Underwater acoustic scattering studies on the sub-sea pressure housings

D. Nikhil Sai Prasanna*,A.Thirunavukkarasu, A. Malarkodi and G.Latha
Ocean Acoustics, National Institute of Ocean Technology, Ministry of Earth Sciences, Chennai, TamilNadu

Abstract

Understanding the acoustic scattering signature of underwater objects helps in improving existing target detection and classification. This also helps in the selection of the optimum material to use in any underwater acoustical research activities. Acoustic scattering of different objects that are submerged in an underwater environment is studied in this work. In India, under Ocean Acoustics program of National Institute of Ocean Technology (NIOT), cylindrical pressure housings are used in the mooring system for the measurement of the underwater ambient noise system in the shallow waters of Indian seas. These cylindrical pressure housings are used to accommodate electronics and power pack for the ambient noise measurement system. Experiments were conducted in an underwater acoustic test facility of NIOT to characterize the acoustic scattering from cylindrical pressure housings made of different metallic alloys such as aluminium, stainless steel and titanium. The scattered pressure for different pressure housings were recorded in the free field condition. The target strength was computed from the back-scattered signal and the frequency response of the system was plotted to better understand the acoustic material characterization and the physics governing the interaction of sound with targets. The results were examined to better understand the acoustic reflection capabilities of different metallic pressure housings.

Keywords: Acoustic scattering; scattered pressure; target strength; directivity index; sound pressure level

1. Introduction

Listening to the ambient noise in oceans has been of prominent research activity being done by the Ocean acoustics group of NIOT. Usage of hydrophones array in an underwater environment for long term passive acoustic measurements has been employed to cater for oceanographic as well as strategic applications. In case of an autonomous measurement system, hydrophone array as well as Vector sensor array (VSA) have been used successfully for surveillance applications. The main aim of using these equipment is for detection, localization and classification of underwater objects. These equipment are placed under the water in the oceans at a specific depth through a mooring system. The mooring system contains a pressure housing that is used to accommodate electronics and power pack for the ambient noise measurement system. The sound waves coming from various submerged objects may interfere with the pressure housing placed just above the hydrophones or VSA and a possibility of interaction with the origin sound waves may affect the sound signal received. This superposition of the original sound wave

Corresponding authors: (E-mail: nikhil.niot@gov.in)

with the geometric scattering returns from the pressure housing makes it difficult to detect and classify objects [1]. In order to avoid or minimize this scattering effect from the nearby placed components, understanding their acoustic scattering capabilities is needed [2]. This is accomplished by examining the acoustic scattering from an air-filled pressure housings made of different metallic alloys such as aluminum, stainless steel and titanium. The free-field scattering studies on water filled cylindrical shells were studied by J. R. La Follett et al [3]. Few of the studies are solely focused on proud-segment models such as Zampolli et al [4]. Most of the scattering studies were only done for aluminum material and there were no any studies for stainless steel and titanium material cylindrical shells. In this context, the current experiment is done to examine the scattering capabilities of different material housings.

Section 2 discusses the theoretical background and the methodology followed with scattering experiment, the aim being to familiarize the reader with the complexity of the physics involved in the scattering experiment and the test setup preparation. Section 3 illustrates the experiment results of the three different metallic pressure housings. This includes the recorded scattered pressure readings with respect to the incident pressure field and the other significant parameters of the experiment such as target strength of the individual pressure housing. Section 4 presents the conclusions derived out of the study and future work being planned.

2. Methodology

2.1. Theoretical Background

In general, a sound wave in water medium creates an oscillatory pressure disturbance. If an underwater object is strike by any such oscillating pressure, elastic (solid) waves propagate throughout all parts of the structure and the object vibrates exerting an oscillating pressure on the surrounding medium. These pressure waves that are exerted by an object in water when strikes by a sound wave are called scattered waves. Depending on the incident sound wave direction and frequency, the vibrations in the object will change, which will also the change the scattered waves. The intensity of the scattered pressure wave exerted when insonified by a planar wave is expressed by the target strength [2], TS:

$$TS(f,\theta) = \text{Lim}_{r\to\infty} 20\,\text{Log}_{10}\left(\frac{r|p_s|}{r_0|p_{inc}|}\right) \quad (1)$$

where, f is frequency, θ is the incident sound wave aspect angle, p_s is the scattered wave pressure, p_{inc} is the amplitude of the acoustic field incident on the target. r is the magnitude of the vector from the object to the receiver position, where the TS is being measured.r_0 is a reference distance, which equals 1m, is included to normalize and make the logarithm dimensionless. The resulting values of target strength (TS) of an object that has been insonified over a frequency band-width and for each frequency over a wide range of aspect angles are plotted as a template, termed as acoustic scattering signature of an object [2]. Computing such kind of acoustic templates for an object will not only tell about the shape of the object, but also its internal composition.

2.2. Experiment setup

The experiment was conducted in an Acoustic test facility at NIOT. The facility consists of a large trapezoidal tank with dimensions of 16m×9m×7.3m. The test setup was prepared taking into the effect of the reverberations (surface or hard wall boundary) [5]. The source and receiver are kept 0.5m apart and the pressure housing for which the target frequency

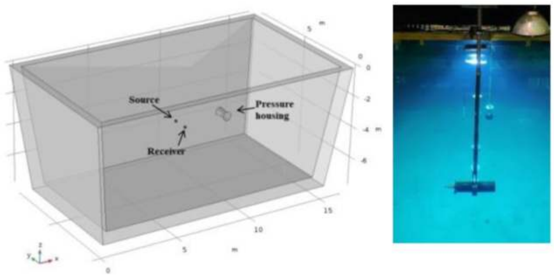

Fig.1. Experiment test setup

response needs to be evaluated is placed at 2m distance from both the source and receiver for carrying out free field measurement. The experimental test setup configuration is shown in Fig.1. Each of the pressure housing was suspended to an equivalent depth as the source so as to measure the backscattering of plane waves incident on it. The different pressure housings used for the study are given in the table 1. With a turntable controller situated on the trolley bed, it is possible to obtain different source-target angles, referred to as aspect angles. The term aspect angle is defined as the angle between the horizontal x-axis of the plane x-y and unit vector, $\hat{r}_{cyl}$ perpendicular to the cylinder axis. It is possible to rotate the object of study for a complete 360° with required speed. One of the important parameter of this experiment is azimuthal angle, φ, defined as the angle between the incoming plane wave vector,$\vec{k}$and a unit vector, $\hat{r}_{cyl}$ perpendicular to the cylinder axis. In this current experiment setup, the target is kept at an initial aspectangle (θ) of 0°, that corresponds to and azimuthal angle (φ) of 352.875°. Considering the symmetry of the target, the scattering study is done for each cylinderfor every 1° azimuthal angle incrementation i.e., frombroad-side (φ=0°) to end-on (φ=90°) configurations, corresponding to the aspect angle of θ=7.125° to θ=97.125°.

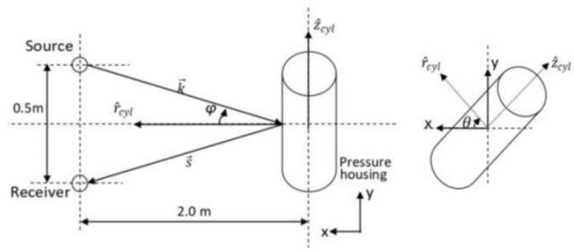

Fig.2. Free field back scattering experiment geometry setup

Table1—Different pressure housings used in the experiment

SNo	Material	Dimensions Dia (mm)×Height (mm)	Thickness (mm)	Density (kg/m^3)	Speed of sound in the material (m/s)
1	Aluminium	150×450	5	2580	3100
2	Stainless Steel 316L	330×700	5	8027	3272
3	Titanium (Grade-5)	340×700	10	4430	3125

3. Results and Discussions

To facilitate comparison of acoustic scattering from pressure housings made up of different material and sizes, all results are discussed in terms of ka, where k is the wave number ($2\pi/\lambda$, where λ is the wavelength of the insonifying plane wave) and a is the outer radius of the pressure housing. This term ka can be called as dimensionless frequency [1]. The study frequency range for all the three pressure housings scattering experiments was chosen as 1 kHz to 30 kHz of discrete frequency sine pulses of 2 µs duration. With respect to this incident pressure field onto the housing, the scattered pressure was recorded at the receiver side. The backscattering voltage was recorded for each cylinder for every 2° azimuthal angle i.e., from broad-side (φ=0°) to end-on (φ=90°) configurations, corresponding to an θ=7.125° to θ=97.125°. The acquired backscattering time series data is processed by performing a Fast Fourier Transform (FFT) [6]. This recorded voltage is converted to pressure by dividing each voltage value with the receiving sensitivity of the receiver hydrophone used. The main interest of this study is the target strength analysis. Thus, all the pressure amplitudes obtained are converted into the target strength (TS) values, as a function of ka and azimuthal angle, by using the equation 1. The individual pressure housing scattering study results are now discussed.

3.1. Aluminium pressure housing

An Aluminium pressure housing having an outer radius *a*=0.075m, thickness *t*=0.005m and length *l*=0.45m is discussed in this section. For the frequency bandwidth of 1 kHz to 30 kHz, the resulting *ka* range of the experiment was found to be 1.9-9.4. The resulting TS values are plotted against *ka* and azimuthal angle (φ), with TS displayed as intensity, known as acoustic template [3]. There is a great deal of information from this kind of template shown in Fig.3. The geometric setup shown in Fig.2 shows the incident wave is symmetric about the two pressure housing azimuthal angle positions viz., φ=0° (broad-side) and φ=90° (end-on). This can be attributed to the specular reflection from the side and end of the cylinder respectively. The bright features at φ=90° is more prominent than at broad-side configuration. This sudden enhancement of the backscattering at end-on configuration is due to the reduction of distance between the source and the target. Another distinguishing feature observed near the azimuthal range of 30 to 50 is the formation of medium bright band i.e., -20dB features for ka range of 8 to 16 approximately [7]. The reason for this can be attributed to the fact that the region being insonified is side cross-section of the housing and the backscattering observed in this region is more diffused [8].

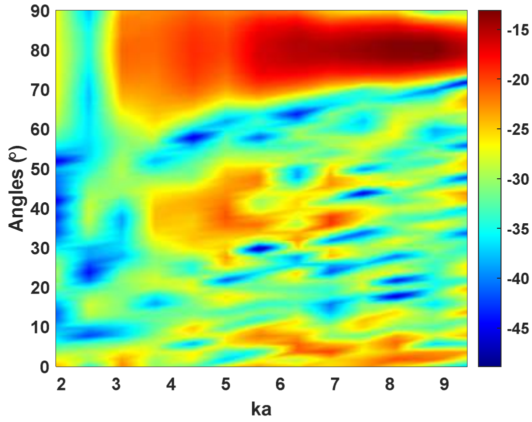

Fig.3. Acoustic template of Aluminum pressure housing

3.2. Stainless Steel pressure housing

The stainless steel pressure housing having an outer radius *a*=0.17m, thickness *t*=0.005m and length *l*=0.7m is discussed in this section. For the frequency bandwidth of 1 kHz to 30 kHz, the resulting *ka* range of the experiment was found to be 1.4-21.3. The resulting acoustic template for the acquired experimental data is shown in Fig.4. For SS housing also, the same kind of specular reflection was observed at broad-side and end-on configurations due to similar geometrical setup.

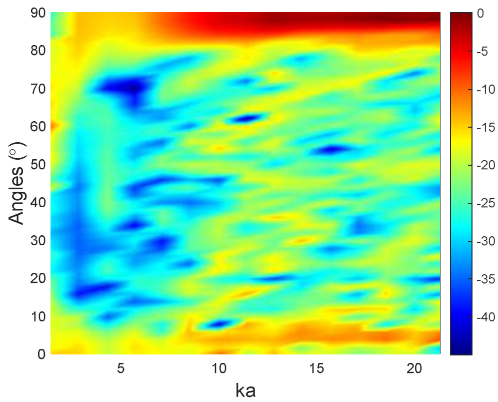

Fig.4. Acoustic template of SS pressure housing

Incase of SS housing, the bright band formation takes place at an azimuthal angle greater than 80° when compared to aluminum, in which it started appearing from φ=65° configuration. Apart from this feature, the spectrum shows the same kind of response as that of aluminum but with higher TS values for overall ka range.

3.3. Titanium pressure housing

The Titanium pressure housing having an outer radius *a*=0.12m, thickness *t*=0.01m and length *l*=0.84m is discussed here. For the frequency bandwidth of 1 kHz to 30 kHz, the resulting ka range of the experiment was found to be 1-15. The resulting acoustic template for the acquired experimental data is shown in Fig.5 Similar to the case of Aluminum and SS housing spectrum responses, this template also clearly shows the bright specular reflection at *φ*=0° (broad-side) and *φ*=90° (end-on) configurations.

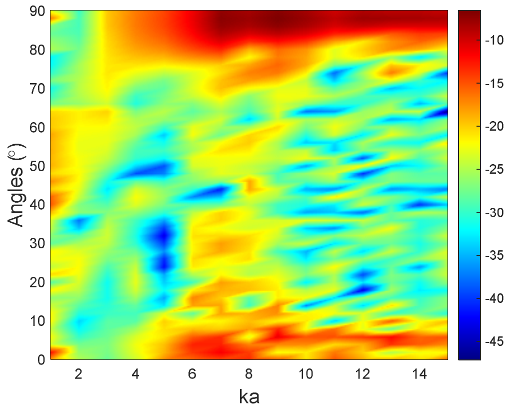

Fig.5. Acoustic template of Titanium pressure housing

The specular reflection near to broad-side configuration is much prominent than that of the other two pressure housings. The medium bright band formation is observed in the *ka* range of 6 to 9 and at aziumthal angle range of 10 to 40. This is due to more diffusion taking placeat side cross-section of the housing.There is also a set of medium bright features observed at *φ*=40° to *φ*=65° for *ka* range less than 3. To better gauge the variation of the frequency response of the three housings, six different azimuthal angle slices are taken out of their acoustic templates and shown in Fig. 6. It is evident from this comparison figures, the scattering characteristics exhibited by SS housing is more than the remaining housings. In closer examination of all three housings acoustic template slices, a sudden peak was observed for all three housings at a specific *ka* value [9]. This may be attributed to the fact that the resonant frequency of the transducer used is around 12kHz, which corresponds to a *ka* value of 11 in case of Aluminium housing, 9 in case of SS housing and 11 in case of titanium housing.

4. Conclusions

Although the shape of the specimen studied is cylindrical in case of all the three pressure housings, the acoustic templates plotted for the three housings clearly differ from each other due to different material properties. From the comparison graphs plotted in Fig.5, the stainless steel housing recorded brightest features (-0.5 dB) among all and titanium housing exhibited good scattering signature/acoustic template compared to others. There is a strong agreement among all the three, especially at broad-side and end-on configurations. The variation in bright feature intensity observed at broad-side and end-on configurations is due to the fact that the ends of cylinder are completely closed, thereby having more area of incidence. Few other discrepancies observed in the templates of the three housings are due to many factors, one of which is clearly the material composition and reflection capabilities. The other being the variation of housings dimensions used and the possibility of multiple insonification/ reflection in case of 30°-60° azimuthal angle configurations. Especially in angled configurations, there is less surface area being insonified, because of which there are less bright features recorded in the template. As *ka* value increases, which means at higher frequencies, the reflected sound amplitude is less and this was clearly evident in all the three acoustic templates.

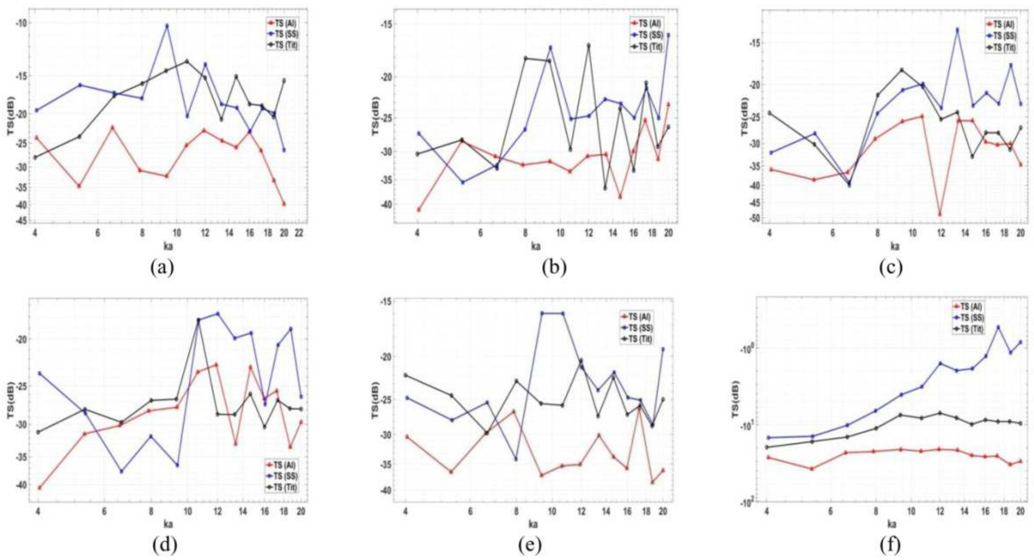

Fig.5. Comparison of the target strength as a function of ka at specific azimuthal angles for Aluminium (red), Stainless Steel (blue) and Titanium (black) pressure housings, corresponding to (a) φ=0° (broad-sdie)(b) φ=15° (c) φ=30° (d) φ=45° (e) φ=60° (f) φ=90° (end-on)

4.1 Future work

In future work, a Finite-element-model is presently being developed to observe/record the scattered pressure from the pressure housings and to validate the experimental data acquired from the back-scattering study done at ATF tank facility. It is also being planned to study non-metallic pressure housings made up of different materials like composite, plastic etc.

Acknowledgement

Authors are grateful to Director, National Institute of Ocean Technology (NIOT), India for encouraging this work. The authors gratefully acknowledge Ministry of Earth Sciences (MoES) for funding this research work. The authors are sincerely grateful for the help received by the ATF team of Ocean Acoustics group in conducting the experiment.

References

[1] Aubrey L. EspaNA, Kevin L. Williams and Daniel S. Plotnick, "Acoustic scattering from a water-filled cylindrical shell: Measurements, modeling and interpretation," J. Acoust. Soc. Am. (2014)

[2] J. R. La Follett, K. L. Williams, and P. L. Marston, "Boundary effects on backscattering by a solid aluminum cylinder: Experiment and finite element model comparisons," J. Acoust. Soc. Am. (2011).

[3] David S. Burnett, "Computer simulation for predicting acoustic scattering from objects at the bottom of the ocean," Acoustics Today, winter 2015, vol 11, issue 1. (2015).

[4] M. Zampolli, A. L. Espana, K. L. Williams, S. G. Kargl, E. I. Thorsos, J. L. Lopes, J. L. Kennedy, and P. L. Marston, "Low- to mid-frequency scattering from elastic objects on a sand sea floor: Simulation of frequency and aspect dependent structural echoes," J. Comput. Acoust. 20(2), 1240007. (2012).

[5] Fulin Zhou, Jun Fan and Bin Wang, "Acoustic scattering from a stiffened finite cylindrical shell with external rings," MATEC Web Conferences, 283, 03002 (2019), FCAC 2018. (2019)

[6] L. R. Dragonette, S. K. Numrich, and L. J. Frank, "Calibration technique for acoustic scattering measurements," J. Acoust. Soc. Am. 69, 1186–1189 (1981).

[7] K. L. Williams, S. G. Kargl, E. I. Thorsos, D. S. Burnett, J. L. Lopes, M. Zampolli, and P. L. Marston, "Acoustic scattering from an aluminum cylinder in contact with a sand sediment: Measurements, modeling, and interpretation," J. Acoust. Soc. Am. 127, 3356–3371 (2010).

[8] K.N. Stoev, K. Sakurai, "Review on grazing incidence X-ray spectrometry and reflectometry,"Spectrochimica Acta Part B, 54, 41–82(1999).

[9] Charles A. Rohde, Theodore P. Martin, Matthew D. Guild, Christopher N. Layman, Christina J. Naify, Michael Nicholas, "Experimental Demonstration of Underwater Acoustic Scattering Cancellation,"Nature, scientific reports (2015).