TARGET ECHO STRENGTH OF A SCALED STEEL BODY WITH INNER STRUCTURE AND THIN HULL

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Abstract: *A scaled model of a steel cone under a thin metal sheet was constructed, built and its monostatic target echo strength has been measured in a water tank. In parallel the target echo strength of the same body was calculated with various numerical methods (BEM, FEM, ray-tracing). The comparison of both results showed some differences under certain aspect angles due to some experimental challenges. With an improved experimental setup these differences could be minimised.*

Keywords: *target echo strength, scaled body, thin hull, experiment modelling comparison*

1. INTRODUCTION

The size of the target strength of a body determines its detectability for active sonar systems. The determination and diminishment of the target strength is a dominant topic for all sonar applications, from Anti Submarine Warfare to repelling mammals from fishernets. Contemporary calculation models allow different successful approaches to determine the target strength via the solution of the Helmholtz equation. These increasingly complex calculation models require increasingly complex validation experiments for their verification.

In this paper a scaled steel cone with a one-sided triple mirror was covered with a thin (compared to the used wavelength) cylindrical steel sheet. The dependency of the target strength on the aspect angle was determined experimentally and also calculated with a boundary element method (BEM) and a ray traycing method (BEAM). The computational and experimental results have been compared and interesting angles have been identified.

2. BASICS

In its simplified form the sonar equation is given by:

$$RL = SL - 2 \cdot TL + TS$$

where RL denotes the received level, SL the source level, TL the transmission loss and TS the target echo strength, as in [1]. Solving for TS yields:

$$TS = RL - SL + 2 \cdot TL \quad .$$

The case of neglectable TL (at a distance of 1 m, TL is 0 dB) gives:

$$TS = RL - SL$$

such that TS can be evaluated easily from measurements of RL and SL.

3. TANK EXPERIMENT

The water tank of WTD 71 is a 5 m x 5 m x 3 m tank built of concrete with rubber sound absorbers at the walls, in order to suppress multiple reflections. By placing the transmitter / receiver unit in the centre of the water volume the runtime between emission of the signal and arrival of the reflected signal at the receiver can be maximised to appoximately 2 ms.

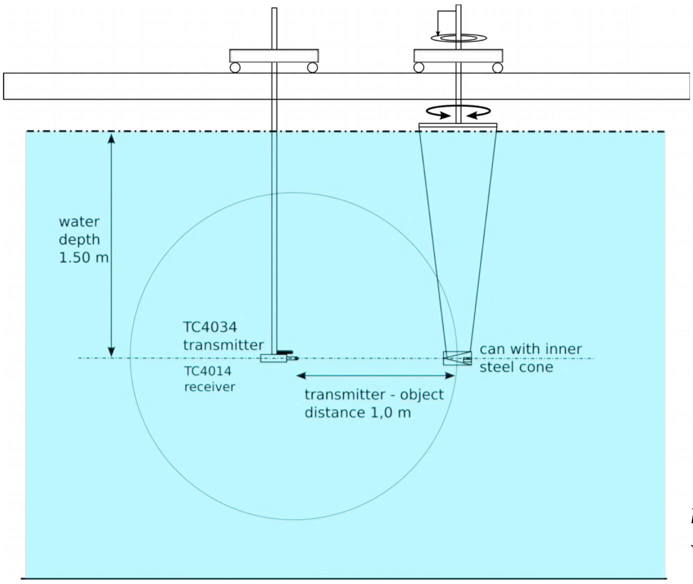


Fig. 1: left: *tank experiment transmitter/receiver in the centre of the water volume*, *above: steel cone and can*

The object consists of a massive steel cone with a length of 100 mm, a diameter of 50 mm and an aperture angle of 2 x 14 ° on a round bottom steel plate (1 mm) with 57 mm diameter with a twofold triple mirror in the right side of the cone. This cone was embedded within a hollow cylinder, made from a thin 0.08 mm steel sheet (part of a can), representing the hull. Transmitter and receiver of the experiment were arranged vertically above each other with a mutual distance of 26 mm and located at the position in the centre of the water volume, as shown in Fig. 1. Strictly speaking, this represents a bistatic situation with an aperture angle of 1.5 ° at 1 m distance, which was regarded as approximately monostatic with respect to the vertical direction.

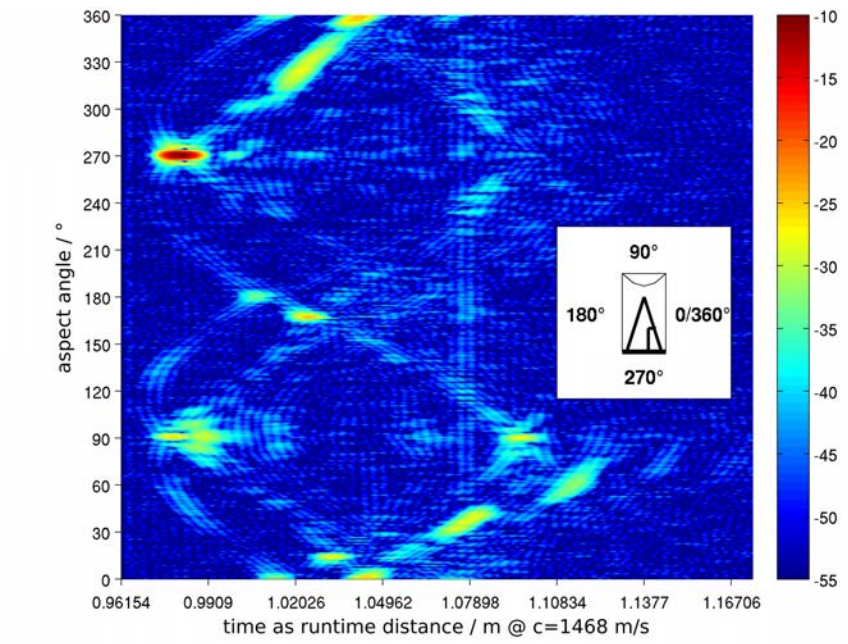


Fig. 2: *time-resolved contributions to the target echo strength of the object vs. aspect angle*

The object was rotated horizontally within the water in steps of 1 °, and at each aspect angle the resulting reflections were recorded as time series. From the cross-correlation between the reflected time series and the transmitted signal the impulse response at the given aspect angle can be obtained. From the known transmit and receive sensitivities of the transceivers the real target echo strength of the object can be computed. Fig. 3 shows the monostatically calculated and the experimentally obtained target echo strength.

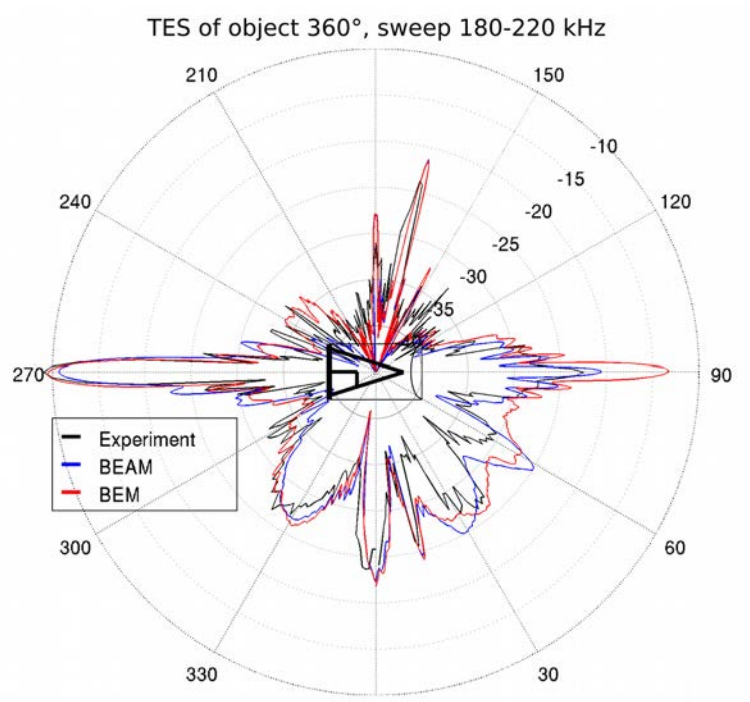


Fig. 3: *polar plot of target echo strength of the object, resulting from monostatic BEM and BEAM calculations and from the experiment*

When compared to the calculated monostatic target echo strength (as shown in Fig. 3), the most important reflections of this object are given in the following table:

Aspect Angle	Reflection
0 °	Triple mirror (as double mirror), Hull
14 °	Cone surface
30 ° - 45 °	Triple mirror (left)
45 ° - 65 °	Triple mirror (right + bottom refl.)
90 °	Horn effect + Bottom reflection (see below)
152 °	Multiple reflexion Cone surface - Hull
166 °	Cone surface (180 ° - 14 °)
180 °	Hull
270 °	Bottom plate of the Cone
310 ° - 345 °	Triple mirror (right)

Table 1: Reflections of the object, depending on the aspect angle.

4. *MODELLING THE TARGET ECHO STRENGTH*

Nearly all reflections found in the experiment could be confirmed by the computational modelling. The greatest difference between the two modelling methods and the experiment occurred at the aspect angle of 90 °. At this angle BEM and BEAM give target strengths of -14 dB and -21 dB, respectively, while the experiment provides a value of -23 dB. Due to this disagreement, further evaluation and modification of the experiment were performed. It was realised that the energy of the wave, when hitting the cone exactly along the cone axis, is integrated up over the cross section of the cone along the cone surface (horn effect). This integrated energy is nearly completely reflected at the circular bottom plate ring of the object, thereby producing the relatively high target strength of -14 dB. This interpretation was confirmed by FEM analysis, shown in Fig. 5.

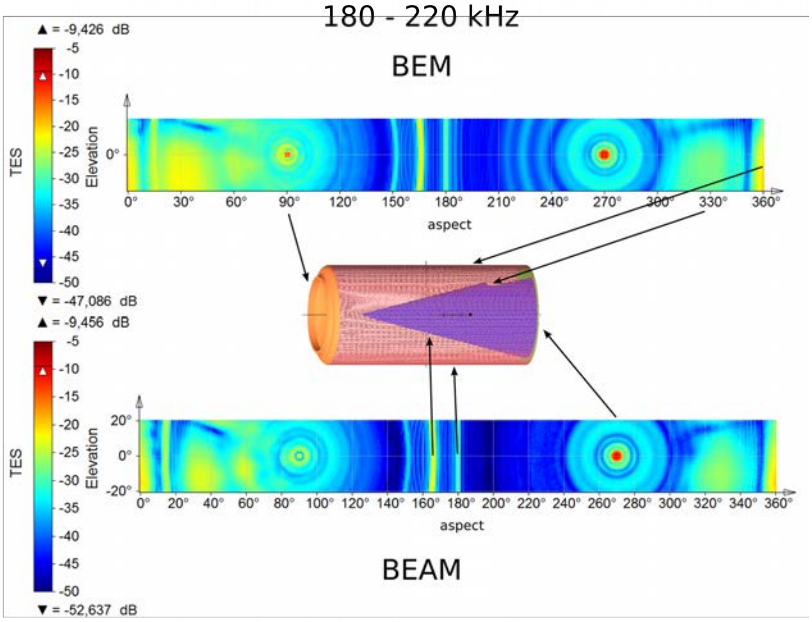
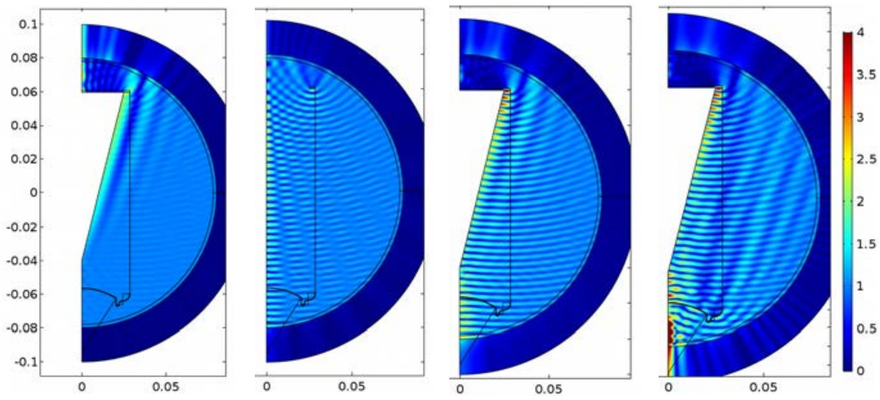


Fig. 4: *numerical BEM and BEAM calculation in comparison of aspect and elevation angle of the target object*

In the experiment the target strength reflection at 90 ° consists of two contributions, the contribution of the reflection of the thicker indentation at the lower end of the can (shown at the top of the inset of Fig. 2) and the contribution of the above stated horn effect / bottom ring reflection (occurring later in time in Fig. 2). These contributions sum up to the total target echo strength.



only cone surface (horn effect) TS = -34 dB	only bottom circle ring TS = -21 dB	cone + circle ring TS = -12 dB	cone + circle ring + hull TS = -14 dB

Fig.5: Results of Finite Element Modelling of reflections at aspect angle of 90 °, considering only parts of the object

Regarding the discrepancy between calculated models and experiment, it was found that the monostatic approximation of the actually bistatic experimental situation was incorrect. The small vertical distance between transmitter and receiver results in a considerable difference of the target strength at an aspect angle of 90 °. To compensate for this unwanted bistatic effect, an additional transmitter was placed at the same vertical distance under the receiver, in order to render the transmitting field symmetric with respect to the receiver plane. Due to interference effects two in-phase transmitters cause a transmission field with Moiré effects occurring in different positions of space. Outside of the cancelation zones of the Moiré pattern, the symmetric transmission field can be used, after a recalibration step. Repetition of the measurements, including this modification (this time only with the inner steel cone without the hull) provided an increased target strength of -14.4 dB at the aspect angle of 90 ° (see Fig. 7), in concordance with the results of the numeric modelling.

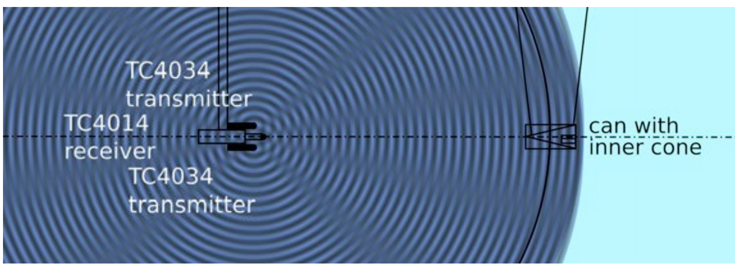


Fig. 6: *Moiré pattern of the transmitted field for the experiment with two transmitters; note the symmetry w.r.t. the receiver plane*

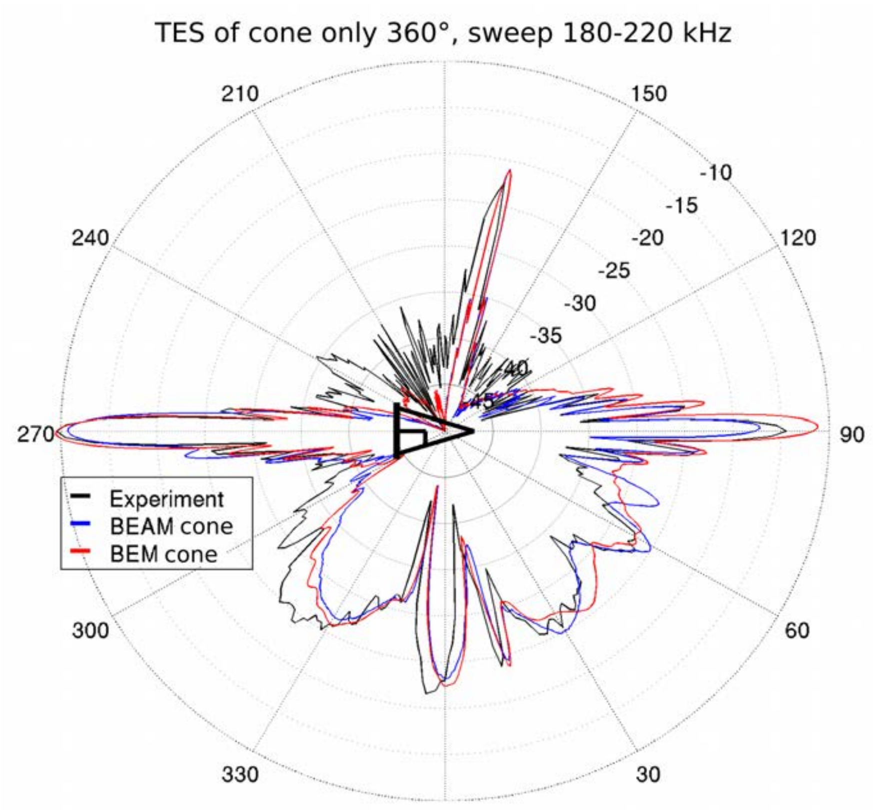


Fig. 7: *polar plot of target echo strength of the object (steel cone without hull), resulting from monostatic BEM and BEAM calculations and from the experiment*

5. RESULTS

The target echo strength (TS) of a scaled body consisting of a massive steel cone structure and a thin steel sheet hull was determined as a function of aspect angle through numerical modelling and experiment. The experiment was performed in a water tank and compared with the calculated TS of different calculation methods (BEM, BEAM, FEM). After compensation for an unwanted bistatic effect within the experiment, good to very good agreement (better than 2~dB over a wide interval of angles) between theoretical and experimental results for determining the target echo strength has been achieved.

REFERENCES

[1] **Robert J. Urick:**, Principles of underwater sound, 3rd edition, Peninsula Publishing, LosAltos, California, 1983