ACOUSTIC BACKSCATTERING FROM CYLINDERS: NEAR-FIELD CORRECTIONS

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1. Introduction

To design active sonars, one needs to know how strongly the intended target forms an echo from the incident sonar ping. This target characteristic is called the *target strength* (TS) and is defined to be the reflected intensity at 1 m from the target divided by the incident intensity, expressed in decibel units. In this paper, we are interested only in the *backscattered* TS; that is, the source and the receiver are co-located. For reference, a perfectly reflecting sphere 4 m in diameter has a TS of 0 dB if the wavelength is much smaller than the sphere diameter.

Although theoretical TS formulae exist for simple shapes, there is no substitute for accurate measurement. Fig. 1 is a schematic diagram of the TS measurement procedure. In the course of making TS measurements of hollow aluminum cylinders of length 91 cm and diameter 28 cm in the frequency range 30-36 kHz, we realized that our measurements were being corrupted at beam aspect because the source and receiver were in the near-field of the target. Fortunately, we were able to increase the range and reduce this effect, but we also derived a correction to the near-field TS measurements that could be applied if sufficient range were unavailable. The derivation and application of this beam-aspect TS correction is the subject of this paper.

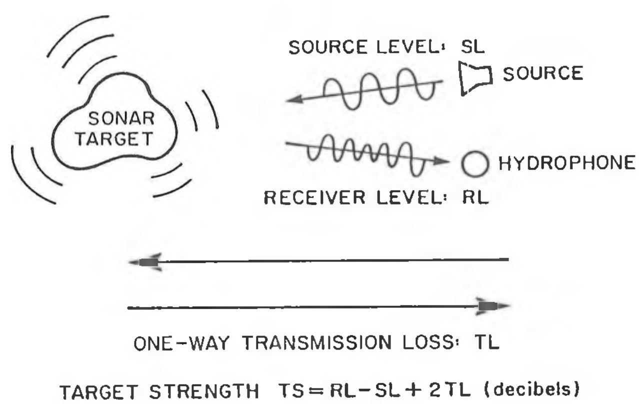

Figure 1 *Schematic diagram of target strength measurements.*

2. Target Strength Measurements at Two Ranges

Fig. 2 shows measured TS vs. aspect angle at 36 kHz for the test cylinder at 17 m range. Note the highlights at end aspect and beam aspect, caused by strong reflections at the flat end caps and straight cylinder sides, respectively. Also, note that the highlights are fairly narrow and high. Fig. 3 shows a similar measurement of the same target, but at a shorter range of only 6 m. The highlights are noticeably broader and lower.

3. Theory: Deriving the Correction

Consider a line source of length L with a receiver situated a distance R along the perpendicular bisector, as shown in Fig. 4. If R is large enough, the waves from all points of the line arrive in phase, and the received intensity is enhanced according to the ratio L/λ. As the receiver is brought nearer to the source, the distance from the ends becomes longer than that from the middle. When the phase difference is of the order $\lambda/4$, there will be noticeable destructive interference, and the received intensity is reduced. This happens when $R \approx L^2/2\lambda$. If there is a source located with the receiver, and if the line is a scattering target, a similar analysis applies, but the phase difference is doubled.

If one sums all the contributions along the cylinder length

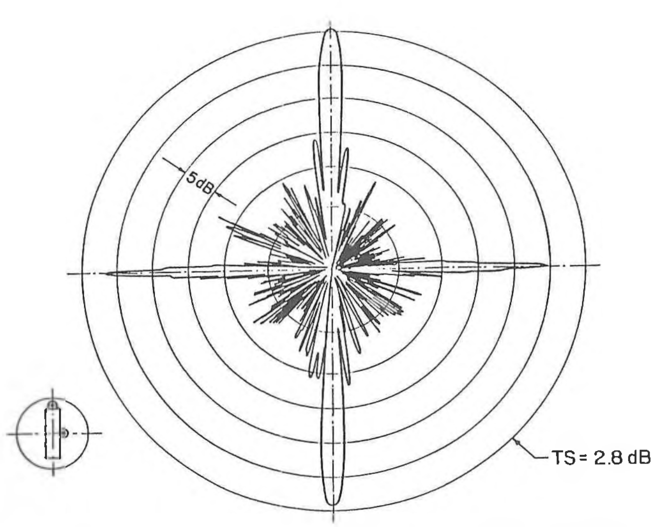

Figure 2 *Target strength vs. aspect angle at 36 kHz for the test cylinder at 17 m range.*

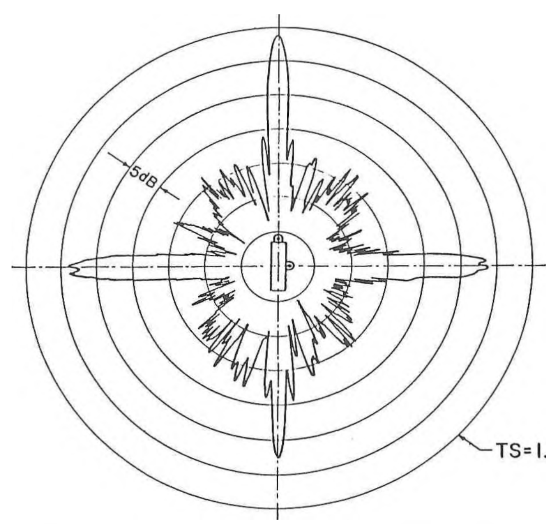

Figure 3 *Target strength vs. aspect angle at 36 kHz for the test cylinder at 6 m range.*

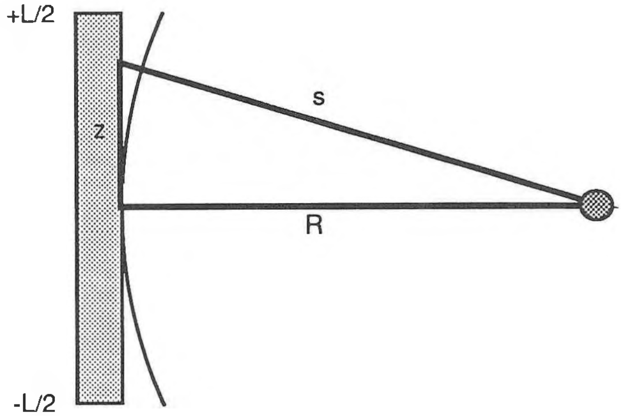

Figure 4 *Geometry for the near-field TS correction.*

coherently, the following correction to the near-field beam-aspect target strength is found:

$$\Delta TS = 20 \log \left| \frac{e^{-i2kR}}{L} \int_{-L/2}^{+L/2} e^{i2ks(z)}\, dz \right| , \qquad (1)$$

in which k is the acoustic wavenumber and $s = \sqrt{R^2 + z^2}$. When z«R, then $s \approx R + z^2/2R$, and a constant phase term can be factored out. Then, the integral can be written in the form

$$\Delta TS \approx 10 \log \left(p^{-2} \left[C^2(p) + S^2(p) \right] \right), \qquad (2)$$

in which $p = L/(\lambda R)^{1/2}$ and C(p) and S(p) are Fresnel sine and cosine integrals[1], respectively The parameter p determines whether the target is in the far field or not. The correction factor ΔTS is plotted vs. the parameter p in Fig. 5. Note that the correction is less than 1 dB if p<1, but it increases rapidly for p>1. We can say that the sonar is in the far field of the target if p<1, that is, if $R>L^2/\lambda$. A related near-field correction for transducer calibration is discussed by Bobber[2] and for radio antennae by Bickmore[3].

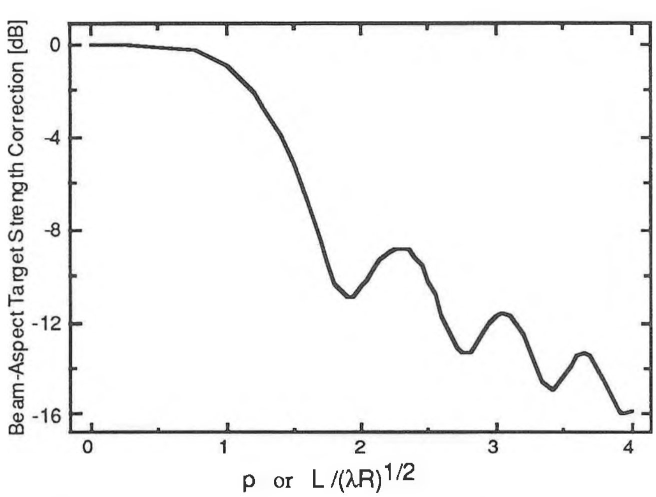

Figure 5 *Near-field reduction of cylinder TS at beam aspect.*

	30 kHz	33 kHz	36 kHz
R = 6 m	-8	-10	-7
R = 17 m	0	0	0

Uncorrected Measured Beam-Aspect TS [dB]

+

	30 kHz	33 kHz	36 kHz
R = 6 m	9.0	9.6	10.4
R = 17 m	1.1	1.2	1.5

Calculated Near-Field Correction [dB]

=

	30 kHz	33 kHz	36 kHz
R = 6 m	+1	-0.5	+3.5
R = 17 m	+1	+1	+1.5

Corrected Measured Beam-Aspect TS [dB]

≈

30 kHz	33 kHz	36 kHz
+0.5	+1.0	+1.5

Theoretical Beam-Aspect TS [dB]

Figure 6 *The correction of near-field beam-aspect target strength measurements for the test cylinder.*

4. Calculations: Applying the Correction

Fig. 6 demonstrates the correction of near-field beam aspect target strength measurements for the test cylinder at three frequencies. Notice that the corrected values are more alike than the uncorrected values and they agree favourably with the theoretical values calculated from Urick[4].

5. Conclusions

Theoretical analysis of the near-field of a line source produced a correction term that helps to explain the discrepancy between near-field beam-aspect target strength measurements and the theoretical TS formula. This reconciliation between theory and experiment gives us the confidence to apply the theoretical TS expression to other targets.

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[1] Abramowitz, Milton, and Irene A. Stegun, *Handbook of Mathematical Functions* (Dover, 1965), p. 300.

[2] Bobber, Robert J., *Underwater Electroacoustic Measurements* (Naval Research Laboratory, Washington, 1970).

[3] Bickmore, Robert W., "On focusing electromagnetic radiators," Can. J. Phys. 35, 1292-1298 (1957).

[4] Urick, Robert J., *Principles of Underwater Sound, 3rd Edition* (McGraw-Hill, New York, 1983).