary Fresnel scattering result. A single pair of planes is shown in Fig. 1. The darkened section between them shows the section of the hull belonging to a single isophase zone. The projected area, A_i, of the portion of this zone which is not shadowed by the hull on a plane parallel to the wavefront is used in scaling the signal (the derivative of the incident pulse) scattered back to the sonar. The echo is formed by summing the scaled signals from all isophase zones formed by the hull structures with appropriate arrival delays.

Echoes produced in this way are deterministic functions which have none of the variability present in echoes observed at sea. The echoes can be made to behave like observed echoes by introducing variability in the arrival delay structure from the isophase zones. Introduction of variability in propagation time from the ideal direct path time has been introduced using characteristics of the signal reflected to the target from the sea surface. The selected root-mean-square random arrival delay and the horizontal and vertical delay correlation distances depend upon sea state, wind speed, and the velocity profile. The process of their selection is described in Section II.

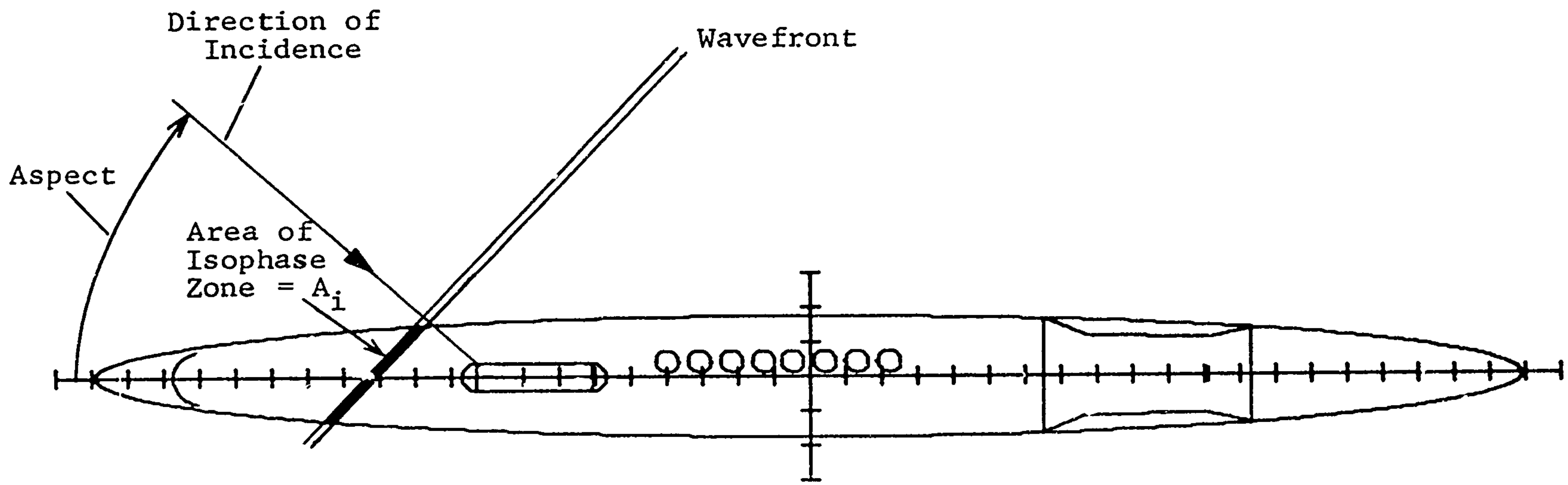

FIG. 1 - CONSTRUCTION FOR DETERMINING THE SCATTERED AMPLITUDE FROM A SINGLE ISOPHASE ZONE ON THE TARGET HULL

The delay variability (called delay "jitter") is introduced by first dividing each isophase zone A_i into $k = 2h/y$, in-line pieces A_{i1}, A_{i2}, A_{i3}, ..., A_{ik}, where h is the vertical height of the zone and y is the vertical correlation distance of the arrival delay. Alternate A_{ij} are assigned random arrival delays from a Gaussian distribution with standard deviation determined by environmental parameters. The intervening A_{ij} are assigned delay values midway between the randomly selected values.

The random numbers from one isophase zone to the next, say those assigned to $A_{(i+1)j}$ and A_{ij}, are correlated with a correlation distance x determined by environmental conditions. If r_{i+1} is the new random number selected for $A_{(i+1)j}$, then the delay $\delta_{(i+1)j}$ associated with $A_{(i+1)j}$ is

$$\delta_{(i+1)j} = (1 - f)\delta_{ij} + fr_{i+1} , \quad (1)$$

in which f is a positive number less than unity that determines the correlation distance.

The correlated delay jitter computed in this way is used to sum suitably scaled (with the A_{ij}) and delayed (with the δ_{ij}) replicas of the derivative of the incident pulse. The resulting echoes behave like real echoes. Highlight structure is present but realistic variations are noted in this structure from one trial to the next. Target strength calculations (referred to 0 dB, defined by a 2-yard-radius sphere) depend upon the number k and the root-mean-square delay jitter J for low values of these parameters, but the dependence almost disappears when k exceeds four and J exceeds 1/(8f). The studies on correlation distance have not been completed but a few examples are presented in the next sections.

CHOICE OF THE AMPLITUDE AND PHASE FLUCTUATION PARAMETERS

The choice of the amplitude and phase fluctuation distributions required for the target strength program cannot be made precisely. To the precision which has been achieved to date in target strength computation, it would be difficult to decide whether the amplitude distribution is a delta, a uniform, or a Gaussian distribution if the behavior of the target strength distribution obtained is used as the measure. The phase fluctuations in individual arrivals will produce amplitude fluctuations in the sum waveform even though the amplitudes of the individual arrivals were of equal amplitude. The limiting distribution of the envelope of the sum of the overlayed arrivals is distributed Rayleigh for all distributions of the individual arrival amplitudes, including the distribution in which all amplitudes are equal.

In the computations made to date with the program, all the amplitudes A_{ij} in the partitioning of a single isophase zone response have been given the same value. It is a minor program change to introduce other distributions to describe the amplitude partitioning of a single isophase zone. This has not been done to date because the effect of such a change on the echo will be minor and effort has been placed in areas where effects are more pronounced. In future work a Rayleigh envelope distribution subroutine will probably be implemented in the program.

The random phase standard deviation required for the program is calculated using Eq. (1) and the value $\sqrt{\overline{H^2}}$ from Lobdill's memorandum. Additional input parameters required for use in Eq. (1) are the sonar wavelength, and the grazing angle ψ of the incident wave at the surface for the source-target geometry and velocity profile. The parameter $\sqrt{\overline{H^2}}$ is determined from the wind speed with Lobdill's Fig. 1 if the sea state is fully developed.

One additional parameter, surface loss, can also be included. This is a minor correction, but it is available from the environmental parameters already listed.

GEOMETRICAL STRUCTURES AVAILABLE FOR REPRESENTING THE HULL

The original program utilized in computing target strengths made use of an ellipsoid of revolution to represent the hull and two hemicylinders attached to three planes (sides and top) to represent the sail. Smaller structures are not of great significance in the estimation of target strength, but they are of great importance if realistic highlight structure is to be observed in the echo. In addition, an ellipsoid which matches the curvature at the bow of the hull is too "fat" at the midsection and also fails to match both bow and stern curvatures simultaneously, when these curvatures differ.

Additional geometrical forms have been added to those available to the program. These forms include hemispheres, cones, and plates. These additional shapes enable the data analyst to construct hull forms which match the hull as closely as desired throughout its length. It is also possible to put guide planes in the model and ends of the pressure hull inside the fairwater. It is also possible to make the stern-half taper different from the bow-half taper. Presumably a better fit to the aspect dependence of measured target strengths can be obtained with the more accurate hull model.

EXAMPLES OF HIGHLIGHT STRUCTURES

The highlight structures expected from particular hull features are a prominent part of the simulated echoes if these structures are included in the hull description provided the program. Examples of the echo forms are shown in Figs. 2 through 5 for 0°, 30°, 45°, and 60° aspects, respectively. In each diagram a submarine hull is oriented at the proper aspect for an ensonifying wave incident from the left. The structures indicated on the hull which are important in producing highlights are shown as a part of the target.

The (a) figures are shown without delay jitter. The highlights are distinct. A case of severe delay jitter (0.5λ) but with strong longitudinal correlation is shown in the (b) figures. Jitter in the amount of 0.5λ is sufficient if it is used alone to destroy all highlight features in the echo, but with 167λ correlation, a correlation longer than the pulse length, almost all jitter effects are lost. This result shows that high longitudinal correlation plus large jitter will not degrade highlights.

The (c) figures (Fig. 2(c) through Fig. 5(c)) are relatively low jitter examples with moderate correlation. The correlation distance is about two-thirds the pulse length in these examples. These echoes are rather "noisy" looking at aspects greater than 15°. The highlight structures remain until overlap begins near beam aspect. It should be pointed out that the relative sizes of the highlight structures in the echo vary from trial to trial.

The (d) figures show the effect of halving the correlation distance. This results in an increase in the "noisiness" of the echoes. The reduction of the amplitude of the first

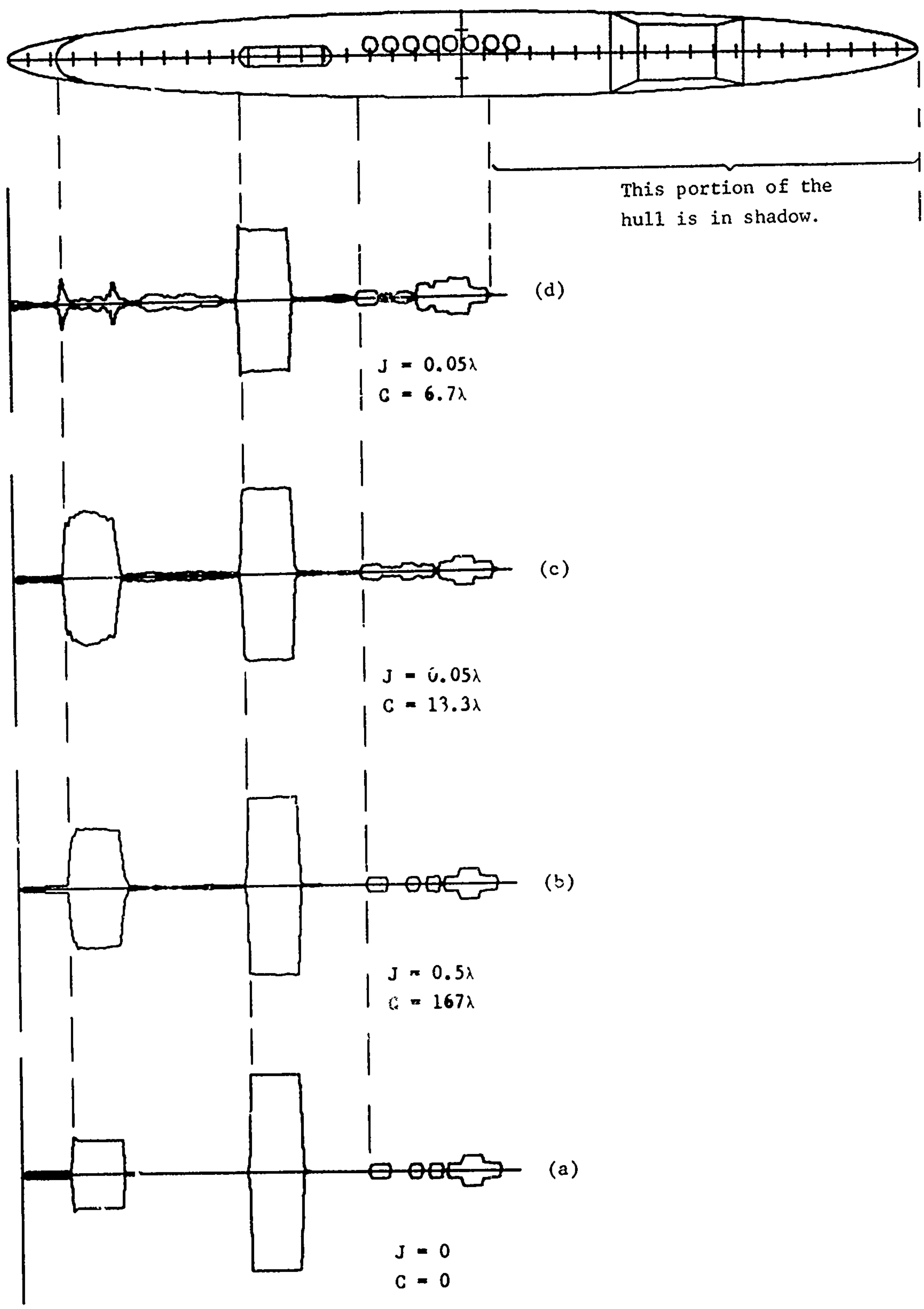

FIG. 2 - ECHO EXAMPLES (10 msec CW, Aspect 0°, 6 Points/Cycle, J = RMS Delay Jitter, C = Number of Correlated Wavelengths)

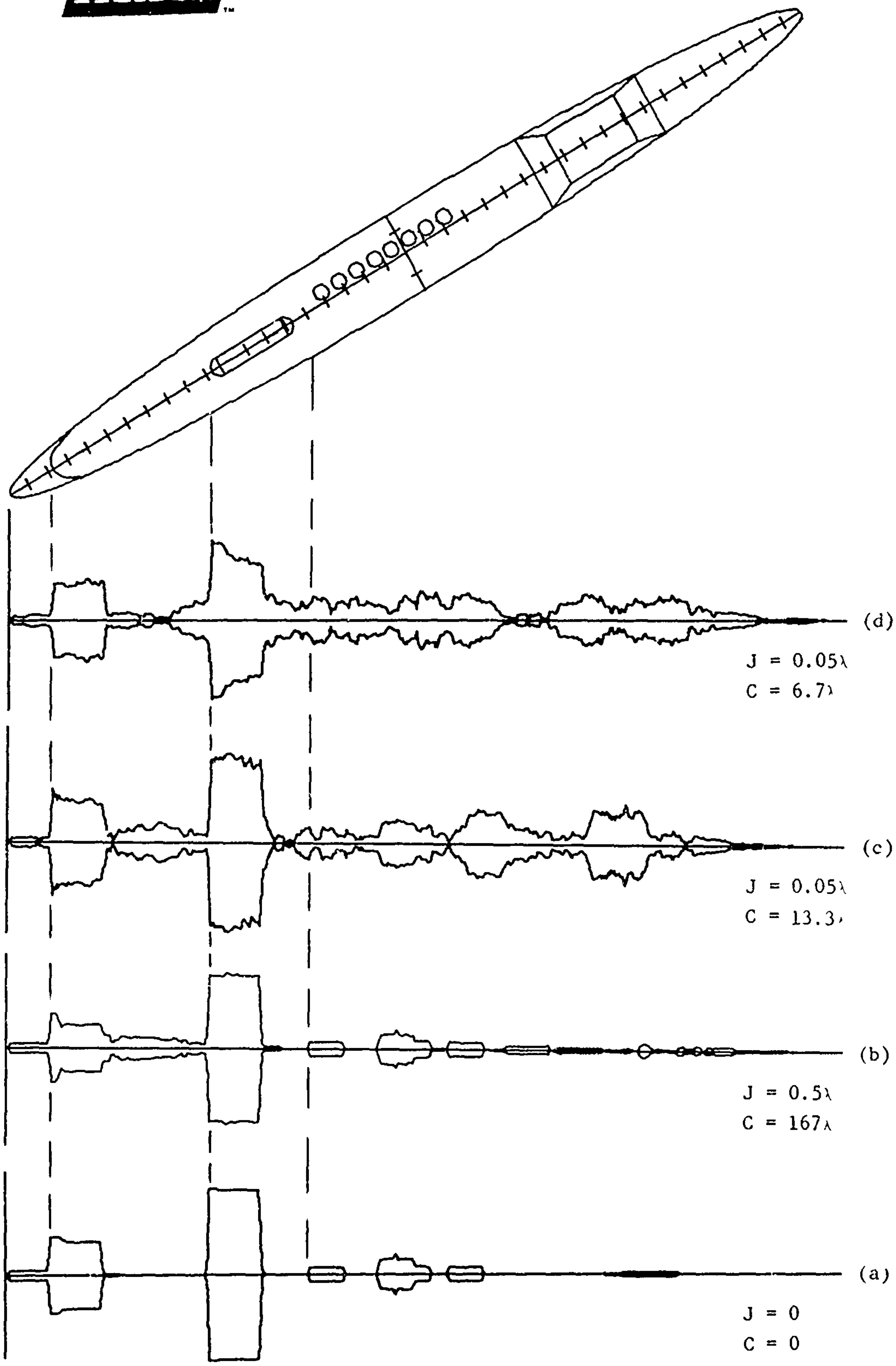

FIG. 3 - ECHO EXAMPLES (10 msec CW, Aspect 30°, 6 Points/Cycle, J = RMS Delay Jitter, C = Number of Correlated Wavelengths)

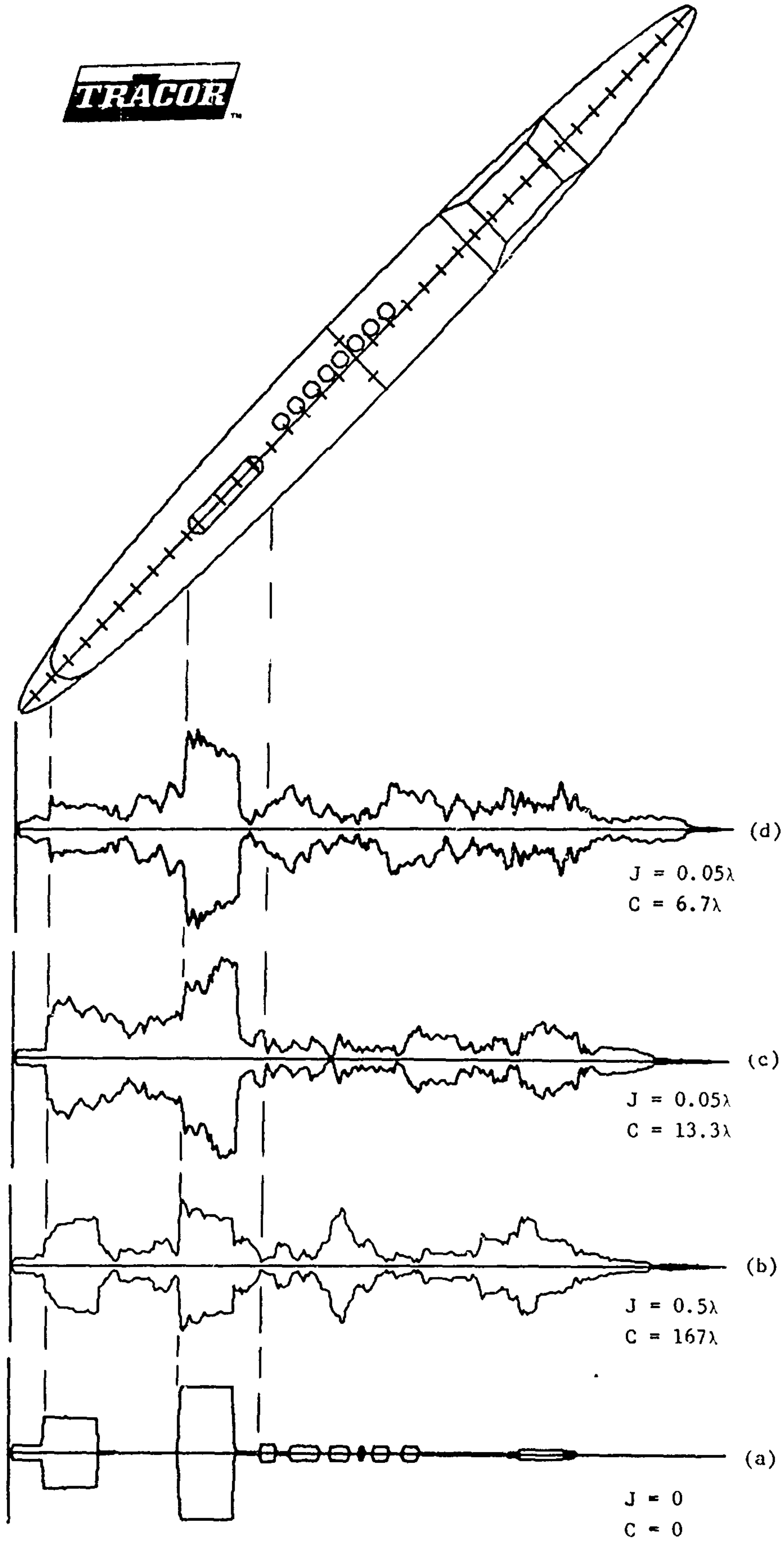

FIG. 4 - ECHO EXAMPLES (10 msec CW, Aspect 45°, 6 Points/Cycle, J = RMS Delay Jitter, C = Number of Correlated Wavelengths)

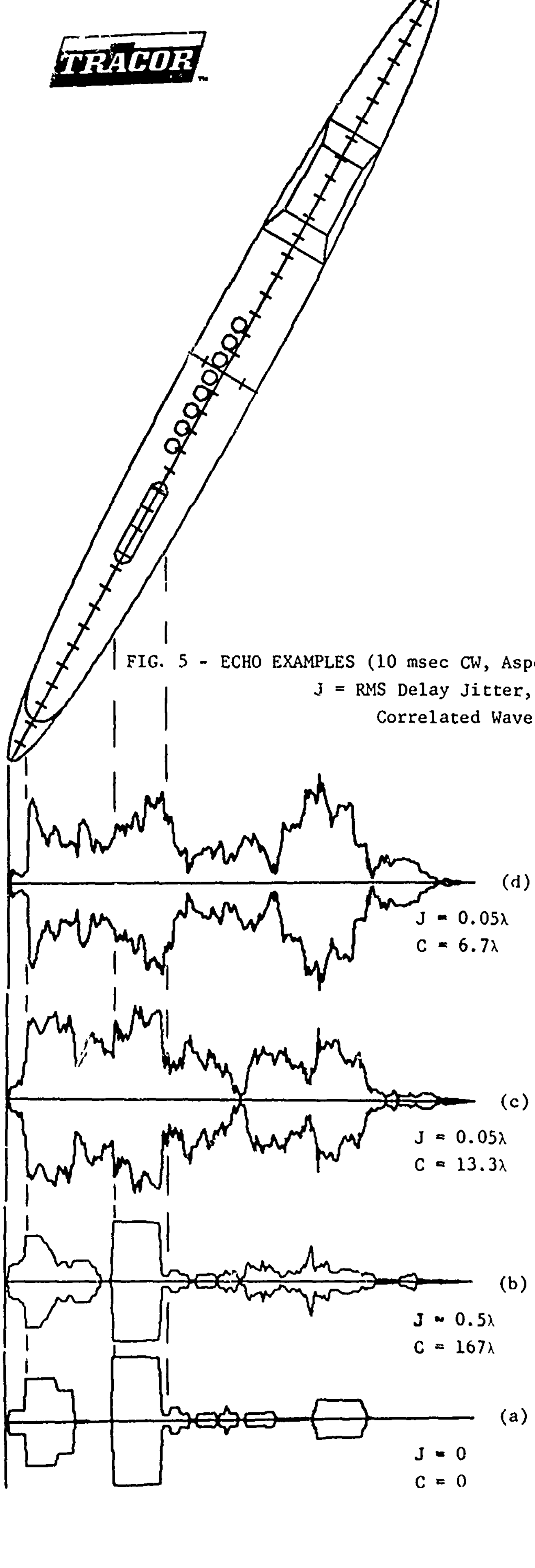

FIG. 5 - ECHO EXAMPLES (10 msec CW, Aspect 60°, 6 Points/Cycle, J = RMS Delay Jitter, C = Number of Correlated Wavelengths)

highlight in Fig. 2(d) illustrates how the accidents of phasing in the jittered arrivals occasionally cause the absence of a strong, expected highlight. Somewhat more variability is observed in the bow aspect echo structures recorded at sea than is shown in the Fig. 2(d) example.

TARGET STRENGTH DISTRIBUTIONS

Target strength distributions at single aspects or over all aspects can also be computed with the model. The mean and standard deviation of the distribution depend upon the jitter parameter and the correlation distances selected by the techniques described by Lobdill. Most of the experience with the target strength model has been obtained without correlation between the random delays δ_i and δ_{i+1} assigned to adjacent isophase zones. Experience with the program, used in this way, has shown that median target strength decreases as the jitter parameter J is increased. After J exceeds a small value, such as $\lambda/10$, the median target strength changes only slightly with further increase of J. The measured median target strength is in agreement with the median target strength obtained in the large J limit. Little work has been done with the correlation parameter C except to learn that there is some dependence of the median of the distribution upon C and that the standard deviation of the distribution depends upon C. The sensitivity to C has not been assessed but will be investigated early in any future work on the target strength model.

Figure 6 shows an example in which the median target strength obtained from the model is in close but not precise agreement with the median of the distribution of target strengths measured at sea. In this example the hull characteristics for the model were made to match the hull used in the measurement at sea. The target strength scale has been normalized to 0 dB median for the measured value. It is important to note that there is no scaling or normalization in the program except for the comparison of the simulated echoes to the target strength of a 2-yard-radius sphere. In the example shown in Fig. 6 both the measured and computed distributions have been scaled in the same way to allow presentation of this result in an unclassified form.

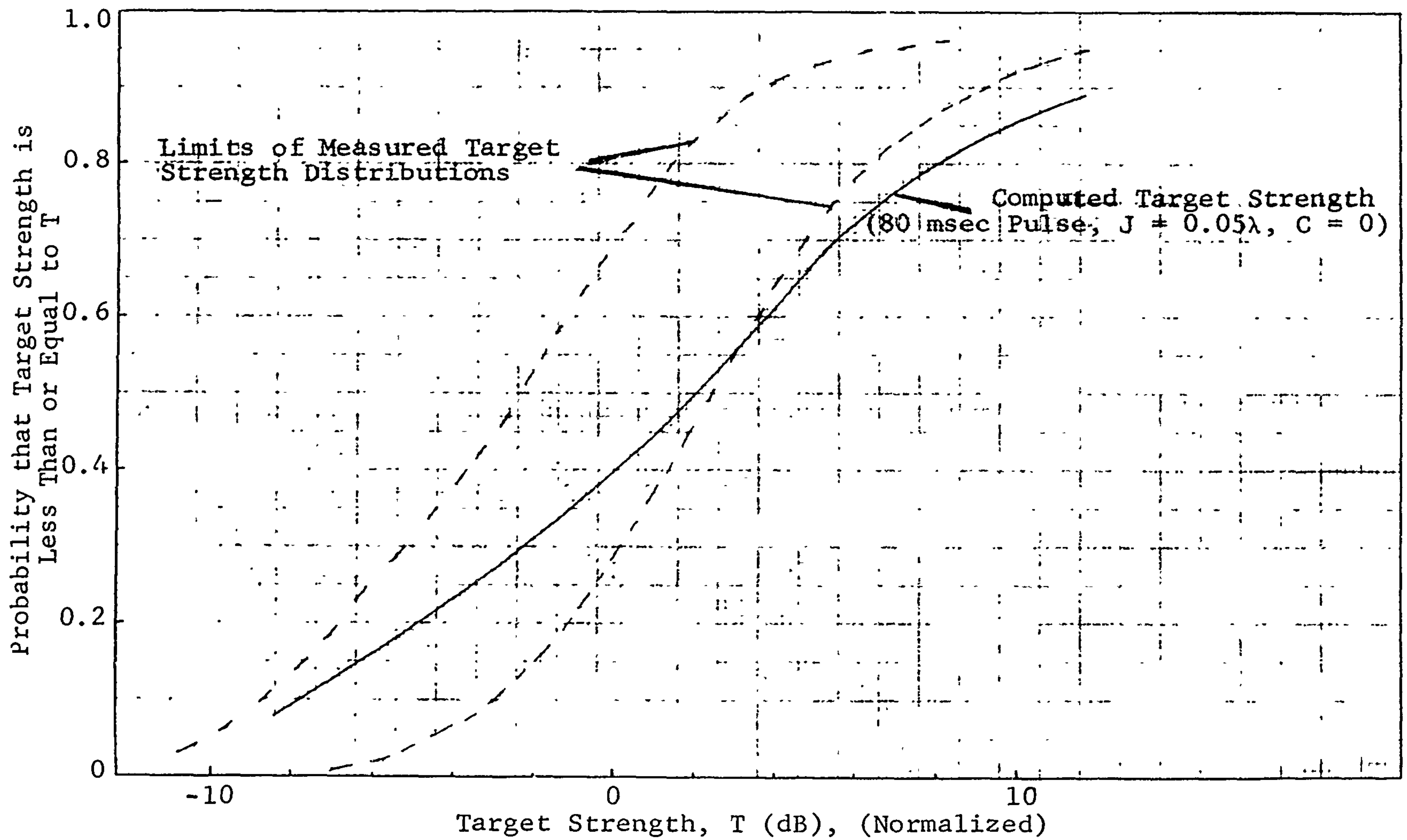

FIG. 6 - A COMPARISON OF TARGET STRENGTH DISTRIBUTIONS MEASURED AT SEA AND A COMPUTED DISTRIBUTION

The slope of the computed target strength distribution is somewhat lower than the measured slope. This is the poorest slope match among four hull types which have been attempted. The slope can be altered, in particular it becomes steeper if correlation between adjacent samples is introduced.

Figure 7 shows the effect of introducing correlation into the delays from adjacent scattering regions on the hull. It is clear that correlation can change the slope of the distribution sufficiently to provide a slope match. It is not clear, at this time, whether it is possible to have a slope match and distribution-median match simultaneously. It is also unsettled whether the environmental conditions which have been considered will provide the proper parameter values so that agreement between the measured and computed distributions will occur.

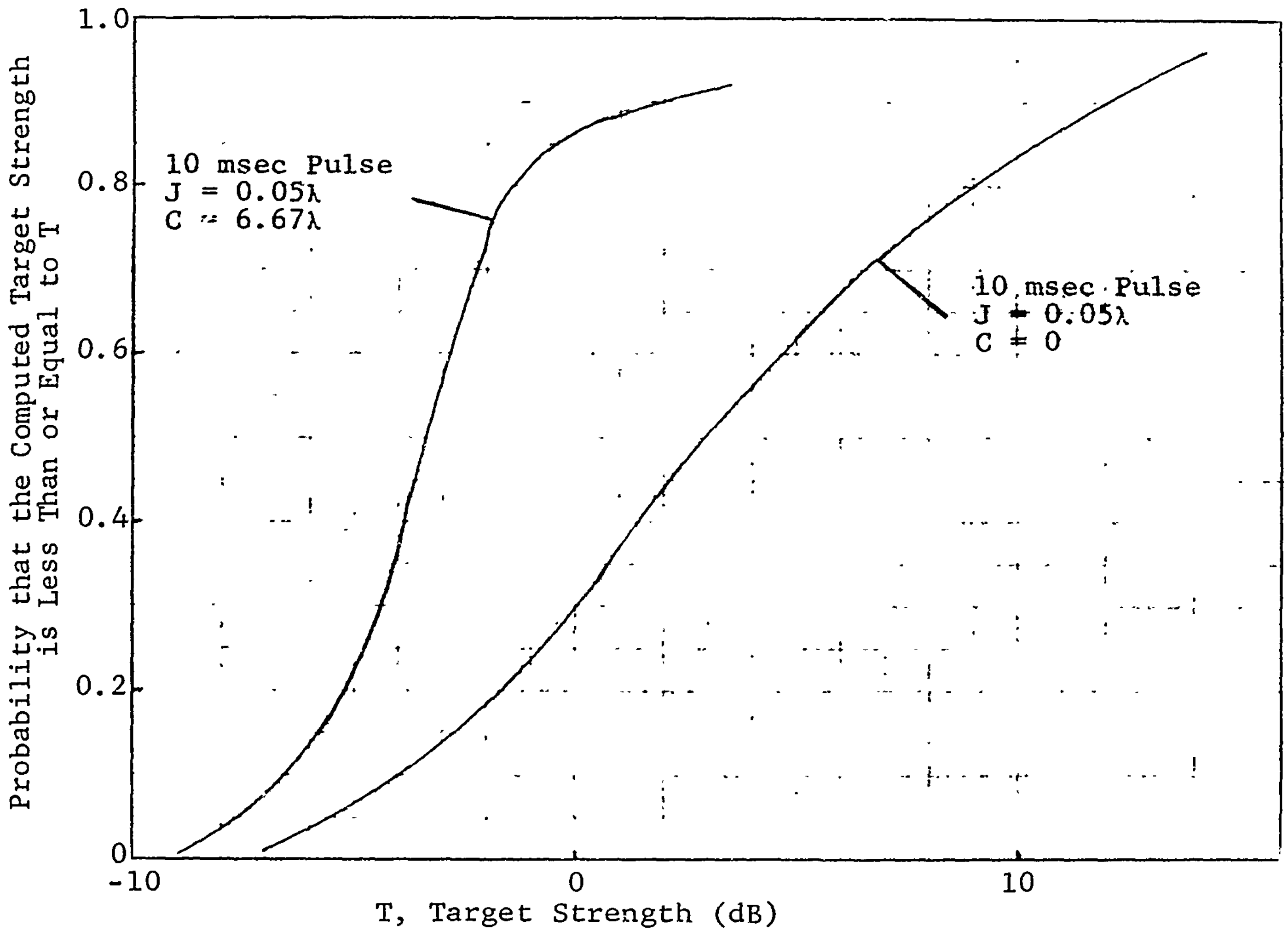

FIG. 7 - A COMPARISON OF TARGET STRENGTH DISTRIBUTIONS WITH DIFFERENT PHASE CORRELATION PARAMETERS

SUMMARY AND RECOMMENDATIONS

The work which has been accomplished under this program was carried out in parallel with the December 31, 1971 end date. The upgrading of the program proceeded initially along lines suggested from the work done in 1964 and 1965. This upgrading was directed toward increasing the variety of available hull shapes and improving the hull summing algorithm. The work on determining a physical basis for the delay jitter parameter was begun simultaneously. The latter work proceeded to the point where it became apparent that correlation between delays, belonging to scattering contributions from adjacent positions on the hull, was necessary in the physical model of jitter. This result was obtained early enough so that correlation was incorporated in the program. The theoretical work did not show how to select the jitter and correlation parameters from environmental conditions early enough so that complete validation of the model could be attempted before the end of the time allotted to the project. The validation of the model in terms of environmental constraints must therefore be the subject of future work.

The specific achievements obtained by the work under this project are in two areas. The first is concerned with specific computer program results:

1. The program has been translated so that it runs on the UNIVAC 1108.

2. The program for computing target strength has been improved to include more detail and greater accuracy in representing the target hull structure.

3. The scattered-pulse summing algorithm has been improved for sinusoidal signal forms so that computation time has been reduced by an order of magnitude.

4. The ability to correlate the arrival delays from positions along the hull with separately specified horizontal and vertical correlation distances has been included in the program.

5. The program can be used to make a scale drawing of the submarine hull used in the program.

6. Echo examples, target strengths, and target strength distributions are available from the program.

The second task involved the determination of a physical basis for the delay jitter. This work has been quite fruitful. The literature contains both experimental and theoretical results which show that arrival delay uncertainty depends upon the propagation conditions and the wave distribution on the ocean surface under the conditions used in most target strength measurements. Given sea state (or wind speed if the sea state is fully developed), the velocity profile, and the Rayleigh parameter* associated with the surface scattered wave, it is possible to assign rms delay jitter and correlation distances to the target strength program. The rms jitter determined in the Lobdill paper are the one-way jitter parameters associated with the sum of overlayed arrivals from the source to the target via the surface scattering path. The corresponding two-way jitter parameter is twice the value predicted by Lobdill. The program, using Lobdill's input parameters, will provide the contribution to the echo by the surface reflected path. The program without jitter will provide the contribution to the echo by the direct path. The

*Section II of this report.

sum of the two contributions provides a simulated echo which can be used to estimate a "computed target strength."

A few areas have now clearly surfaced as worthwhile for future efforts in the target strength program. In addition there are others which were given low priority in the present project. The following are specific recommendations for future efforts:

1. Carry out validation procedures for the target strength program using the environmental conditions encountered by Leiss and the measured target strength distributions reported by Leiss. Special attention should be given to the one hull for which our predictions differ significantly from the Leiss results.

2. Investigate the formation of echoes from simple structures in which a double hull form is encountered. A double-hulled broadside cylinder or sphere will be adequate for estimating the scaling factor required for scattering from the inner hull.

3. Investigate the feasibility of removing the over-layed sum step from the target strength computation and replacing this step with a sum distribution obtained directly from the random number distribution. A method of approach has been outlined under the present project, but this work was set aside in order to concentrate on other areas. If such a change can be justified analytically and accomplished in the target strength computations, additional economy in computer time can be achieved.

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II. SURFACE REFLECTIONS: THEIR EFFECTS ON REAL OR SIMULATED ECHOES IN TARGET STRENGTH DETERMINATIONS

by

J. J. Lobdill

1.0 INTRODUCTION

The TRACOR target strength prediction model, which involves the simulation of echoes from a submarine, requires that random "jitter" be applied to the ideal calculated arrival times of contributions from various parts of the submarine in order that simulated echoes resemble real echoes and that target strengths calculated from simulated echoes compare reasonably well with those obtained from real echoes. This suggests that there are physical phenomena occurring in reality which have not been accounted for analytically in the model. The present study has been stimulated by this consideration.

In the following section it is shown that for most experimental determinations of target strength a surface reflected propagation path is involved in addition to a direct path. In Section 3.0 the experimental and theoretical results available in the unclassified literature which are useful in describing the characteristics of a pulse received at the target via the surface path are summarized. Conclusions and recommendations are given in Section 4.0.

2.0 EXPERIMENTAL MEASUREMENTS OF TARGET STRENGTH

In 1964 W. J. Leiss of ORL issued a series of reports [Ref. 1] describing experimental determinations of the target strengths of eight submarines of varying types and dimensions. These reports have been reviewed to determine whether or not a surface reflected propagation path was involved. For all measurements the source vertical beamwidth was 12°, and the target ranges varied from about 650 yds. to 2500 yds. For the source and target depths stated in the reports, a simple calculation showed that the surface path was within the main beam of the source transducer under most conditions. Many of the measurements were made with the target at periscope depth (keel depth ~55 ft) and the source at a depth of 30 ft. For these source and target depths and for all pulse lengths transmitted, the surface path certainly influences the echo and hence, the target strength determination.

Some of the operational and environmental data taken during Leiss' experiments are summarized in Table 1.

TABLE 1

OPERATIONAL AND ENVIRONMENTAL DATA FROM LEISS [Ref. 1]

Source Characteristics

Pulse lengths: 5 msec to 320 msec
Beamwidth: 12°, horizontal and vertical
Source depths: 30 ft to 300 ft
Frequency: 20.5 kHz

Target Characteristics

Target length: 219 ft to 425 ft
Maximum target width: 25 ft to 33 ft
Target depths: Variable

Operational Conditions

Target aspect: Variable
Target range: ~650 yds. to 2500 yds.

Environmental Conditions

Water depth: 500 ft to 12,000 ft
Layer depth: 0 ft to 300 ft
Below layer thermal gradients: +2° F/100 ft to -21.5° F/100 ft
Sea state: 0 to 4+

3.0 THE SURFACE REFLECTED PROPAGATION PATH

The existence of a surface reflected path in the experiments reported by Leiss and the fact that the current TRACOR target strength prediction model considers only the direct propagation path stimulated an investigation of the surface reflected path to determine whether its effect on echoes could explain the requirement for "jitter" in the model. An extensive survey of the literature dealing with the surface reflected propagation path was conducted and has resulted in an understanding of the physical phenomena involved which will allow simulation of echoes consisting of contributions from both the direct and the surface reflected paths (and combinations of the two). Also it seems probable that random phenomena associated with the surface path can provide a physical explanation of the jitter requirement.

A satisfactory characterization of the pulse arriving at the target via the surface path is one which describes the amplitude, arrival time, and fluctuations thereof at any point on the target and the correlation of the amplitude and phase as functions of range and depth at the observation point. In this study phase and amplitude fluctuations at the observation point due to interaction of the pulse with the ocean surface are considered. Fluctuations due to thermal inhomogeneities in the ocean have not been treated.

3.1 A Review of the Literature

As is the case with most topics in acoustics, the problem of describing the scattering of acoustic energy from an uneven surface was first studied by Lord Rayleigh [Ref. 2] who solved the problem for normal incidence of a monochromatic wave on a sinusoidal pressure release surface for the case in which the surface amplitude is small compared to the wavelengths of the surface wave and the acoustic wave. His solution involved an infinite set of simultaneous equations expressing the amplitude coefficients of a discrete set of plane waves which were assumed to describe the scattered field.

In 1953 Eckart [Ref. 3] published the first treatment of the problem in which the Helmholtz integral was applied, and the specific case of forward scattering by the ocean surface was considered. It was necessary in the analysis to invoke the Kirchoff approximation which assumes that the wave is locally reflected by a plane surface. This approximation is useful for surfaces that are not too rough and are not shadowed.

Since Eckart's paper appeared, the problem has received a great deal of attention from both theoreticians and experimentalists. For completeness, the most important of the published works on this subject are listed in the bibliography [Refs. 1-14]. Theoretically the problem is rather unwieldy whether the general approach of Rayleigh or that of Eckart is taken. Most of the papers follow Eckart and express the reflected pressure field in terms of the Helmholtz integral with the Kirchoff approximation for the boundary conditions. Some of the most impressive theoretical work has been done by É. P. Gulin [Refs. 4, 5, 6] in the USSR. Gulin's theory is supported by experimental measurements made at sea and reported by Gulin and Malyshev [Refs. 7, 8]. In the United States the theoretical problem of reflection from various pressure release surfaces has been treated by C. W. Horton, et al, of DRL and The University of Texas at Austin [Refs. 9, 10, 11, 12], and their theoretical calculations of the characteristics of the reflected wave field compared well with measurements made at DRL under controlled conditions [Refs. 9, 11, 12, 13].

Gulin and Horton agree that for practical sonar beam-widths the area on the surface responsible for shaping the reflected pulse at the observation point is large enough that in the Helmholtz integral it is necessary to use the Fresnel diffraction approximation [Refs. 4, 11, 12].

3.1.1 Phase and Amplitude Fluctuations - In the Fresnel approximation the Helmholtz integral formulation yields expressions for the mean square fluctuations of the pressure amplitude and phase which depend upon the frequency, the specular angle of reflection, the path length of the specularly reflected ray, the insonified surface area, and the two-dimensional spatial covariance function of the surface irregularities. The expressions are in the form of complicated integrals over the insonified surface area. (See Eq. 29 and 30 of Ref. 11.) Horton [Ref. 11] and Gulin [Ref. 4] have succeeded in evaluating these expressions for different surface covariance functions and for various assumptions concerning the ratio of the surface correlation distance to the length of the insonified area (distances measured in a vertical plane containing the source and observation point). Both authors found that rms fluctuations of the phase and amplitude depend upon the parameter $K\sqrt{\overline{H^2}} \sin \psi$ where K is the wave number, $\frac{2\pi}{\lambda}$, $\sqrt{\overline{H^2}}$ is the rms wave height, and ψ is the grazing angle at the surface. The parameter $K\sqrt{\overline{H^2}} \sin \psi$ is called the Rayleigh parameter.

For values of the Rayleigh parameter <0.7, Gulin and Malyshev [Ref. 7] found experimentally that the rms amplitude fluctuation increased linearly with the Rayleigh parameter according to the formula

$$\text{rms amplitude fluctuation } (\%) = \frac{100}{\sqrt{2}} K\sqrt{\overline{H^2}} \sin \psi . \qquad (1)$$

Above a Rayleigh parameter of 0.7 the fluctuations "saturated," i.e., oscillated about a constant average value.

Measurements by Horton, et al, [Ref. 11] indicated a saturation value of 2 for the Rayleigh parameter. However, their surface covariance function was not like that of ocean waves. M. V. Brown [Ref. 14] analyzed experimental data taken at sea and concluded that the saturation value of the Rayleigh parameter was about 1. In all experiments reported the saturation value of amplitude fluctuation was 50% regardless of the form of the surface covariance function.

Phase fluctuation measurements appear to have been made only by Horton, et al [Ref. 11]. Their results showed phase fluctuations increasing linearly with Rayleigh parameter in the same way as for amplitude fluctuations, saturating at a phase fluctuation of 50% (re 1 radian)* for values of the Rayleigh parameter in excess of 2. The theoretical results of both Gulin [Ref. 4] and Horton [Ref. 11] predicted that phase and amplitude fluctuations in percentage should be approximately equal for small values of the Rayleigh parameter (i.e., below saturation). Hence, one can assume that Eq. (1) probably describes the phase fluctuations associated with the measurements of Gulin and Malyshev.

3.1.2 Probability Density Functions for Amplitude and Phase Fluctuations - This subject has not been treated extensively in the literature. The only paper we know of that addresses this topic is the paper by Gulin and Malyshev [Ref. 7]. Their experimental data indicate that for values of the Rayleigh parameter less than 0.37 the amplitude distribution for surface reflected pulses is approximately Gaussian. For larger values of the Rayleigh parameter the amplitude distribution is characterized by a "generalized Rayleigh distribution." For the definition of this distribution the authors refer to B. R. Levin, Theory of Random Processes and Its Application in Electronic Engineering (in Russian), Moscow, Soviet Radio Press (1957), and to Ya. L. Al'pert, V. L. Ginzburg, and E. L. Feinberg, "Propagation of Electromagnetic

*Phase fluctuations were expressed in percentage of 1 radian. Hence, 50% rms phase fluctuation would be an rms value of 0.5 radians.

Waves" (in Russian), Moscow, GTTI (1953). Neither of these references is available in the TRACOR library or at The University of Texas.

Probability density functions characterizing phase fluctuations have not been reported. In characterizing the surface reflected paths it is necessary to assign some form to the probability density function for phase fluctuations. Currently a Gaussian form is being assumed. For further discussion of this subject see Section 3.2.2.

3.1.3. Time Correlation Intervals for Amplitude and Phase Fluctuations - Gulin and Malyshev [Ref. 7] report that the time correlation interval for amplitude fluctuations decreases as the Rayleigh parameter increases. Their Fig. 11 shows that for Rayleigh parameters of ~0.3 and ~0.7 the time correlation intervals are ~5 sec and ~2 sec, respectively. The interpretation of these data in relation to the simulation of echoes for target strength predictions is that for a given value of the Rayleigh parameter the amplitude fluctuation selected at random from the appropriate population for the outbound path to the target can be applied in most situations to the return path. No measurements were given for the correlation interval of the phase fluctuations. However, it seems reasonable to assume that measurements for amplitude fluctuations would apply also to phase fluctuations.

3.1.4 Spatial Correlation of Amplitude and Phase Fluctuations - The theoretical paper by Gulin [Ref. 6] and the supporting experimental work reported by Gulin and Malyshev [Ref. 8] appear to be the only published work on this topic. Measurements were made at frequencies of 4, 7, and 15 kHz and rms wave heights, $\sqrt{\overline{H^2}}$, of 0 to 40 cm (Sea State 0 to ~4) and for receiver orientations such that correlation along all 3 spatial axes could be determined. The results presented in Ref. 8 compared well with predicitions based on the theory of Ref. 6. The conclusions of these studies were that (a) for small values of the Rayleigh parameter, the amplitude spatial correlation coefficients usually take the form of damped oscillation functions. As the Rayleigh parameter increases (above a value of 1) the correlation coefficients decline more rapidly and the oscillatory behavior disappears. (b) At small grazing angles the amplitude correlation along a vertical line decays much more rapidly than the horizontal correlation (along a line nearly perpendicular to the wave fronts). (c) The rms phase deviation between receivers, which is related to the phase correlation coefficient was also measured with the result that phase correlation intervals were found approximately equal to the amplitude correlation intervals as suggested by the theory presented by Gulin in Ref. 6. (d) Correlation intervals for vertical displacement were found to be about 1 meter, and for horizontal displacement along the line connecting source and receiver the correlation interval was about 5-6 meters.

3.1.5 Surface Reflection Coefficient - The surface reflection coefficient is the ratio of the reflected intensity to the incident intensity. Expressed in dB this quantity is known as surface loss. Surface loss measurements indicate that it is a negative decreasing function of the Rayleigh parameter. For Rayleigh parameter values ≤1 surface losses decrease from a value of 0 dB at Rayleigh parameters ≤0.2 to about -2 dB at a Rayleigh parameter of 1. (See Figs. 1-4 of Ref. 12.)

3.2 A Characterization of the Surface Reflected Pulse

In target strength measurements where a surface path exists, the echo from any element of area on the target consists of four components corresponding to the four possible round trip paths. Both the outbound and the return surface path may be characterized. The target is treated as an extended body and divided up into segments between which the phase and amplitude fluctuations are assumed to be correlated as described in Section 3.1.4. The source/receiver, if the experiments of Leiss [Ref. 1] are to be simulated, may be considered a point. For a given source depth, target depth, aspect, and range separation the following procedure will characterize the reflected pulse at the desired observation point:

1. By ray theory determine:

    a. the angle of incidence on the surface,

    b. the path length to the surface,

    c. the path length from the surface to the observation point, and

    d. the travel time.

2. Calculate the Rayleigh parameter from the known values of wavelength, rms surface displacement, and surface grazing angle.

3. Determine transmission loss for the path using a surface loss value obtained from data given in Section 3.1.5.

4. Use transmission loss to set an unperturbed value of amplitude.

5. Calculate ideal phase using all travel times and phase shifts previously stored for the particular round trip path type being considered.

6. Choose amplitude and phase fluctuations from a population characterized by an rms value determined as in Section 3.1.1, a density function determined as in Section 3.1.2, and spatial correlation functions as described in Section 3.1.4.

7. Apply amplitude and phase fluctuations to ideal amplitude and phase.

Except for steps 2 and 6 the procedure is straightforward. Some considerations associated with steps 2 and 6 are discussed in Sections 3.2.1 and 3.2.2 below.

3.2.1 Calculation of the Rayleigh Parameter - The Rayleigh parameter, $K\sqrt{\overline{H^2}}\sin\psi$ is related to sea state through the factor $\sqrt{\overline{H^2}}$ which is the rms amplitude of the waves on the ocean surface (measured from the equilibrium surface). Assuming that the sea is fully developed the value of $\sqrt{\overline{H^2}}$ is related to the wind speed according to the following equation:

$$2\,\overline{H^2} = 0.242\ (V/10)^5, \qquad (2)$$

where $\overline{H^2}$ is in ft.^{2} and V is the wind speed in knots. This equation obtains from Eq. 2.5, page 45 of Ref. 15 which states

$$E = 0.242\ (V/10)^5$$

where E is defined on page 6 of the same reference as twice the variance of a large number of samples of the amplitude. Figure 1 is a plot of wind speed vs. rms wave amplitude derived from Eq. (2).

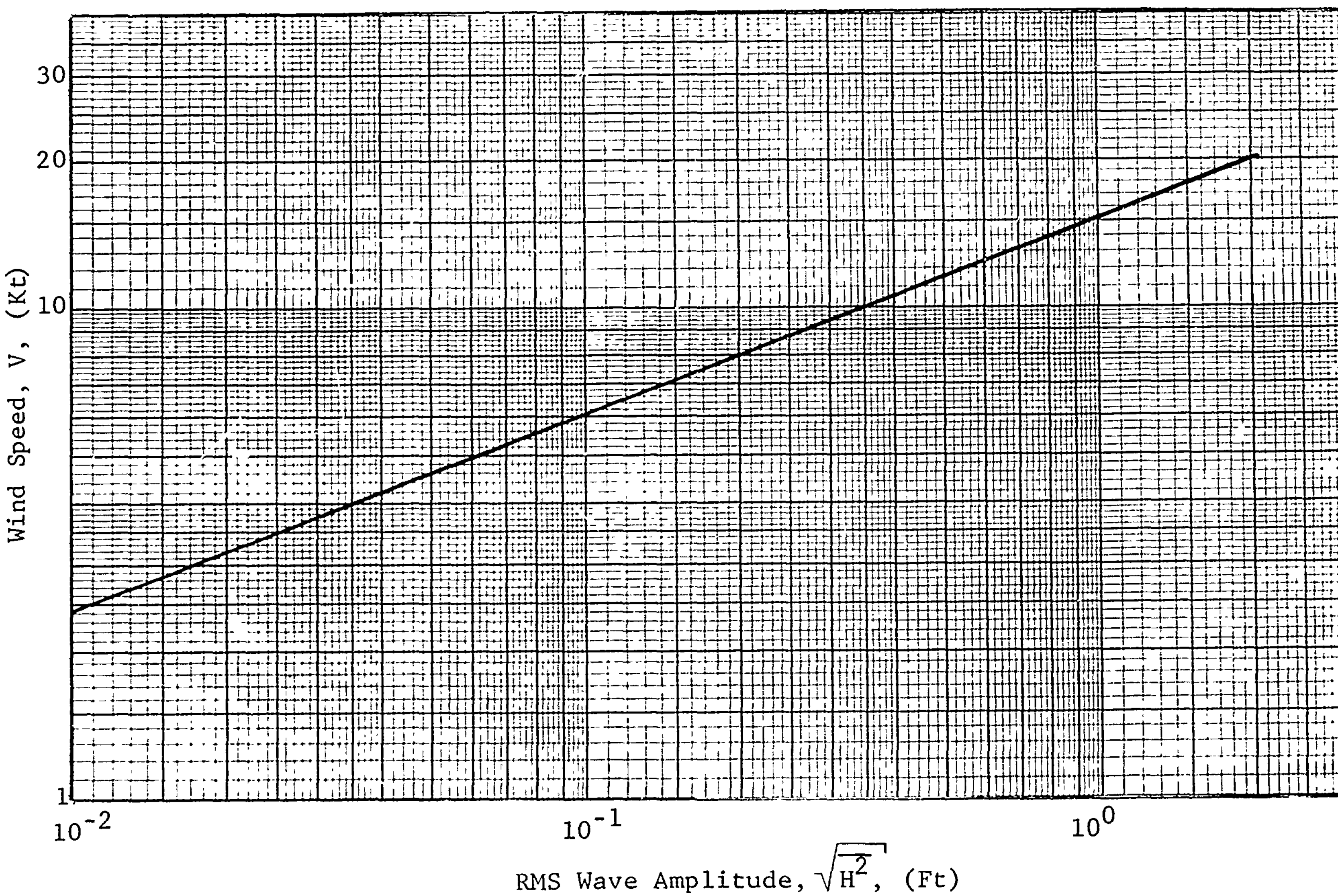

FIG. 1 - WIND SPEED VS. RMS WAVE AMPLITUDE, DEEP WATER, FULLY DEVELOPED SEA

For a fully developed sea, Table 2 gives the relationship between wind speed and sea state (from a chart published in 1950 by Woods Hole Oceanographic Institution).

TABLE 2

SEA STATE VS. WIND SPEED (FULLY DEVELOPED SEA)

Sea State	Wind Speed (Knots)
0	0-4
1	4-7
2	7-12
3	12-15
4	15-19
5	19-23

Table 1 of Section 2.0 indicates a range of sea states from 0 to 4+ for Leiss' experiments. Assuming a fully developed sea, the wind speeds ranged from about 0 to 19 knots, and according to Fig. 1 the rms wave amplitude, $\sqrt{\overline{H^2}}$ ranged from 0 to about 1.75 ft.

For a source depth of 30 ft. and a target depth of 55 ft., sin ψ varies from 0.0435 to 0.01133 as the range increases from 650 yd. to 2500 yd. The applicable value of K, the wave number, is $\frac{2\pi(20.5)}{4.85} \approx 26.6$ ft.$^{-1}$. During the experiments then, the Rayleigh parameter values ranged from 0 to about 2 when the source platform and the target were at periscope depth.

3.2.2 Characterization of Phase and Amplitude Fluctuations - In the target strength model echoes are simulated by summing up a large number of contributions from small elements of area on the hull. Each contribution which contains surface reflected energy will have random phase and amplitude obeying some sort of statistics. In the summation one supposes that the central limit theorem will make the predicted target strength values insensitive to the form of the probability density which describes the phase and amplitude fluctuation associated with the echo from each small element of area on the hull. This supposition has not yet been validated.

Assuming that Gaussian statistics apply, and considering Rayleigh parameter values between 0 and 0.7, the probability density for amplitude and phase fluctuations can be completely specified. The variance is given by Eq. 1 and the mean is zero.

Correlation distances for vertical and horizontal displacements on the target are given in Section 3.1.4. Suitable forms for the spatial correlation functions can be selected from those given in Refs. 6 and 8.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A realistic simulation of Leiss' experimental determinations of target strength should include the effects of surface reflected energy. A review of the literature indicates that surface reflection produces random phase and amplitude fluctuations which could explain the requirement for "jitter" in the TRACOR target strength model. Enough theoretical and experimental work has been done to allow the simulation of a surface reflected pulse with a reasonable degree of realism for source and target at periscope depth.

It is recommended that a model of the surface path as described in Section 3.2 be implemented and incorporated into the target strength model. Results obtained with the model thus modified should be compared with the measurements of Leiss and the predictions obtained using jitter.

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III. TARGET STRENGTH PROGRAMS

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TARGET STRENGTH PROGRAMS

All programs are written in FORTRAN for the Univac 1108.

I. "BACSCT"

This is the old CDC 3200 program with minor modifications which allow it to run on the 1108.

This program models a submarine as an ellipsoid and a box which is capped with two half cylinders. The ellipsoid shadowing the sail is simulated. Given the look angle, a frequency, and the submarine dimensions, the program computes amplitudes which are proportional to projected areas of isophase slices. This array of amplitudes is written to magnetic tape.

The program has as input the namelist "IN." The parameters are:

ALPHA - Depression - Elevation Angle in Degrees (Negative for Depression)

THTA - Aspect Angle in Degrees

FREQ - Frequency

K - Number of Isophase Zones for One Cycle

HHL - Half Hull Length }
RAD - Hull Radius } Defines Ellipsoid

LSS - Length of Sail (Without End Caps)

HSH - Half Sail Height

RSEND - Radius of Sail End (Half Sail Width)

CTEND - Distance Forward to Rear of Sail (Without End Cap)

SELEV - Sail Elevation Above Center Line

All variables are real except integer K.

After initial values are set, they need not be reset in subsequent data sets. Typically, only ALPHA is changed.

II. "SUB"

This program is identical to "BACSCT" except that any number of right circular cones and hemispheres may be added to the hull-sail model.

Cones may have any dimension. The only limitation is that their axis must be the axis of the ellipsoid. Cone bases are not included in area.

Hemispheres may be any size and they may be positioned anywhere. However, they have only an up or a down orientation; their bases must be horizontal. Hemisphere bases are not included in area.

No shadowing of the cones and spheres is considered.

Input is via cards. First "NHS" and "NC" in (2(1x, I4)) format. "NHS" is number of hemispheres and "NC" is number of cones. Then, "NC" cards containing "R1," "R2,", "H," "CR" in (4(1x, F9.3)) format. "R1" is radius of forward cone base. "R2" is radius of rearward cone base. "H" is the distance between cone bases. "CR" is the distance from the sub center to the forward base. "CR" is positive for cones toward stern.

The next "NHS" cards contain "R1," "D1," "D2," "D3" in (5(1x, F9.3)) format. "RS" is sphere radius. "D1," "D2" and "D3" define hemisphere position. "D1" is distance forward or back from ellipsoid center. (Positive--towards bow.) "D2" is horizontal distance from and perpendicular to axis. (Positive--towards wave front.) "D3" is vertical distance. (Positive--up.) "AS" indicates orientation; 0 or positive for top half of sphere or negative for bottom half.

The namelist "IN" follows. Only "IN" may be repeated.

Output is to tape as in "BACSCT."

III. "TGS"

"TGS" reads amplitude arrays generated by "BACSCT" or "SUB" and generates echos. First the amplitude array is read from tape. Then a longer array, with correlated jitter is computed. The derivatives of signals are scaled with the correlated jitter array and the scaled signals are added with appropriate delays to form the echo. The target strength is computed and the echo may be plotted.

The program must be recompiled to change these parameters.

NN - Maximum Amplitude Array Length

OVLP - Extra Storage on Ends to Allow for Jittering

NDIV - Number of Pieces in Each Isophase Zone

NS - Number of Isophase Zones Per Cycle

NCYCLE - Number of Cycles in Signal

NTRY - Number of Times to Jitter Each Amplitude Array

"FCTR" sets the zone to zone correlation. "FCTR" is the fractional independence ("FCTR" = 0, complete correlation; "FCTR" = 1, complete independence).

"NR," "WLJ," "IFG," "NRS" are read from a card in (I5, F10.3, 20I2) format.

"NR" is the number of tape records (amplitude arrays) to read. "WLJ" is the standard deviation of the jitter in units of wave lengths. "IFG" is an array of "NTRY" flags to signal plot or no plot. (0 for no plot, positive for plot.) "NRS" is the number of records to skip before reading "NR" records. "NRS" may be negative, zero, or positive.