SERDP

UXO Characterization for Underwater Acoustic Test Beds

MR23-3978

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Final Debrief

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Project Team

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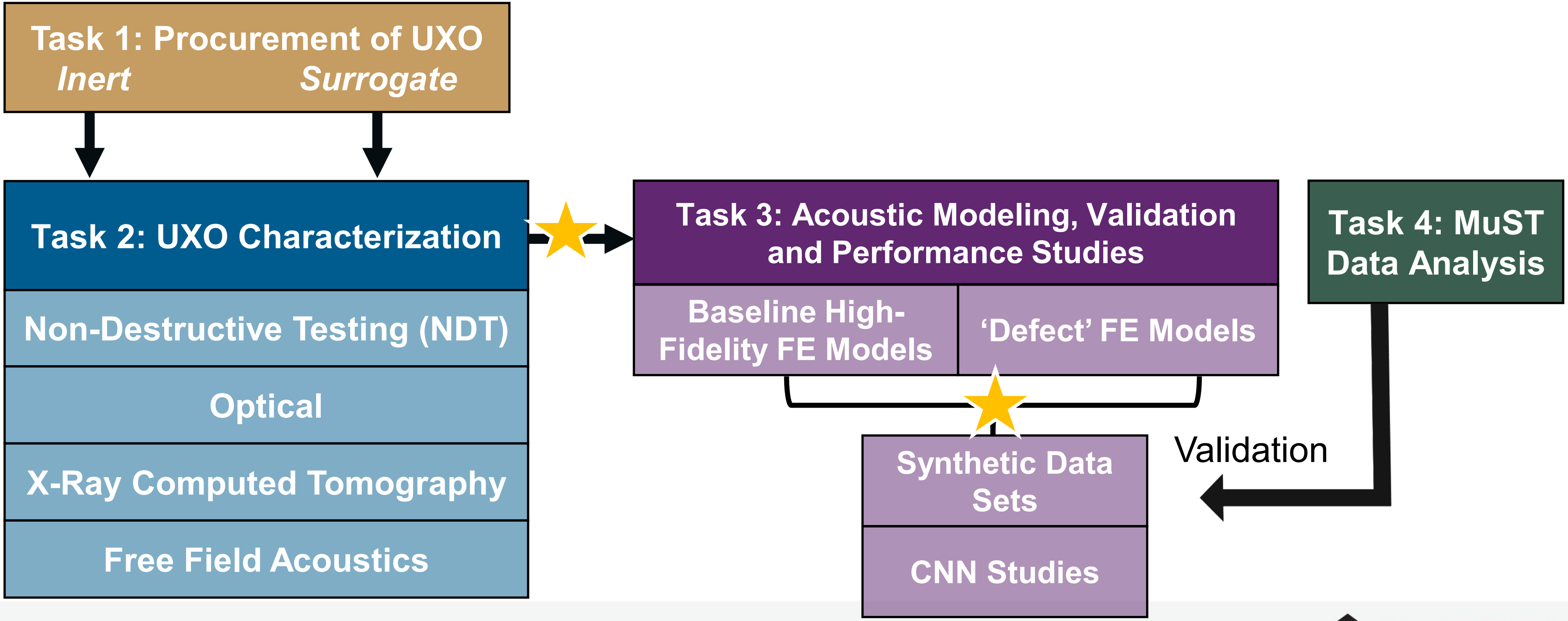
Bottom Line Up Front

- What technology or methodology is being evaluated during this demonstration?
  - Methods for characterizing surrogate/inert UXO
  - How closely do the surrogate UXO have to match those of the inert UXO
  - Generation of simulated data to support UXO identification/classification strategies
- What's been going well?
  - Physical dimensioning, online research, CT scans, meshing and modeling (for most objects), data survey tools
  - Generation of simulated MuST data and initial CNN assessments
- What's not working well?
  - Characterization: Measurement of material properties, free field acoustic experiments
  - Modeling: Conversion of CT image data to a 3D surface mesh
- What support do you need?
  - Connections with live-site experts

Technical Objectives

1. Arrive at a well-characterized set of surrogate/inert UXO
2. Utilize validated acoustic modeling techniques to quantitatively analyze the effects that variability in UXO characteristics has on the measured response
3. Assess how precisely the characteristics of surrogate UXO must match those of inert UXO

Technical Approach



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Results – Overview/Outline

- Task 1: UXO procurement
- Task 2: Characterization techniques
- Task 3: Acoustic modeling
  - Building high-fidelity models
  - General characterizations (no TIER simulations)
- Task 4: MuST data survey and characterization
  - Volumetric data visualization via k-space widget
- Task 3:
  - Synthetic data generation (using the TIER model)
  - CNN studies

Results – UXO Procurement

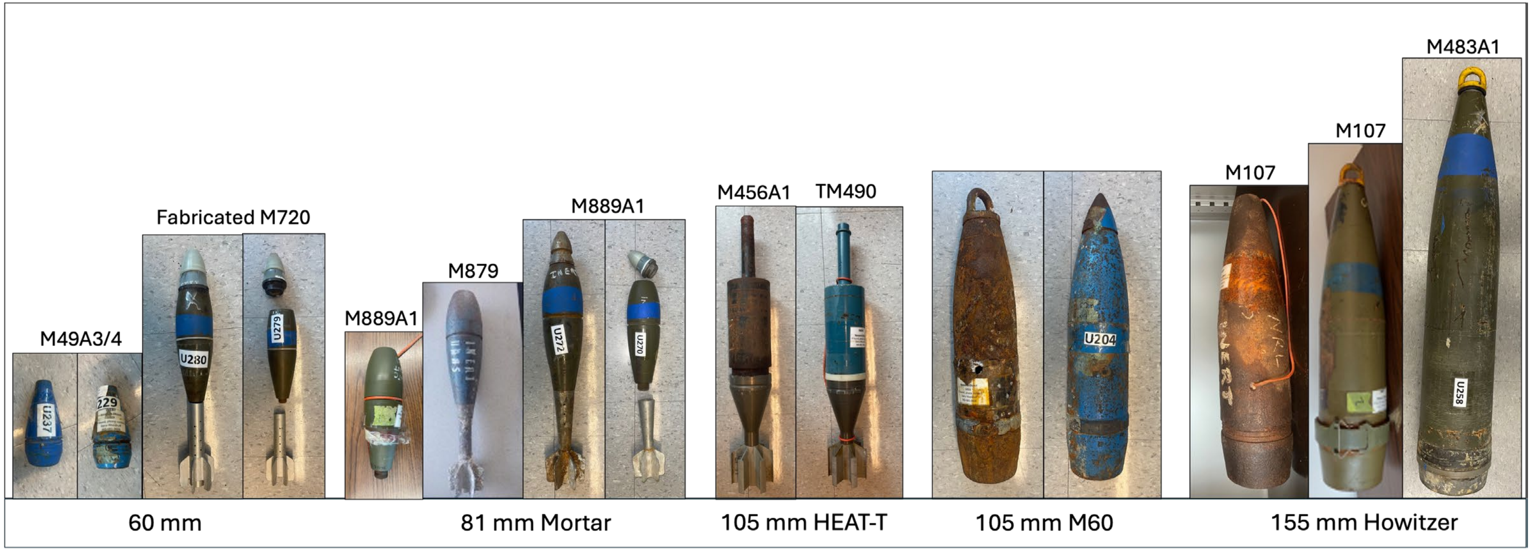
- Early conversations with Program Office and Test Bed Developers led to a clarification ….

  Surrogate = Inert

- Munitions for Test Beds in U.S. are provided by U.S. Army Aberdeen Test Center (ATC)
- Pacific Northwest National Laboratory (PNNL) set up a short-term loan of inert UXO to APL-UW
- Early interaction with PNNL (prior to project kick-off) allowed us to request specific items from ATC's inventory list

Results – UXO Procurement

- Five classes of munitions were provided, each class having multiple objects in different physical conditions.



Results – Characterization Methods

Most Useful:

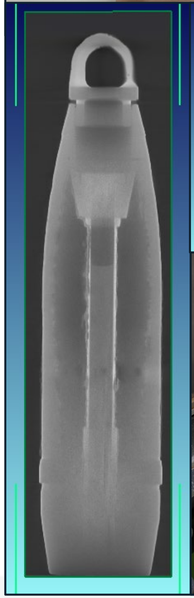
- Physical dimensioning
- Literature research
- X-ray Computer Tomography (CT) scans
- NDT thickness gage

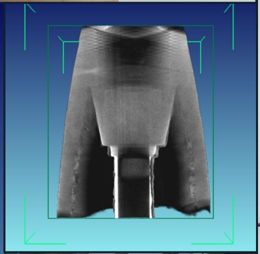
Most Challenging:

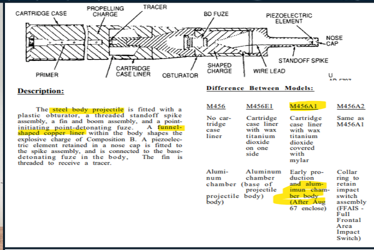
- Underwater acoustic measurements

Unnecessary:

- Optical methods







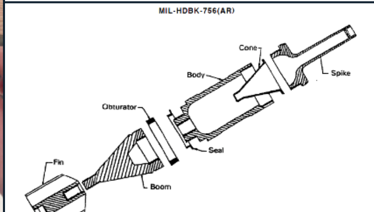


Figure 7-1. 105-mm M456A2 Projectile Parts

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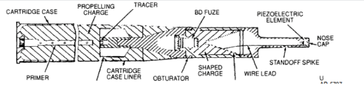
TASK 2

Results – Literature Research

- Literature research provided details regarding interior components
- Crucial in determining material properties
- Offers information to consider regarding inert versus live UXO



Description:

The steel body projectile is fitted with a plastic obturator, a threaded standoff spike assembly, a fin and boom assembly, and a point-initiating point-detonating fuze. A funnel-shaped copper liner within the body shapes the explosive charge of Composition B. A piezoelectric element retained in a nose cap is fitted to the spike assembly, and is connected to the base-detonating fuze in the body. The fin is threaded to receive a tracer.

Difference Between Models:

M456	M456E1	M456A1	M456A2
No cartridge case liner	Cartridge case liner with wax titanium dioxide on one side	Cartridge case liner with wax titanium dioxide covered with mylar	Same as M456A1
Aluminum chamber (base of projectile body)	Aluminum chamber (base of projectile body)	Early production and aluminum chamber body (After Aug 67 enclose)	Collar ring to retain impact switch assembly (FFAIS - Full Frontal Area Impact Switch)

MIL-HDBK-756(AR)

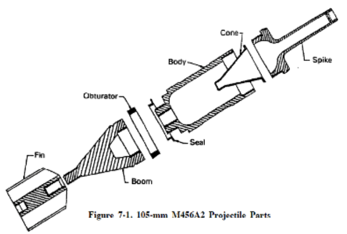


Figure 7-1. 105-mm M456A2 Projectile Parts

Example: Aluminum

- Literature indicates that "secondary aluminum" became the primary source for ordnance manufacturing.[1] "Secondary aluminum" refers to the process of taking scraps of aluminum and using them to create other parts, either via casting or machining. Ordnances were created using a die-casting process.
- Literature searches have not produced any specific info regarding the typical type of aluminum alloy used in ordnance manufacture.
- Based on present day literature and applications, aluminum cast alloy series 3xx.x is the preferred alloy for die casting applications.[2]
- Specifically, Aluminum A380 is the most common material for die casting applications.[3]

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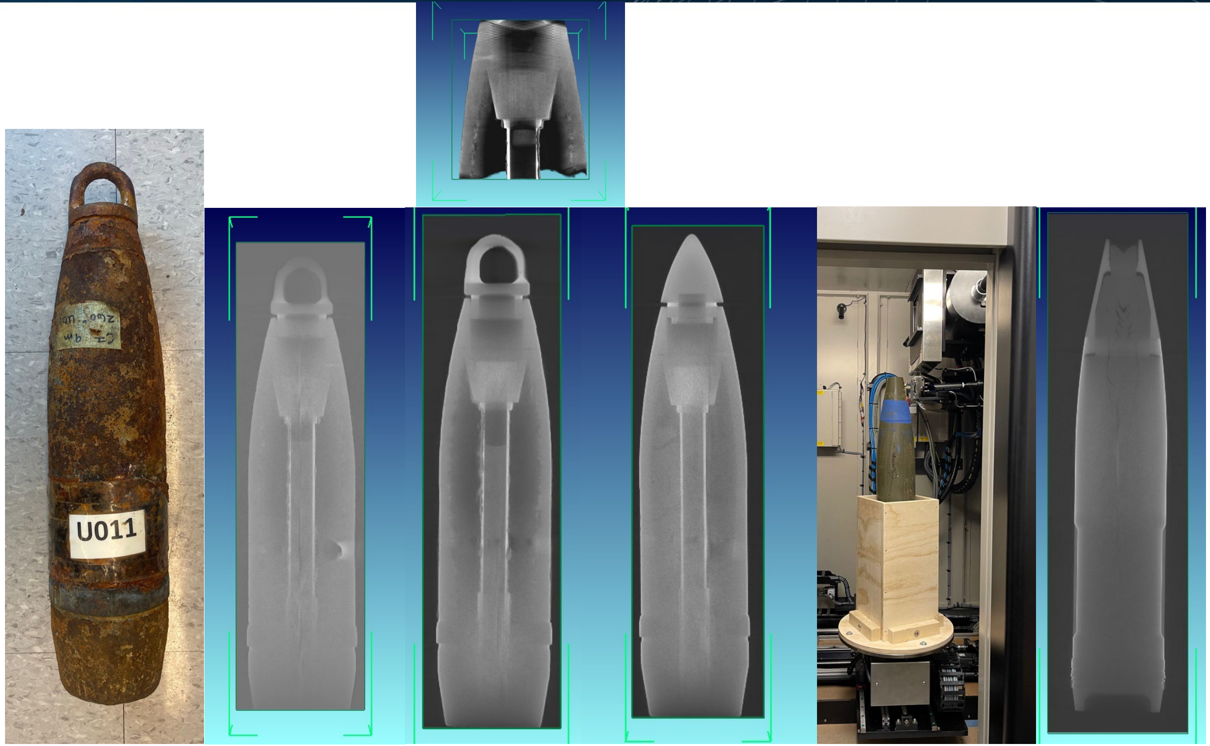
Results – UW X-ray CT Facility

- University of Washington X-ray Computed Tomography Facility (CTF)[4]
- Staffing at CTF was problematic
- Multiple rounds of scans were attempted, designed to test the limitations of the facility
- 105mm is achievable,155mm is problematic
- Biggest challenge is post-processing CT DICOM image files into a 3D STL format ingestible by COMSOL



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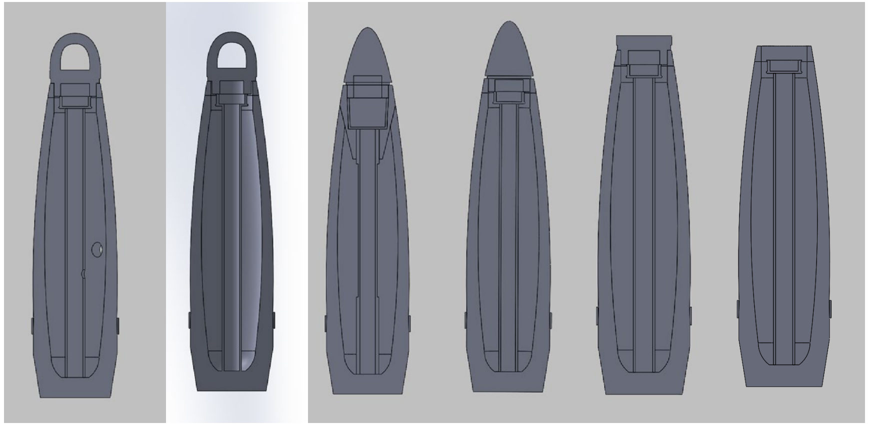
Results – Acoustic Modeling

Procedure for building high-fidelity models

- **Create CAD drawing using Solidworks**
- Import the CAD model into commercial finite element (FE) software COMSOL Multiphysics
- Repair mesh and geometry (mostly for 3D cases)
- Conduct mesh convergence tests
- Compute bistatic scattering amplitudes using the Hybrid 2D/3D FE/Propagation model[5]
- Convert bistatic amplitudes to lookup tables for use in Target-In-the-Environment Response (TIER) Model[6]

Results – Building CAD Models

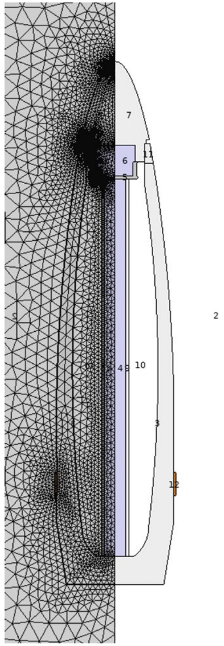
- CAD models were built using SolidWorks 2023
- Created up to six variations of each object
- 3D models for non-axisymmetric variations were provided to Dr. Ahmad Abawi in support of SERDP MR21-1275.



Results – FE Modeling

Procedure for building high-fidelity models

- Create CAD drawing using Solidworks
- **Import CAD model into commercial finite element (FE) software COMSOL Multiphysics 6.2**
- **Repair mesh and geometry (mostly for fins & internal parts)**
- Assign materials and conduct mesh convergence tests
- Compute bistatic scattering amplitudes using the Hybrid 2D/3D FE/Propagation model[5]
- Convert bistatic amplitudes to lookup tables for use in Target-In-the-Environment Response (TIER) Model[6]



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TASK 3

Results – FE Modeling

Procedure for building high-fidelity models

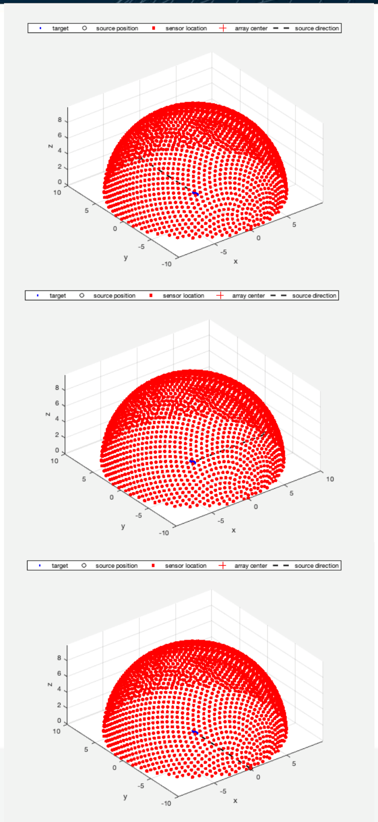
- Create CAD drawing using Solidworks
- Import CAD model into commercial finite element (FE) software COMSOL Multiphysics 6.2
- Repair mesh and geometry (mostly for fins & internal parts)
- **Assign materials and conduct mesh convergence tests**
- Compute bistatic scattering amplitudes using the Hybrid 2D/3D FE/Propagation model[5]
- Convert bistatic amplitudes to lookup tables for use in Target-In-the-Environment Response (TIER) Model[6]

Object	Filler
60 mm M720 body	water (open)
60 mm M720 body w/ fuze cap and tail	air
60 mm M720 body w/ fuze cap and tail	water
60 mm M49A2 body	water (open)
81 mm M889A1 mortar body, aluminum material	water (open)
81 mm M889A1 mortar body, steel material	water (open)
81 mm M889A1 mortar body with fuze cap and tail	air
81 mm M889A1 mortar body with fuze cap and tail	water
81 mm M889A1 mortar body with tail	water (open)
105 mm HEAT practice round with tail	air
105 mm HEAT practice round with tail	water
105 mm M456A1 HEAT with tail and internal components	all cavities air filled
105 mm M60 body and internal components	water (open)
105 mm M60 with fuze cap and internal components	all cavities air filled
105 mm M60 with fuze cap and internal components	all cavities water filled
105 mm M60 with fuze cap and internal components	water (outer) air (burster well & fuze cup)
105 mm M60 with flat end cap and internal components	all cavities air filled
105 mm M60 with flat end cap and internal components	all cavities water filled
105 mm M60 with flat end cap and internal components	water (outer) air (burster/fuze cup)
105 mm M60 high fidelity model from CT scan	air
105 mm M60 high fidelity model from CT scan	water
155 mm M107 Howitzer body	water (open)
155 mm M107 Howitzer body with buckle	water (open)
155 mm M107 Howitzer with flat endcap and buckle	air
155 mm M107 Howitzer with flat endcap and buckle	water
155 mm M483A1 Howitzer body	water (open)
155 mm M483A1 Howitzer with flat endcap	air
155 mm M483A1 Howitzer with flat endcap	water

Results – Bistatic scattering

<u>Procedure for building high-fidelity models</u>

- Create CAD drawing using Solidworks
- Import CAD model into commercial finite element (FE) software COMSOL Multiphysics 6.2
- Repair mesh and geometry (mostly for fins & internal parts)
- Assign materials and conduct mesh convergence tests
- **Compute bistatic scattering amplitudes using the Hybrid 2D/3D FE/Propagation model[5]**
- Convert bistatic amplitudes to lookup tables for use in Target-In-the-Environment Response (TIER) Model[6]



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Results: Bistatic scattering 105 mm M60

- Examples of the free field backscattering response for various 105mm M60s

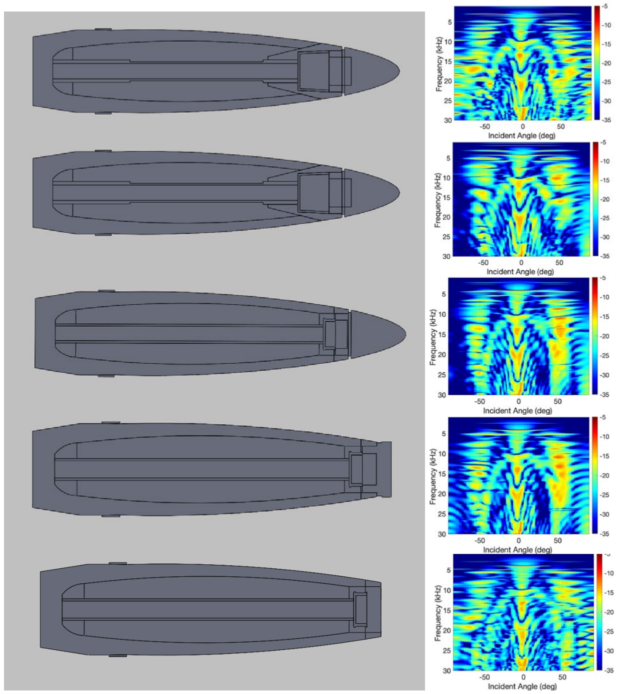
water-filled

air-filled

air-filled

air-filled

water-filled



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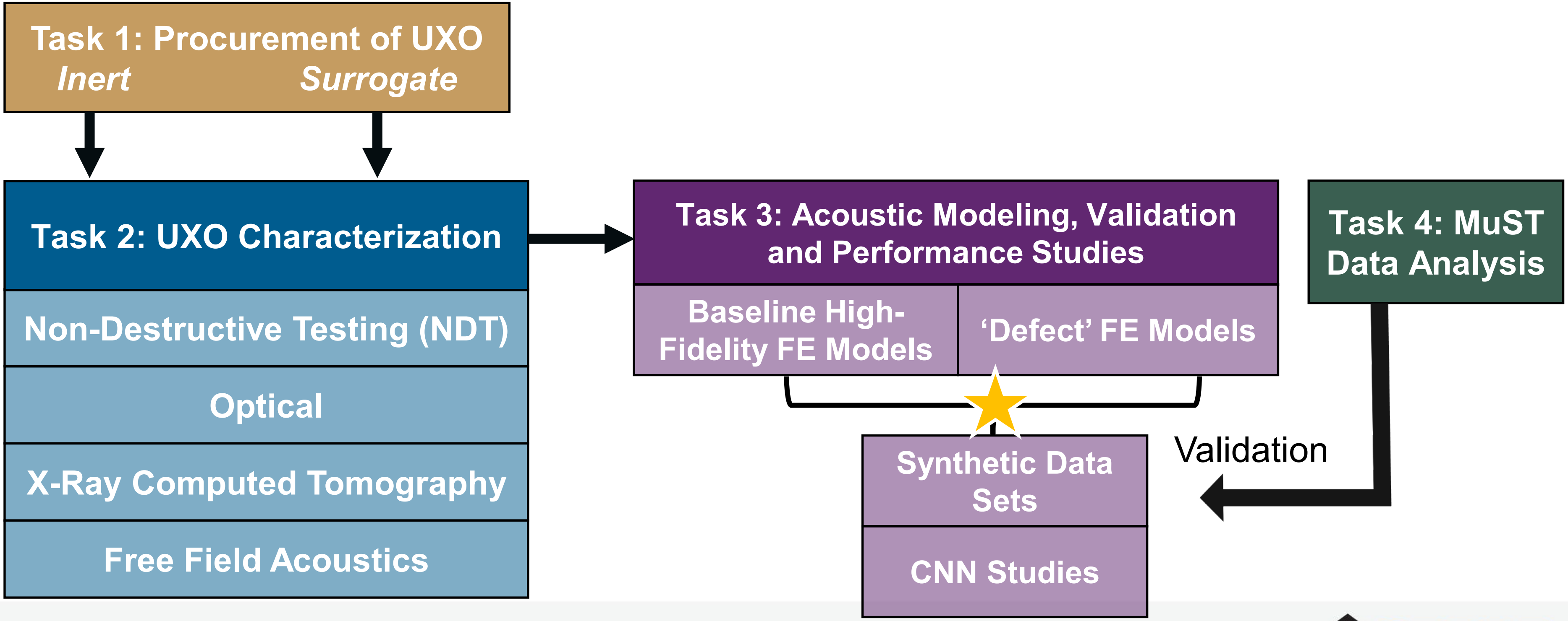
Technical Approach



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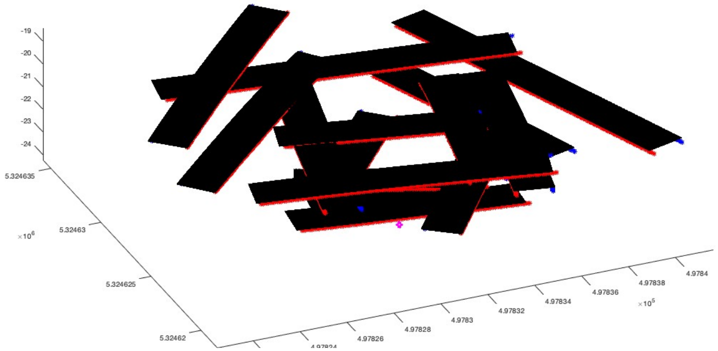
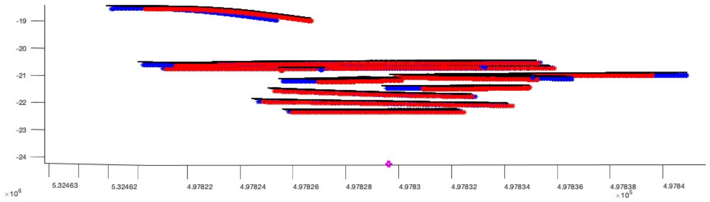
Results: MuST Data Survey

- Typical MuST collection:
  - 15 tracks or “looks” at an object
  - Each track is 200-400 pings
  - On average 19200 individually recorded signals (300 pings X 64 array elements)
- Several Post-Mission Analysis (PMA) tools exist for MuST
  - Mosaic Tool
  - Wavenumber “k-space” widget





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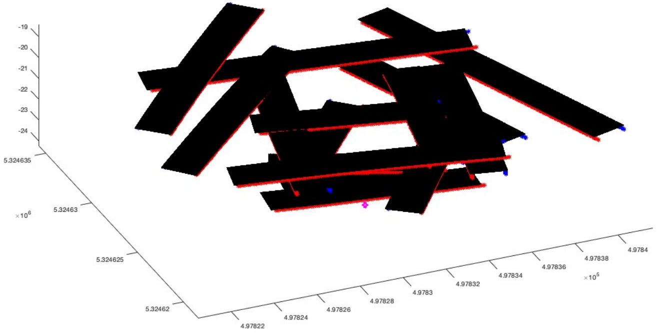
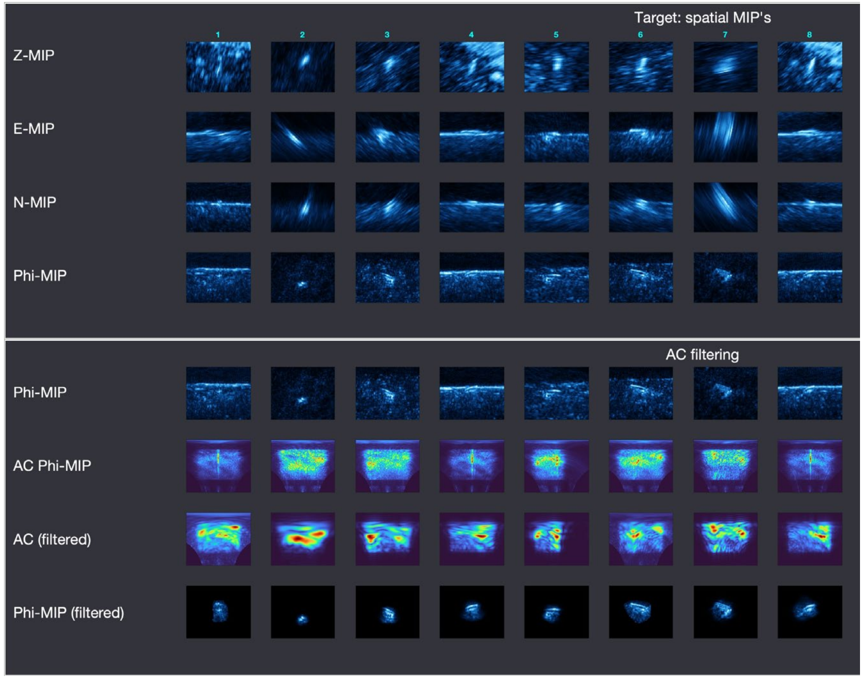
Results: MuST Data Survey

- Mosaic Tool
  - 2D spatial maximum intensity projections (MIPs) and acoustic color (AC) representations of each track

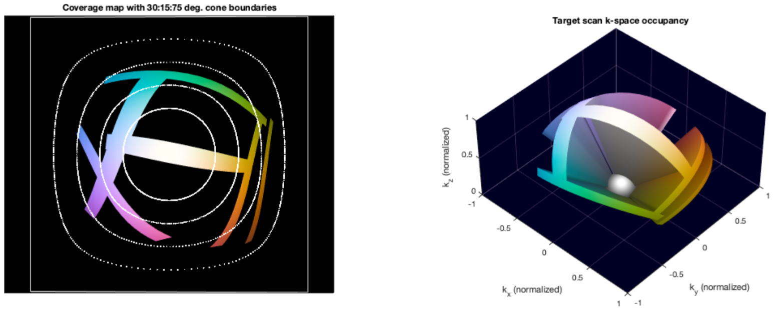


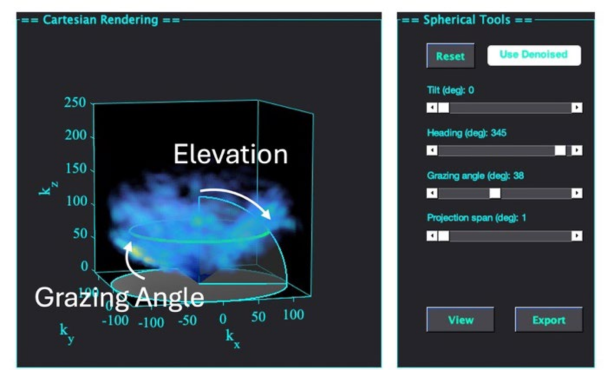


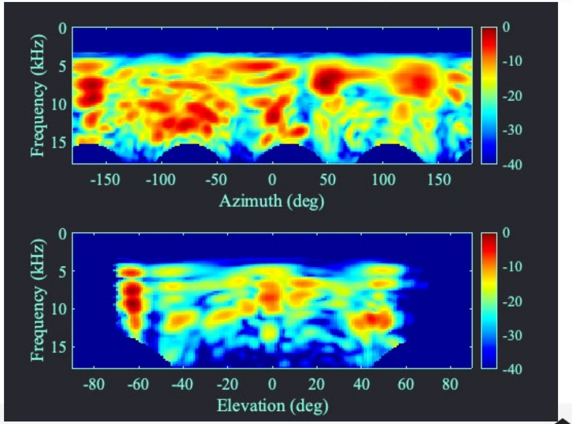
Results: MuST Data Survey

- 3D wavenumber “K-space” widget:
  - Each of the linear tracks occupies a portion of the 3D k-space
  - Renders a 3D volumetric representation of the data
  - You can export a series of 2D data products, projections of the 3D data onto 2D planes

Target wavenumber coverage







Conical plane gives the “traditional” acoustic color

The pie wedge yields the elevation response

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Results: MuST Data Survey

- Validation Cases:
  - Sequim Bay 2021 data set includes several of the munitions that were physically characterized at APL.

MUST Label	PNNL Label	Burial	Tilt (deg)	Orientation (deg)
U204	U204	proud	0	350
U002	U002	1/2 buried	-2	30
TOI11	U011	1/2 buried	15	180

Will focus on U204 in this presentation (challenging target, simple deployment condition)

U002 – 155mm Howitzer w/ open end

U204 – 105mm M60 with fuze plug

U011 – 105mm M60 with lifting plug

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Results: TIER Simulations for MuST

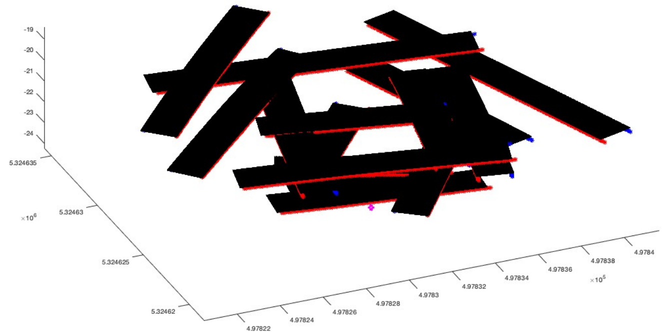
- Initial procedure:
  - Utilize PNNL ground truth file to identify candidate targets for validation
  - Examine the MUST data for these candidates to ensure data looks good
    - Was the seafloor subtraction successful?
    - Were there enough good looks at the object?
  - “Pre-condition” the data to fill in any missing info that TIER may require
  - Sensor positions and other system info are extracted directly from the data and fed to TIER.
  - TIER simulates identical sensor and array positions
  - Beamform all the TIER data with the same procedure used for MUST data
  - The result is a post-processed TIER data file (IM_dats file) that can be ingested by the MUST visualization tools

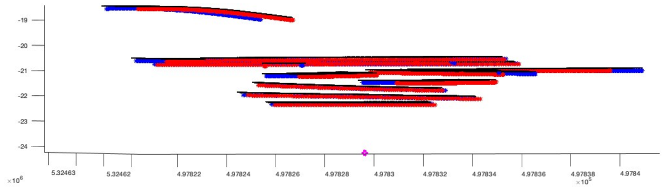
Results: TIER Simulations for MuST

- Lessons Learned during validation step
  - Quickly learned that the ground truth may not be as reliable as we thought (from a target orientation/burial standpoint)
  - Examining representations in multiple spaces (spatial, acoustic color and wavenumber) was crucial for diagnosing alignment errors
  - Representations with information from all looks compiled together were hard to decipher

Results: TIER Simulations for MuST

- 15 tracks over a target
- Typically run at least 3 target orientations
- Each track is ~200-400 pings
- On average 19200 individually recorded signals (300 pings X 64 array elements)
- A signal is sampled at 97.7 kHz over a 30ms time window
- Computation time is approx. 7 min per track
- Tracks can be run in parallel
- Each track is 1.6 GB
- 19 GB of data
- Beamforming process takes 20 min if you have a Nvidia GPU
- The bottleneck tends to be all the data transfer





Results: TIER Simulations for MuST

MuST Data

TIER Simulation

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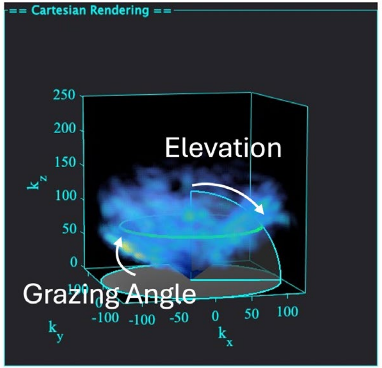
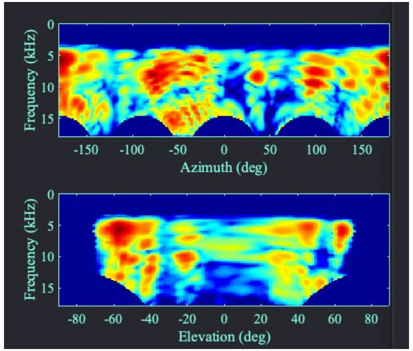
Results: TIER Simulations for MuST

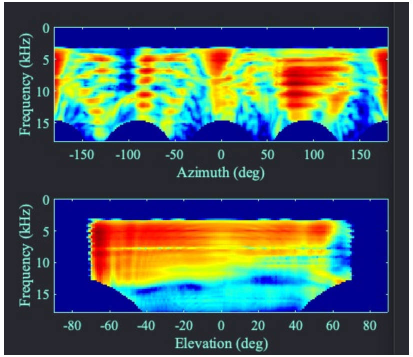
MuST Data (all tracks)



MuST Data

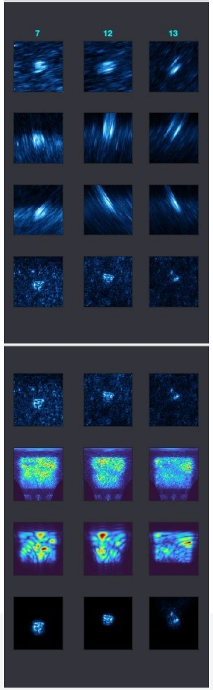


TIER Simulation

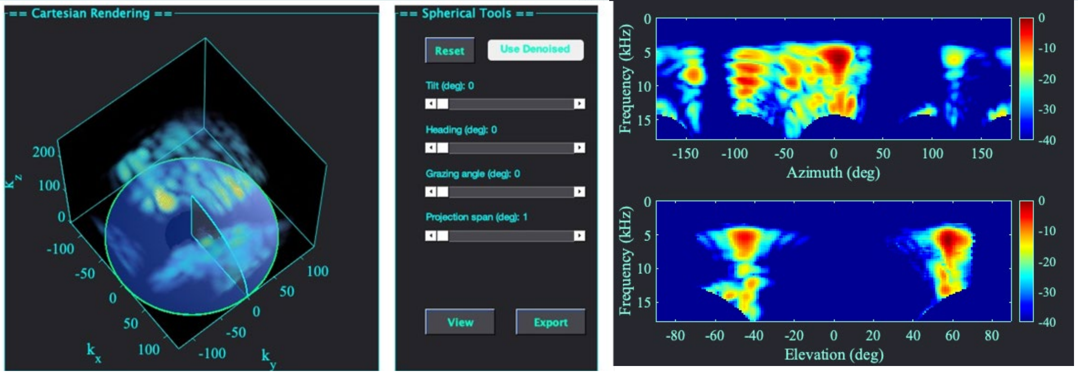


Results: TIER Simulations for MuST

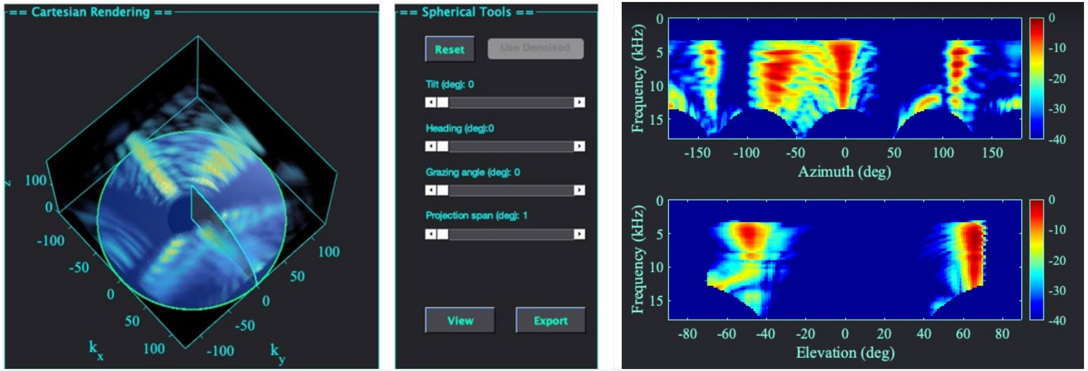
Examine only the tracks that span broadside to 40deg.



MuST Data



TIER Simulation



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Results: CNN Analysis

- Technical objective:
  - Utilize validated acoustic modeling techniques to quantitatively analyze the effects that variability in UXO characteristics has on the measured response
- Goal was to accomplish this via MuST CNN classifier rather than “eye-ball” comparisons of data products
- Generated simulated data for the U204 utilizing 6 different variations of M60
- Requires establishing CNN pipeline for TIER data that is identical to that used on MuST data
  - TIER simulated data products (AC and image) were pre-processed with identical procedure used on MuST data products
  - Utilize the CNN classifier developed via training on all MuST data collected to-date
  - AC and image scores are averaged on a track-by-track basis to provide the final class score

Literature version
Fuze endcap (WF/AF)

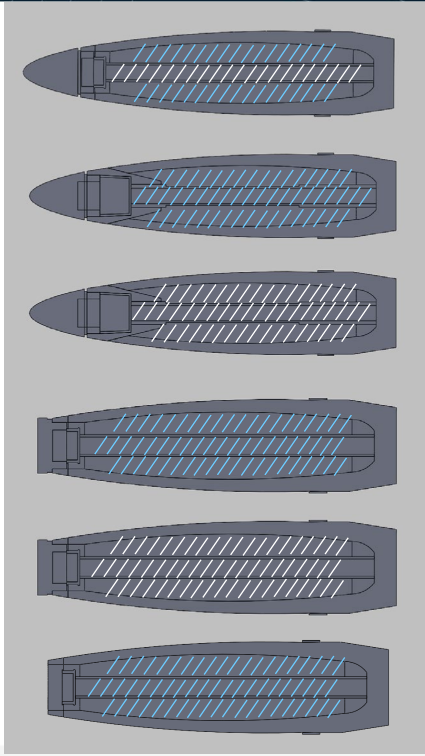
CT Scan (WF)

CT Scan (AF)

Literature version
Flat End (WF)

Literature version
Flat End (AF)

Open End (WF)



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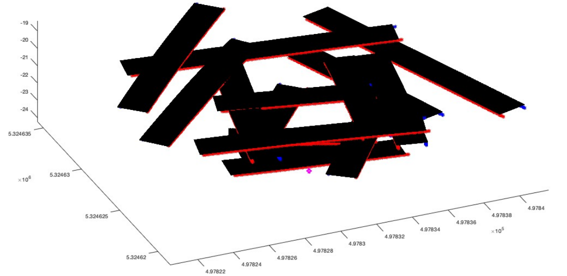
Results: CNN Analysis

MuST Data



AC filtering

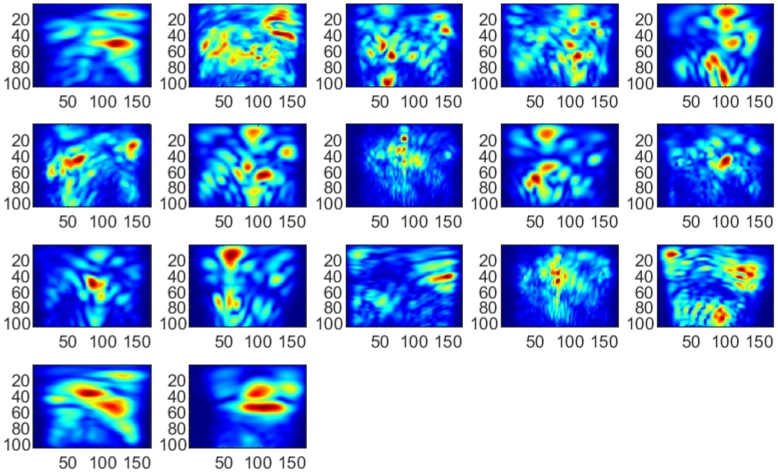
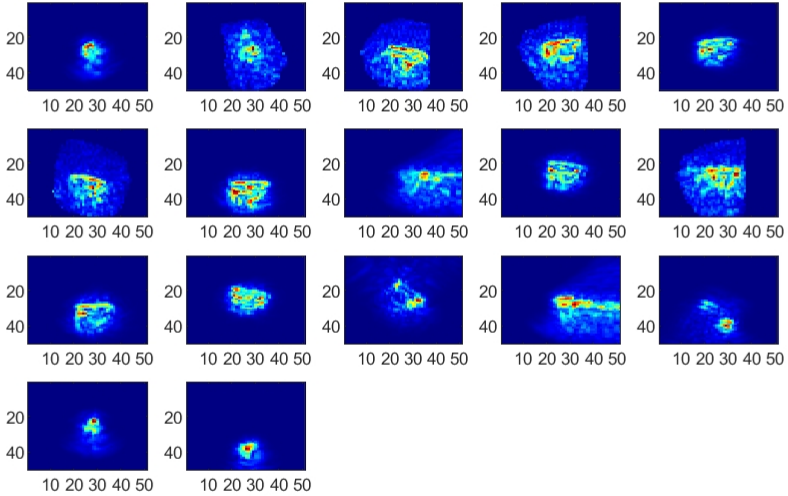


Image domain



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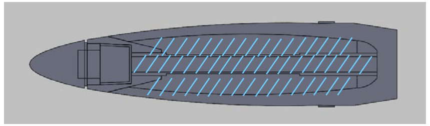
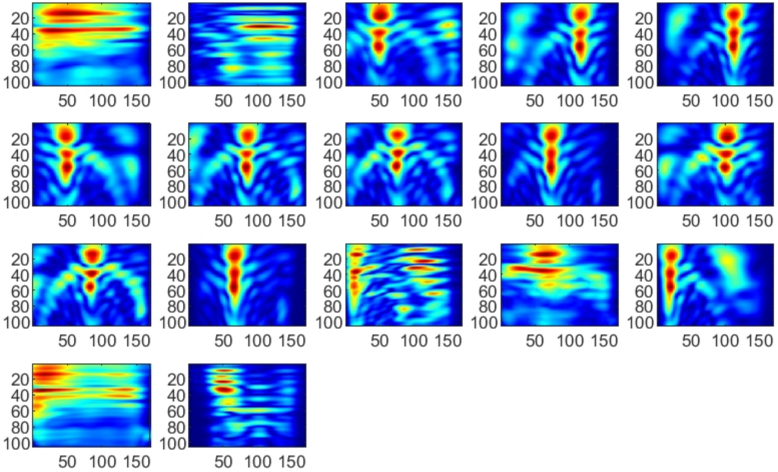
Results: CNN Analysis

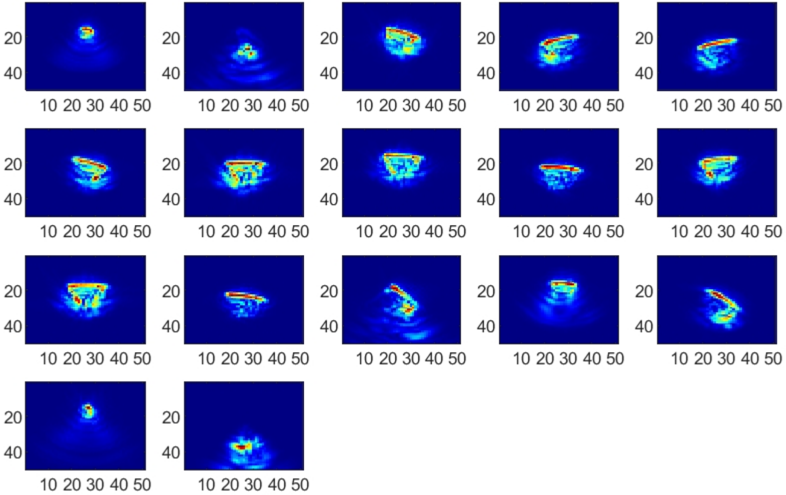
TIER Data
CT Scan (WF)



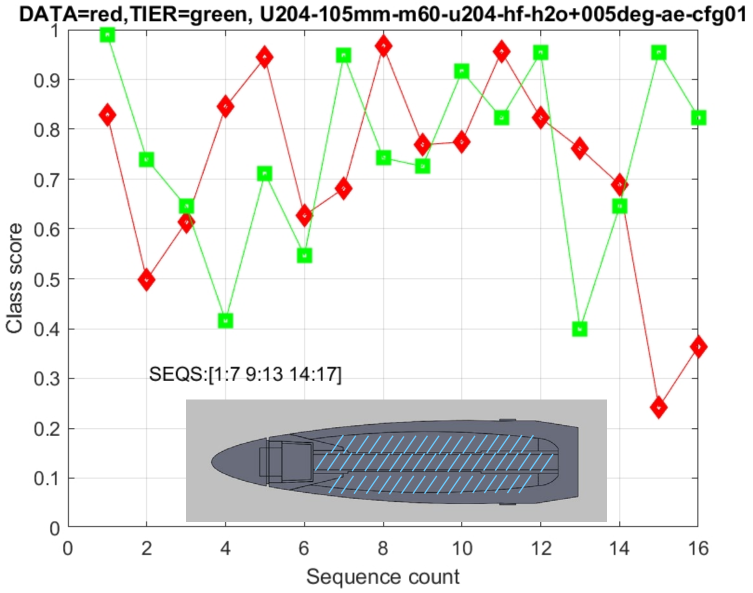
TIER AC filtering



TIER Image domain



Results: CNN Analysis



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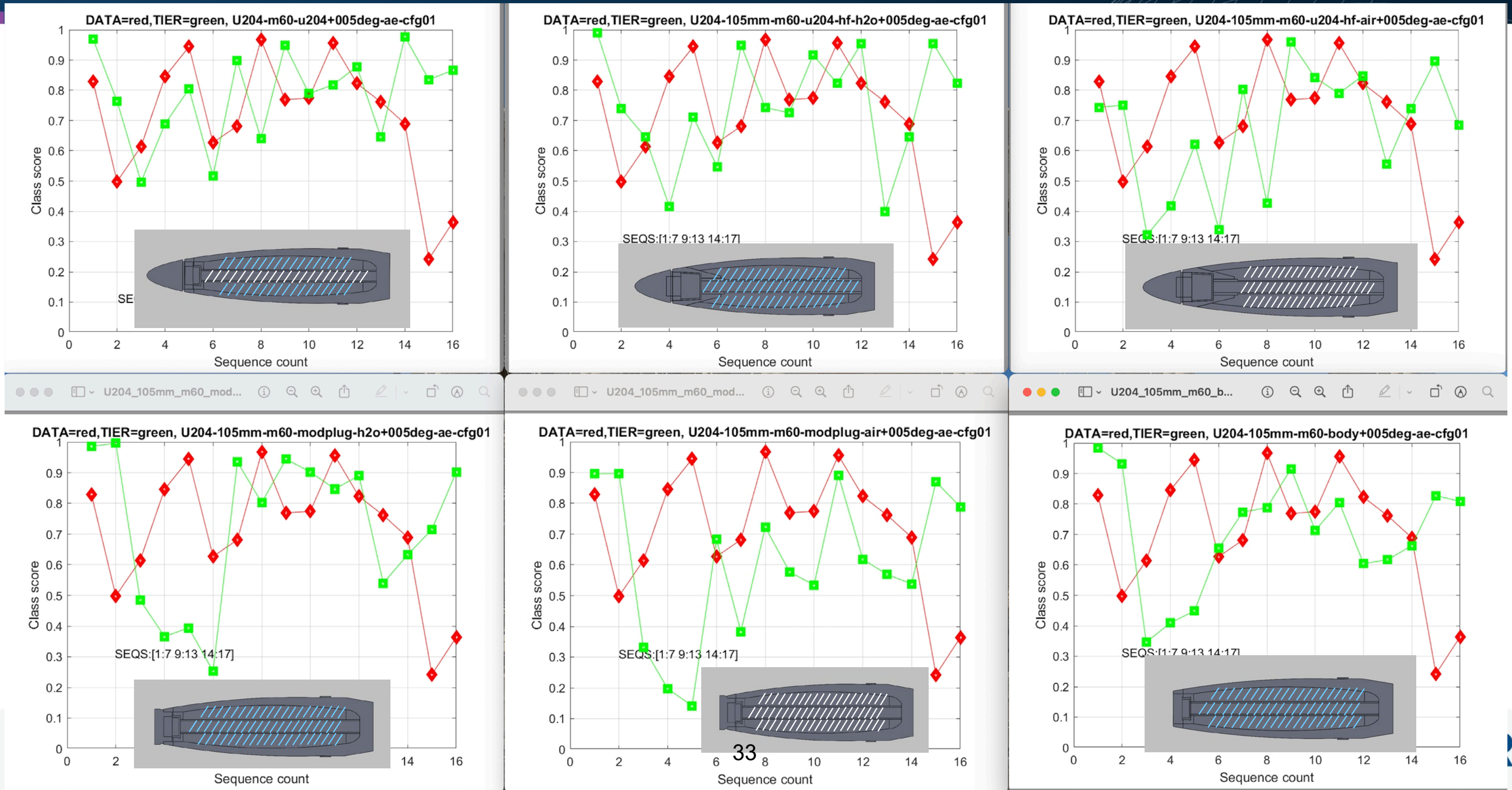
TASK 3

Results: CNN Analysis



Next Steps

- Final report will be submitted this week.
- Based on IPR feedback, propose a follow-on ESTCP project centered on providing simulated data and corresponding analysis that supports answering problems faced as systems transition to live-site deployments

Technology Transfer

- Completed:
  - SERDP/ESTCP Webinar presented on July 25, 2024
  - CAD models provided to Dr. Ahmad Abawi in support of SERDP MR21-1275
  - TIER simulated data provided to Dr. Kevin Williams (ESTCP MR23-7596) for preliminary CNN analysis presented here
- In-progress:
  - TIER model is currently being developed into a tool for the community under ESTCP MR23-3974 (Dr. Steven Kargl)
- Future possibilities:
  - CAD models and/or TIER simulated data can be provided to other SERDP/ESTCP project performers
  - Sidebar and workshop participation that brings together modelers, system developers and live-site experts

Backup slides

MR-3978: UXO Characterization for Underwater Acoustic Test Beds

Performers: **Dr. Aubrey España (PI), Dr. Steven Kargl (Co-I), Mr. Nick Michel-Hart (Co-I), Ms. Evelena Burunova, Mr. Ben Brand**

Technology Focus

- Characterize and create acoustic models for inert/surrogate UXO currently in use at underwater UXO acoustic test bed sites

Research Objectives

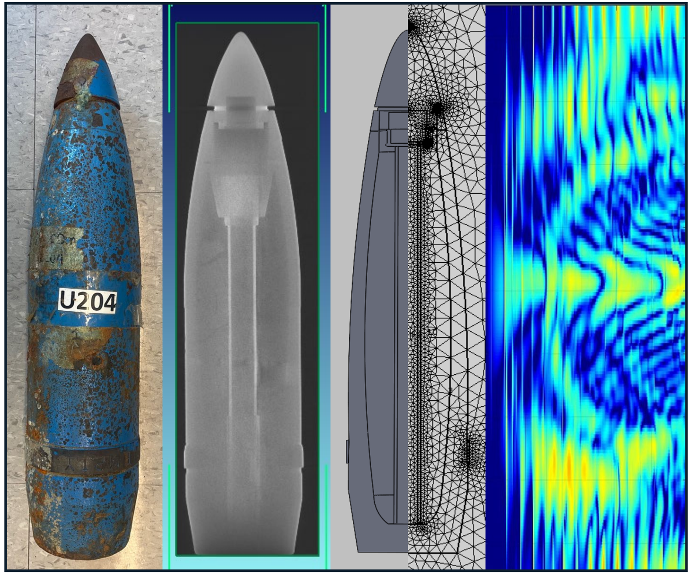
- *Establish methods for characterizing the physical properties of inert/surrogate UXO.*
- *Build CAD models for the UXO with varying degrees of fidelity*
- *Utilize acoustic models to characterize the effects of variability in UXO model fidelity*

Project Progress and Results

- *Physically characterized 5 classes of inert UXO*
- *Created 20 variations of CAD models and executed the acoustic models to create bistatic scattering tables*
- *Transforming these model results into a format that can be ingested directly into MuST processing tools (both live and post-mission)*

Technology Transition

- *Acoustic model results can be utilized during missions over live sites*
- *The knowledge, characterization techniques and modeling procedure can be used to shift focus to characterizing objects at live UXO sites.*



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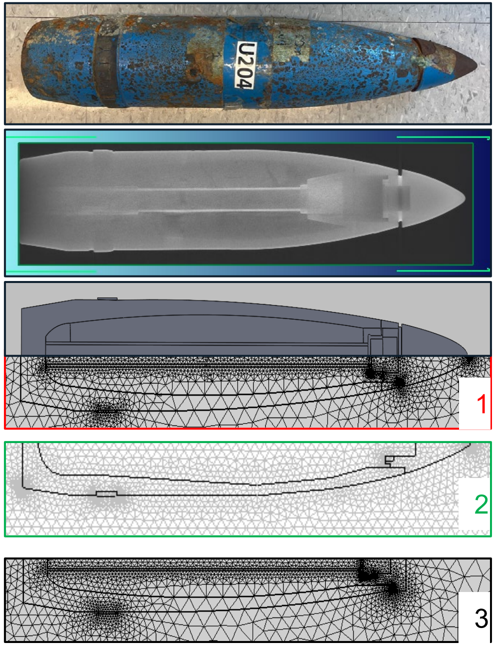
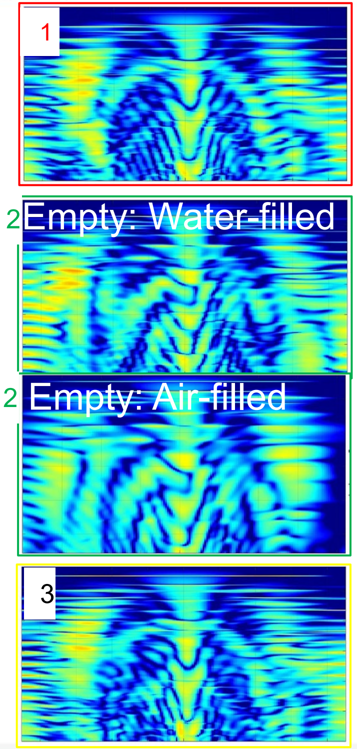
Plain Language Summary

- Assessing performance of systems during demonstrations at test bed sites is complicated by the fact that each test bed has different sets of surrogate/inert UXO
- Furthermore, it is unknown how closely the characteristics of the surrogate UXO need to match those of the inert versions
- This project aims to characterize inert UXO to a high level of fidelity by utilizing a variety of technologies (dimensioning, NDT, X-ray CT scans, acoustic measurements) and build CAD models for several variations added to the high-fidelity versions
- A combination of acoustic model results and analysis of MuST data from deployments at Sequim Bay Test Bed are used to qualitatively analyze the effects of varying conditions and properties within UXO classes
- By the end of the SEED Project, we expect to have accomplished the following:
  - Established a clear method for physically characterizing and building models for inert UXO
  - Transition the acoustic model results to a tool that is currently being used in post-mission analysis of MuST data, but which we anticipate will become a more critical piece during upcoming live-site missions
  - Have a better qualitative assessment of the relative importance of various physical characteristics of inert UXO

Impact to DoD Mission

- High-fidelity acoustic model results have been computed for a wide variety of inert UXO
- These model results are being integrated into a tool for use in the MuST system during live-site deployments
- To-date, an issue that has not been addressed is the fact that the UXO systems were developed and tested over inert UXO
- There can be significant differences between inert versus live-site UXO
- This SEED effort has established the methodologies and tools necessary to quantitatively investigate the impact of these differences





Publications

- SERDP/ESTCP Webinar on July 25, 2024

Literature Cited

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2. JR Davis. Alloying: Understanding the Basics, ASM International, p351 – 416, (2001).
3. https://www.mesinc.net/wp-content/uploads/2015/05/Die-Casting-Aluminum-Selection-Guide.pdf
4. University of Washington X-ray Computed Tomography Facility, https://www.ce.washington.edu/research/facilities/xray
5. A.L. Espana, K.L. Williams, D.S. Plotnick, and P.L. Marston, “Acoustic scattering from a waterfilled cylindrical shell: Measurements, modeling, and interpretation," The Journal of the Acoustical Society of America, vol. 136, pp. 109-121, 2014.
6. S. Kargl, A. L. Espana, K. Williams, J. L. Kennedy, and J. Lopes, “Scattering from objects at a water-sediment interface: Experiment, high-speed and high-fidelity models, and physical insight," IEEE Journal of Oceanic Engineering, vol. 40, pp. 632-642, 2015.

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Backup material

Results – NDT Thickness Gage

- NDT gage can be used to measure shell thickness &/or material's acoustic velocity
  - If thickness of material is known then NDT is used to determine the acoustic velocity
  - If acoustic velocity is known then NDT is used to measure shell thickness
- Challenge: working with two unknowns
- Achieving any form of readings for corroded munitions was challenging
- Transducer size matters: smaller transducers work best on curved surfaces and thin materials
- Once thickness or acoustic velocity was determined then obtaining readings (peaks) on NDT plot was possible

NDT: Olympus Panametrics-NDT 25MX PLUS
Transducer: Olympus M116, 20/0.125”

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Results – Building High-Fidelity Models

Meshing:

- Axisymmetric shells were straight-forward
- UXO with internal components or fins were extremely challenging
- Maintained close collaboration with Dr. Abawi

105mm M60 Projectile –

IMMEDIATE ACTION ITEMS

- Run full 3D Update #2 model
- Run axisymmetric model

TASK	PERSON	STATUS	COMMENTS
Preliminary Solidworks model to Ahmad	Evelena	Complete	• Preliminary design did not have hole or fuze adaptor, nor was the rotating band a separate part
Preliminary 3D Comsol Mesh	Ahmad	Complete	• Meshed just fine
Updated Solidworks model	Evelena	Complete	• Update #1 - Made the rotating band near endcap separate domain, plug and fuze adaptor design, added a hole in the side. • Update #2 – minor adjustment to well cup. • Update #3 – Remove intersecting lines near well cup.
Finalized 3D Comsol Mesh	Ahmad	Complete - Update #2 is meshed	• Update #1 - Sent SAT file to Ahmad on 2/6/23 • Update #2 - Sent SAT file to Ahmad on 9/27/23 • Update #3 – Sent SAT file to Ahmad on 1/30/24
Material Parameters	Evelena	Complete	• Material info sent to Ahmad on 2/6/23
3D computation	Ahmad	Complete	• Which version was run?
Transfer of 3D files to Steve	Ahmad	Complete	
Implementation of 3D results into TIER	Steve	Complete	
Axiscat computation	Evelena	In-progress	• Axiscat run for this object with plug in end, but hook cutoff. Cavity is water-filled, burster well is air-filled. • Which axyismmetric version was run, and how does it compare to Ahmad?

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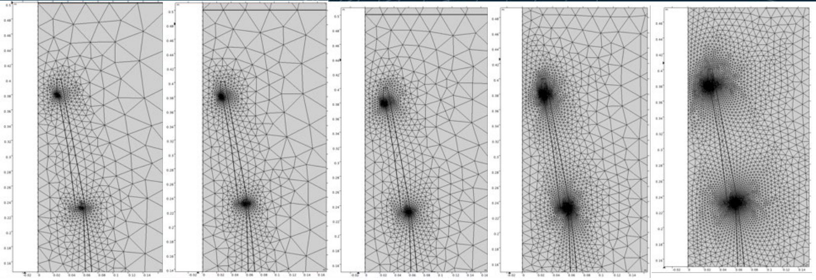
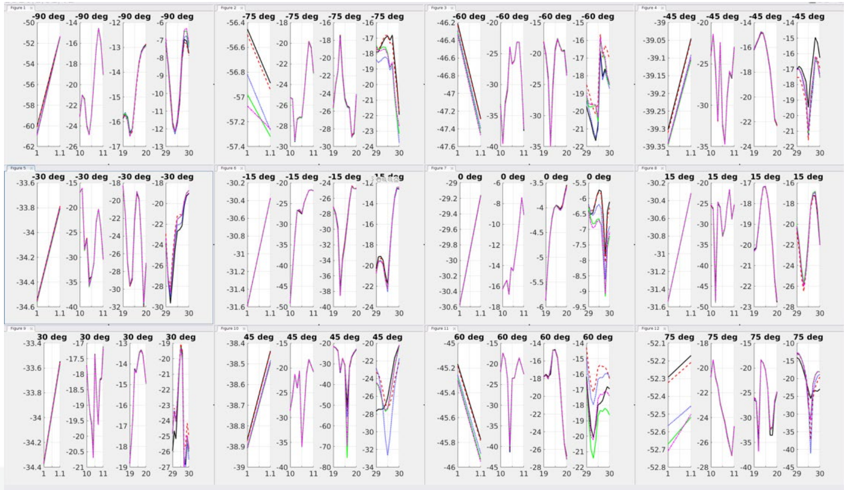
Results – Acoustic Modeling

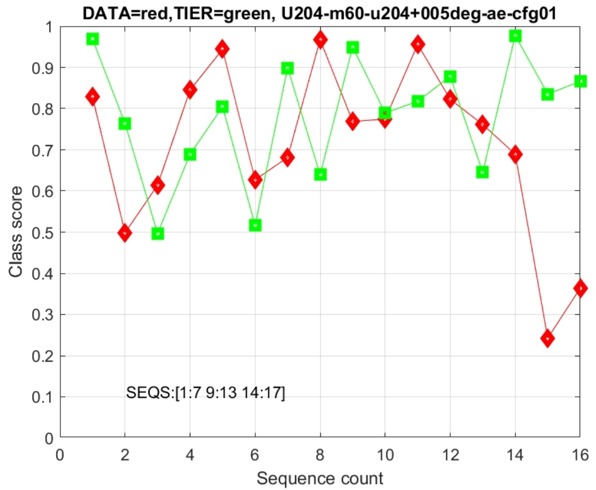
Procedure for building high-fidelity models

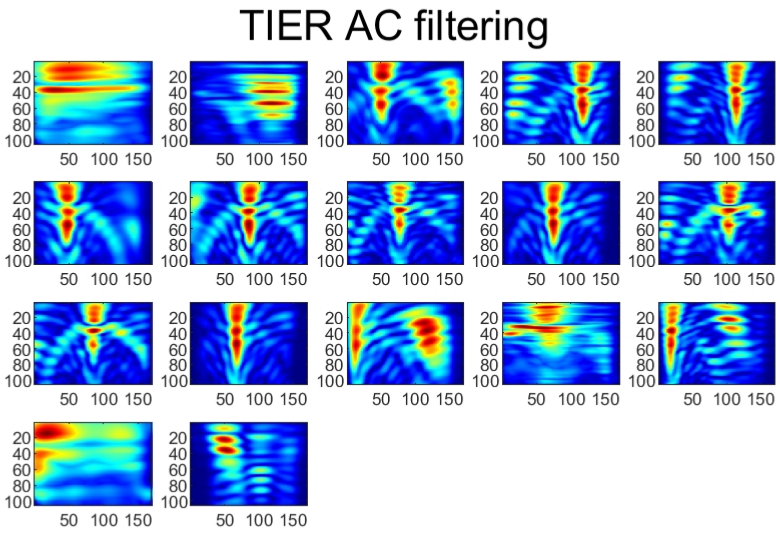
- Create CAD drawing using Solidworks
- Import the CAD model into commercial finite element (FE) software COMSOL Multiphysics 6.2
- Repair mesh and geometry (mostly for fins & internal parts)
- **Assign materials and conduct mesh convergence tests**
- Compute bistatic scattering amplitudes using the Hybrid 2D/3D FE/Propagation model[5]
- Convert bistatic amplitudes to lookup tables for use in Target-In-the-Environment Response (TIER) Model[6]

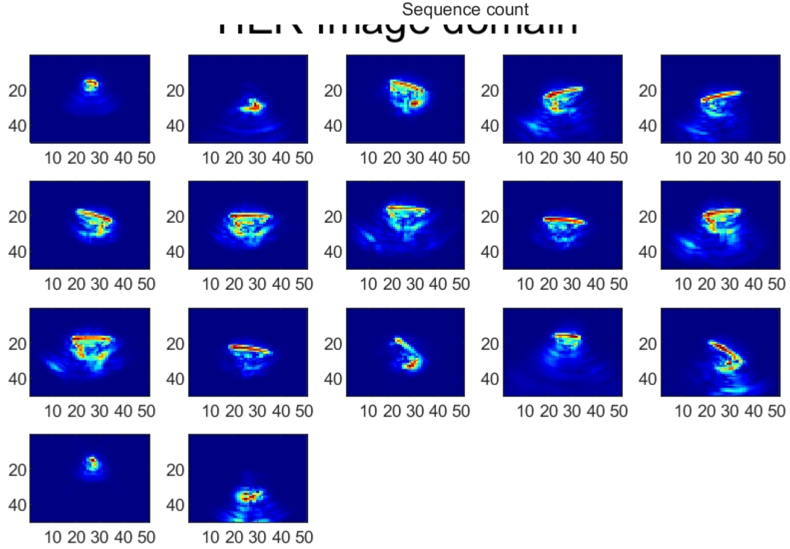




Results: CNN Analysis







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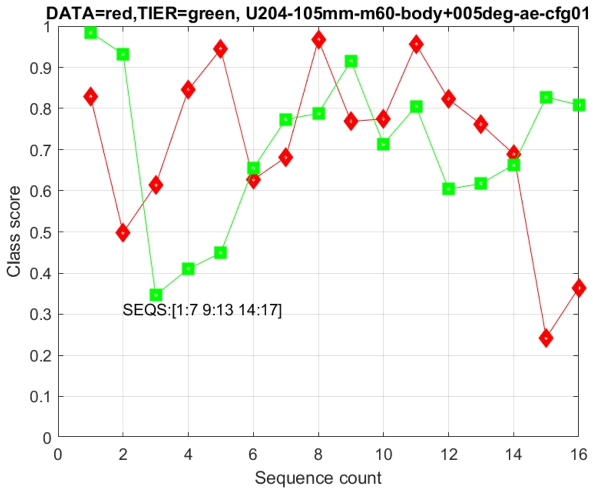
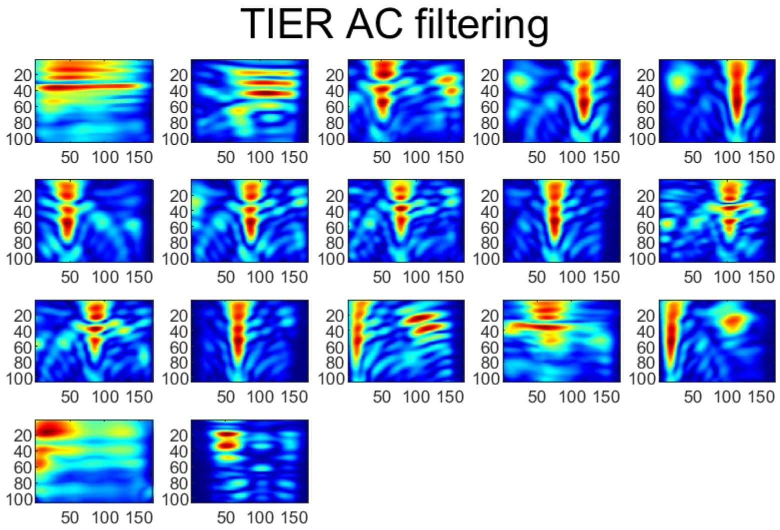
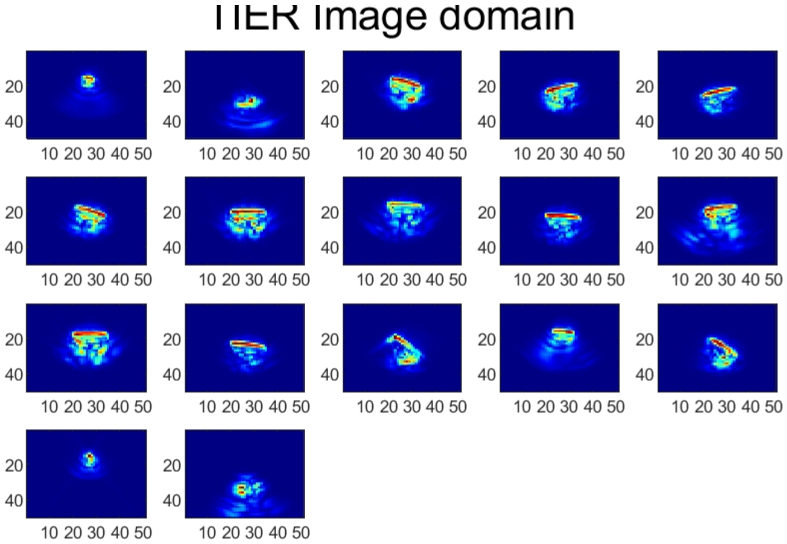
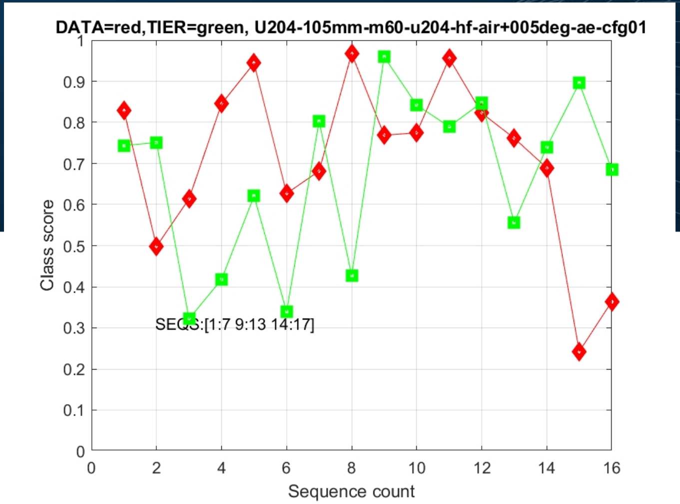




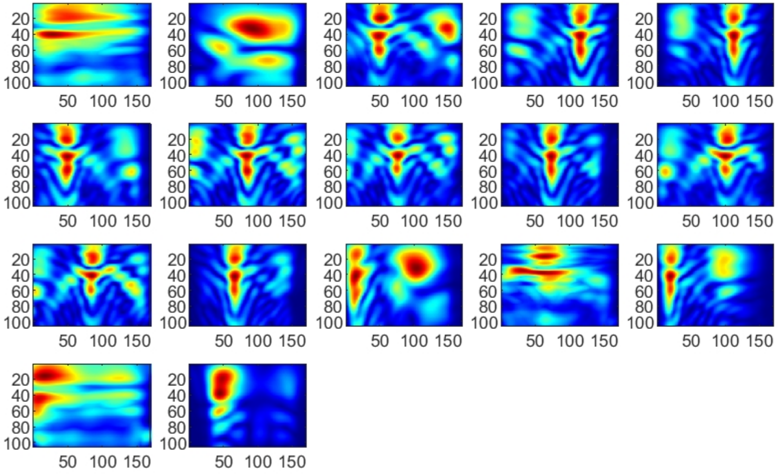


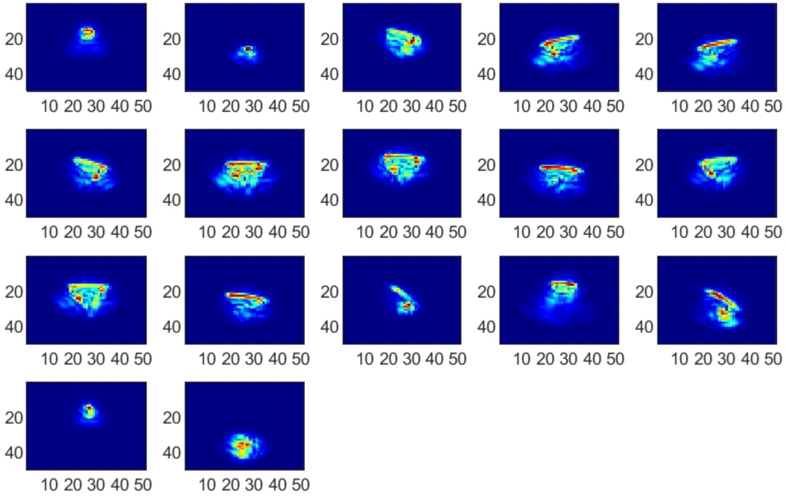
TASK 3

Results: CNN Analysis



TIER AC filtering





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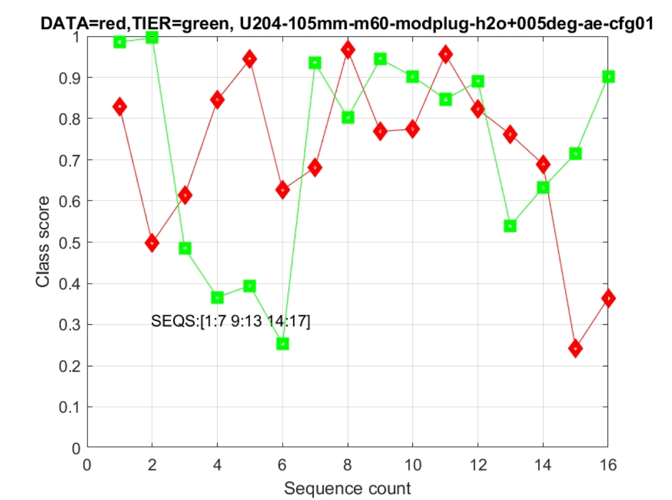
Results: CNN Analysis



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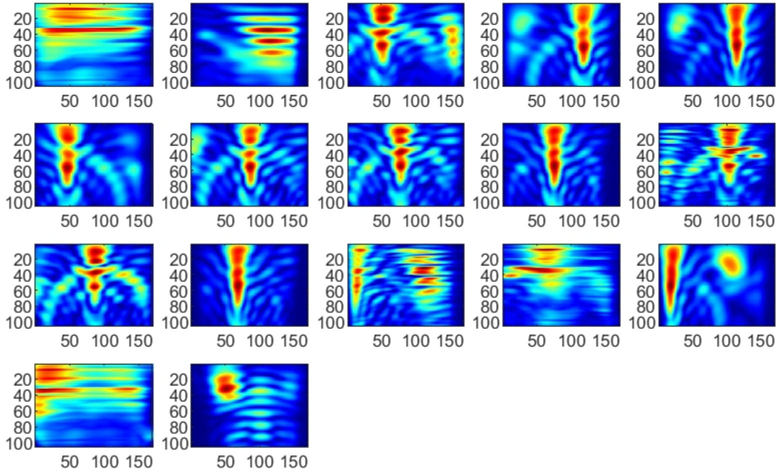

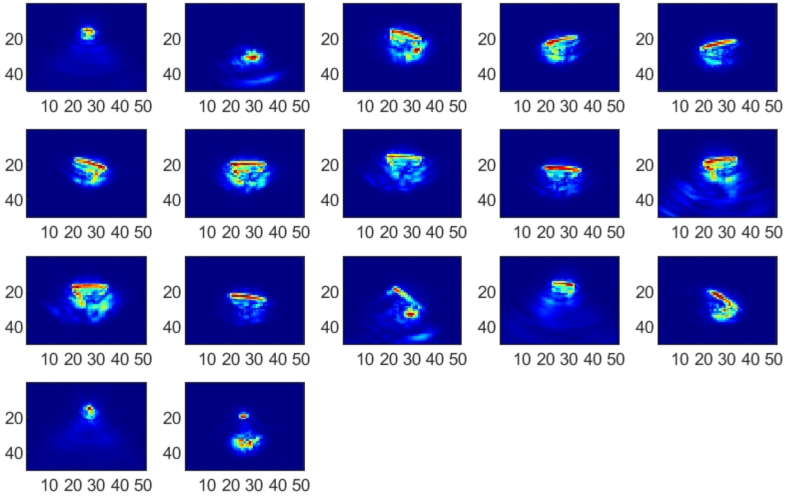

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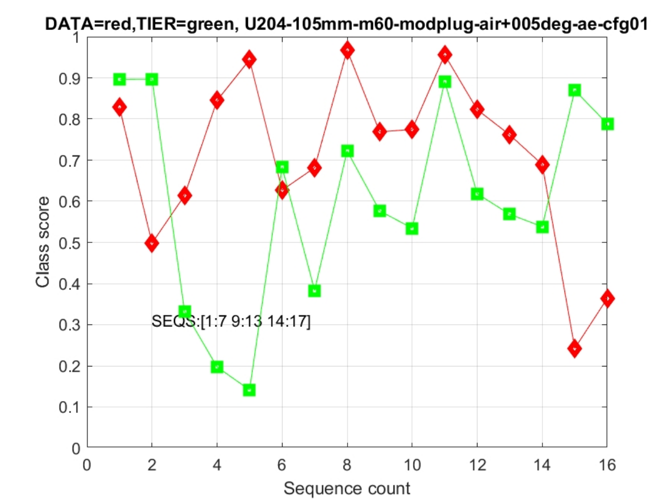

TIER AC filtering