G. 6 + 7 Target Strength and Noise Measurements

Sunday 27th of March, 13.00-17.30

Stations

6) Target strength and transducer efficiency (Peter T Madsen and Magnus Wahlberg)

7) Underwater noise measurements (Mardi Hastings and Mark Johnson)

Sunday 27th	**Group 1-3**	**4-6**
13.00 – 15.00	A	A
15.30 -17.30	B	B

A) Target Strength and Transducer Efficiency

Tutors: Peter T Madsen and Magnus Wahlberg **Duration:** 2 hours

Transducer efficiency
The efficiency of sound production is measured as the quotient between the emitted far-field acoustic intensity relative the applied voltage. Usually we express this in decibels so that the transmitting efficiency (TE) is

$$TE = 20 \log_{10}[p_{out}/ (p_o V_{in})]$$

and has the unit *dB re. 1µPa @ 1 m per V.* If the sound field is not measured at a distance 1 m from the transducer, we have to compensate for this when calculating the TE:

$$\text{TE (in dB re 1 µPa @ 1m per V)} = \text{RL (in dB re. 1µPa @ 1m)} - \text{U (in dB re. 1V)} + 20 \log_{10}(r),$$

where r is the range from the transducer to the hydrophone and $U = 20 \log_{10}(V_{in})$. We assume spherical spreading. -*Please repeat this calculation using linear units to reassure that you get it right!*

We may reverse this formula to calculate the pressure obtained in the far field from a transducer with known TE as

$$\text{RL (in dB re. 1µPa)} = \text{U (in dB re. 1V)} + \text{TE (in dB re 1 µPa @ 1m pr. V)} - 20 \log_{10}(r),$$

where U is the voltage at the input of the transducer. - *Check how this formula follows from the corresponding linear formula!*

Just as with hydrophones, transducers will have a frequency response, directivity and transducer efficiency very much determined by their resonance frequency, and therefore by their size. The *ka* product is lurking here (remember lecture by Magnus on basic underwater acoustics). See the appendix of the program for the frequency response of some of the transducer used in this class. Not a single loudspeaker is feasible for all frequencies. Large transducers can generate sound more efficiently at lower frequencies than small transducers. Small transducers may generate less directional sound at a certain frequency than a larger transducer.

Underwater loudspeakers are usually much larger and heavier than in-air speakers. -*Can you figure out why?*

Target strength

Target strength (TS) is defined as the ratio between the sound energy, incident on the target, and the return (echo), referred to a unit distance (conventionally 1 m) from the acoustic center of the target (Fig. 1, from Urick, 1983).

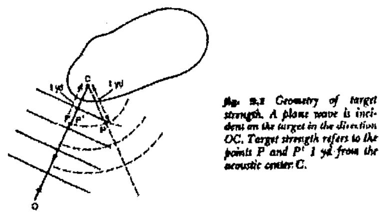

Fig. 1. Definition of the target strength, TS

This is similar to the way source levels are reported. Since the wanted number is a ratio, it does not matter much which unit is used to describe the magnitude of the incident sound and its echo (p-p, rms, energy, etc), *as long as the same unit is applied.* The dB-notation is ideally suited for such calculations. If the target is complex with strong internal reflections and glints, energy units are to be preferred.

The target should be so small compared to the area covered by the ensonifying sound beam so that it can be regarded as a single point. Then the TS will not depend on the range to the sound source. If however the cross section of the target is larger than the cross section of the impinging sound beam, the intensity of the calculated 'target strength' depends on the distance to the source, as a larger and larger part of the target will reflect the impinging sound when the source is moved away from it. In such cases we prefer to speak about surface or volume reverberation rather than target strength. Secondly, both the target and the receiver must be in the acoustic (Fresnel) far field.

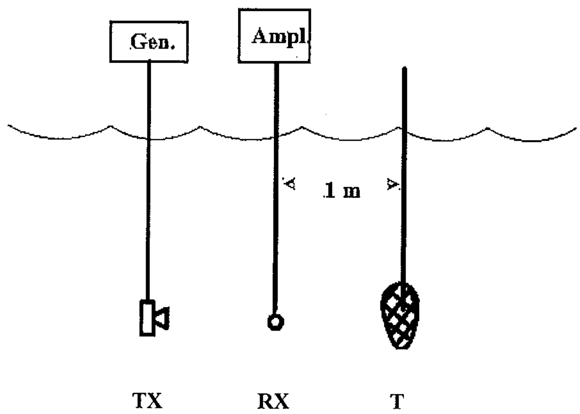

Fig. 2. Set-up for target strength measurement

In a setup as sketched in the Fig. 2, the receiving hydrophone is given a dual function, recording both the incident and the reflected sound. Placed half way between the transmitter and the target, the hydrophone will register a level twice as large as that impinging on the target. In such cases, subtract 6 dB from the measured incident level before proceeding. The echo, however, is registered at the correct level.

While the concept of measuring TS is charmingly simple as in Fig. 2. above, transferring that simplicity to real life is not at all simple. First, the acoustic environment should be considered. To avoid interference from other targets, the measurements must be performed in conditions where echoes from other objects, surface, bottom, tank walls, etc. are either neglible, or (the more likely case) occurring late enough for the echo to be recorded without contributions from unwanted targets (range gating).

This dictates the use of short pulses, which complicates sound generation, as well as measurements. In most cases, a well-defined frequency (single-line spectrum) is wanted. This is in principle not achievable with a short pulse. For targets small re. *ka* (see *Wahlberg Basic Underwater Acoustics*) the target strength is reduced (cfr. Fig. 3.). Consequently, use a frequency with a wavelength well below the cross-section of the target.

Fig. 0.0 Ratio of acoustic to geometric cross sections of a fixed rigid sphere. The oscillations in the range 1 < ka < 10 are due to interference by the creeping wave. For small ka (low frequencies) the ratio varies as the fourth power of ka; for large ka the ratio is unity.

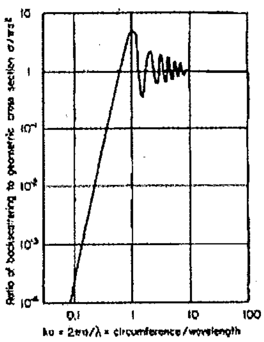

Fig. 3. Ratio of backscattering to geometric cross section of a fixed, rigid sphere.

It is advised to make a sketch of the expected time of arrival and duration of echoes from structures in the ensonified water volume, and to identify such targets, using a target on a rod that can bee moved around in the water volume. If possible, use a transmitter with directivity. This will reduce interference from other targets, notably those behind the transmitter. Make sure that the distance from the transmitter to the target is large enough to assure uniform illumination of the target, and that the acoustic axis of the transmitter is directed towards the acoustic center of the target.

A requirement is to define the aspect angle, i.e. the angle of the target with respect to the direction to the measuring transducers. Since targets can be rotated in 3 dimensions, it is easy to see that a complicated protocol may be generated. For some targets, such as fishing net, or fish, reflectivity is likely to change with time. In the case of nets, a film of air may surround the filaments or be trapped in knots, and then later disappear by absorption in the water. In live material, bubbles are created in the tissue due to decomposition. Such bubbles may vastly influence TS.

Procedure

1. Identify the elements of the setup, including the target and its suspension, test that sound is being projected from the transmitter, and that sound is being recorded by the receiver.
2. Calculate the Transducer Efficiency and measure the received level on the target..
3. Make a sketch of the time-of-occurrence of likely echoes and estimate the strength of the target, using tables in the appendix.
4. Make a test measurement; identify and eliminate troublesome echoes. Also, remove the target, and observe that its suspected echo disappears.
5. Perform the actual measurement and calculate TS for the target in question.
6. Discuss errors and measurement problems.

Appendix Target strength of simple forms

(copied from Urick, R. 'Principles of underwater sounds', 3.rd. ed., 1983)

Abbrev.: see 3.rd row, 1.st entry. For a discussion of *ka*, see chapter by M. Wahlberg, this volume.

Table 9.1 Target Strength of Simple Forms

Form	t Target strength $= 10 \log t$	Symbols	Direction of incidence	Conditions	References
Any convex surface	$\frac{a_1 a_2}{4}$	$a_1 a_2$ = principal radii of curvature r = range $k = 2\pi$/wavelength	Normal to surface	$ka_1, ka_2 \gg 1$ $r > a$	1
Sphere Large	$\frac{a^2}{4}$	a = radius of sphere	Any	$ka \gg 1$ $r > a$	1
Small	$61.7 \frac{V^2}{\lambda^4}$	V = volume of sphere λ = wavelength	Any	$ka \ll 1$ $kr \gg 1$	2
Cylinder Infinitely long Thick	$\frac{ar}{2}$	a = radius of cylinder	Normal to axis of cylinder	$ka \gg 1$ $r > a$	1
Thin	$\frac{9\pi^4 a^4}{\lambda^2} r$	a = radius of cylinder	Normal to axis of cylinder	$ka \ll 1$	3
Finite	$aL^2/2\lambda$	L = length of cylinder a = radius of cylinder	Normal to axis of cylinder	$ka \gg 1$ $r > L^2/\lambda$	4
	$aL^2/2\lambda (\sin \beta/\beta)^2 \cos^2 \theta$	a = radius of cylinder $\beta = kL \sin \theta$	At angle θ with normal		
Plate Infinite (plane surface)	$\frac{r^2}{4}$		Normal to plane		

Table 9.1 Target Strength of Simple Forms (Continued)

Form	t Target strength $= 10 \log t$	Symbols	Direction of incidence	Conditions	References
Finite Any shape	$\left(\frac{A}{\lambda}\right)^2$	A = area of plate L = greatest linear dimension of plate l = smallest linear dimension of plate	Normal to plate	$r > \frac{L^2}{\lambda}$ $kl \gg 1$	5
Rectangular	$\left(\frac{ab}{\lambda}\right)^2 \left(\frac{\sin \beta}{\beta}\right)^2 \cos^2 \theta$	a, b = side of rectangle $\beta = ka \sin \theta$	At angle θ to normal in plane containing side a	$r > \frac{a^2}{\lambda}$ $kb \gg 1$ $a > b$	4
Circular	$\left(\frac{\pi a^2}{\lambda}\right)^2 \left(\frac{2J_1(\beta)}{\beta}\right)^2 \cos^2 \theta$	a = radius of plate $\beta = 2ka \sin \theta$	At angle θ to normal	$r > \frac{a^2}{\lambda}$ $ka \gg 1$	4
Ellipsoid	$\left(\frac{bc}{2a}\right)^2$	a, b, c = semimajor axes of ellipsoid	Parallel to axis of a	$ka, kb, kc \gg 1$ $r \gg a, b, c$	6
Average over all aspects Circular disk	$\frac{a^2}{8}$	a = radius of disk	Average over all directions	$ka \gg 1$ $r > \frac{(2a)^2}{\lambda}$	5
Conical tip	$\left(\frac{\lambda}{8\pi}\right)^2 \tan^4 \psi \left(1 - \frac{\sin^2 \theta}{\cos^2 \psi}\right)^{-3}$	ψ = half angle of cone	At angle θ with axis of cone	$\theta < \psi$	7