# Synthetic Aperture Sonar (SAS) and Acoustic Templates for the Detection and Classification of Underwater Munitions

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## Introduction

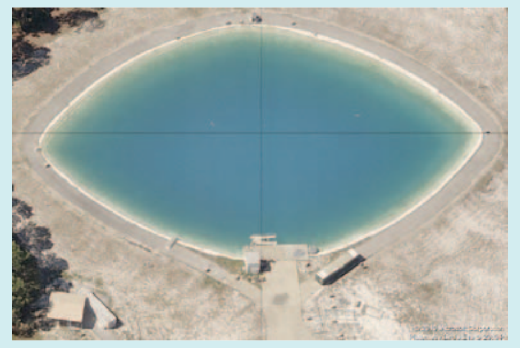
During Pond Experiment 2010 (PondEx10), acoustic responses from four inert unexploded ordnances (UXO), 5 scientific targets (solid cylinders, pipes, and replica of a UXO), and two rocks were collected at the test pond facility of the Naval Surface Warfare Center, Panama City Division (NSWC PCD). The UXO were either proud on a flat water-sediment interface, buried just beneath the sediment interface, or partially buried. Synthetic aperture sonar (SAS) data were taken for several orientations of the UXO with respect to the path of the SAS platform. The steep grazing angle of approximately 40° permitted an acoustic field to penetrate to buried targets via ordinary refraction, while at a shallow grazing angle of 20° only proud targets were interrogated. Two frequency bands were used to span a 1 to 50 kHz range. SAS images for the targets at various orientations are displayed. The reduction of data sets to acoustic templates is shown. Acoustic templates provide a possible means to classify a detected object as a UXO-like target.

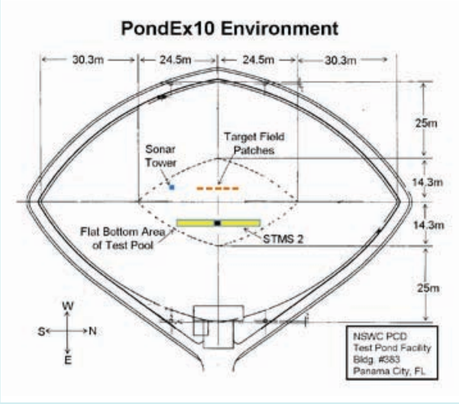
## Objective

The overall objective is to investigate the use of broad band sonar in the detection, classification, and identification of underwater munitions. A central hypothesis is that the environment alters the acoustic response of a target significantly, so the target-in-the-environment must be taken into account during the development of robust detection, classification, and identification strategies.

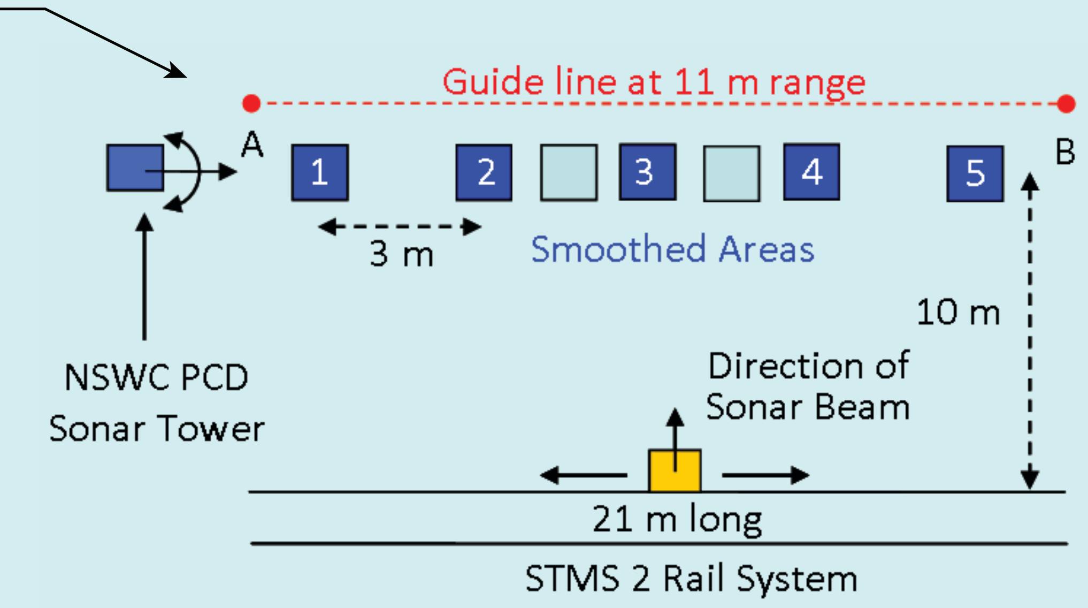
## Experiment Site, Layout, and Materials

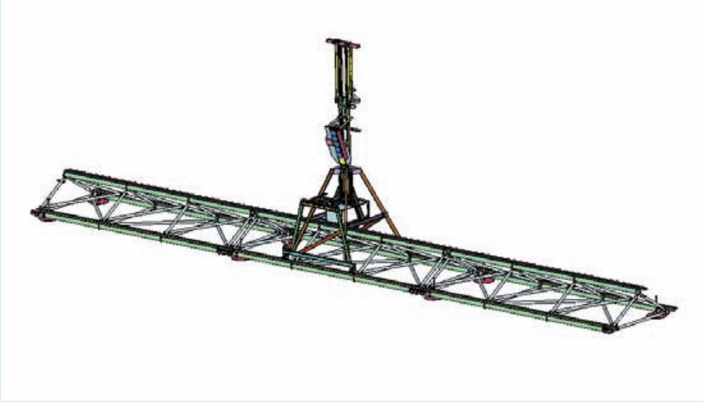
Fresh water pond at the NSWC PCD and an engineering schematic of the pond with the experimental layout **(right)**. The pond holds 9 million gallons of water, is 110 m by 80 m in dimensions, and is 14 m deep. A 1.5 m thick layer of sand covers the bottom. Biological growth and fouling of the targets and equipment are prevented by filtration and chlorination. A more detailed description can be found in [1] and [2].





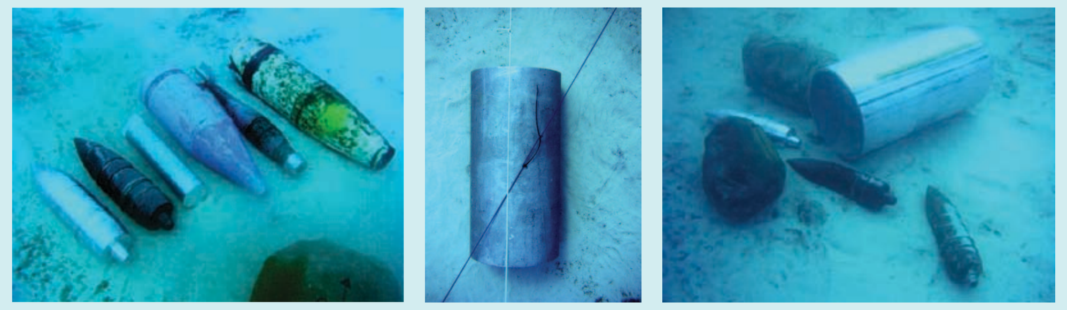
Layout of the 10 m target field.
Divers deployed the STMS2 rail system to establish a baseline for the geometry, and then surveyed in two screw anchors at an 11 m ground range from the rail (points A and B). A lightweight guide line is stretched between the screw anchors and marked at 4, 7, 10, 13, and 16 m from the left. These locations are enumerated as Target Patch #1 through #5, and mark the sites of 1 m$^2$ patches, where targets are deployed (dark blue). When 7 targets are present, the additional targets are placed between Target Patches #2 and #3 and Target Patches #3 and #4 (light blue). Target Patches are smoothed by the divers. The NSWC PCD sonar tower is positioned to collect bistatic scattering from the targets. The mobile tower, placed on the rail system, holds acoustic sources and receiving arrays.





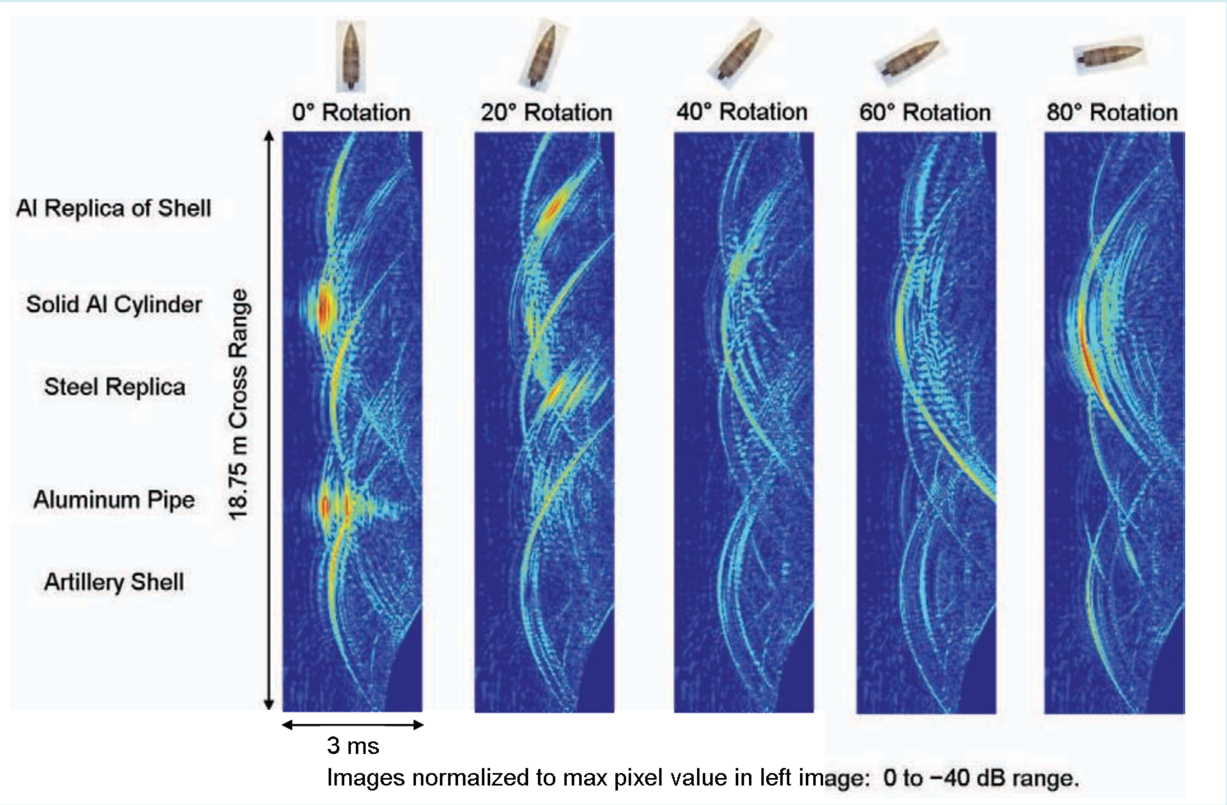
CAD drawing of the 21 m APL-UW rail and mobile tower system **(left)**. Source and receiver arrays tilted at a 20° depression angle **(right)**. The source and receiver are approximately 4 m above the mean sediment interface, which yields a 20° grazing angle at a target located 10 m from the rail.

Targets used during PondEx10 were a solid aluminum cylinder, an aluminum pipe, an inert 81 mm mortar, a solid steel artillery shell, two machined aluminum UXO, a machined steel UXO, a de-militarized 152 mm TP-T round, a de-militarized 155 mm empty howitzer projectile, a small aluminum cylinder with a notch, and two rocks. The machined UXO, based on a CAD drawing of the solid steel artillery shell, were constructed from materials with known properties. The aluminum cylinder is 2 ft long with a 1 ft diameter; while the pipe is 2 ft long with an inner diameter of 1 ft and 3/8 inch wall thickness.



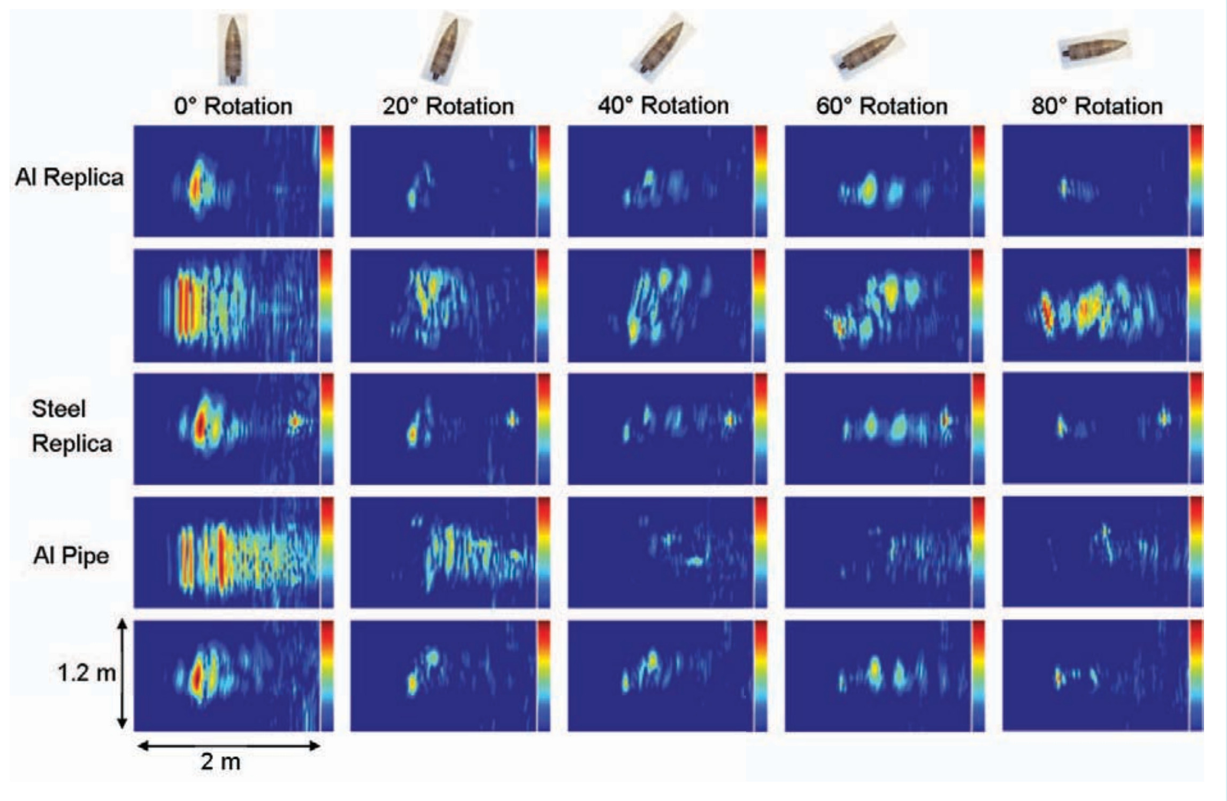
## Data Sets, SAS Images, and Acoustic Templates

Raw acoustic data are pulse compressed by match filtering the pings with a replica of the transmitted signal. During the match filtering, a Hilbert transform converts the real-valued recorded pings to complex-valued signals, and the carrier frequency is removed to obtain baseband signals. The figure **(right)** shows the magnitude of the baseband pulse-compressed pings for five targets (from top to bottom): machined aluminum UXO, solid aluminum cylinder, machined steel UXO, aluminum pipe, and the solid artillery shell. For SAS processing the coherent addition of the complex signals is unaffected by the overlapping signals.

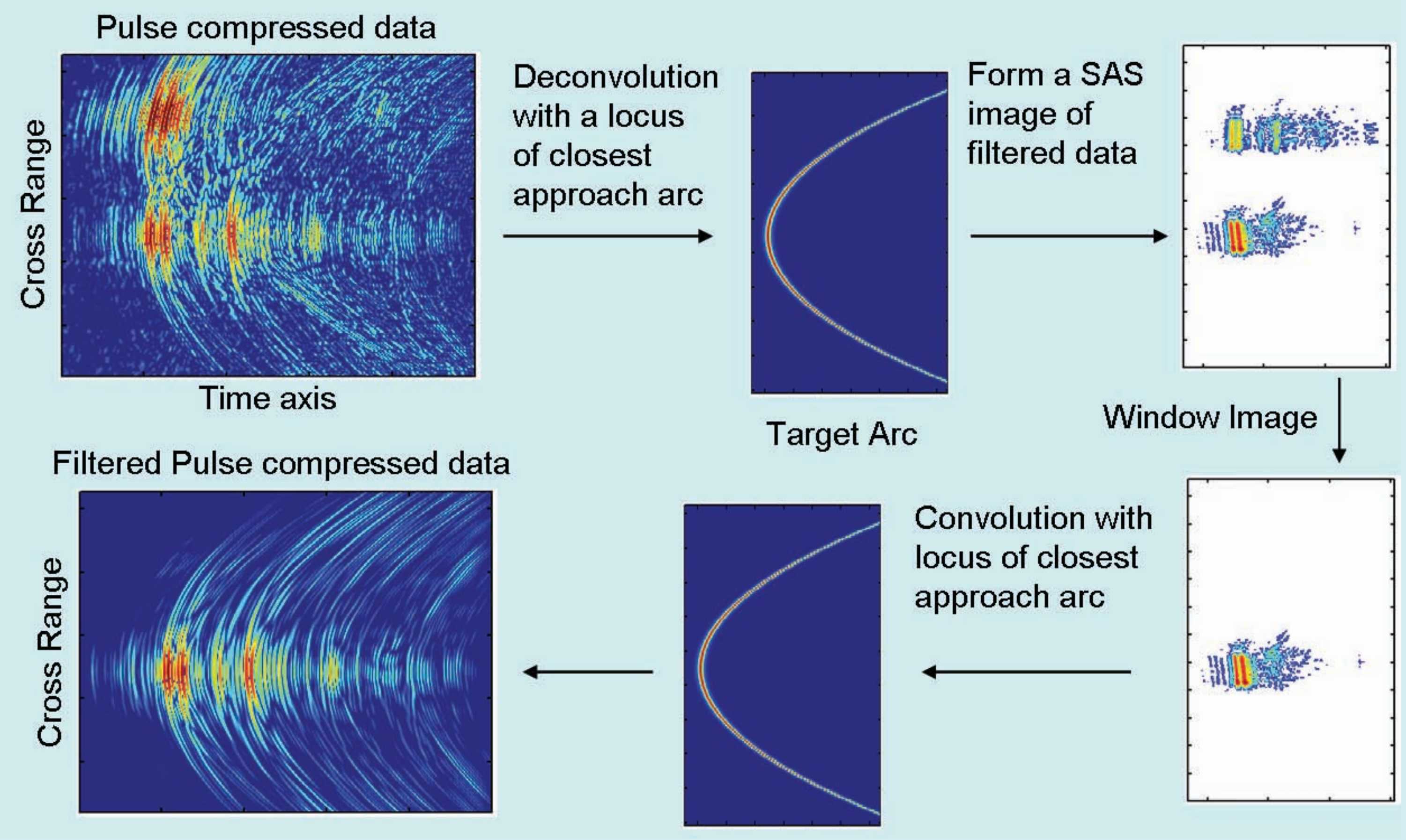


Images normalized to max pixel value in left image: 0 to −40 dB range.

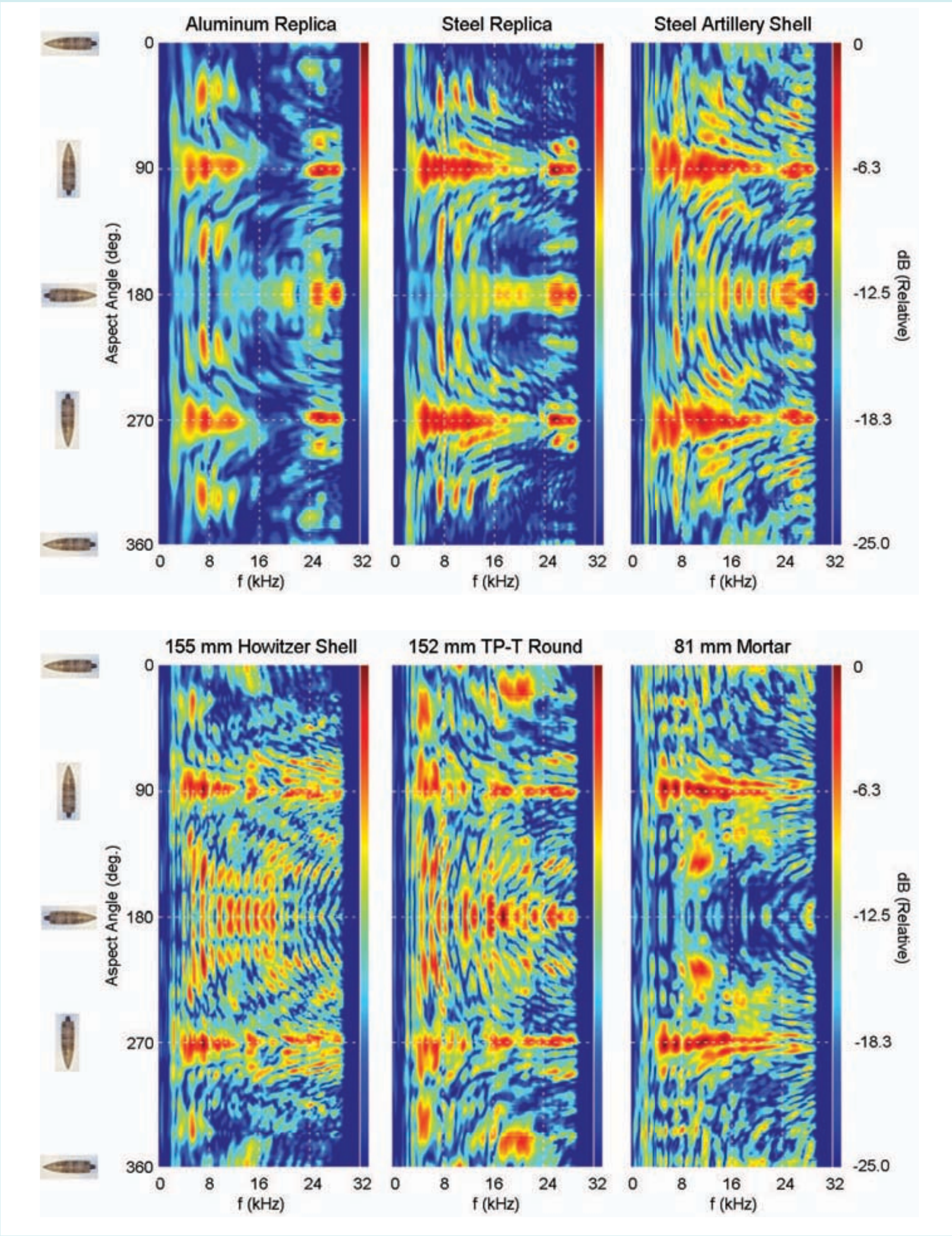
SAS images formed by a time-domain delay-and-sum beamformer. For each pixel in an image, the signals are time shifted to account for propagation from the source to the pixel and then from the pixel to the receiver. Once the time shift is performed, the signals are coherently added to determine a complex reflectivity of the pixel. Time shifting is done for each pixel in a SAS image. SAS images for five targets are shown **(right)**. These images are 1 × 2 m$^2$ patches with a 1 cm$^2$ resolution.



When multiple targets are in the target field and the separation distance between adjacent targets is on the order of a few meters or less, the scattered acoustic fields from neighboring targets interfere. SAS processing is unaffected by this interference due to the underlying coherent processing scheme. However, to generate acoustic templates, a clean separation and isolation of a target's acoustic response is required. The SAS filtering technique developed by Marston et al provides a means to achieve this goal [3]. A pictorial description of the SAS filtering technique is shown below. The deconvolution and convolution steps are linear transformations, which do not add or remove information from the signals. Note the suppression of noise due to reverberation in the filtered data.

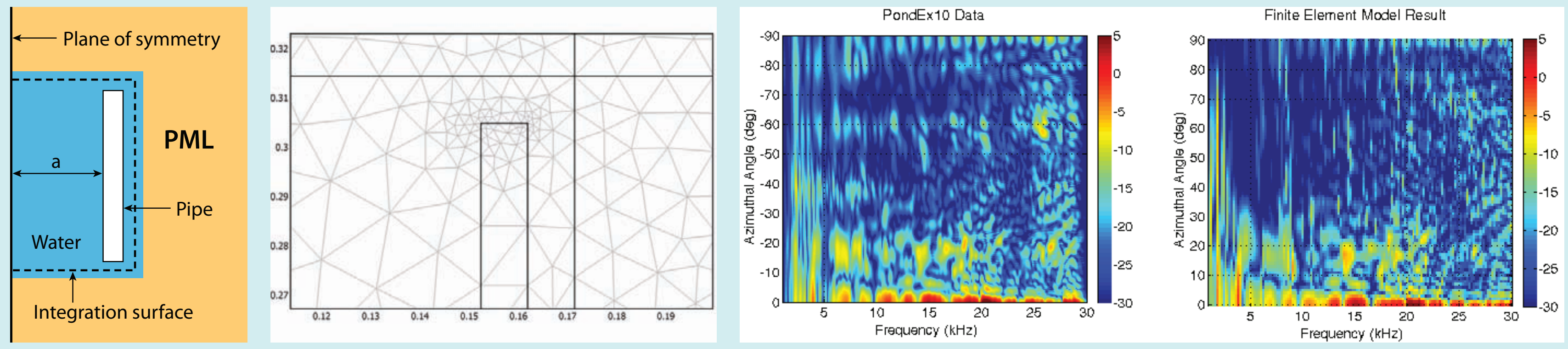


The acoustic templates for six targets **(right)**. These templates depict the normalized target strength as a function of frequency and aspect angle of the target with respect to the direction of the SAS platform. A target in a broad side orientation is parallel to the track of the SAS platform; while the nose of the ordnance points towards the track at 0° and 360°. The top row compares the acoustic templates for the real solid steel artillery shell and the replicas machined from aluminum and steel with known material properties. The structure in the acoustic template is determined by both the geometrically scattered acoustic field and the elastic response of the target. The observed differences in between the aluminum replica and the other two targets suggest that the acoustic template may be used as a “fingerprint” in the classification and/or identification of a target as UXO-like. The bottom row shows the acoustic templates for the other inert UXO used during PondEX10.

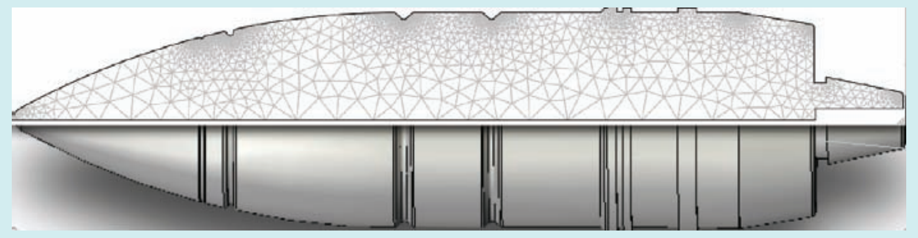


## Current Work

Recently, Espana et al. have extended the 2D FE Model of [1] to accommodate an open-ended pipe. The computational domain **(below)** includes water, the pipe, a perfectly matched layer (PML), and a plane of symmetry, which contains the axis of the pipe. The sharp edges at the end of the pipe require a refined mesh **(below center)**. A prelimary comparison of the PondEx10 acoustic template for the proud pipe and the model result is shown **(below right)**. The model captures the organ pipe structure and an elastic response of pipe.



Finite element model (FEM) grid for the artillery shell **(right)**. The acoustic scattering from the shell is currently being simulated for a shell in the free-field and in a proud state (i.e., sitting on the sediment interface). The results will be processed to give SAS images and acoustic templates. The numerical results will then be compared to measured templates obtained during PondEx09 and PondEx10.



### References

[1] KL Williams, SG Kargl, EI Thorsos, DS Burnett, JL Lopes, M Zampolli, PL Marston, “Acoustic scattering from a solid aluminum cylinder in contact with a sand sediment: Measurements, modeling, and interpretation,” *J. Acoust. Soc. Am., 127,* 3356-3371 (2010).

[2] SG Kargl, KL Williams,TM Marston, JL Kennedy, JL Lopes, “Acoustic response of unexploded ordnance (UXO) and cylindrical targets,” *Proc. OCEANS 2010 MTS/IEEE*, Seattle WA 2010.

[3] TM Marston, PL Marston, KL Williams, “Scattering resonances, filtering with reversible SAS processing, and applications of quantitative ray theory,” *Proc. OCEANS 2010 MTS/IEEE*, Seattle WA 2010.

[4] AL Espana, KL Williams, SG Kargl, M. Zampolli, TM Marston, PL Marston, "Measurements and modeling of the acoustic scattering from an aluminum pipe in the free field and in contact with a sand sediment," Proc. Oceans 2010 MTS/IEEE, Seattle WA 2010.

### Acknowledgment

Work partially supported under SERDP project numbers MR–1665 and MR–1666 and the Office of Naval Research contract number N00014-07-G-0557 (Task 0010).