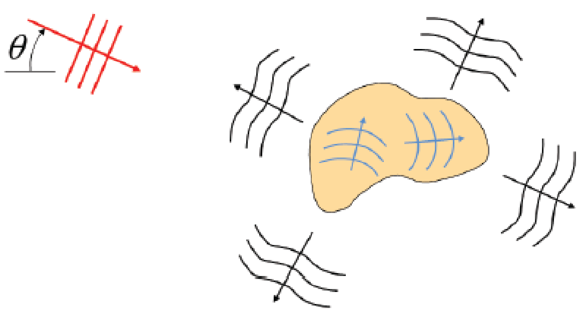
COMSOL CONFERENCE 2023 BENGALURU

Acoustic scattering study of sub-sea pressure housings using finite element method

- D. Nikhil Sai Prasanna
- Project Scientist-1 (Mechanical)
- Ocean Acoustics
- National Institute of Ocean Technology (NIOT), Chennai.

Background and Motivation

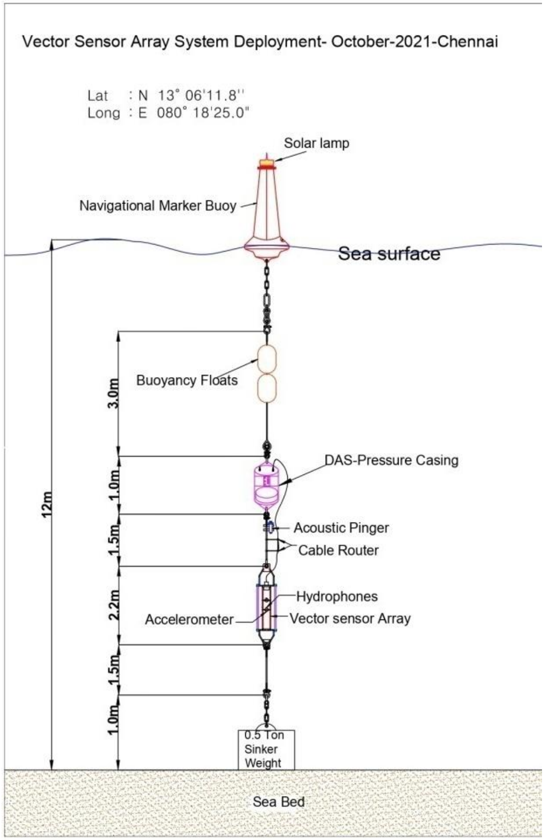
- Understanding the acoustic scattering signature of underwater objects helps in improving existing target detection and classification.
- In general, a sound wave in water medium creates an oscillatory pressure disturbance. If an underwater object is strike by any such oscillating pressure, elastic (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 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 given by the target strength.



Background and Motivation

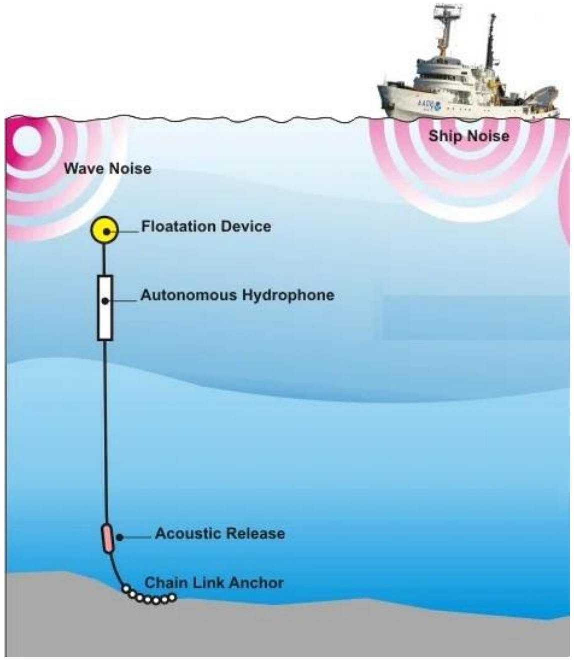
- Listening to the ambient noise in oceans has been of prominent research activity being done by the Ocean acoustics group of NIOT. Usage of hydrophones array in an underwater environment for long term passive acoustic measurements has been employed to cater for oceanographic as well as strategic applications. In case of an autonomous measurement system, hydrophone array as well as Vector sensor array (VSA) have been used successfully for surveillance applications.

- 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.



Objective of the study

- In case of VSA being used as surveillance system, it needs to have less scattering signature underneath the water.
- Design of pressure casing – that include shape of housing, selection of optimum material with respect to it's scattering capabilities.
- The knowledge of the way acoustic waves are reflected from the scattering object is required in order to minimize it's equivalent reflecting area and to keep the system hidden during operation.
- This information serves as a useful resource for selecting the optimum enclosures for underwater acoustical research activities.



Acoustic scattering study

- Module
  - Acoustics Module
- Physics interface
  - Pressure Acoustics, Asymptotic scattering (paas)
  - As the wavelength is much smaller than the scattering object, this model uses the high-frequency approximation of the Pressure Acoustics, Asymptotic Scattering interface.
- Physics involved
  - Solid Mechanics
  - Pressure Acoustics
- Type of analysis
  - Frequency Domain

Methodology

- The cylindrical pressure housing is modeled in 3D and considered as scattering object. The backscattering was measured as a function of rotation angle about an axis perpendicular to the surface for frequencies from 2 to 30 kHz.
- The intensity of the scattered pressure wave exerted when insonified by a planar wave is expressed by the target strength (TS):

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

- f is frequency
- θ is the incident sound wave aspect angle
- p_s is the scattered wave pressure
- p_{inc} is the incident acoustic field
- r is the magnitude of the vector from the object to the receiver position
- r_0 is a reference distance, which equals 1m, is included to normalize and make the logarithm dimensionless.

Global definitions & variables

Parameters

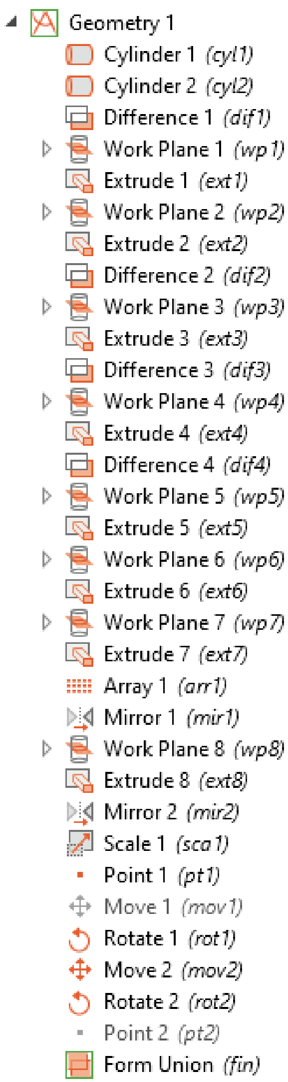
Name	Expression	Value	Description
p_ref	306.8[Pa]	306.8 Pa	Pressure amplitude at source location
f0	2[kHz]	2000 Hz	initial frequency
c0	1480[m/s]	1480 m/s	Speed of sound in water
lam0	c0/f0	0.74 m	wavelength
alpha	0[degree]	0 rad	angular orientation of pressure housing

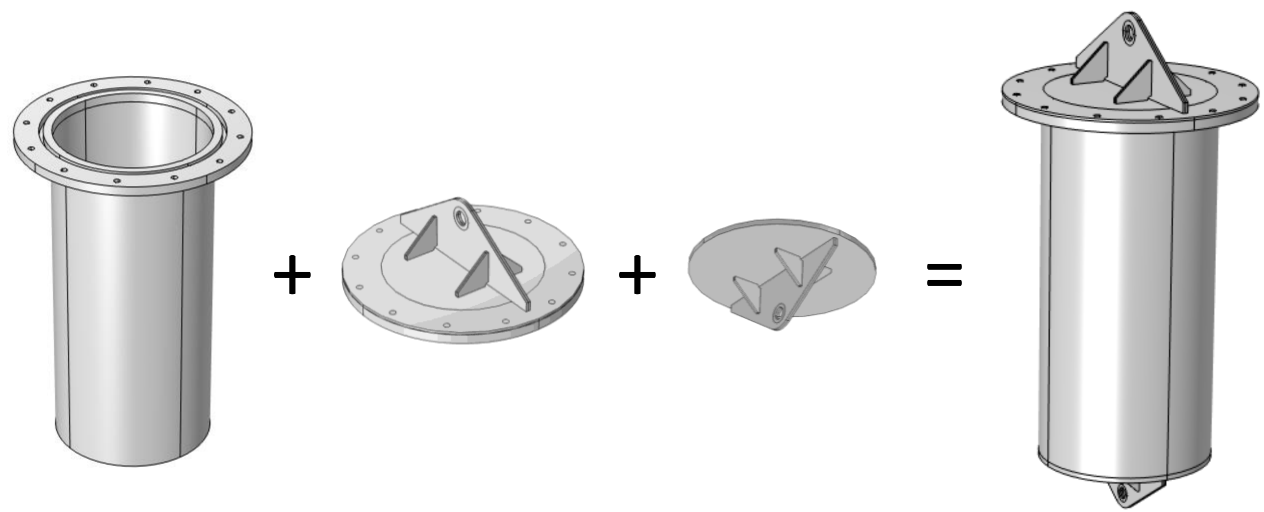
Variables

Name	Expression	Unit	Description
p_in	aveop1(abs(paas.p_b))	Pa	Total Incident pressure
TS	20*log10((abs(paas.p_s)/p_in)*2[m]/1[m])		Target Strength

- An average operator is used to estimate the total incident pressure onto the scattering object.

Geometry



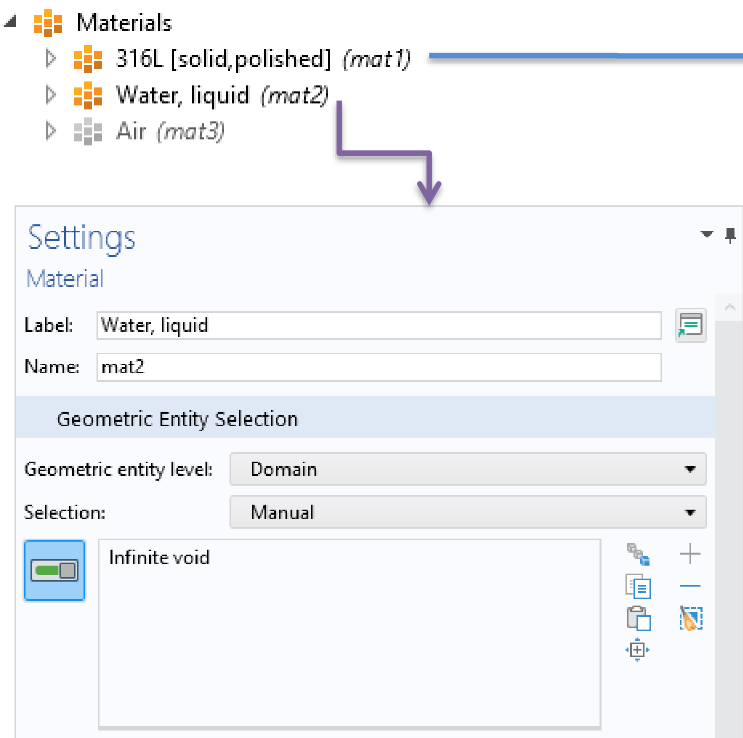


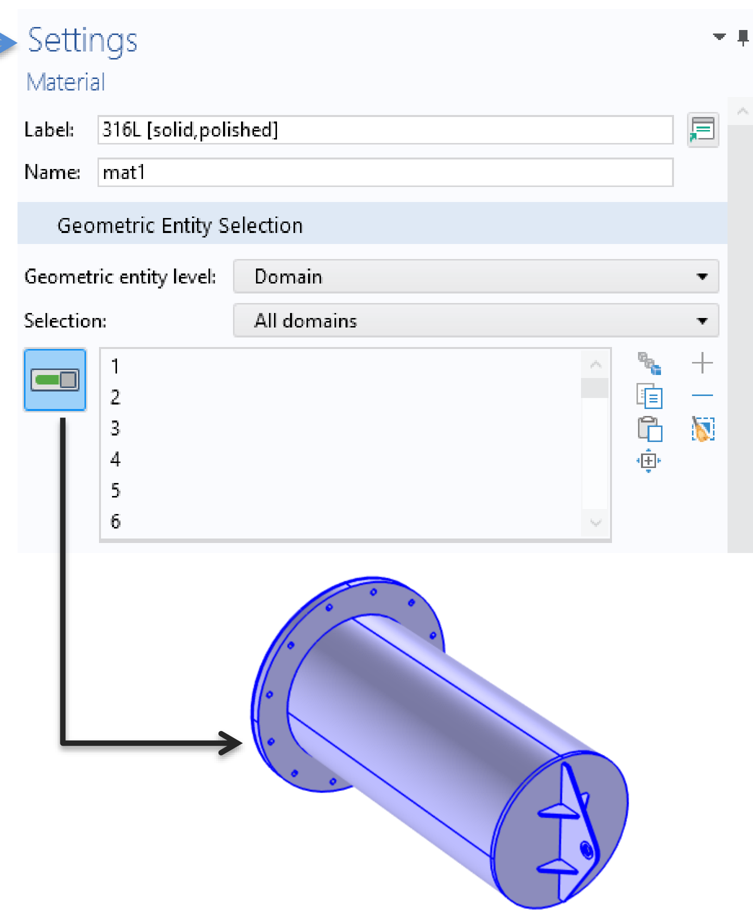
Geometrical information of SS pressure housing:

SNo	Pressure housing geometrical feature	Dimensions (mm)
1	Outer diameter	340
2	Inner diameter	330
3	Length of the cylinder	700
4	Total length of the housing (from top flange eye to bottom flange eye)	900

Materials

- The following materials are assigned to the respective domains.

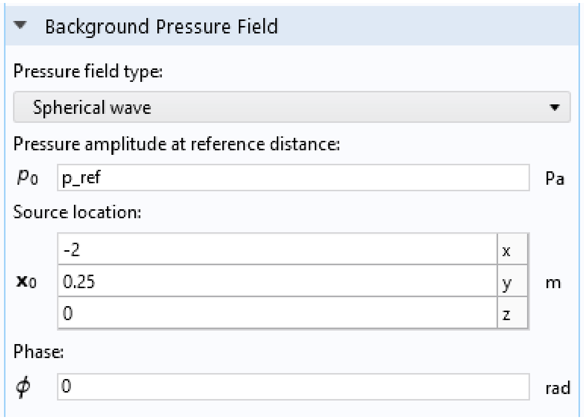


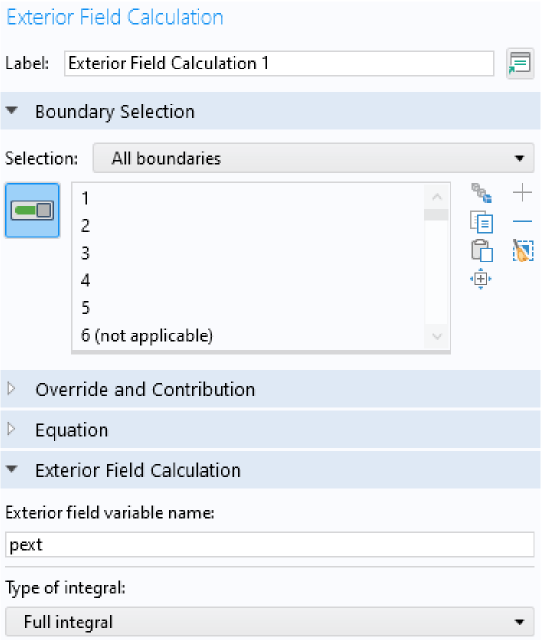


Infinite void represents the domain other than the scattering object.

Model Setup

- Physics interface
  - Pressure Acoustics, Asymptotic scattering (paas)
    - Under the node paas, with the help of the feature: Background Pressure Field, a spherical wave of known amplitude at a given source location is given to the model.

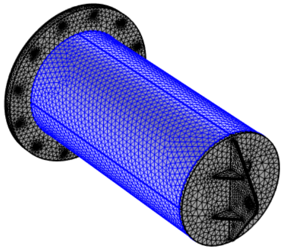


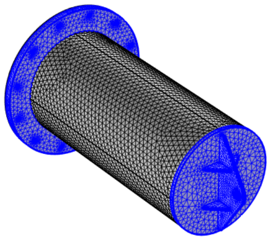


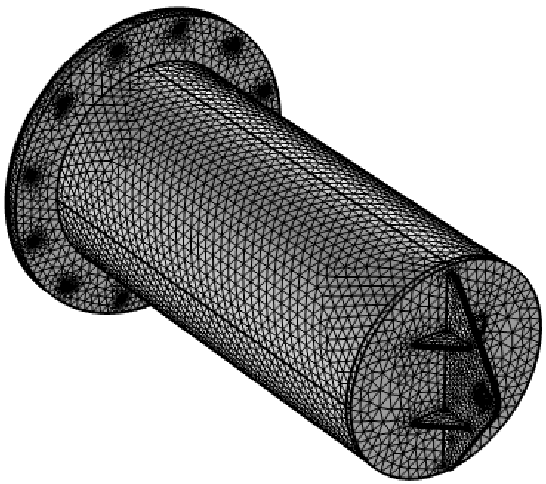
- The scattering object is considered to be the cylindrical pressure housing.
- The exterior field calculation is chosen for all the boundaries of the scattering object.

Mesh

- Cylinder part of the housing
  - Free tetrahedral, Size: Normal
- Top and bottom flange
  - Free tetrahedral, Size: Fine

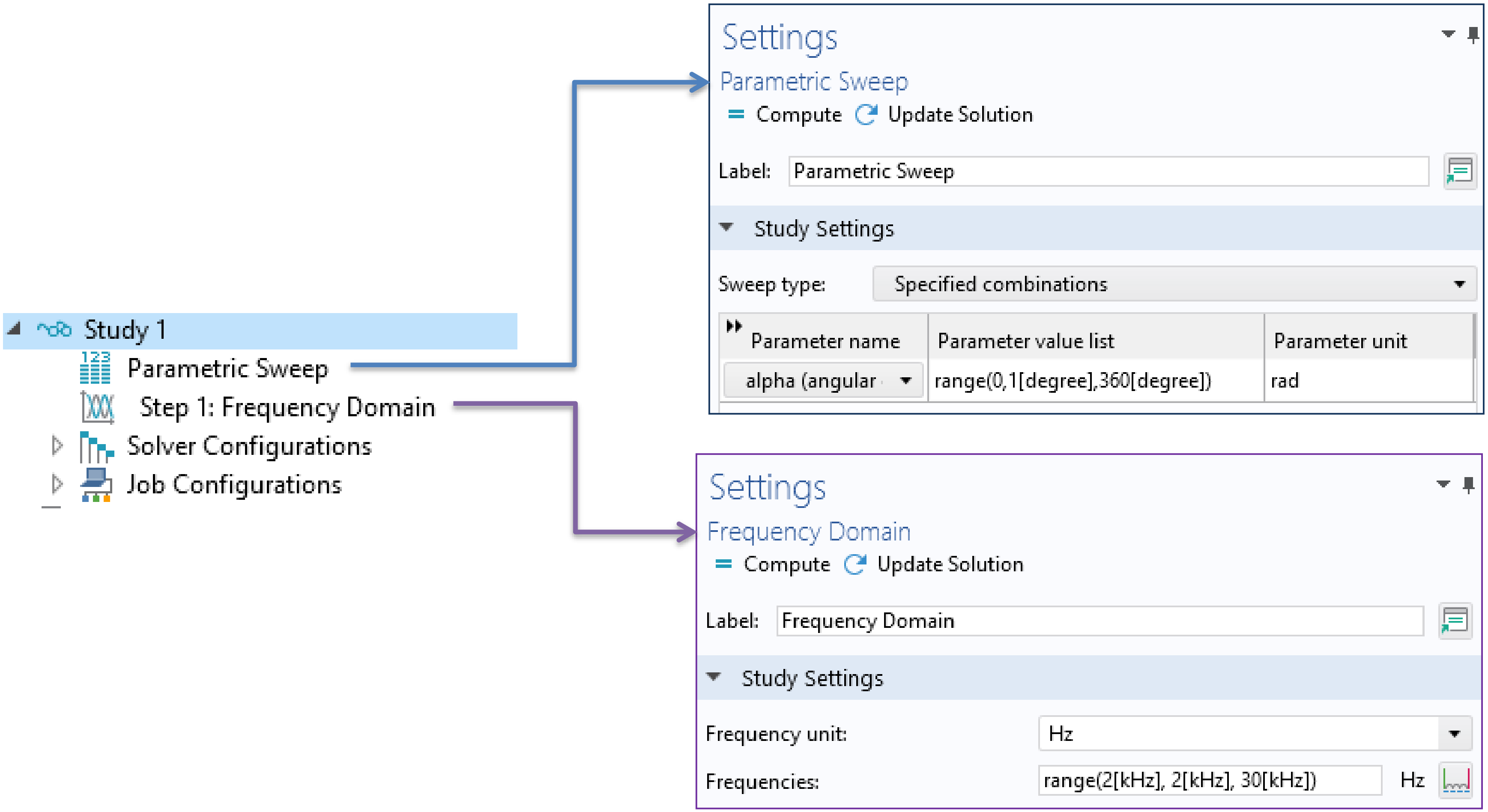






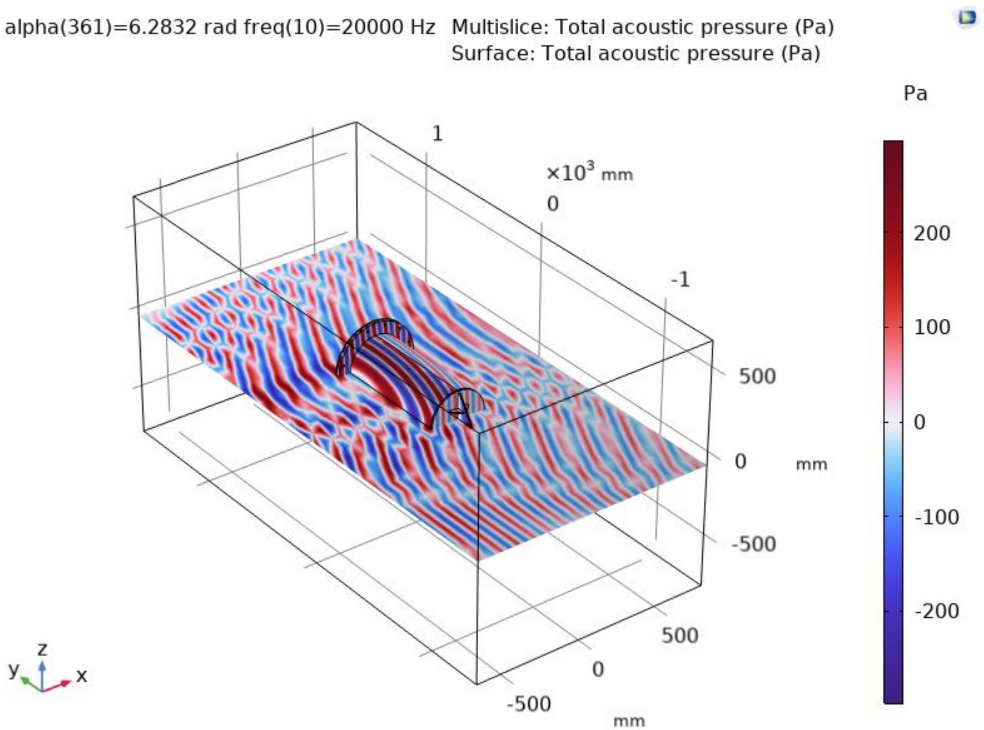
- Mesh information
  - Mesh consists of 33975 domain elements, 36138 boundary elements, and 3904 edge elements.

Study


Study 1
Parametric Sweep
Step 1: Frequency Domain
Solver Configurations
Job Configurations
Settings
Parametric Sweep
Compute
Update Solution
Label:
Parametric Sweep
Study Settings
Sweep type:
Specified combinations
Parameter name
Parameter value list
Parameter unit
alpha (angular
range(0,1[degree],360[degree])
rad
Settings
Frequency Domain
Compute
Update Solution
Label:
Frequency Domain
Study Settings
Frequency unit:
Hz
Frequencies:
range(2[kHz], 2[kHz], 30[kHz])
Hz

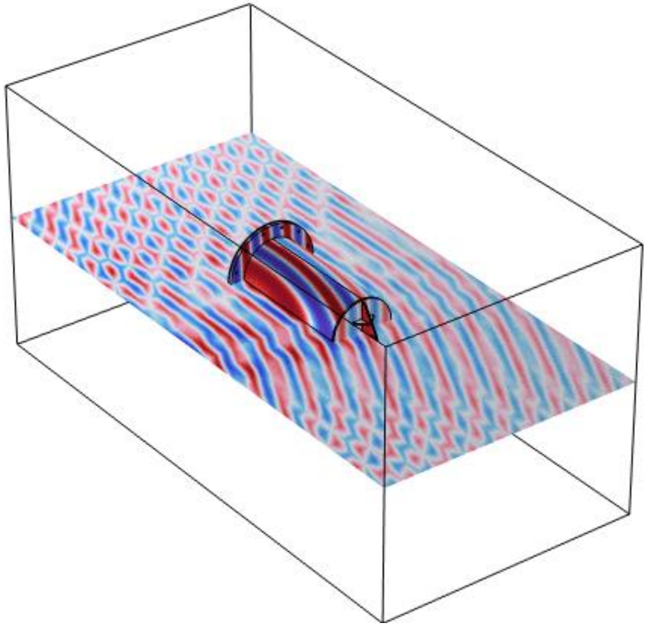
Results

- The comsol model inherently gives the following results:
  - Acoustic pressure (paas)
    - The acoustic pressure can be evaluated at any point of the grid space (cuboid) for all the alpha range and frequencies.



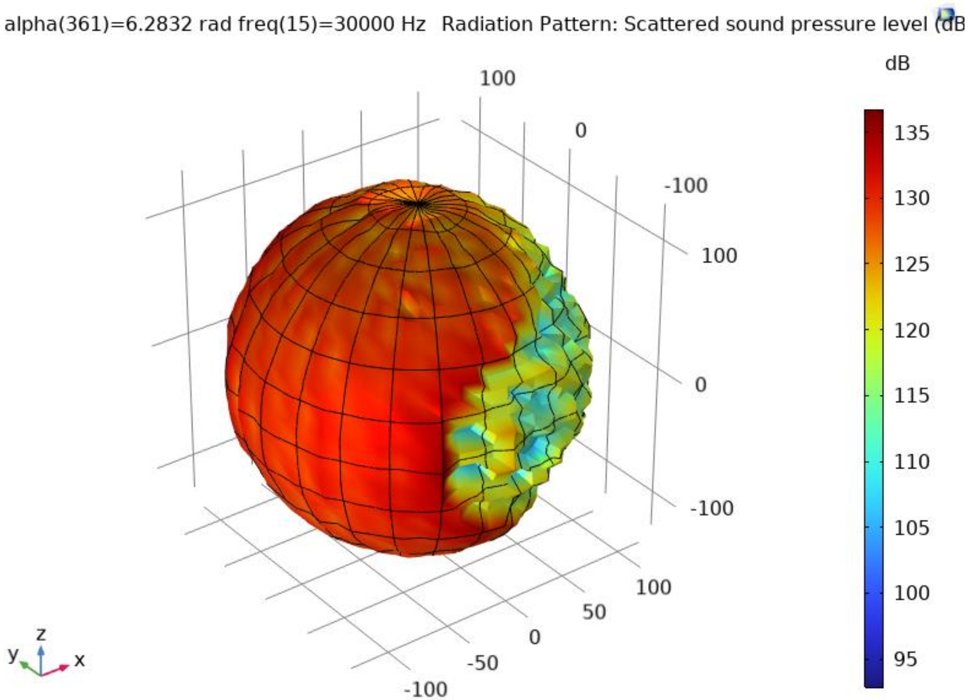
Results

- The comsol model inherently gives the following results:
  - Acoustic pressure (paas)
    - The animation of acoustic pressure for the range of alpha (0° to 90°) for a range of frequencies .



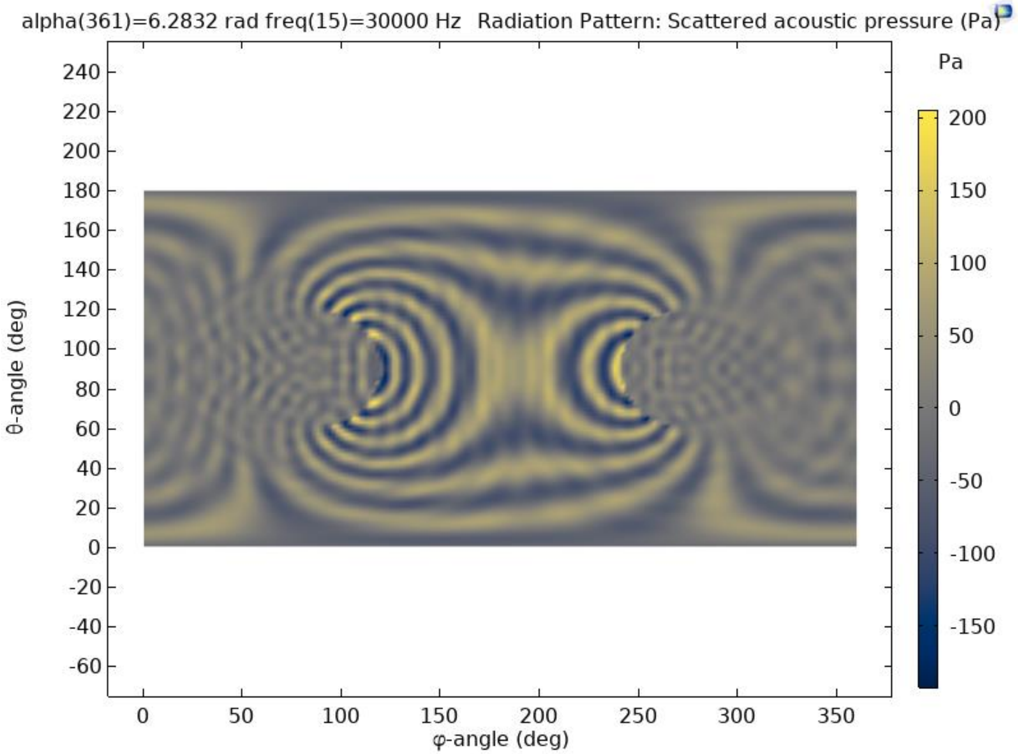
Results

- The comsol model inherently gives the following results:
  - Exterior-Field Sound Pressure Level (paas)
    - The radiation pattern observed for a sphere of radius 350mm, centered at the origin (0,0,0).



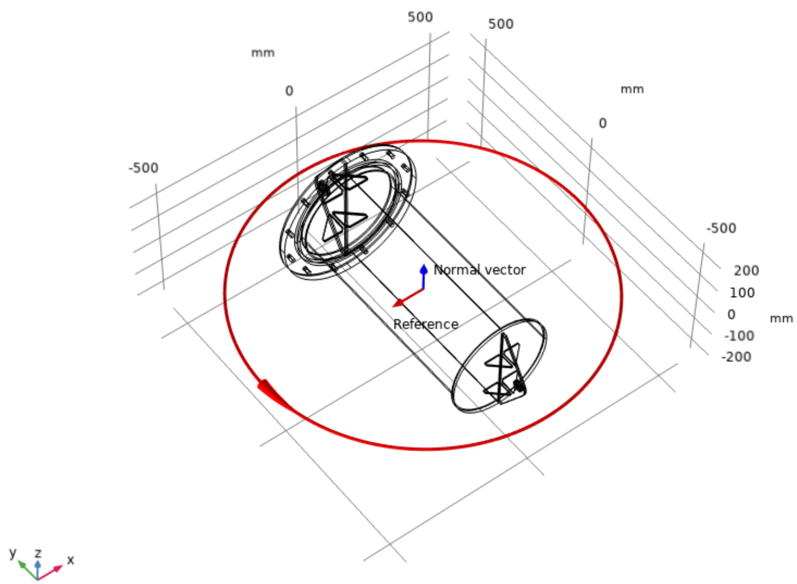
Results

- The comsol model inherently gives the following results:
  - Exterior-Field Pressure (paas)
    - The 2D radiation pattern plot of the scattered pressure with respect to elevation and azimuth angles.

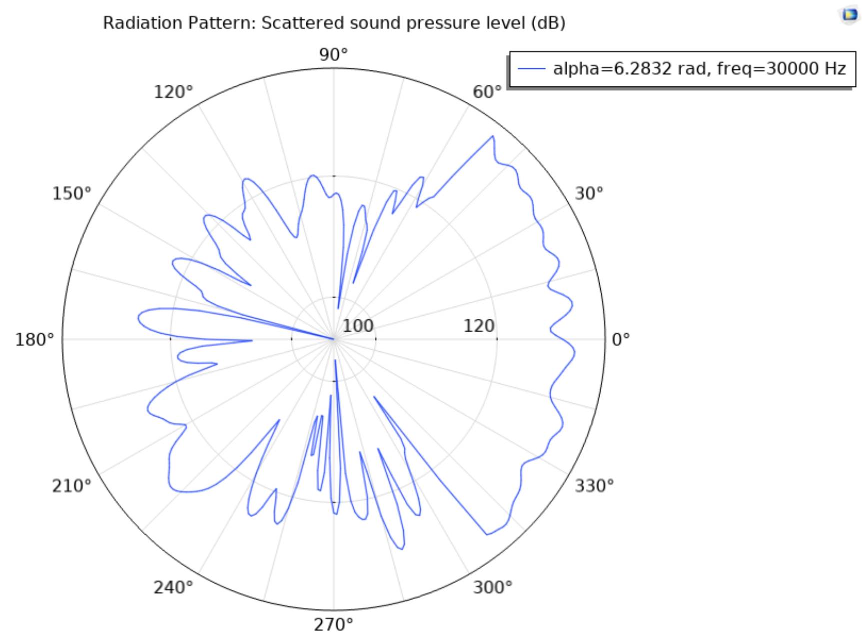


Results

- The comsol model inherently gives the following results:
  - Exterior-Field Sound Pressure Level xy-plane (paas)
    - The polar plot of the scattered sound pressure level for the shown evaluation plane.



Evaluation plane



Results

- With the help of derived values feature, the following expressions were evaluated at a point of interest for all the parameter selection (alpha & freq).

Data

Dataset:	Study 1/Parametric S
Parameter selection (alpha):	All
Parameter selection (freq):	All
Table columns:	Data only

Expressions

Expression	Unit	Description
20*log10((abs(paas.p_s)/p_ref)*2[m]/1[m])		Target Strength
abs(paas.p_s)	Pa	Scattered pressure
paas.Lp_s	dB	Scattered sound pressure level

Table:

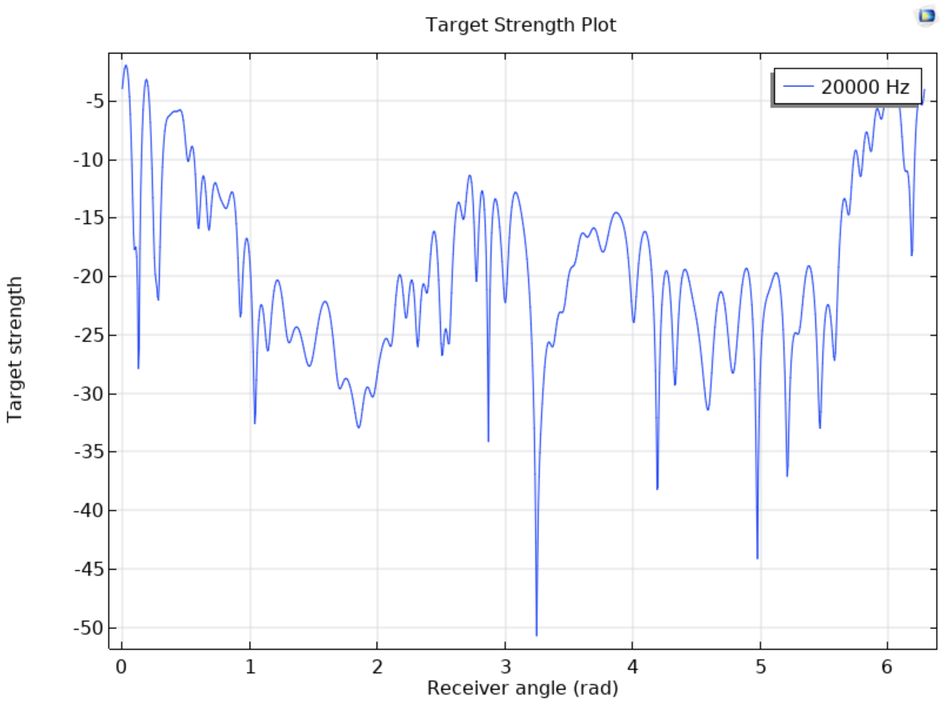
Messages | Progress | Log | Table 6

alpha (rad)	freq (Hz)	Target Strength, Point: 1	abs(paas.p_s) (Pa), Point: 1	Scattered sound pressure level (dB), Point: 1
0.0000	20000	-16.096	24.045	118.59
0.017453	20000	-15.563	25.567	119.12
0.034907	20000	-11.959	38.716	122.73
0.052360	20000	-8.9566	54.701	125.73
0.069813	20000	-11.987	38.592	122.70
0.087266	20000	-19.217	16.788	115.47
0.10472	20000	-19.242	16.739	115.44
0.12217	20000	-30.602	4.5263	104.08
0.13963	20000	-15.302	26.348	119.38
0.15708	20000	-14.454	29.049	120.23

- The values with respect to entire range of aplha and freq are exported into an excel table for further evaluation of results.

Results

- The comsol model inherently gives the following results:
  - Target Strength plot
    - The evaluated target strength values are plotted against the receiver angle for observing the variation of target strength with respect to the angular orientation of the pressure housing.



Results

- For validation of the comsol model results, results were also compared with experimental results and found to be matching.
- The target strength values computed both experimentally and of comsol model are compared.

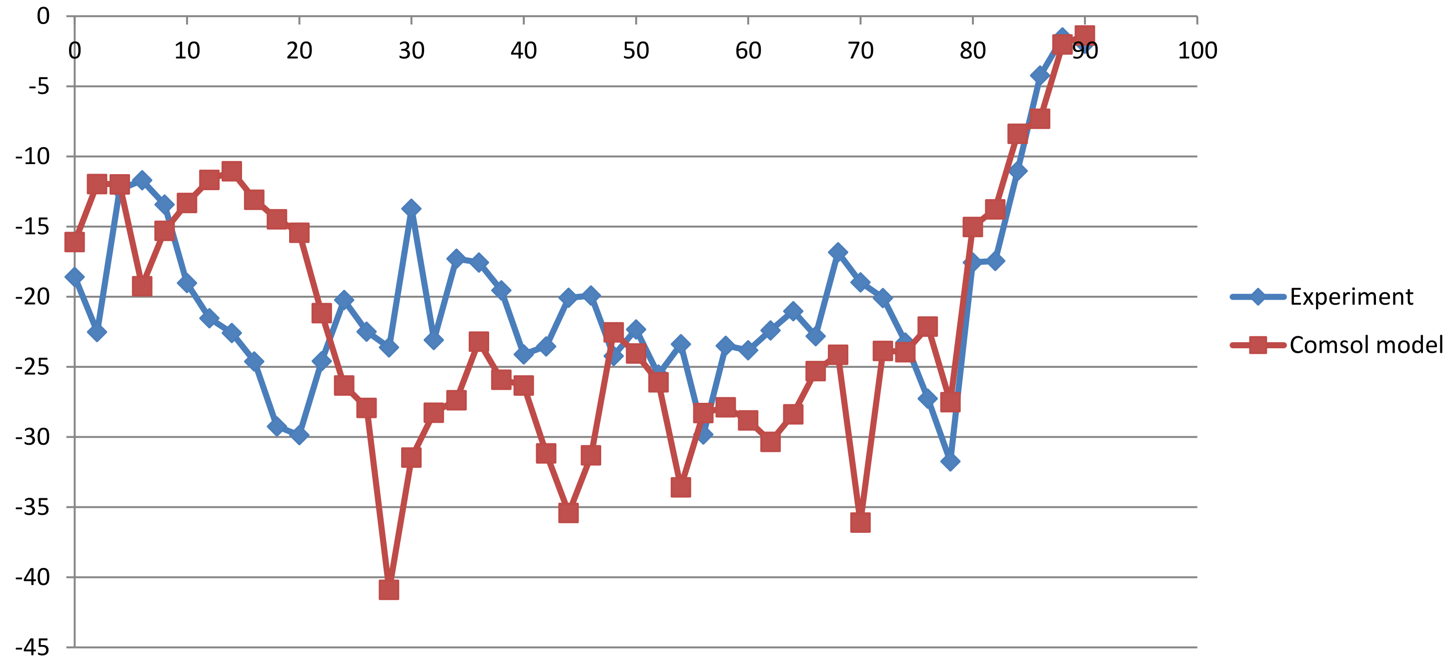


Fig: Target Strength (TS) values comparison of SS pressure housing (α=0° to 90 °)

Results

- The resulting values of target strength (TS) of the scattering object that has been insonified over a frequency band-width and for wide range of aspect angles are plotted as a template, termed as acoustic scattering signature.
- The acoustic scattering signature is plotted for both experimental and comsol model results and both shows significant similarities. The bright band features observed near 0° and 90° are clearly more evident in comsol model plot, compared to experimental plot.
- The x-axis range represents ka, where *k* is the wave number of the incident sound in water, and *a* is the cylinder radius.

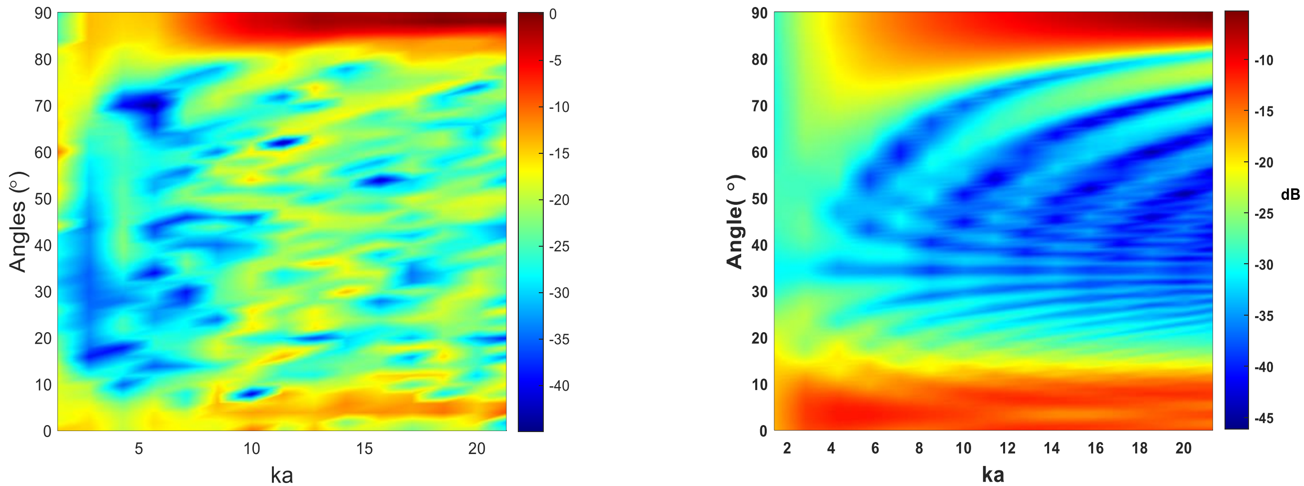


Fig: Acoustic scattering signature of SS pressure housing (a) Experimental (b) COMSOL

Results

- The distribution of the scattered pressure (both experimental and comsol) with respect to the direction is plotted in a polar plot.
- The peak pressure lobes at 90° and 270° is observed both experimentally and of comsol model.
- The comsol model clearly establishes the variation of scattered pressure along the entire range of aspect angles (0° to 360°).

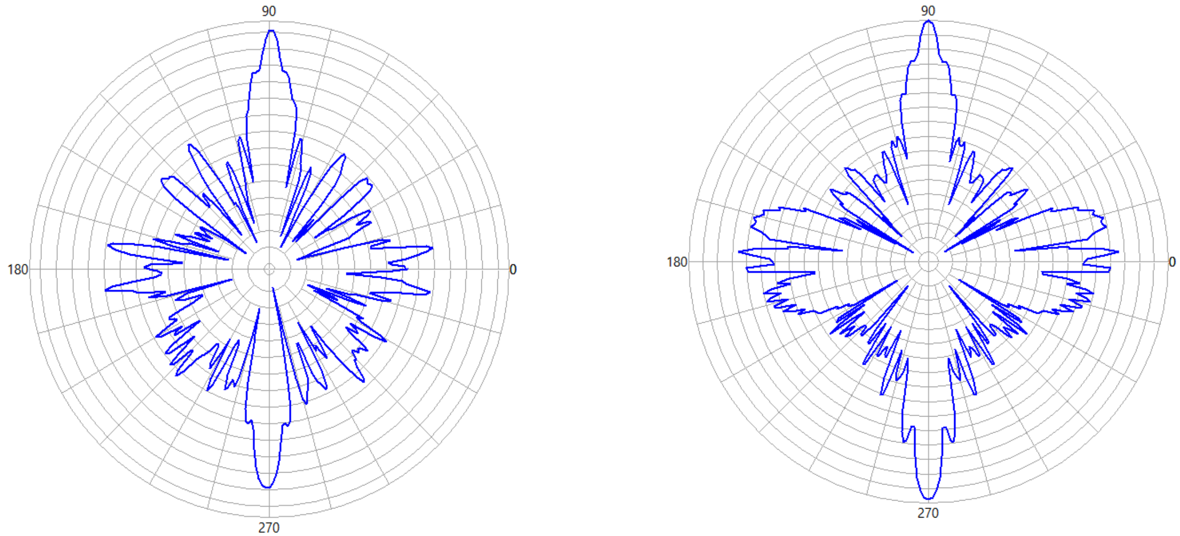


Fig: Directivity plots for SS pressure housing (α=0°) (a) Experimental data (b) COMSOL data

Conclusion

- The comsol model developed was helpful in understanding the acoustic scattering capabilities of the underwater objects. In this case, the cylindrical pressure housing is the scattering object.
- For the considered scattering object, acoustic parameters like the total acoustic pressure, scattered pressure and sound pressure level are evaluated and plotted for better understanding.
- The target strength (TS) values are evaluated for all range of frequencies, which are used to plot acoustic template and found to be matching with the experimental results template. This may be useful in finalizing the orientation of the housing with respect to minimal scattering signature.
- The knowledge of acoustic scattering capabilities of any underwater objects is very much needed prior to using in acoustical research activities.
- The current 3D model can be further modified/altered to study for scattering characteristics of other geometries and materials.

Future work

- It is intended to study the scattering capabilities of pressure housings made up of different materials.
- As the model is validated against experimental results, the same model can be used for studying scattering capabilities of different shaped objects.
- The model can be used to estimate the minimum frequency range that is required to be swept over to plot an acoustic template. The range of aspect angles that needed to be studied can also be estimated.
- The model can be extended further to study objects that are partially buried, fully submerged in a sediment.

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. David S. Burnett, “Computer simulation for predicting acoustic scattering from objects at the bottom of the ocean,” Acoustics Today, vol 11, issue 1. (2015).
3. 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).
4. M. Zampolli, A. L. Espana, K. L. Williams, “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, FCAC 2018. (2019)

- THANK YOU -