Offshore Weapon Scoring Using Rapidly Deployed Realtime Acoustic Sensors

21st Annual Test and Evaluation Forum
10 March 2005

Dr. Jack Kayser
Mr. Miguel A. Cardoza

Trident Research LLC
Austin, Texas

Mr. William F. Wade
Mr. John H. Merts
Mr. David R. Casey
Mr. Richard L. Bennett
46th Test Wing
Eglin AFB, FL

Background

- A new Offshore Test and Training Area (OTTA) was initiated by the Air Force 46th Test Wing at Eglin Air Force Base in the Florida Eglin Gulf Test and Training Range.

- The OTTA provides a large footprint area for testing, training and evaluating standoff weapons.

- USAF 46th Test Wing has been testing different methods for providing accurate weapons scoring in support of the OTTA. One such method was an acoustic realtime system based upon small portable sensors

Offshore Test and Training Area Requirements

- Joint Services Test Range
- Support large footprint and standoff weapons
- Provide off-shore instrumentation to support weapons testing
- Goal: 1 meter accurate scoring

Advantages of Underwater Acoustics

- Greater flexibility and broader operational scenarios than optical or radar-based approaches
  - ⇒ Rapid deployment and recovery (moored platform not required)
  - ⇒ Viable in both day or night operations (optics limited)
  - ⇒ Viable in heavy precipitation (optics/radar limited)
  - ⇒ Viable in rough sea surface conditions (optics/radar limited)
  - ⇒ Viable for munitions with large CEP's (optics/radar limited)

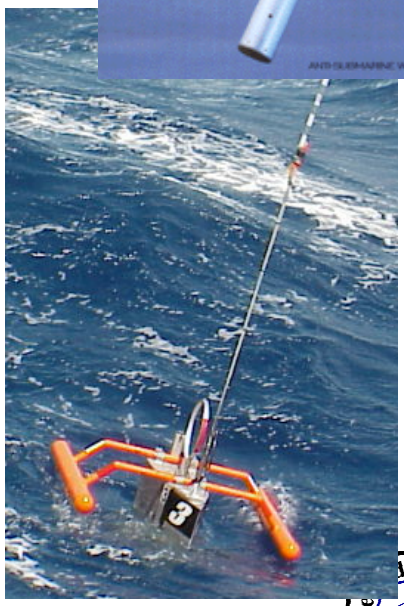
- Provides options for secondary capabilities
  - ⇒ Recovery of inert ordnance in shallow water
  - ⇒ Mammal detection, tracking and range clearance
  - ⇒ Disposable form factor supports aircraft deployment

Prior Uses of Acoustics for Weapons Testing

- Trident Research personnel designed and developed two underwater acoustic weapon scoring systems for the US Navy Fleet Ballistic Missile (FBM) Program

- Aircraft deployable system fielded in 1994
  - ⇒ Custom 12 hours sensor based upon AN-SQQ-41B sonobuoy chassis

- Ship deployable system fielded in 2000
  - ⇒ Custom 24 hour sensor based upon a self-navigating autonomous surface vehicle (ASV)



Limitations in Historical Acoustics Systems

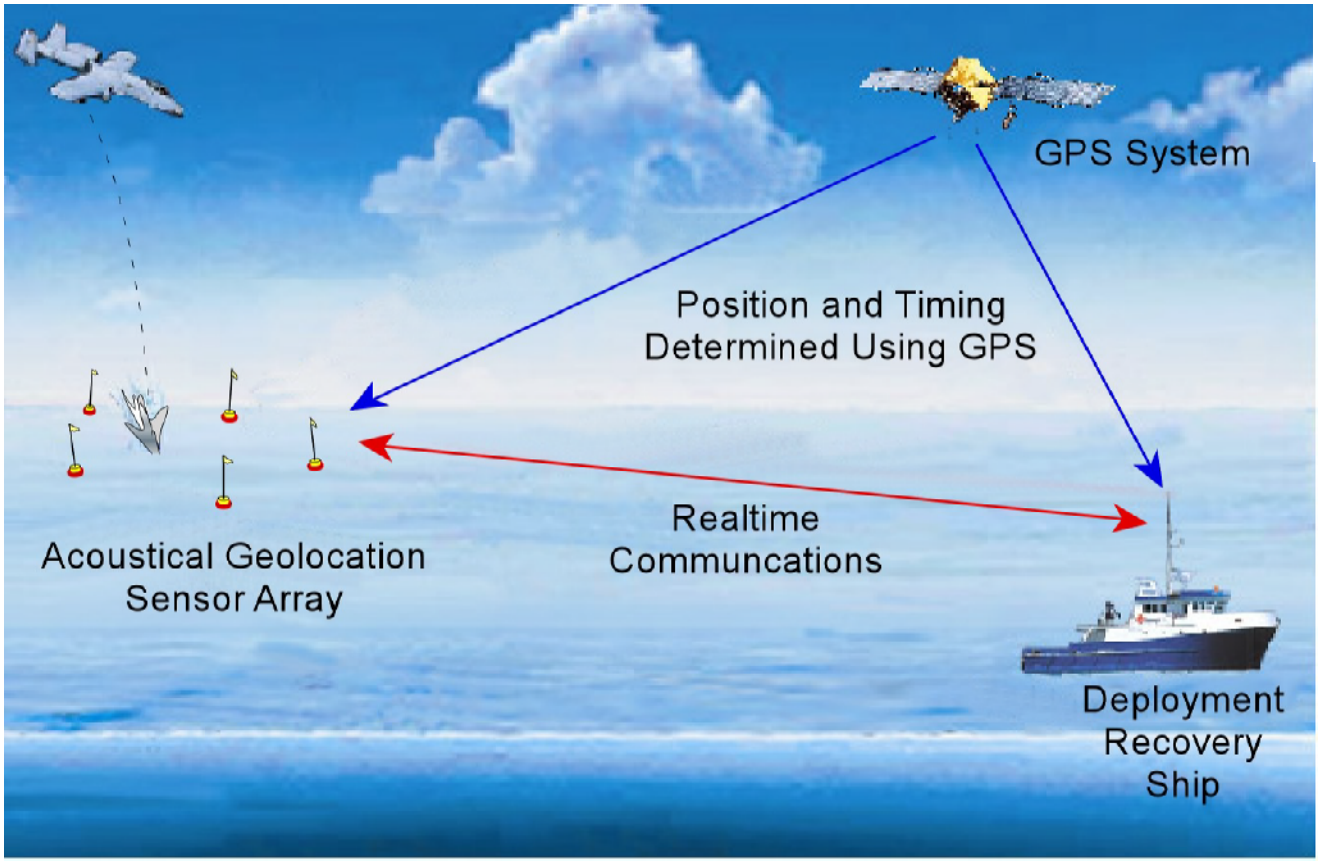
- Both systems served as data collection platforms only
  - ⇒ Unable to provide realtime scoring

- Both provided ~25 ft / axis (1 sigma) accurate scoring
  - ⇒ Insufficient for today's modern Precision Guided Munitions (PGM)

Aircraft Deployed System	
Realtime Scoring	No
Sub-meter Scoring Potential	No
Low-cost Sensor (Disposable)	Yes
Ship Deployed System	
Realtime Scoring	No
Sub-meter Scoring Potential	Yes
Low-cost Sensor (Disposable)	No

Tactical Acoustic Realtime Geolocation/Training

- TARGT™ system satisfies all three critical requirements
- Realtime, highly portable and potential for <1 m scoring

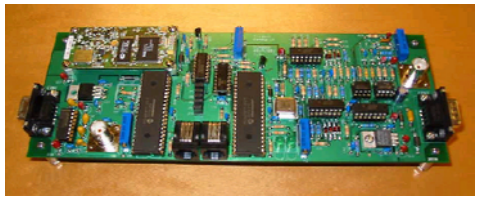


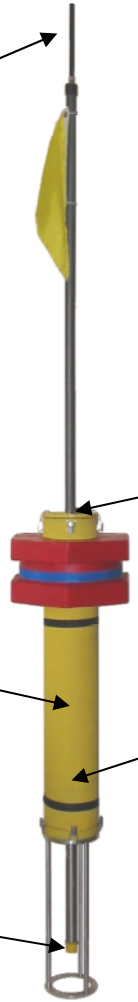
The TARGT Sensor

- At the core of the TARGT system is the Acoustic Geolocation Sensor (AGS)
- The AGS is an integrated acoustic sensor designed to transmit realtime GPS and acoustic timing data in all weather and up to sea state 5 conditions
- Capable of drifting or moored operation
- Tunable to properly time acoustic events from various acoustic targets
- It's light weight and small form factor allows for hand deployment and recovery

AGS Sensor Description

At Sea During USAF Testing





902-928 MHz ISM Band Transceiver

8-Channel, L1 only, Trimble OEM GPS Receiver

Tunable Acoustic Processor for Realtime Splash Detection

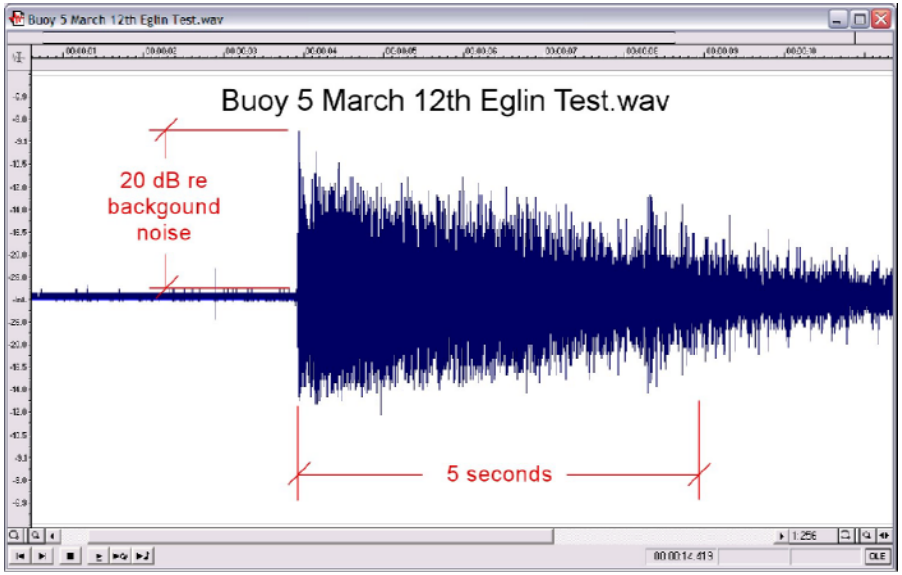
Rechargeable Sealed Gel-cell Battery System

0-20 KHz Broadband Hydrophone

- Tested at-sea in up to sea state 4 conditions
- Capable of drifting or moored operation
- Deployment or recovery in < 1 hour
- Optional comms relay allows for stand-off ranges up to 12 nm
- Light weight (<35 lbs) and small form factor allows for single person deployment and recovery

TARGT Acoustic Scoring Method

- Received acoustic pulses are time stamped in UTC time to <1 millisecond
- Time & L1 GPS data transmitted to ship in realtime where absolute and relative GPS positioning performed
  - ⇒ DGPS pseudorange correction process



Detailed acoustic analysis presented in paper.

- Post-mission, a pseudorange-based DGPS solution computed for each sensor relative to ground station
- Precise sensor coordinates used for impact re-score

Expected TARGT Accuracy

- Analysis of system errors indicated expected positioning accuracy of approximately 3.7 meters using pseudorange-based DGPS processing

Estimated Error Sources Associated With TARGT Post-Mission Scoring.		
Error Source	**Description**	**Approximate Magnitude**
GPS Position	Estimated Error in Computed Differential GPS Position of Buoy Using C/A-code Data	0.50 m – est signal multipath at reference 1.50 m – est signal multipath at buoy 0.60 m – est reference receiver meas noise 2.24 m – est buoy C/A-code meas noise 0.05 m – reference coordinate uncertainty 1.28 m – satellite ephemeris baseline error 0.29 m – residual ionospheric error 0.52 m – est tropospheric baseline error 1.10 – estimated relative dilution of precision **3.65 m – estimated relative position error**
Hydrophone Scope	Residual Error on Hydrophone Scope After Hydrophone Cantilever Model Used to Account for Bias Due To Moored Buoys and Drifting Hydrophone	0.50 m – residual drifting hydrophone error 0.05 m – instrumented mast offset
Acoustical Timing	Detecting Sound Arrival and Assigning Time Value	0.40 m – 8 kHz resolution
Estimated Total	Root Mean Square	**3.71 m – total post-mission error**

Instrumented Target System (ITS)

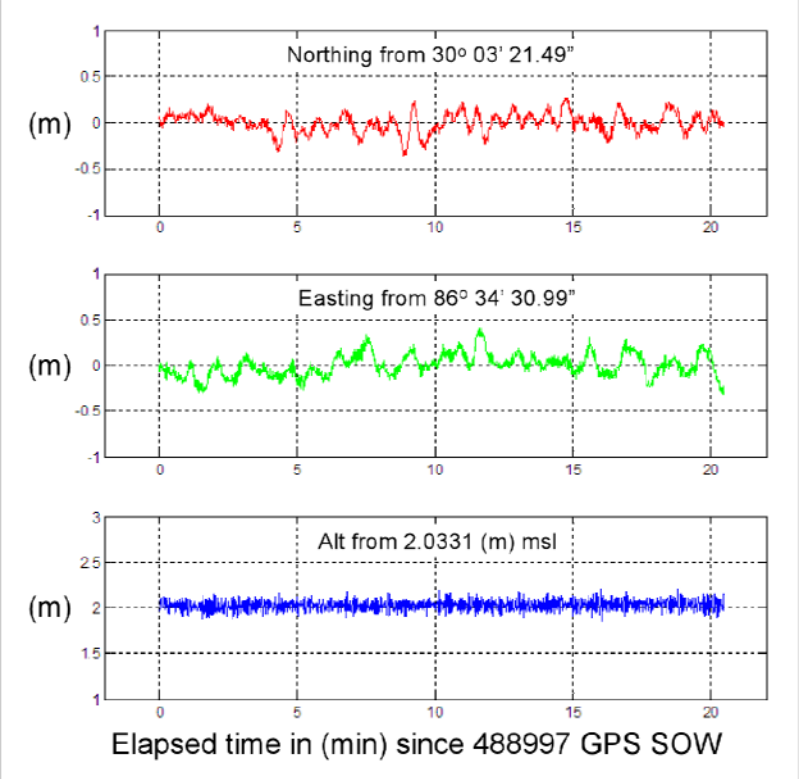
- The 46th Test Wing developed an Instrumented Target System (ITS) to provide 'truth' data for weapons scoring and for assessment of other systems under test

- The ITS consisted of a physical target deck geolocated using GPS, and possessing deck witness panels to provide manually measured x-y distances from the weapon impact point to the GPS determined point on the target

ITS Platform Positioning Accuracy

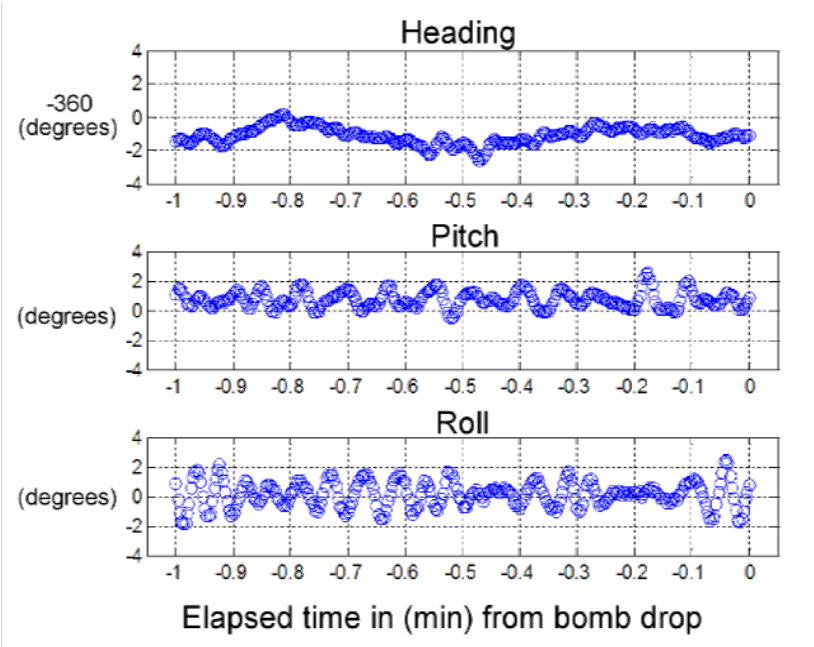
- DGPS processing results indicate the four point mooring system on the ITS platform restricted motion throughout the flight window to < 50 cm

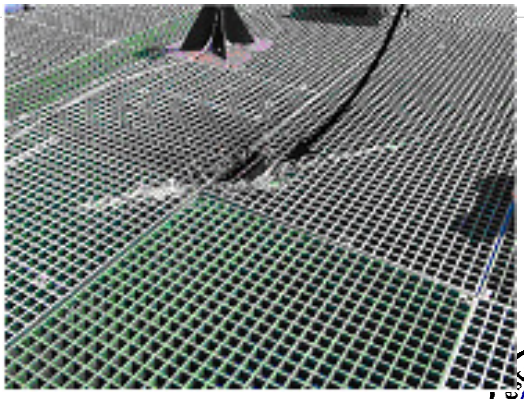
- Post-mission DGPS processing results indicated the ITS platform was positioned to an accuracy of < 20 cm
  - ⇒ Based upon error residuals



ITS Impact Localization Accuracy

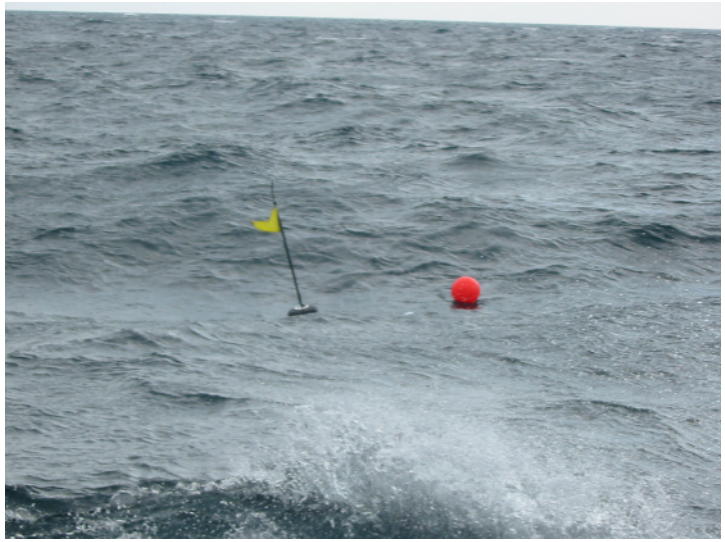
- Processing results indicated the ITS platform heading, pitch, and roll of the platform was determined to better than 0.5 degrees
- Matlab-based software used to compute a correction vector between the phase center of the GPS antenna and the center of the impact hole
- Estimated impact localization accuracy < 60 cm





TARGT Eglin AFB OTTA Testing

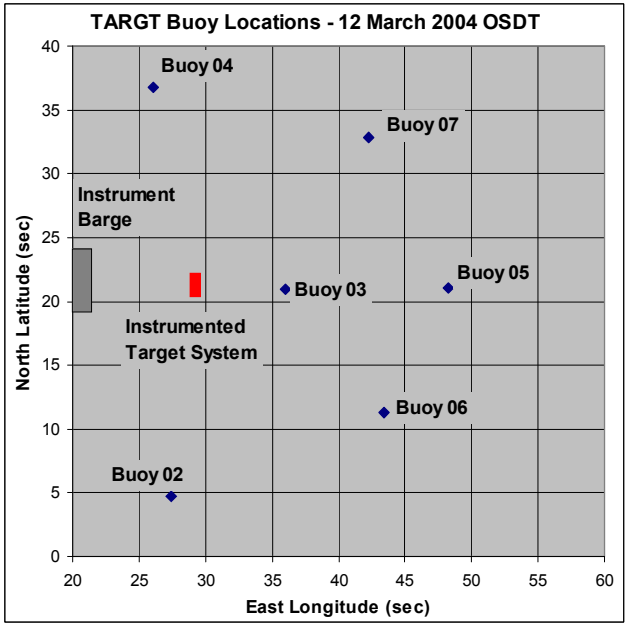
- Three weapons were scored in OTTA testing in March and May of 2004
- The ITS and TARGT systems were successfully deployed and recovered in support of both tests



Prototype AGS Sensor At Sea

Laser Guided Bomb Striking ITS

Acoustic Sensor Deployment and Recovery

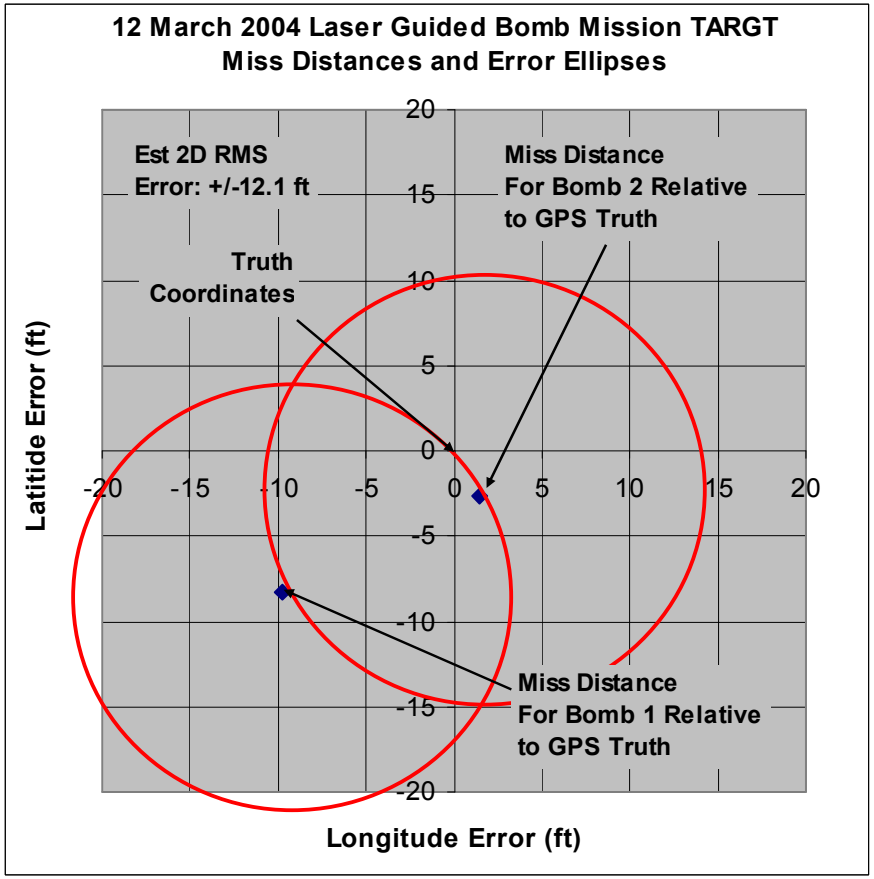


- Six sensors fielded
  - ⇒ 1 x 1 km test area
  - ⇒ Deployment: ~30 min
  - ⇒ Recovery: ~45-80 min

- Calm seas (Sea State ~1-2)
- Single person deployment / recovery from 40 ft commercial charter

Acoustic Scoring Accuracy

- Realtime scores produced in < 5 sec in all tests
- Estimated accuracy
  - ⇒ Realtime Absolute - 7.1 m
  - ⇒ Realtime Relative – 3.0 m
  - ⇒ Post-mission – 3.7 m
- Comparisons to ITS score indicate accuracies of:
  - ⇒ Weapon #1 (Mar) – 3.89 m
  - ⇒ Weapon #2 (Mar) – 0.92 m
  - ⇒ Weapon (May) – 2.60 m



Demonstrated Acoustic Scoring Performance

- Operational CONOPS
  - ⇒ Coverage Area: 1 x 1 km
  - ⇒ Deployment Time: < 40 min
  - ⇒ Recovery Time: < 80 min
  - ⇒ Operational Duration: < 6 hrs
  - ⇒ Support Ship Stand-off Distance: < 7 nm
  - ⇒ Differential GPS Baseline: ~21 nmiles

- Scoring Time and Accuracy
  - ⇒ Realtime Scoring Time: < 5 sec
  - ⇒ Realtime Absolute Scoring: < 8 meters
  - ⇒ Realtime Relative Scoring: < 4 meters
  - ⇒ Post-mission Absolute Scoring: < 4 meters

Future Planned Enhancements

- Sub-meter Accurate Scoring
  - ⇒ Trident presently developing a 2nd generation sensor with improved positioning and reduced measurement errors
  - ⇒ Accuracies of 50-70 cm predicted
- Bottom Munition Recovery
  - ⇒ Use of an adjunct hydrophone sensor may allow for geolocating the impact the munition makes on the bottom of the ocean
  - ⇒ 46th Test Wing planning at-sea test to prove feasibility and assess accuracy and concept of operation
- Mammal Detection and Range Clearance
  - ⇒ Acoustic-based system allows for the potential for detecting mammals in the impact area
  - ⇒ Trident assessing modifications to on-board processing