Ship Acoustics Department

Departmental Report

Effects of Frequency, Temporal, and Spatial Averaging on Image Interference

by

Paul T. Arveson

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ABSTRACT

This report describes a significant phenomenon affecting the propagation of underwater sound at ranges less than 1000 yards: the image interference or Lloyd-mirror effect. Previous models for the effect do not adequately take into account the effects of frequency averaging and spatial averaging due to sea surface roughness and finite source size. These refinements on the basic theory are developed here. Also a clarification of the meaning of the surface reflection coefficient is given for the case of omnidirectional sources and receivers -- the situation that prevails in ship radiated-noise trials.

ADMINISTRATIVE INFORMATION

The Target Physics Branch, Code 1965, of the Ship Acoustics Department, originated and prepared this technical note for use by the David Taylor Naval Ship Research and Development Center (DTNSRDC). The funding came from several projects sponsored by the Naval Sea Systems Command (NAVSEA 55N).

ACKNOWLEDGEMENTS

The author wishes to thank Dr. David Vendittis for many helpful ideas and suggestions that are incorporated in this work.
INTRODUCTION

The reflection and scattering of underwater sound from the ocean surface is a phenomenon that has been studied extensively since the time of Rayleigh (1). In fact, the approach taken by Rayleigh has been followed by many investigators up to the present time. Most of the theoretical literature deals with the Rayleigh problem: a plane wave insonifying a small area on the sea surface. Reports on experiments often deal with an approximation to this; that is, a narrow-beam transmitter and receiver aimed at a small area on the sea surface or some model of the surface.

The situation of interest in ship acoustical trials is best represented by an omnidirectional source and receiver under a moderately rough sea surface. The received signal is time-averaged for a duration that is long compared with the sea surface fluctuations. This is a limiting case that is not directly reported in the literature; however it is relatively easy to devise an adequate expression to account for this case. Only the time-averaged rms pressure is needed; there is no need for consideration of coherent and incoherent scattering, or the statistics of the time-varying surface.

This report proposes simple equations for the time-average rms received pressure from an omnidirectional source in the vicinity of the sea surface.

Figure 1 - Geometry of the image interference effect
At low frequencies where absorption is not significant, and neglecting refraction effects, the mean-square pressure at a receiver in the vicinity of a flat pressure-release surface can be written

\[
\langle p^2 \rangle_t = \frac{p_0^2 r_0^2}{r_1^2} \left[ 1 + \frac{2 \mu r_1^2}{r_2^2} - \frac{2 \mu r_1}{r_2} \cos 2 \pi f_0 T \right]
\]

where \( r_1 \) and \( r_2 \) are ray distances as shown in Figure 1; \( f_0 \) is the signal frequency; \( T = \frac{r_2 - r_1}{c} \) is the time difference in arrivals via \( r_1 \) and \( r_2 \); \( \mu \) is the surface reflection loss coefficient (can vary from 0 to 1). (In the general case where the sound speed \( c \) is not a constant, refraction will be present, so \( r_1 \) and \( r_2 \) will not be straight lines.) For the sake of simplicity, let the reference pressure \( P_0 = 1 \) and \( r_0 = 1 \).

AVERAGE OVER A FREQUENCY BAND

It can be shown (Appendix A) that, for a band of frequencies of bandwidth \( B \) and arithmetic center frequency \( f_0 \), the mean-square received pressure may be written as

\[
\langle p^2 \rangle_T = \frac{p_0^2 r_0^2}{r_1^2} \left[ 1 + \frac{2 \mu r_1^2}{r_2^2} - \frac{2 \mu r_1}{r_2} \sin \frac{\pi B T}{\pi f_0 T} \cos 2 \pi f_0 T \right] \tag{2}
\]

where the factor \( \frac{\sin \frac{\pi B T}{\pi f_0 T}}{\pi} \) may be interpreted as a dimensionless cross-correlation coefficient (with time delay \( T \)), between the sound pressures from the direct and surface-reflected paths. This equation only can apply when the sea surface is smooth enough so that the ocean wave height is small compared to acoustic wavelength, or when the surface scattering is small. If this is not the case, a more
general expression must be obtained that takes account of the sea roughness as well as bandwidth.

**EFFECT OF ROUGH SEA SURFACE**

The following five points constitute a heuristic argument to arrive at a more general theory for the omnidirectional transmission loss as a function of both bandwidth and sea surface roughness (wave height).

1. Most of the discussions of surface loss (2) in the literature apply to narrow-beam sources and/or receivers. Actually the value of \( \mu \) referred to in this case is a **partitioning factor** indicating the relative amount of sound energy that is scattered out of the specular direction, that is, the ratio of specularly-reflected pressure to the total incident pressure. The justification for this interpretation of \( \mu \) is that there is very little actual energy loss due to reflection of sound from the sea surface. The available mechanisms for such real dissipative surface loss are, in general:
   a) Transmission through the surface: causes a very small reflection loss of \(.005 \text{ dB}\)
   b) Absorption by bubbles: also estimated at about \(.005 \text{ dB below } 10 \text{ kHz}\)
   c) Absorption by organisms: varies, but generally very small.

At high frequencies, (say 50 kHz) the loss due to bubbles may become significant at low grazing angles where the sound travels through an extensive thickness of bubbles. Therefore, with this exclusion, we can let \( \mu = 1 \) and remove it from equations 1 and 2.

2. Since ship noise measurements are almost always time-averaged measurements, it is not necessary to treat coherent and incoherent reflected sound separately, as is often done in the literature (2). Equation (2) is expressed in a convenient form such that there can be one correlation factor, \( g \), which will com-
pletely describe the effect of the surface on reflected sound, for any degree of
surface roughness.

3. Equation (2) describes a form of the image-interference effect as a
function of bandwidth B which has the following properties:

a) For B = 0, equation (2) reduces to equation 1, which is the case of image
interference from a flat surface.

b) For B >> 2f₀, equation (2) reduces to the limiting case of wideband noise:

\[ p^2 = \frac{p_0^2 r_0}{r_1^2} \left[ 1 + \frac{r_1^2}{r_2^2} \right] = \left[ \frac{1}{r_1^2} + \frac{1}{r_2^2} \right] \frac{p_0^2 r_0^2}{p_0^2} \]  

which is purely a function of geometry. This function is shown in Figure 2.
The ordinate in this figure is plotted in terms of the increase in pressure
level (in dB) due to the presence of the surface path. The 0-dB line
represents the free-field transmission loss 20 \log r_1. The abscissa is
plotted in terms of the dimensionless geometry parameter \sqrt{dh/r_1}. (The levels
given are strictly applicable only to the case of isovelocity water.) Notice
however, that the maximum contribution from the surface path is only 3 dB. This
indicates why exact theoretical derivations (such as by integrating the results
for narrow-beam theory) are unnecessary and a simple definition of correlation
is sufficient. Measurement precision and omnidirectionality of real transducers
rarely are better than 1 dB.

4. The dimensionless surface roughness parameter commonly applied is the
Rayleigh parameter

\[ R = k \sigma \sin \alpha = \frac{2\pi f \sigma}{\lambda_0} \sin \alpha = \frac{2\pi f_0 \sigma}{c} \sin \alpha \]

where \( \sigma \) is the rms wave height, \( \alpha \) is the grazing angle of the specular ray, and
Figure 2. Increase in mean level of wideband noise signals due to surface-reflected sound as a function of geometry (square-law detector assumed).

NOTE:
THESE CURVES ASSUME LONG TIME AVERAGES AND INCOHERENT SUMMATION OF SIGNALS. FOR GAUSSIAN NOISE THE MINIMUM BANDWIDTH FOR VALIDITY IS $B = \frac{c}{2f_1}$, WHERE $c$ = SPEED OF SOUND.
\( \lambda_0 \) is the wavelength of sound of frequency \( f_0 \). In the case of scattering from a narrow beam of sound, \( \alpha \) has a unique value. This is the case usually treated in the literature. However, in the case of an omnidirectional source, sound is scattered at all angles from a rough surface. Nevertheless, we retain the specular-reflection value for \( \alpha \) in the latter case. The justification for this is that \( \alpha \) is always the angle from which most of the sound will be reflected on a time-average basis, and angles within, say, 10 percent of \( \alpha \) will usually cover a large portion of the scattered sound pressure (3). Therefore the Rayleigh parameter will be retained with the above extension of its definition implied in the case of an omnidirectional source.

If the sea surface is flat, equation (2) applies, for any band of frequencies centered at \( f_0 \). But if we assume a very rough surface, such that \( R > 10 \), it is clear that the reflected ray will be uncorrelated with respect to the direct ray, regardless of the value of \( B \). In other words, even with \( B=0 \), equation (3) will apply when \( R \) is large.

5. Both \( B \) and \( R \) affect the correlation factor. It seems likely that they both affect it to the same degree, because both are dimensionless ratios of lengths, the limiting values are the same, and they are both conservative: they only affect the received phase; there is no amplitude loss. From the above considerations we infer a combined expression for the correlation factor of the form:

\[
g = \frac{\sin(\pi BT + R)}{\pi BT + R}.
\]  

(4)

It is clear that the effects of \( B \) and \( R \) are additive, because when one term is small and the other large, the large one dominates. It also seems reasonable that both \( B \) and \( R \) have equal weight in determining the correlation factor, \( g \).
Therefore, a general expression for the received mean square sound pressure from an omnidirectional point source and receiver under a rough sea surface may be written

\[ \langle p^2 \rangle_r = \frac{p_0^2}{r_2^2} \left[ 1 + \frac{r_1^2}{r_2^2} - \frac{2r_1}{r_2} \frac{\sin (\pi BT + R)}{\pi BT + R} \cos 2\pi \frac{f_0}{T} \right] \]  

(AVERAGE OVER A FINITE-SIZE SOURCE)

Equation (5) may be extended further to include the effect of spatial averaging in a vertical dimension caused by a source of finite size. This situation occurs, for instance, in the case of a cavitating propeller on a surface ship, where the collapsing cavitation bubble is extended in depth and radiates sound across this extended region.

In this case the depth-averaging term has a form that is identical to the Rayleigh parameter, except that the rms wave height \( s \) is replaced by the rms vertical source width \( d \):

\[ Z = 2 \pi \frac{d}{c} \sin \alpha = 2 \pi \frac{d}{c} \frac{f_0}{\lambda} \sin \alpha \]

This is the correlation factor for spatial averaging in the vertical dimension. Clearly this factor is additive with the other factors. Therefore, the resultant image interference equation is obtained by adding all three factors:

\[ g = \frac{\sin (\pi BT + R + Z)}{\pi BT + R + Z} \]

so that the resulting image interference equation becomes
\[ \langle P \rangle_t = \frac{P_0 r^2}{r^2} \left[ 1 + \frac{r_1^2}{r_2^2} - \frac{2r_1}{r_2} \frac{\sin(\pi B T + R + Z)}{\pi B T + R + Z} \cos(2\pi f_0 T) \right] \]  

This model of the image interference anomaly has been implemented in a BASIC-language program for the Hewlett-Packard 9845 computer. A listing is included in Appendix B. The program uses conventional 1/3-octave frequency bands and can accept up to 4 receiver depths in a vertical array, with two commonly-used methods of averaging the data from different receivers.
Appendix A. Derivation of Image Interference Term for a Band of Frequencies

Equation (1) applies only to the case of a single frequency \( f_0 \), whereas it is more usual to measure noise in a band of frequencies \( B = f_2 - f_1 \). In this case the third term in equation (1) must be averaged over frequency:

\[
I = \frac{1}{2\pi BT} \int_{f_1}^{f_2} \cos 2\pi fT \, df.
\]

Defining \( f_0 = \frac{f_1 + f_2}{2} \), \( \theta_1 = \pi f_1 T \) and \( \theta_2 = \pi f_2 T \), we obtain

\[
I = \frac{1}{2\pi BT} \left[ \sin 2\pi f_2 T - \sin 2\pi f_1 T \right]
\]

\[
= \frac{1}{2\pi T(f_2 - f_1)} \left[ \sin 2\pi f_2 T - \sin 2\pi f_1 T \right]
\]

\[
= \frac{1}{2(\theta_2 - \theta_1)} \left[ \sin 2\theta_2 - \sin 2\theta_1 \right]
\]

\[
= \frac{1}{\theta_2 - \theta_1} \left[ \frac{\sin 2\theta_2}{2} - \frac{\sin 2\theta_1}{2} \right]
\]

\[
= \frac{1}{\theta_2 - \theta_1} \left[ \sin \theta_2 \cos \theta_2 - \sin \theta_1 \cos \theta_1 \right]
\]

\[
= \frac{1}{\theta_2 - \theta_1} \left[ (\cos^2 \theta_1 + \sin^2 \theta_1) \sin \theta_2 \cos \theta_2 - (\sin^2 \theta_2 + \cos^2 \theta_2) \sin \theta_1 \cos \theta_1 \right]
\]

\[
= \frac{1}{\theta_2 - \theta_1} \left[ \sin \theta_2 \cos^2 \theta_1 \cos \theta_2 - \sin^2 \theta_2 \cos \theta_1 \sin \theta_1 - \cos^2 \theta_2 \sin \theta_1 \cos \theta_2 \\
+ \cos \theta_2 \sin^2 \theta_1 \sin \theta_2 \right]
\]

\[
= \frac{\sin \theta_2 \cos \theta_1 - \cos \theta_2 \sin \theta_1}{\theta_2 - \theta_1} \left[ \cos \theta_1 \cos \theta_2 - \sin \theta_1 \sin \theta_2 \right]
\]
\[ \frac{\sin(\theta_2 - \theta_1)}{\theta_2 - \theta_1} \cos(\theta_1 + \theta_2) \]

\[ = \frac{\sin nBT}{nBT} \cos 2\pi f_0 T. \]
This program generates anomaly in propagation loss due to surface image interference as well as anomalies due to hydrophone directionality, absorption loss, and detector type. Options are available to account for averaging due to a vertical source width and hydrophone averaging method (average of dB levels or average of powers before dB conversion).

The program does not account for sometimes significant effects due to averaging over range during sample time, refractive anomalies, or bottom reflections.

```fortran
DIM D2(18),Freq(41),P(18),Asum(41),Dbsum(41),Db(18,41)
DIM Fre(41),A(18,41),Akyds(21),X(41),Y(41),PS(6),CSCS88
SHORT Xsum(34)
DATA .0853,.0868,.0885,.184,.13,.164,.215,.293,.415,.604,.9,1.36,2.87
DATA 3.14,4.73,7,18.1,14.1,18.8,23.9,29
MAT READ Akyds
RESTORE
Fmaxm34
UPPER FREQUENCY IS 28,88 Hz
Detml
PRINT "PROPAGATION ANOMALY DATA"
DEEP
INPUT "SQUARE LAW DETECTORS ARE ASSUMED; IF LINEAR ENTER 1",L$
IF L$="1" THEN Det=PI/4
DEEP
INPUT "ENTER LENGTH OF HYDROPHONE ELEMENT IN INCHES",Hy1
Hyd=Hy1/12
DEEP
INPUT "ENTER OCEAN WAVE HEIGHT IN FEET",Wh
DEEP
INPUT "ENTER MEAN SOURCE DEPTH IN FEET",D1
DEEP
INPUT "ENTER SOURCE VERTICAL WIDTH IN FEET",Dx
IF D1>Dx THEN GOTO 468
DEEP
DISP "ERROR -- SOURCE NOT FULLY SUBMERGED"
WAIT 1500
GOTO 370
DEEP
INPUT "ENTER HORIZONTAL RANGE IN YARDS",Cpay
DEEP
INPUT "HOW MANY HYDROPHONES ARE AVAILABLE?",Nhyd
IF Nhyd<40 THEN GOTO 550
DEEP
DISP "BAD INPUT, TRY AGAIN"
GOTO 370
DEEP
INPUT "ENTER DEPTH OF HYDROPHONE IN FEET",D2(I)
NEXT I
START OF COMPUTATIONS

Cpa=3*Cpay
Cpa=Cpa*2
C=5000
Aug=1
Aug=2
DISP "WAIT A MINUTE -- I'M THINKING"
FOR I=1 TO Nhyd
HYDROPHONE DEPTH LOOP
```
Sum = D1 + D2(I)

Diff = D1 - D2(I)

Rsq = Cpaq + Diff^2

Rrsq = Cpaq + Sum^2

R = SQRT(Rsq)

R = SQRT(Rrsq)

P(I) = SQRT(D1^2 + D2(I)^2) / R

Geometry parameter for surface reflections

Theta1 = PI / 2

Theta2 = nPI / 2

RAD

IF Cpa > 0 THEN Theta1 = RTN(Diff / Cpa)

IF Cpa > 0 THEN Theta2 = RTN(Sum / Cpa)

Absorption loss negligible below 1 KHz.

Absorption loss factor for Rr

Lambda = C / Freq

IF F < 21 THEN GOTO 910

Alpha = Akyds(F-29) / 68888

Divide by 36880 to give exp. loss per foot

Absorption loss factor for R

Absorption loss factor for Rr

Dir1 = FNDirect(Theta1, Lambda, Hyd)

Dir2 = FNDirect(Theta2, Lambda, Hyd)

C1 = E1 * Dir1

C2 = E2 * Dir2

Sin = Sum / R

Bandwidth in hertz

Integral over source width (NEW VERSION)

Integral due to surface roughness (Rayleigh)

X = Z1 + Z2 + Z3

Corr = SIN(X) / X

Lloyd mirror eqn.

Db(IF) = 10 * LGT(A(IF) * D * t)

NEXT F

Asum(F) = 0

Dbsum(F) = 0

FOR I = 1 TO Nhyd

Asum(F) = Asum(F) + A(I,F) * Det

Dbsum(F) = Dbsum(F) + Db(I,F)

NEXT I

Asum(F) = 10 * LGT(Asum(F) / Nhyd)

Dbsum(F) = Dbsum(F) / Nhyd

Asum = AVERAGE OF POWER VALUES IN DB

Dbsum = AVERAGE OF DB VALUES

NEXT F

Deep

Plot done = 0

STORE:

STORE ASUM VALUES ON DISK WITH SUPPORT DATA

Deep

Yesno = 0

INPUT "STORE COMPUTED VALUES ON DISK? (CONT=NO, 1=YES)", Yesno

IF Yesno = 0 THEN GOTO Print

Deep

EDIT "ENTER MASS STORAGE UNIT SPECIFIER", Msus1$

MASS STORAGE 10 Msus1$

Deep

INPUT "ENTER NEW FILE NAME", Name$

SS = " "

CREATE SUPPORT DATA STRING
1338  FIXED 1
1348  Hl#=VAL$(Hy1)
1350  Wh#=VAL$(Wh)
1358  Sd#=VAL$(D1)
1360  Sw#=VAL$(Dx)
1366  Hr#=VAL$(Cpay)
1370  Hd2#=VAL$(D2(1))
1372  Hd3#=VAL$(D2(3))
1376  Hd4#=VAL$(D2(4))
1380  C#=%Name$&"$&"HL="hHl$&"S$&"WH="hWh$&"S$&"WHR="hMr$&"HR="hMr$&"
1384  C#=%Name$&"$&"HD="hHd1$&"S$&"Hd2$&"S$&"Hd3$&"S$&"Hd4$
1388  PRINT C#
1390  FOR K=1 TO 34
1392  XsumCK)-sum(K)
1394  NEXT K
1396  CREATE Name$,1
1398  ASSIGN 01 TO Name$
1400  PRINT #1;Xsum
1402  PRINT 1;C#
1404  PRINT "LLOYD-MIRROR DATA STORED IN FILE ";Name$
1408  PRINT "FROM FILE ";Name$
1410  PRINT "SQUARE LAW DETECTORS ASSUMED" IF L#<>"1" THEN PRINT "LINEAR DETECTORS ASSUMED"
1414  PRINT "OCEAN WAVE HEIGHT = ";Mh;
1416  PRINT "MEAN SOURCE DEPTH = ";D1;
1418  PRINT "SOURCE VERTICAL WIDTH = ";Dx;
1420  PRINT "HORIZONTAL RANGE = ";Cpay;
1422  IMAGE LIN(M)
1424  PRINT "HYDROPHONE DEPTH (FEET) AND ANGLE (DEG.)"
1428  IMAGE 12X;4<DDD,4X>;"PWR AVG. DB AVG."
1430  PRINT USING 1730;D2(1),D2(2),D2(3),D2(4)
1434  PRINT USING 1750;Angle(1),Angle(2),Angle(3),Angle(4),Aug1,Aug2
1438  PRINT "FREQUENCY"
1440  PRINT FOR F=1 TO 10
1444  IMAGE DDDDD,D,3X,6<DDD,D,3X>
1448  PRINT USING 1800;Fre(F),Db(1,F),Db(2,F),Db(3,F),Db(4,F);Asum(F);Dbsum(F)
1452  NEXT F
1454  FOR F=11 TO Fmax
1458  IMAGE 2X;DDDDD,3X,6<DDD,D,3X>
1460  PRINT USING 1840;Fre(F),Db(1,F),Db(2,F),Db(3,F),Db(4,F);Asum(F);Dbsum(F)
1464  NEXT F
1468  IF Hc=1 THEN PRINT PAGE
1470  IF Yn<>1 THEN GOTO LastLine
1472  PRINT "WANT PLOT? (1=YES)",Yn
1474  IF Yn<>1 THEN GOTO LastLine
1476  Pit: fGENERAL DATA AND CURVE PLOTTING, CARTESIAN COORDINATES
1478  GRAPH SETUP DATA
1480  Ymax=10
1482  Ymax=41
1484  Xmax=16
1486  Xmax=8
1488  Nvert=8
2000 Nhors=40
2010 Xlabel$="FREQUENCY BAND, Hz"
2020 Ylabel$="ANOMALY, dB"
2030 Xsp=ABS(Xmax-Xmin)/Nhors
2040 Ysp=ABS(Ymax-Ymin)/Nvert
2050 Ygap=ABS(Ymax-Ymin)*.005
2060 Plotgraph:  GENERAL GRAPH SETUP **********
2070 PRINT PAGE
2080 PLOTTER IS "GRAPHICS"
2090 GRAPHICS
2100 FRAME
2110 SETGU
2120 LOCATE 12,118,16,93  Defines graph area within 100 X 123 frame
2130 SETUU
2140 SCALE Xmin,Xmax,Ymin,Ymax
2150 LINE TYPE 3
2160 GRID 18,5,1,-38
2170 LINE TYPE 1
2180 AXES 1,5,Xmin,Ymin
2190 AXES 1,5,Xmax,Ymax
2200 ! LABEL GRAPH **********
2210 DEG
2220 LDIR 90
2230 LORG 0
2240 CSIZE 2.4
2250 FOR I=1 TO 41  ! Label x-axis numbers
2260 MOVE I,Ymin-Ygap
2270 LABEL Fre(I)
2280 NEXT I
2290 LDIR 0
2300 LORG 0
2310 FOR J=Ymin TO Ymax STEP Ysp  ! Label y-axis numbers
2320 MOVE Xmin,J
2330 LABEL J
2340 NEXT J
2350 SETGU
2360 CSIZE 3.3
2370 MOVE 65,2
2380 LORG 5
2390 LABEL Xlabel$  ! Label x-axis title
2400 MOVE 3,50
2410 DEG
2420 LDIR 90
2430 LORG 4
2440 LABEL Ylabel$  ! Label y-axis title
2450 LORG 1
2460 LDIR 0
2470 MOVE 110,1
2480 CSIZE 2.4
2490 LABEL "LLOYD"
2500 SETUU
2510 UNCLIP
2520 Plotdata:  PLOTS DATA FROM UP TO 6 FILES USING 6 DIFFERENT SYMBOLS
2530 P$(1)="+
2540 P$(2)="*"
2550 P$(3)="X"
2560 P$(4)="O"
2570 P$(5)="O"
2580 P$(6)="*"
2590 FOR I=1 TO Nhyd
2600 SETUU
2610 LORG 5
2620 CSIZE 2.4
2630 FOR J=1 TO Fmax
2640 X(J)=J
2650 Y(J)=8b(I,J)
2660 IF Y(J)>Ymax THEN Y(J)=Ymax
2670 IF Y(J)<Ymin THEN Y(J)=Ymin
2680 IF X(J)>Xmax THEN X(J)=Xmax
2690 IF X(J)<Xmin THEN X(J)=Xmin
2700 MOVE X(J), Y(J)
2710 LABEL P$<I>
2720 NEXT J
2730 SETGU
2740 MOVE 40+18*I,90
2750 LABEL P$<I>
2760 MOVE 40+18*I,95
2770 LABEL D2< I >
2780 NEXT I
2790 Finish:  
2800 WAIT 4000
2810 DEEP
2820 Copy=0
2830 INPUT "WANT HARDCOPY? (1=YES)", Copy
2840 IF Copy=1 THEN DUMP GRAPHICS
2850 Plotdone=1
2860 PRINT PAGE
2870 Lastline:  
2880 END
2890 I
2900 DEF FNDirect(Theta, Lambda, Hyd)
2910 I HYDROPHONE VERTICAL DIRECTIVITY FUNCTION
2920 Arg=ABS(Pi*Hyd*SIN(Theta)/Lambda)
2930 Direct=1
2940 IF Arg>6 THEN Direct=SIN(Arg)/Arg
2950 RETURN Direct
2960 FNEND
2970 END
REFERENCES


Note: An extensive survey of the literature on surface scattering as it may apply to ship acoustical trials was conducted by Applied Hydro-Acoustics Research, Inc. under contract to DTNSRDC in 1974. The survey was published in a final report No. TR 116. This survey included 72 reports and various related literature on the subject. This report includes some of the findings of that survey.