Long Time Series Measurements of Munitions Mobility in the Wave-Current Boundary Layer

MR-2320

Joe Calantoni

U.S. Naval Research Laboratory

In-Progress Review Meeting

15 May 2018

SERDP

DOD ▪ EPA ▪ DOE

MR-2320: Mobility and Burial Measurements

Performers: Joe Calantoni (U.S. Naval Research Laboratory)

Technology Focus

- *Evaluating suite of instrumentation to make high fidelity, long-term observations of hydrodynamic forcing, sedimentology, and munitions mobility and burial including "Smart Munitions"*

Research Objectives

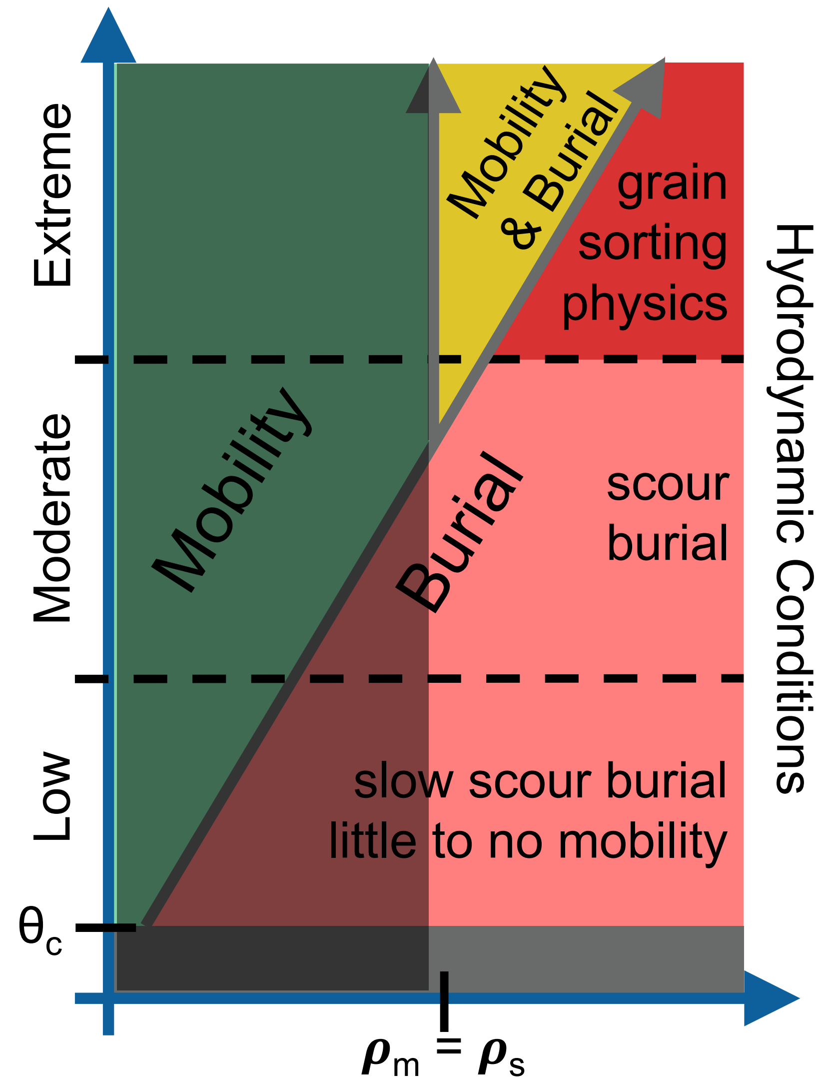
- *Our objective is to provide in situ time series measurements of boundary layer hydrodynamics while simultaneously monitoring the resulting mobility and burial of munitions*

Project Progress and Results

- *Executed three field experiments for range of conditions*
- *Quantified the role of munitions bulk density on mobility and burial for range of munitions characteristics in situ*
- *Directly measured munitions bulk density for 70 items*
- *Developed sediment instability model for extreme burial*
- *Correlated statistics of mobility to water wave statistics in situ*

Technology Transition

- *Prepare and distribute documentation for all aspects of experimental methods, including design, fabrication, deployment, recovery, and signal processing*
- *Complete and distribute database of munitions characteristics including estimates of bulk density distributions*
- *Reduce dimensionality of the problem regarding munitions characteristics and environmental forcing conditions*



Social Media Content

Underwater munitions bury in the sand… *Joe Calantoni from the U.S. Naval Research Laboratory performs a tabletop demonstration to explain the physics of munitions burial in underwater environments. As water waves grow large during storms they generate momentary failure of the sand bed. The physics of granular sorting determines whether munitions will bury or rise to the surface.*

Project Team

- PI, Joe Calantoni (U.S. Naval Research Laboratory)
- Co-PI, Alex Sheremet (University of Florida)

Other significant contributors:

- Ed Braithwaite, Blake Landry, Christy Swann, Sam Bateman, Ryan Mieras*, Jan Watkins*, Donya Frank*, Adam Seyfarth**, & Rob Hagg** (NRL)
- Harald Klammler*, Tracy Staples & Uriah Gravois (UF)
- Diane Foster & Meagan Wengrove (UNH)
- Jesse McNinch (USACE)
- Carter Duval (UD)

Problem Statement

- Needs in the underwater environment include:
  - Assess predict location of munitions relative to the bed
  - Assess environment where munitions are found
- Need to couple munitions mobility with hydrodynamic & sedimentary processes
- Environmental forecasting critical for optimizing sensor performance

23 April 2014

http://www.dailymail.co.uk/travel/article-2611037/Mappleton-beach-cordoned-Second-World-War-bomb-blown-EIGHT-rockets-sands.html

Technical Objective

Our objective is to provide in situ time series measurements of boundary layer processes responsible for munitions mobility while simultaneously monitoring the mobility of surrogate munitions.

Technical Approach Overview

- Observations guided by hypothesis for the conditions that favor munitions mobility versus burial *in situ*
- Developed / fabricated / deployed
  - ♦ Range of munitions caliber (20 mm – 155 mm)
  - ♦ Range of munitions density (plastic to steel)
  - ♦ Smart surrogates (embedded IMU)
- Executed three field experiments (7 m – 20 m depths)
  - ♦ Apr-May 2013 at Panama City Beach, FL (sandy; max h_s= 2 m)
  - ♦ Jan-Mar 2015 at Duck, NC (sandy; max h_s= 5 m)
  - ♦ Feb-Apr 2017 at Wallops Island, VA (mixed; max h_s= 3 m)
- Performed measurements of bulk density of surrogate and inert munitions at Blossom Point Facility (Dec 2016)
  - ♦ Produce probability distributions for range of munitions density

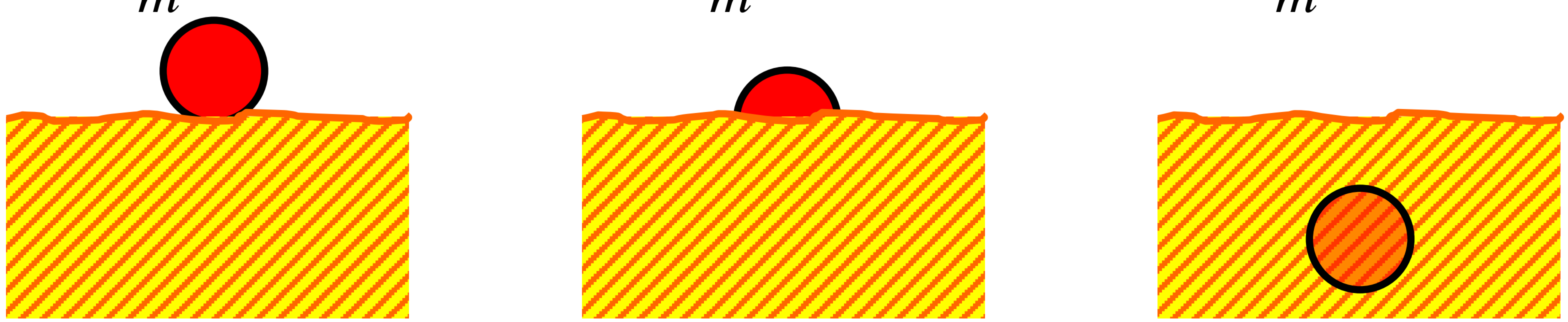
Mobility versus Burial Hypothesis

Cartoon on the role of relative density for munitions mobility and burial in sandy sedimentary environments

relative density, s_m, is the ratio of density of munitions to the density of sediment

$$s_m = \frac{\rho_m}{\rho_s}$$

$s_m < 1$ | $s_m \approx 1$ | $s_m > 1$



MOBILITY ⟷ **BURIAL**

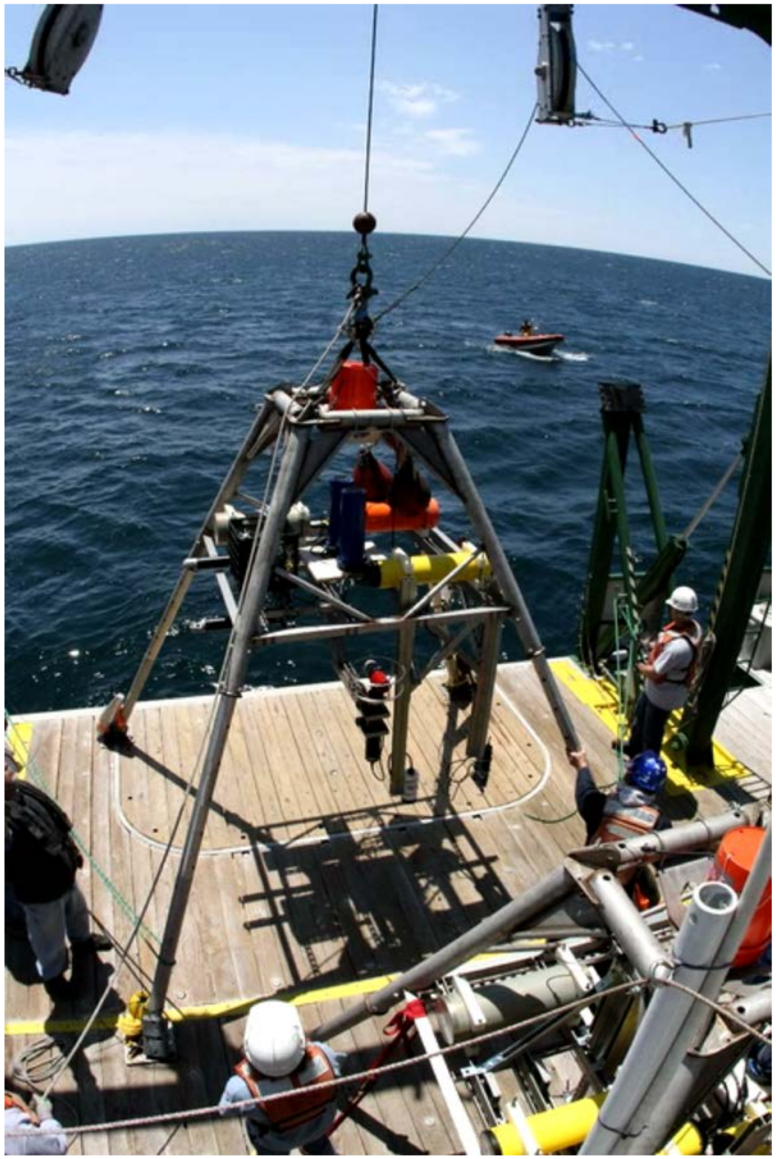
(see "Why the Brazil Nuts are on Top…", Rosato et al., Physical Review Letters, 1987; "Reverse Brazil Nut Problem…", Hong et al., Physical Review Letters, 2001)

Fabricated Surrogate Munitions

- 20 mm to 155 mm calibers
- Included shape effects
- Range of bulk densities
- Range of rolling moments
- Attached acoustics pingers

Surrogate Smart Munitions

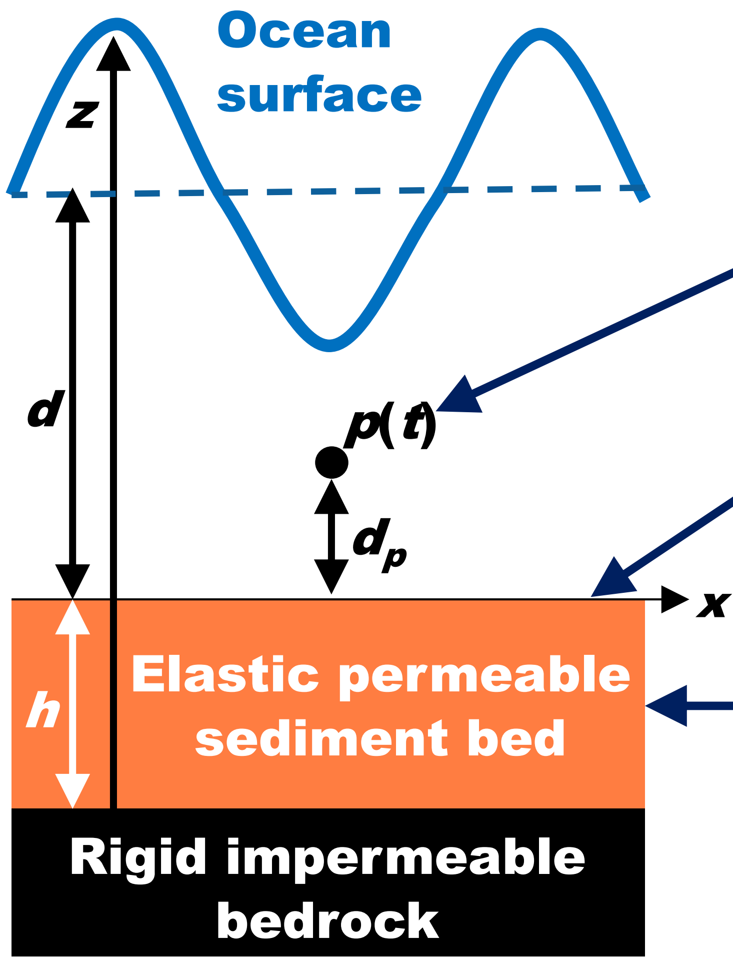
Field Instrumentation



Results Overview

- Applied wave-induced sediment instability analysis to TREX data set
- Refined method for determining range of munitions bulk density using Army Technical Manuals
- Wallops Island munition mobility analysis

Wave-induced Sediment Instability Analysis



Observed pressure

$$p(t) = \sum_{m=1}^{M} a_m \cos\left(-\omega_m t + \varepsilon_m\right)$$

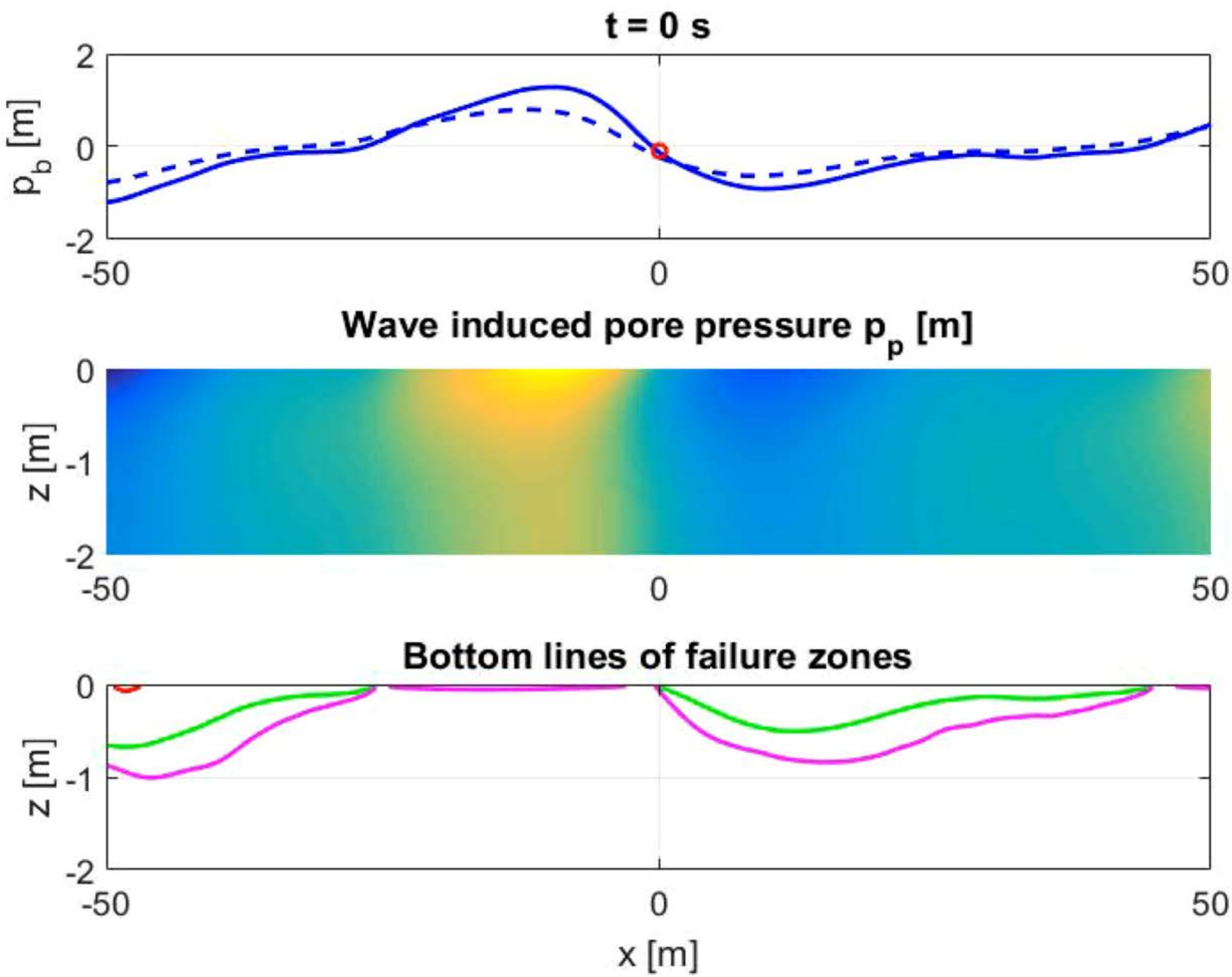
Pressure distribution at seabed

$$p_b(x,t) = \sum_{m=1}^{M} \frac{a_m}{\cosh k_m d_p} \cos\left(k_m x - \omega_m t + \varepsilon_m\right)$$

Sediment pore pressure and effective stresses

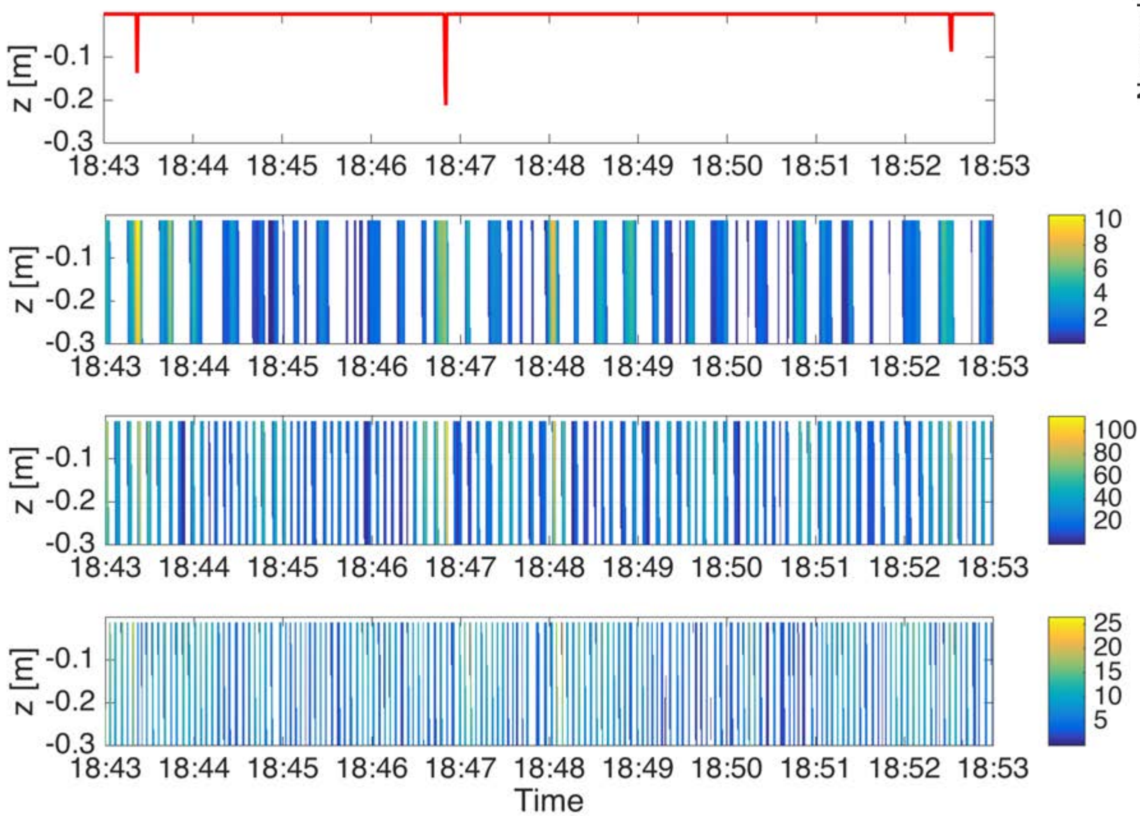
p_p, σ'_x, σ'_z and τ_{xz} result as functions of x, z and t

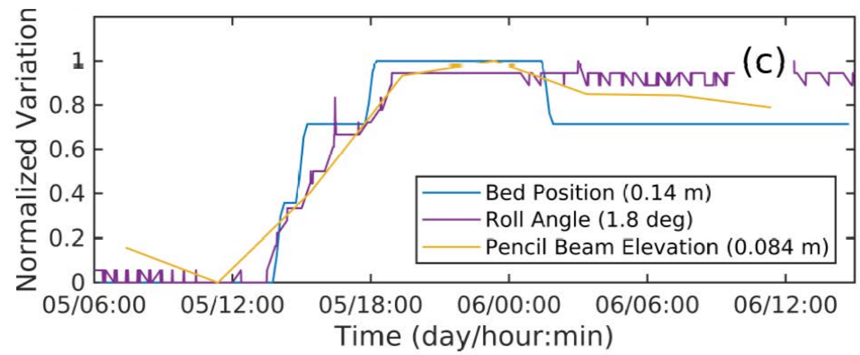
Predicted Bed Failure during Duck 2015

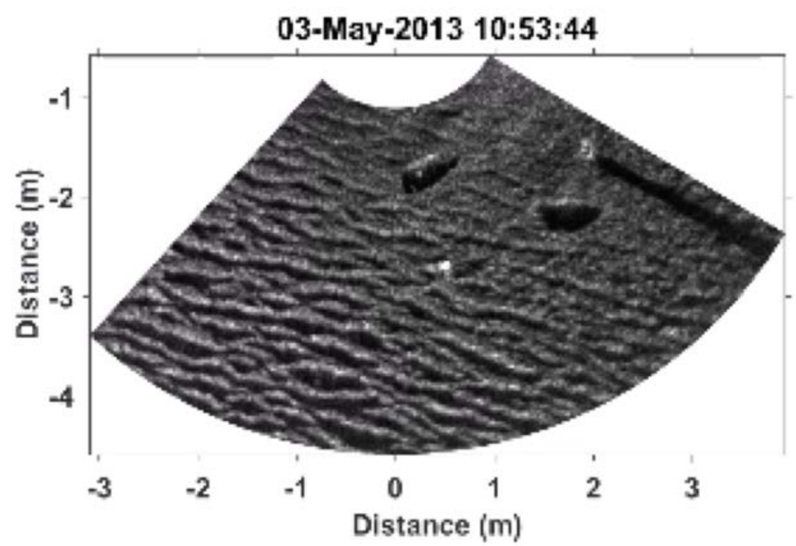


Predicting Bed Failure during TREX

- Analysis explains sinking of quadpod instrument platform



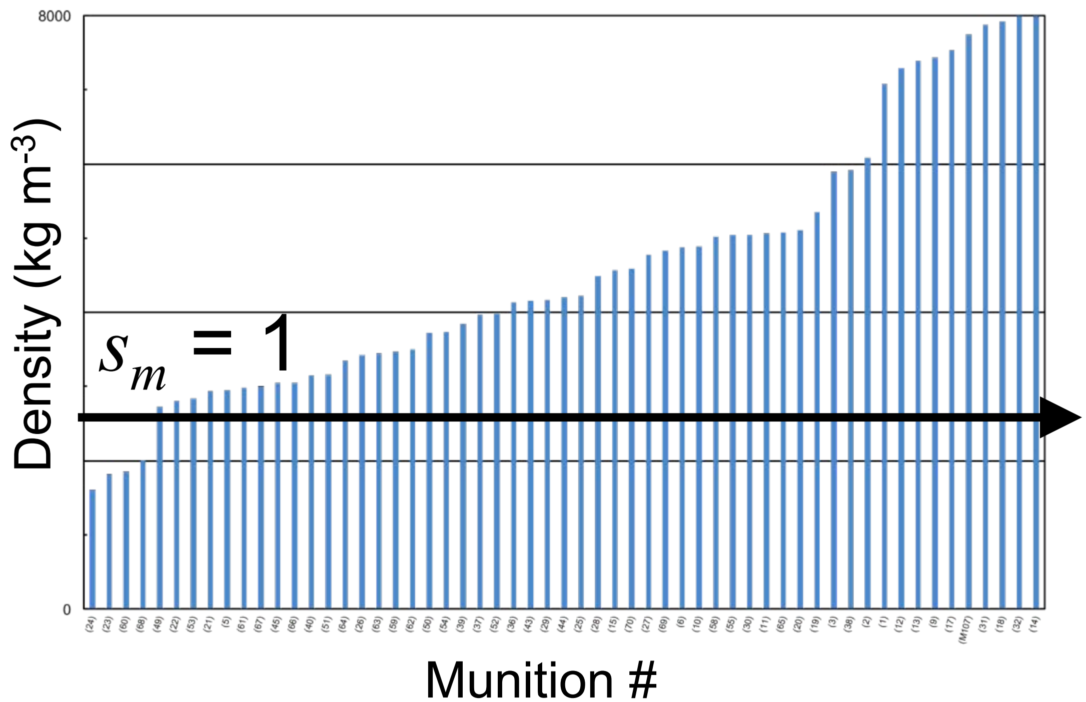




Measured Density of Munitions

- Interrogated 70 items in the inert/surrogate inventory at Blossom Point, MD
  - Items range from inert certified UXO to simple pipe surrogates
- Weighed items → MASS estimates
- 3D laser scans and hand measurements used to build CAD models → VOLUME estimates

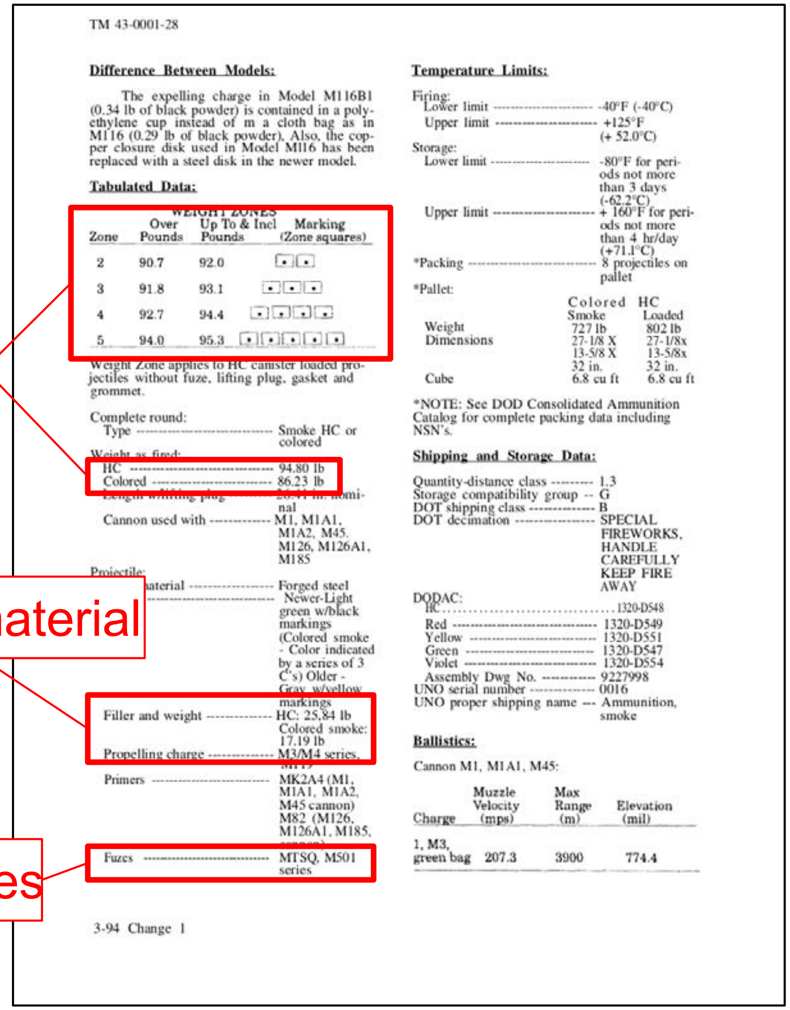
$$\textbf{DENSITY} = \frac{\textbf{MASS}}{\textbf{VOLUME}}$$



Estimating Weight Range of Munitions

- Army Ammunition Data Sheet
  - Technical Manual 43-0001-28
- Each munition has “options”
  - Weight zones/ranges
  - Filler materials
  - Fuze types
- Data extracted from the manual is copied into a JSON database with a standardized format
- Each munition has a distribution of possible weights, computed by combinatorial expansion of the possible “options”

155mm M116



TM 43-0001-28

Difference Between Models:

The expelling charge in Model M116B1 (0.34 lb of black powder) is contained in a polyethylene cup instead of m a cloth bag as in M116 (0.29 lb of black powder). Also, the copper closure disk used in Model MI16 has been replaced with a steel disk in the newer model.

Tabulated Data:

WEIGHT ZONES

Zone	Over Pounds	Up To & Incl Pounds	Marking (Zone squares)
2	90.7	92.0	▣▣
3	91.8	93.1	▣▣▣
4	92.7	94.4	▣▣▣▣
5	94.0	95.3	▣▣▣▣▣

Weight Zone applies to HC canister loaded projectiles without fuze, lifting plug, gasket and grommet.

Complete round:
Type ---------- Smoke HC or colored

Weight as fired:
HC ---------- 94.80 lb
Colored ---------- 86.23 lb
nominal
Cannon used with ---------- M1, M1A1, M1A2, M45, M126, M126A1, M185

Projectile:
...aterial ---------- Forged steel
---------- Newer-Light green w/black markings (Colored smoke - Color indicated by a series of 3 C's) Older - Gray w/yellow markings
Filler and weight ---------- HC: 25.84 lb Colored smoke: 17.19 lb
Propelling charge ---------- M3/M4 series,
Primers ---------- MK2A4 (M1, M1A1, M1A2, M45 cannon) M82 (M126, M126A1, M185,
Fuzes ---------- MTSQ, M501 series

3-94 Change 1

Temperature Limits:

Firing:
Lower limit ---------- -40°F (-40°C)
Upper limit ---------- +125°F (+ 52.0°C)

Storage:
Lower limit ---------- -80°F for periods not more than 3 days (-62.2°C)
Upper limit ---------- + 160°F for periods not more than 4 hr/day (+71.1°C)

*Packing ---------- 8 projectiles on pallet

*Pallet:

	Colored Smoke	HC Loaded
Weight	727 lb	802 lb
Dimensions	27-1/8 X 13-5/8 X 32 in.	27-1/8x 13-5/8x 32 in.
Cube	6.8 cu ft	6.8 cu ft

*NOTE: See DOD Consolidated Ammunition Catalog for complete packing data including NSN's.

Shipping and Storage Data:

Quantity-distance class ---------- 1.3
Storage compatibility group -- G
DOT shipping class ---------- B
DOT decimation ---------- SPECIAL FIREWORKS, HANDLE CAREFULLY KEEP FIRE AWAY

DODAC:
HC 1320-D548
Red ---------- 1320-D549
Yellow ---------- 1320-D551
Green ---------- 1320-D547
Violet ---------- 1320-D554
Assembly Dwg No. ---------- 9227998
UNO serial number ---------- 0016
UNO proper shipping name --- Ammunition, smoke

Ballistics:

Cannon M1, M1A1, M45:

Charge	Muzzle Velocity (mps)	Max Range (m)	Elevation (mil)
1, M3, green bag	207.3	3900	774.4

JavaScript Tool for Data Management

U.S. NAVAL RESEARCH LABORATORY

Enter munition information

Identifying info

Title: PROJECTILE, 155-MILLIMETER: SMO

Name (*Required): 155mm M116

Manual: TM 43-0001-28

Page: 304

Class: Select a class…

Dimensions

Caliber as given: 155 mm

SI unit (m) guess: 0.155

Length as given: 26.41 in

SI unit (m) guess: 0.670814

Weight as given: 94.80 lb

SI unit (kg) guess: 43.000556676

Descriptors

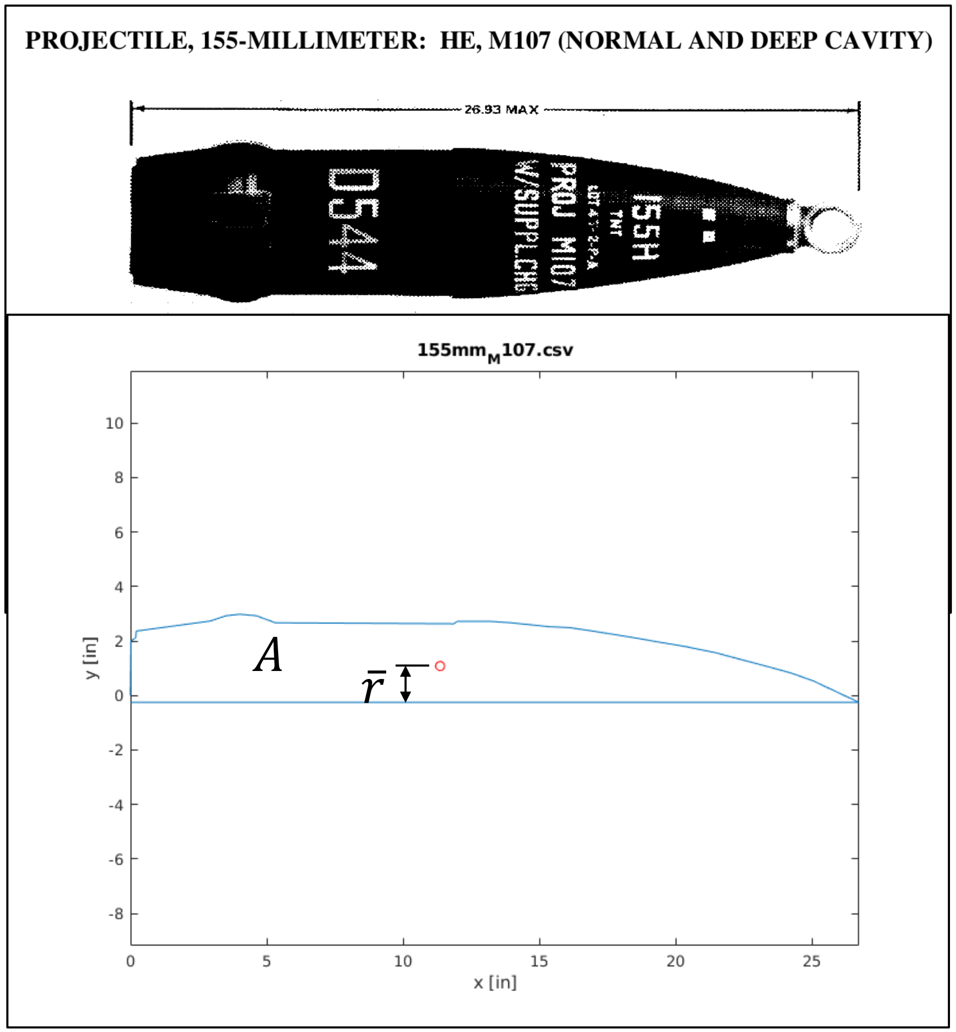
Color:

Cannons used with

JavaScript

JSON

Estimating Volumes of Munitions



- TM 43-0001-28 has a schematic image of each munition
- The 2D outline is extracted using WebPlotDigitizer
  - ♦ Manually adjusted for poor-quality images
  - ♦ Approximating nose/fuze shape
- Matlab scripts compute the munition volume using theorems of Pappus and Guldinus

$$V = \theta \bar{r} A$$

- 3D scans of some munitions can be used to verify results

Munitions Density Distributions

- 155 mm caliber example
- Each estimated volume is combined with all combinations of estimated weights to produce a density distribution for every entry in the manual
- Distributions for all munitions of a single caliber are combined into an overall likelihood distribution
    - ♦ Likelihood is the prior probability of a munition having a certain density

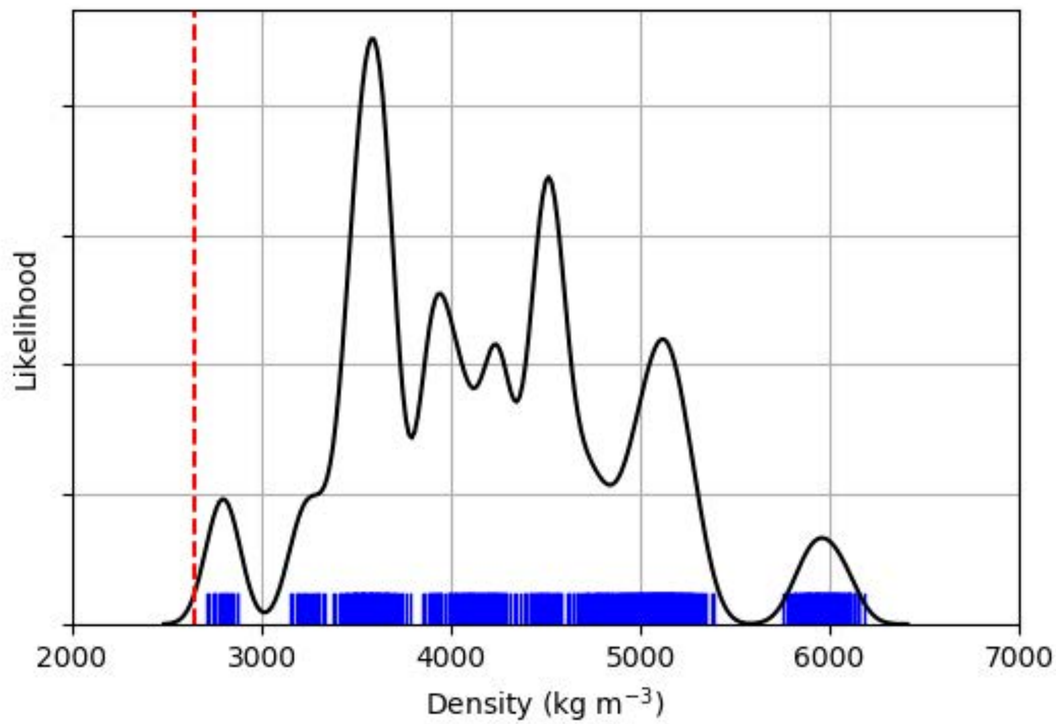
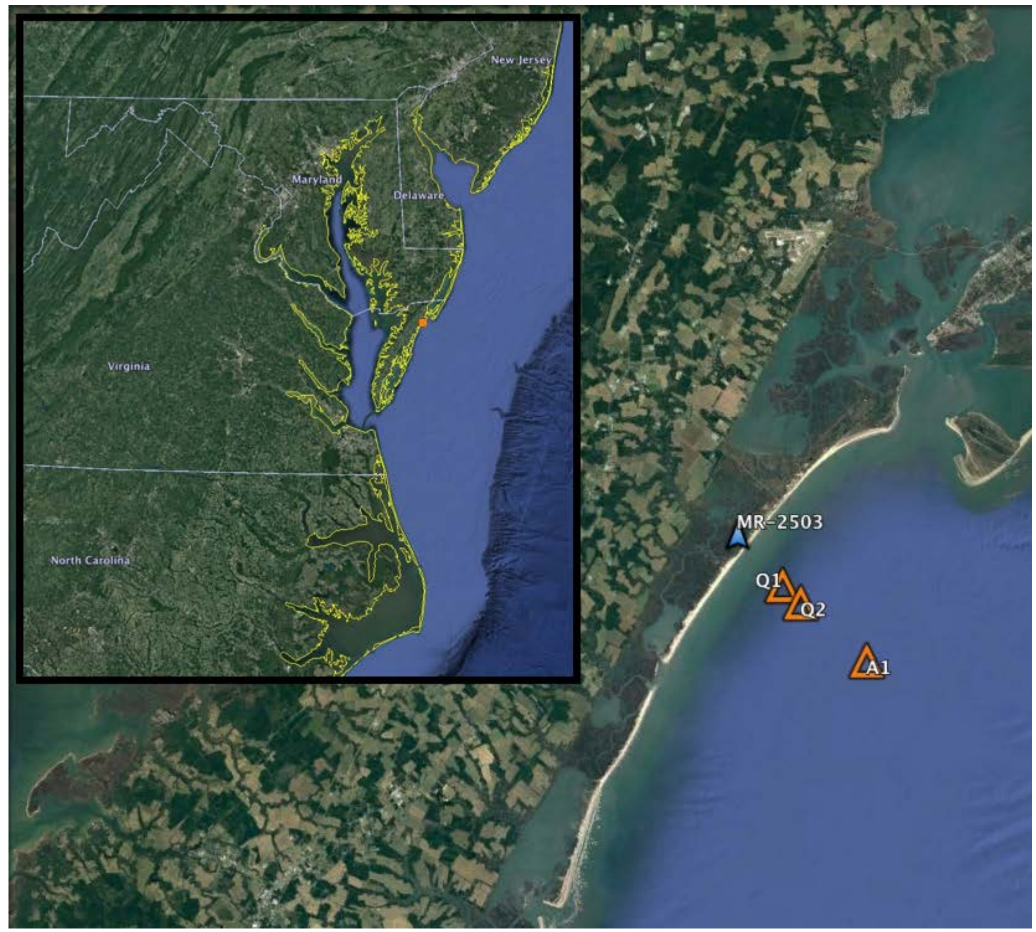


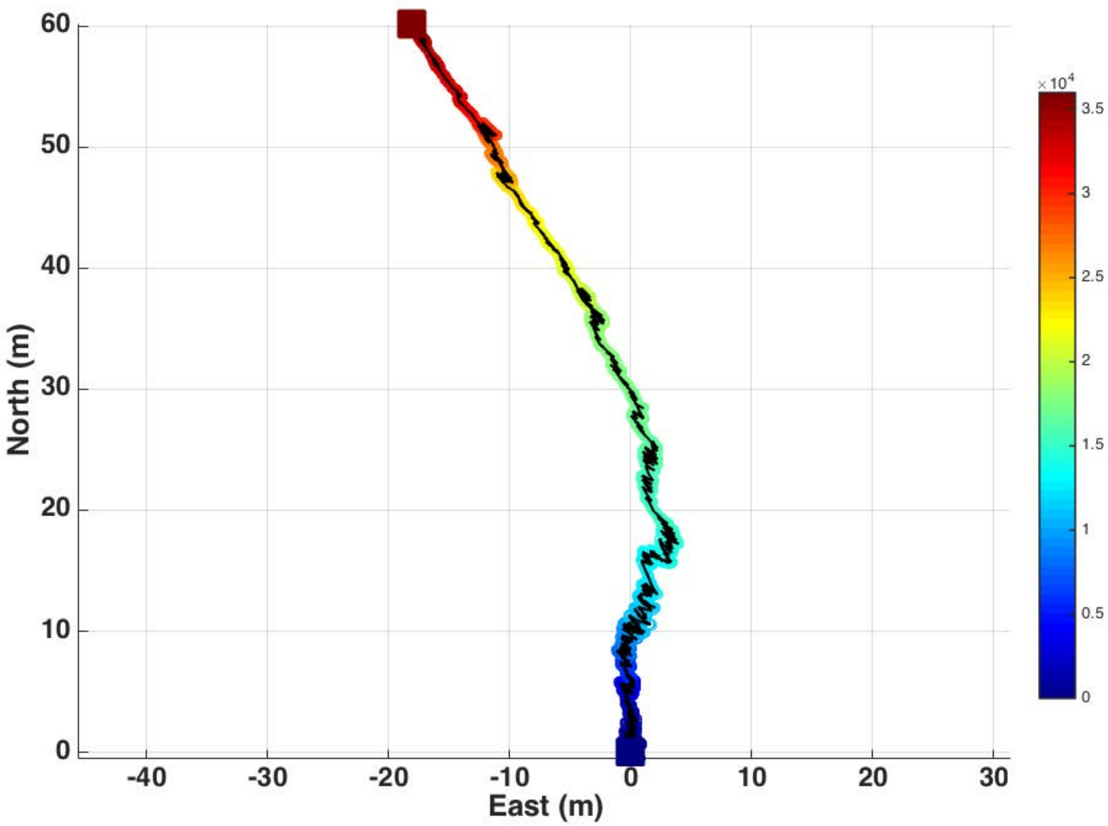
Figure: Plot of likelihood distribution for all 155mm caliber munitions shows kernel density estimate of likelihoods (black), combination of munition “weight options” (blue) and the density of quartz sand, 2650 kg m^{-3} (red).

Wallops Island Munitions Mobility Experiment WIMM-X

- Collaboration with MR-2503
- Sediment cores on 12 Jan 2017
- Deployment on 17 Feb 2017
- Maintenance on 9 Mar 2017
- Recovery on 19-20 Apr 2017
- Deployed quadpods at 9 m and 11 m water depths
- Smart munitions with IMUs logging at 16 Hz continuous
  - ♦ Three calibers at each location (81 mm, 4.2 inch, and 155 mm)

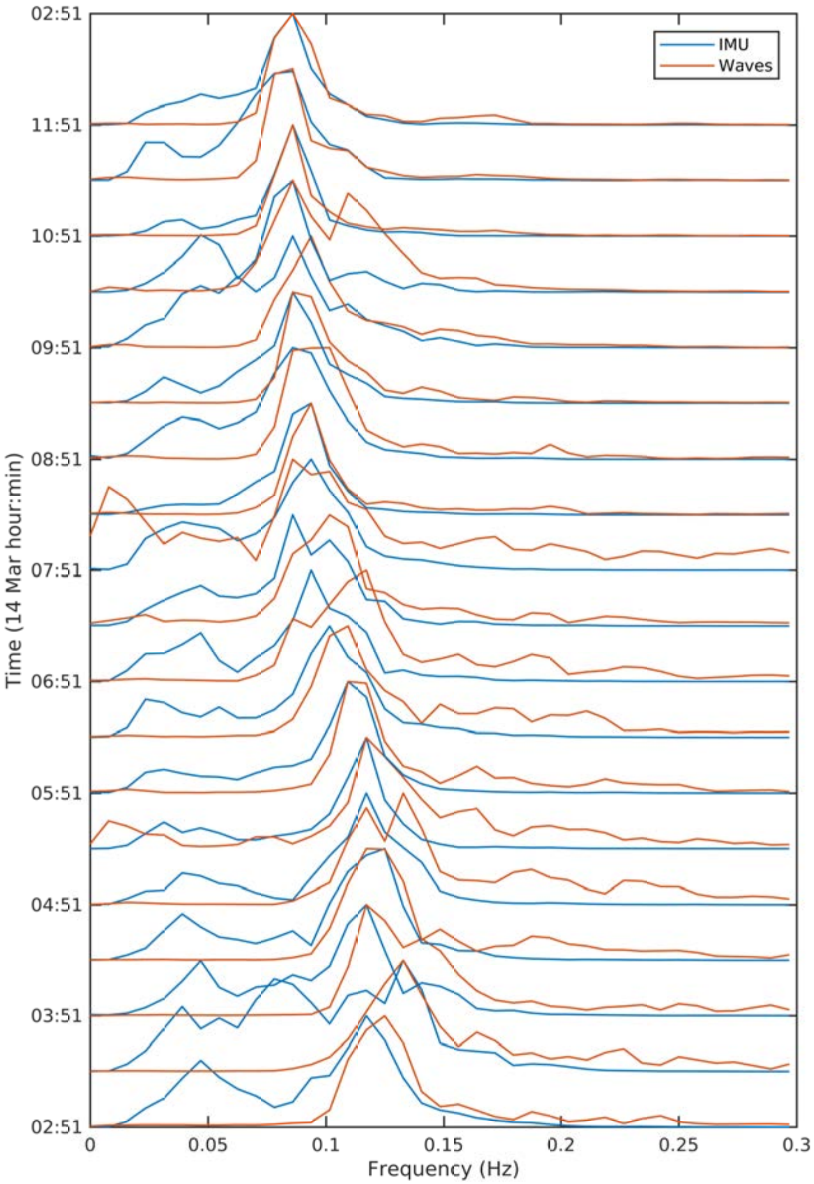


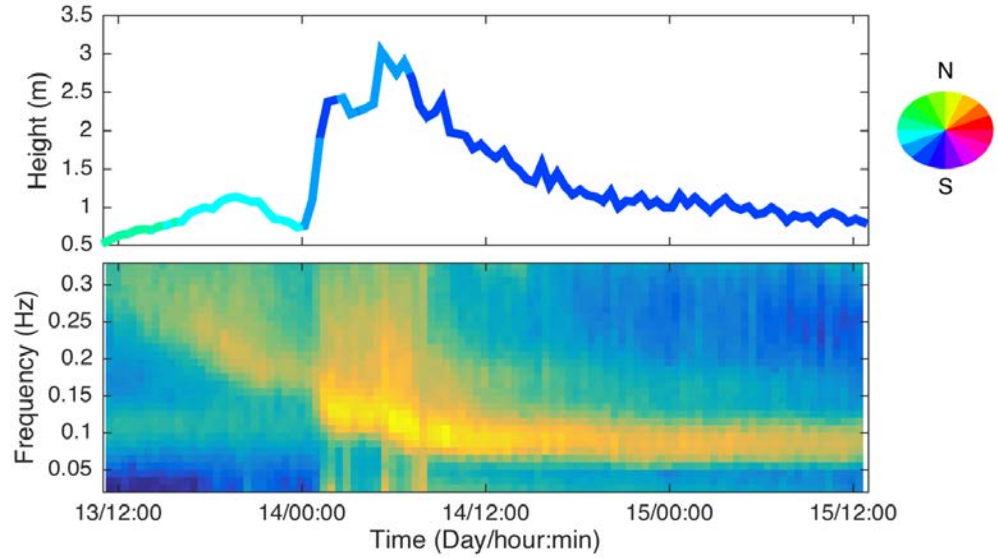
WIMM-X Smart Munitions Mobility

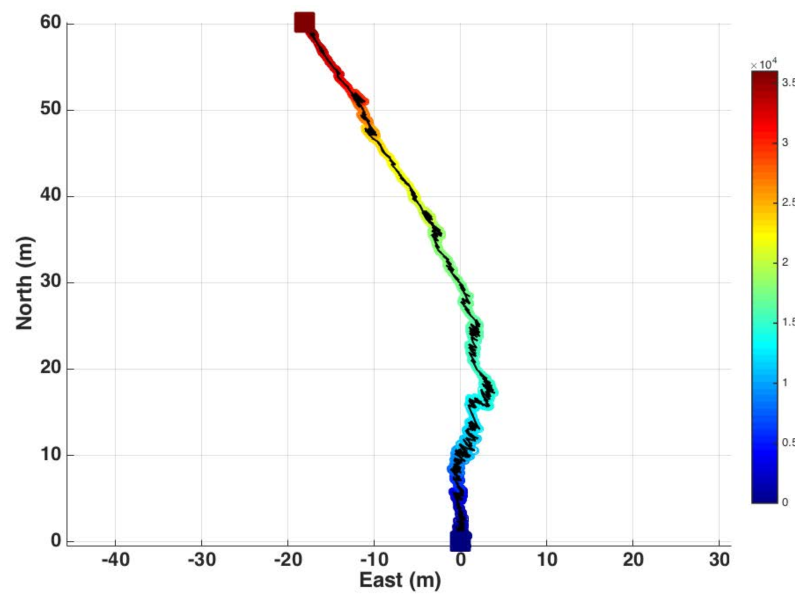


- Start of mobility during storm at 14 March 2017 at 0228
- Integration interval is 9.9 hours (16 Hz continuous)
  - ♦ 570,240 points
- Peak significant wave height near 2.8 m during interval
- Total integrated displacement was 206.4 feet with 344 degree heading
- Diver measured displacement was 202.0 feet with 340 degree heading

WIMM-X Mobility by Waves







Ongoing WIMM-X Analysis

- Publish IMU integration results and algorithm
- Compare near bed orbital excursion length scale with high spatial frequency oscillations
- Cast observed mobility in context of bathymetry and sedimentology analysis

Summary

- Currently in 6th year of execution for MR-2320
- Peer-reviewed publications (1 in print, 2 in review, 3 in preparation)
  - Conference proceedings (2 in print)
- Reports (1 completed and 1 outstanding)
  - Publish interim report online documenting TREX13 experiment
  - Final Report comprehensive report
- Next steps
  - Unify laboratory and field observations
  - New SERDP proposal under review titled, “Towards Developing Demonstrations for Munitions Mobility and Burial in the Underwater Environment”

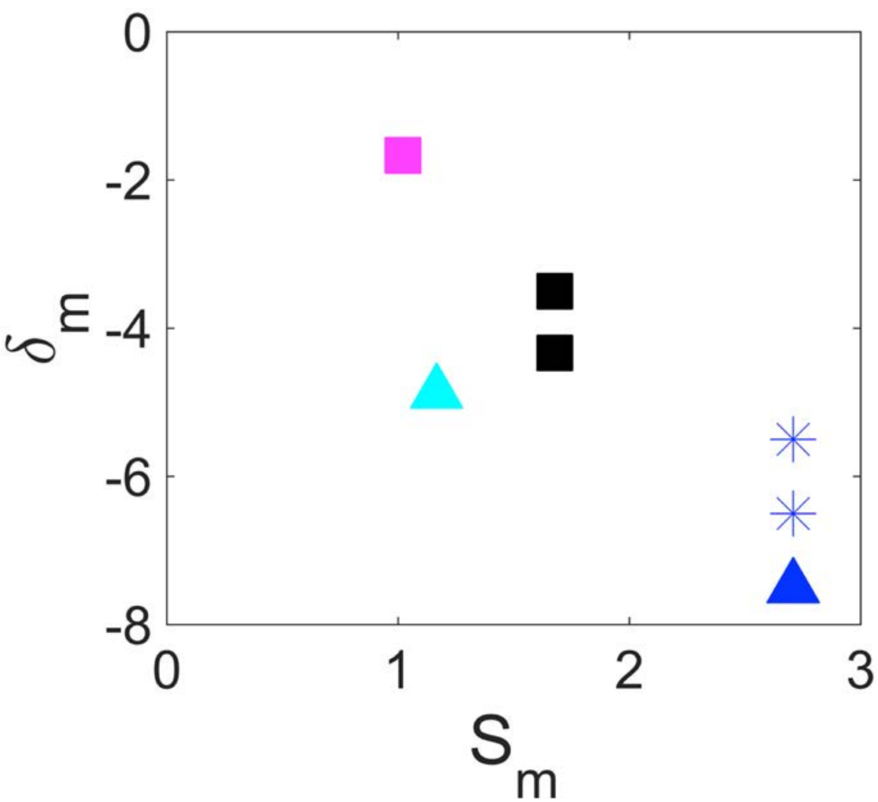
Transition Plan

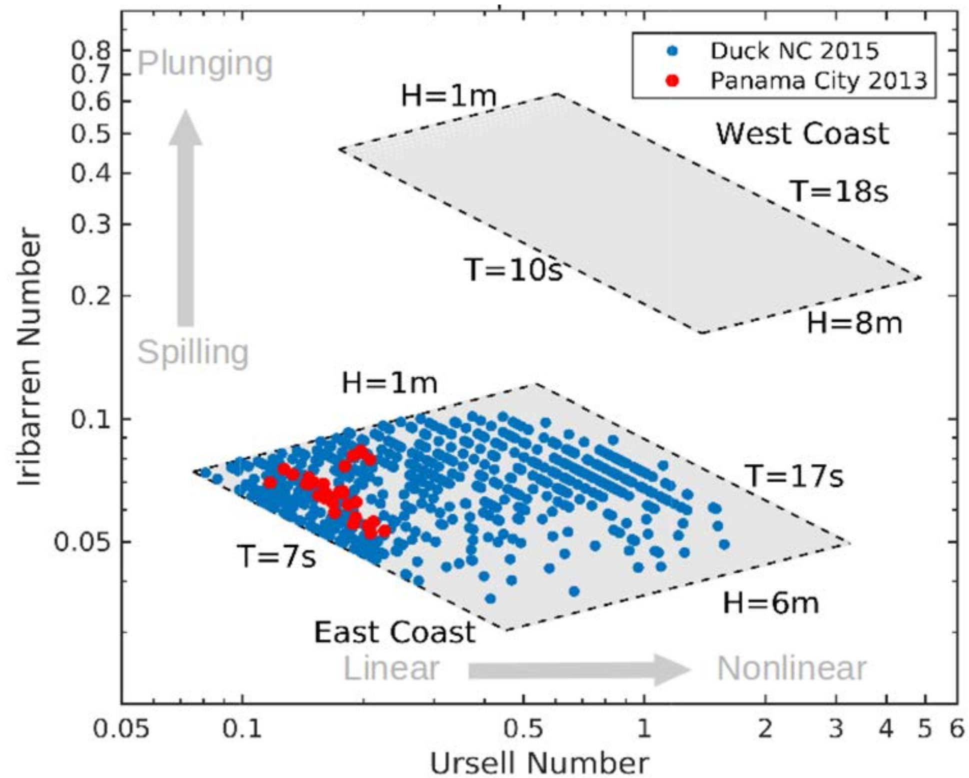
- Prepare and distribute documentation for all aspects of experimental methods, including design, fabrication, deployment, recovery, and signal processing
- Complete and distribute database of munitions characteristics including estimates of bulk density distributions
- Proposed new SERDP effort, “Towards developing demonstrations for munitions mobility and burial in the underwater environment

Proposal to Develop Demonstrations

Objectives:

1) to reduce the dimensionality of the problem





2) to complete our observations of the role of water wave characteristics

Proposed CONOP for Site Managers

- Establish data collection for necessary environmental parameters for both sensor performance and mobility and burial modeling
- Perform site surveys to detect and classify munitions (i.e., map contamination)
- Run forecast/hindcast models of coupled hydrodynamics and probabilistic predictions for munitions over individual storm events
- Decide remediation versus manage in place

Demonstration of mobility and burial modeling begins with prediction and observation over single storm events

BACKUP MATERIAL

These charts are required, but will only be briefed if questions arise.

Publications

Klammler, H., Sheremet, A., and **J. Calantoni**, *in review*, Seafloor burial of surrogate UXO by wave-induced sediment instability, *submitted to IEEE Journal of Oceanic Engineering*.

Frank, D.P., Landry, B.J., and **J. Calantoni**, *in review*, Development of smart munitions for assessing mobility in oscillatory flows, *submitted to Journal of Atmospheric and Oceanic Technology*.

de Moustier, C., and **J. Calantoni**, *in review*, Cross-spectrum analysis of tidal measurements offshore Panama City Beach, FL, *submitted to IEEE Journal of Oceanic Engineering*.

Penko, A., **Calantoni, J.**, and B.T. Hefner (2017), Modeling and observations of sand ripple formation and evolution during TREX13, *IEEE Journal of Oceanic Engineering*, *42*(2), 260-267.

Frank, D.P., Landry, B.J., and **J. Calantoni** (2016), Investigating munitions mobility in oscillatory flows with inertial measurement units, OCEANS 16, *IEEE Oceanic Engineering Society*, Monterey, CA, 19-22 September.

Calantoni, J. (2014), Informal Workshop on Burial and Mobility Modeling of Munitions in the Underwater Environment, Final Workshop Report, SERDP and ESTCP Office, Distribution Statement A.

deMoustier, C. and **J. Calantoni** (2014), Target detection with sector scanning imaging sonars, *Underwater Acoustics Proceedings*, edited by Papadakis and Bjorno, Rhodes, Greece, 22-27, June.

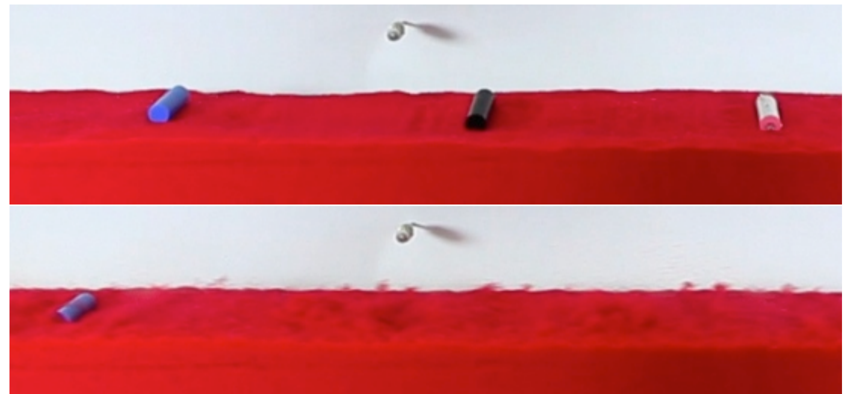
Presentations and Events

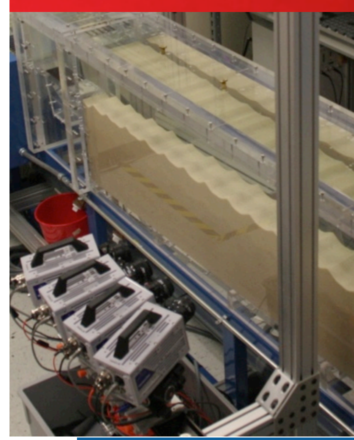
During the last 12 months:

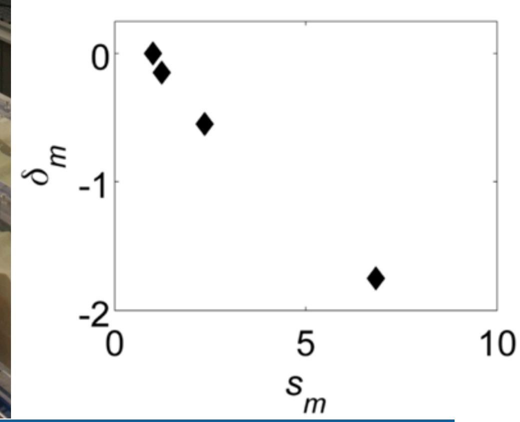
1) 3rd Informal Workshop on Munitions Mobility and Burial Modeling (co-organized)
2) Keynote presentation for Munitions Response session at 2017 Symposium (speaker)
3) Special session at the AGU Fall Meeting, “Munitions in the Underwater Environment” (convener)
4) Oral presentation at the Ocean Sciences Meeting on munitions burial (speaker)
5) NAVFAC 2018 Environmental Restoration Training (speaker)
6) Plenary at Mine Warfare Improvement Program (speaker)

Role of Munitions Bulk Density - Lab

- Scaled sediment density with nylon beads (0.5 mm)
- Cylindrical munitions of varying density (10 X 2 cm)
- Generated sheet flow conditions for nylon beads
    - ♦ 1 – 2 cm thick mobile layer
- Plotted non-dimensional burial depth (by diameter) versus relative density
- Need extreme storm conditions to test in the field with full scale munitions

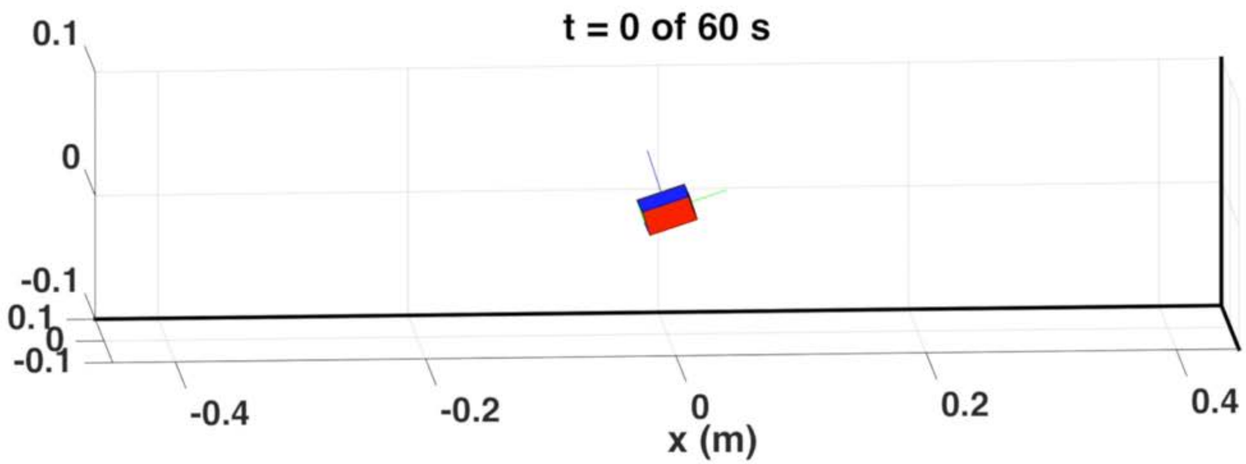


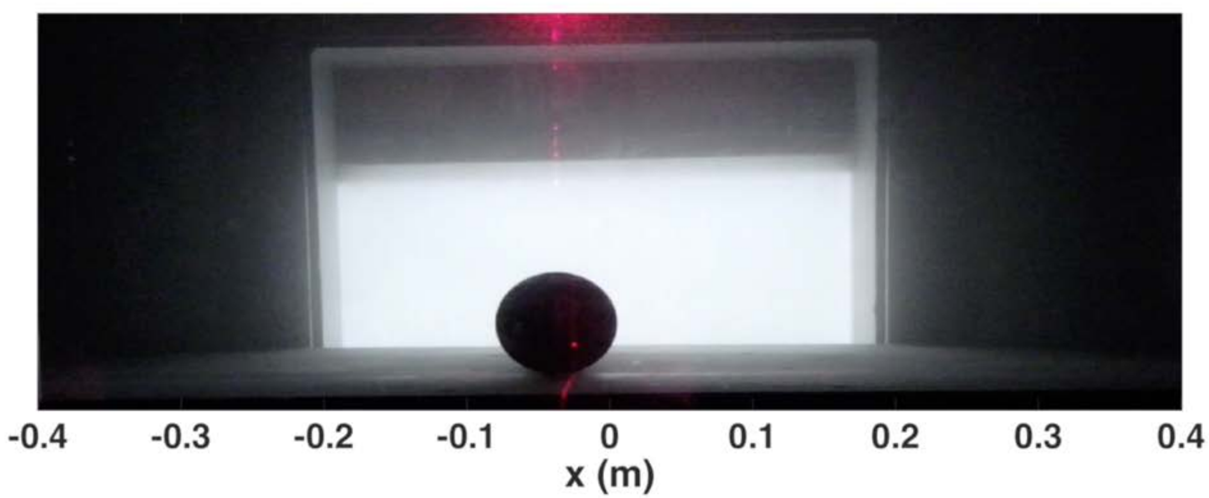




Sediment Dynamics Laboratory, Naval Research Laboratory, Stennis Space Center, MS

Smart Munitions – Laboratory Testing





- Collaboration with MR-2410
- COTS IMU embedded in nose

- Large Oscillatory Water-Sediment Tunnel (UIUC)
- Laser and camera system for optical tracking

Signal Processing Algorithm Summary

- Attitude Heading Reference System (AHRS) data fusion algorithm (proprietary x-IO code) to remove drift from gyroscope and heading
- Butterworth low pass filter to reduce noise
- Measured angular velocities are transformed from the sensor coordinate system to earth coordinates
- Binary condition for motion is set by choosing threshold values for acceleration and angular velocities
- Linear velocities are estimated from transformed and binary threshold angular velocities for rolling dominated motion
- Estimated linear velocities are low-pass filtered
- Linear velocities are numerically integrated for displacement

Bed Failure Criteria

A – Critical shear stress
Local shear failure (Mohr-Coulomb criterion)

B – Zero effective stress
Cohesionless sand cannot resist tensile stresses

C – Zero vertical effective stress
Localized cancelling of buoyancy plus upward seepage forces against gravity (liquefaction)

D – Vertical uplift of sediment column
Similar to C, but for vertical sediment columns

E – Horizontal shear of sediment column
Generalized Sleath criterion for plug flow

WIMM-X Sedimentology

- Initial analysis performed with grab sampler
- Diver push cores at instrument locations during deployment, maintenance, and recovery
- Cores at Q1 location have been analyzed