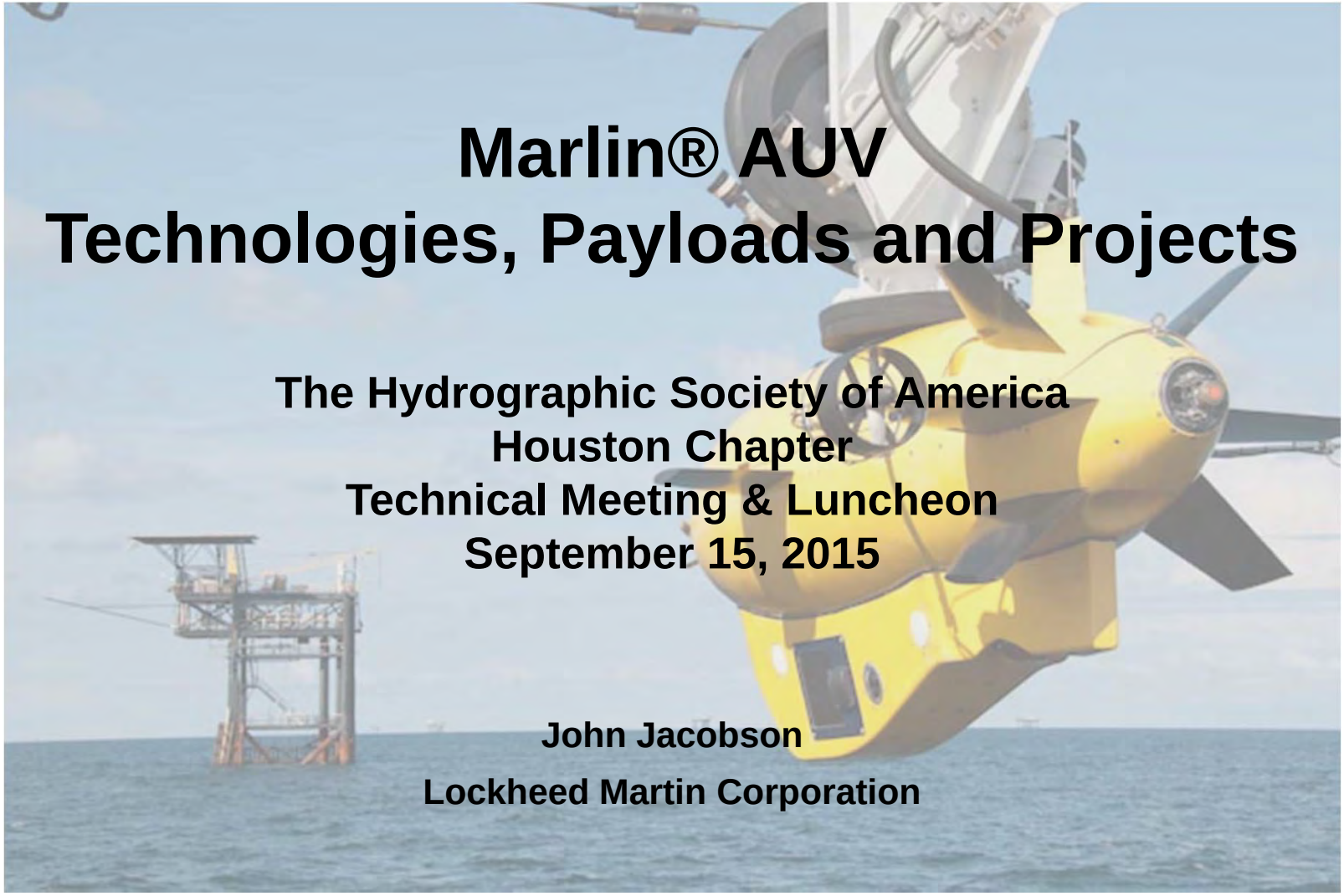


Marlin® AUV
Technologies, Payloads and Projects

The Hydrographic Society of America
Houston Chapter
Technical Meeting & Luncheon
September 15, 2015

John Jacobson

Lockheed Martin Corporation

Agenda

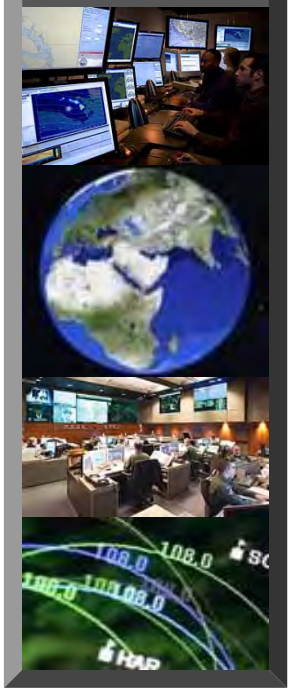
- Introduction
- Marlin® AUV Technologies
- Marlin® Mk3 Payloads
- Recent Projects

Lockheed Martin Corporation

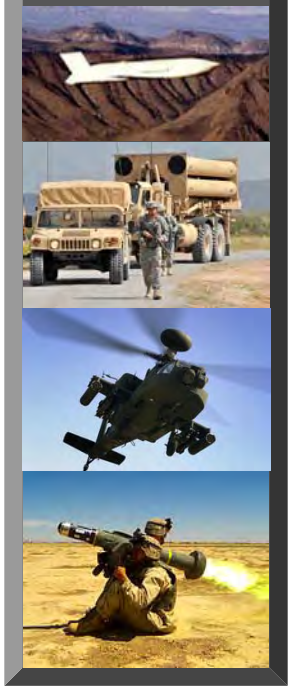
LOCKHEED MARTIN

Aeronautics

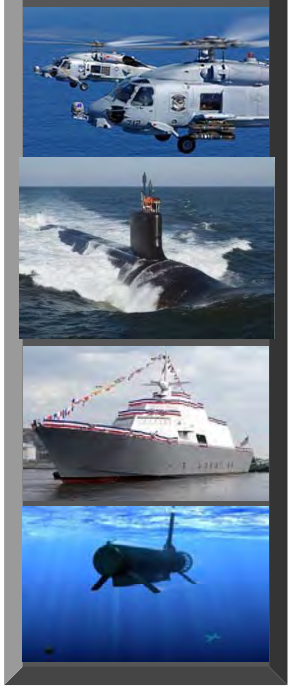
Information Systems & Global Solutions



Missiles & Fire Control



Mission Systems & Training



Space Systems

Lockheed Martin Palm Beach Facility

Easy Access to Offshore Test Ranges

The Marlin® AUV Family

Marlin® Mk2

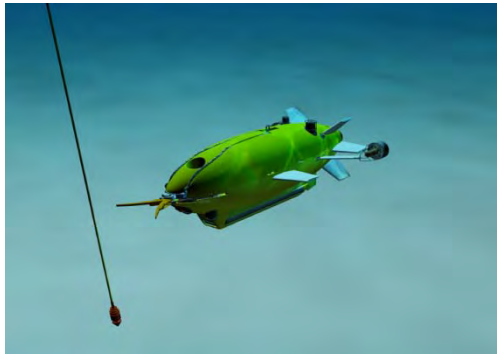
- 300 Meter Depth Rated
- Field Proven, thousands of hours in-water
- Extensive Trials Experience
- Available for Commercial Operations

Marlin® Mk3

- 4000 Meter Depth Rated
- Detailed Design Completed
- Construction / Field Trials Pending

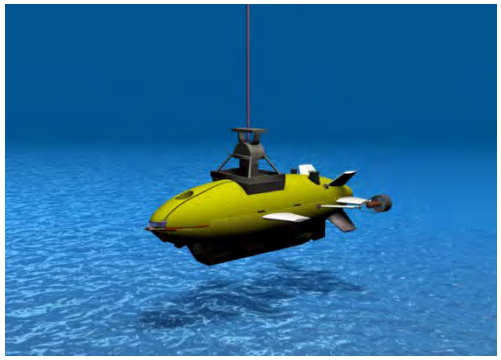
Marlin® Technologies

Autonomous Homing and Docking



Homing

Docking

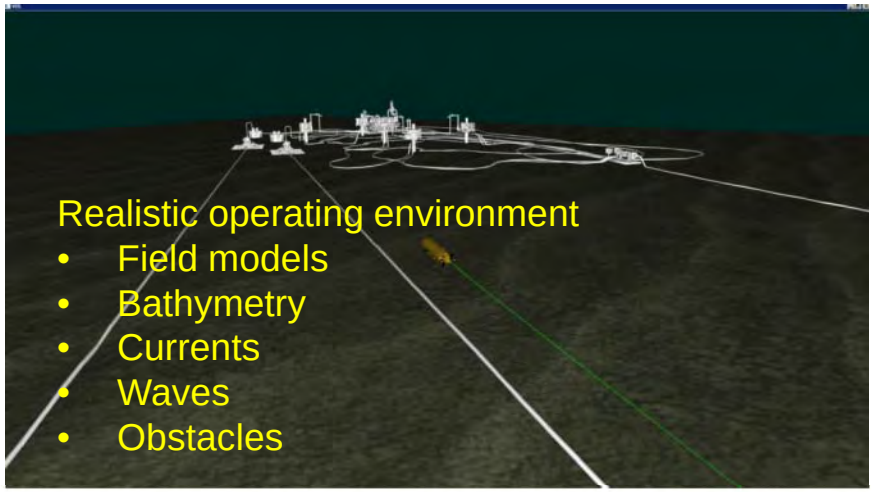


Recovery

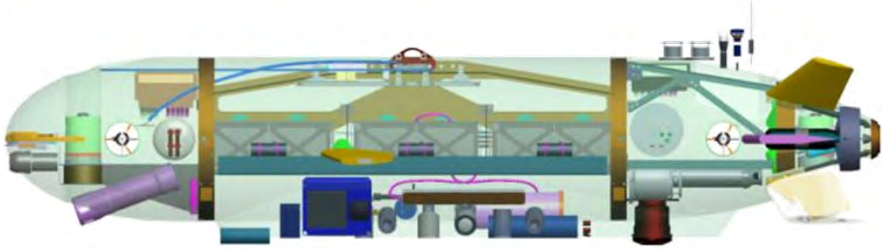
- Reverse USBL System provides beacon location and bearing to vehicle
- Homing and Docking sensor data fused with Inertial navigation sensor data
- Kalman Filter based fusion and tracking
- Provides ability to recover vehicle at depth

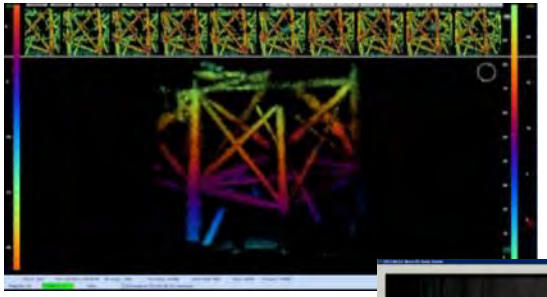
Proven Homing & Docking Technology Adapts to Many L&R Concepts

Marlin® AUV Simulation Lab

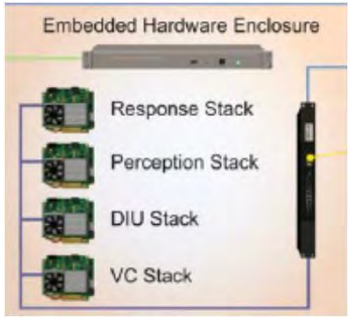


- CONOPS design and visualization
- Technology development
- Mission dry runs
  - Pipeline tracking
  - Facility inspections
  - Docking
- Monte Carlo simulation
- Requirements verification
- Failure/Fault handling

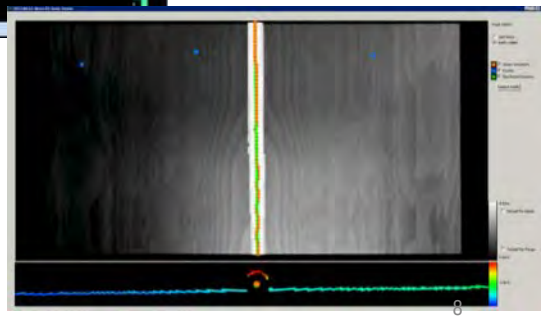




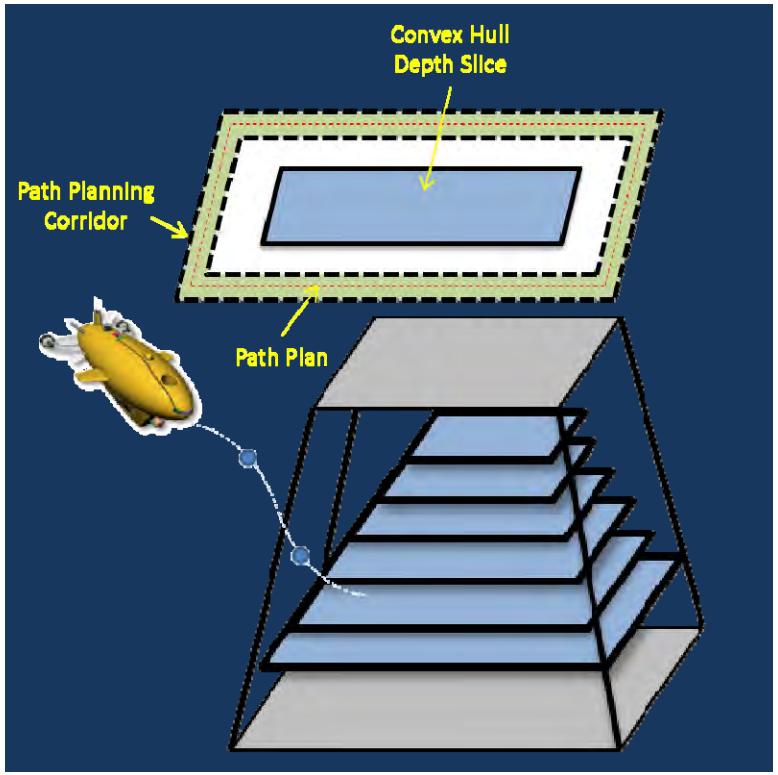
High Fidelity Simulation:
- Vehicle dynamics
- Navigation system
- Sensor data
- Uncertainties
- Contingencies, faults, failures

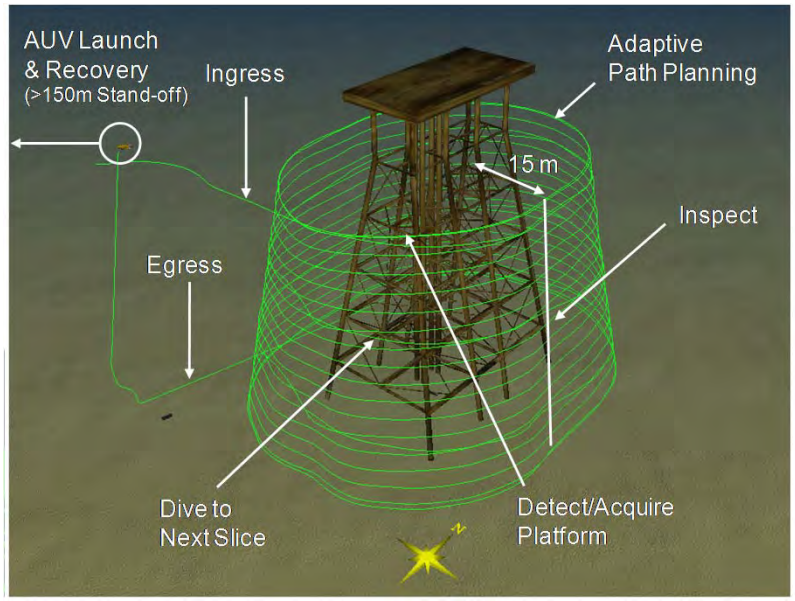


Sensor data



Autonomous Path Planning: Optimized & Safe

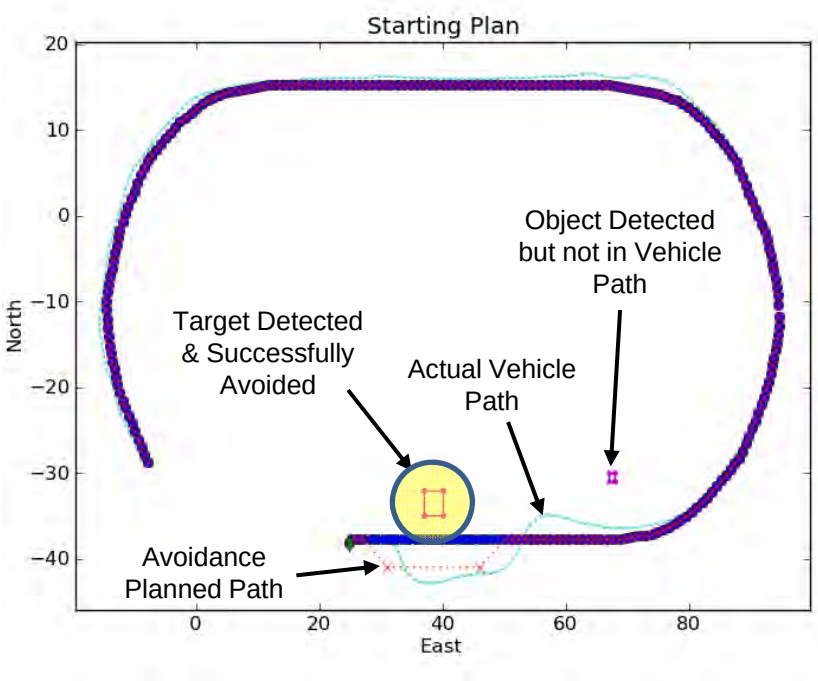




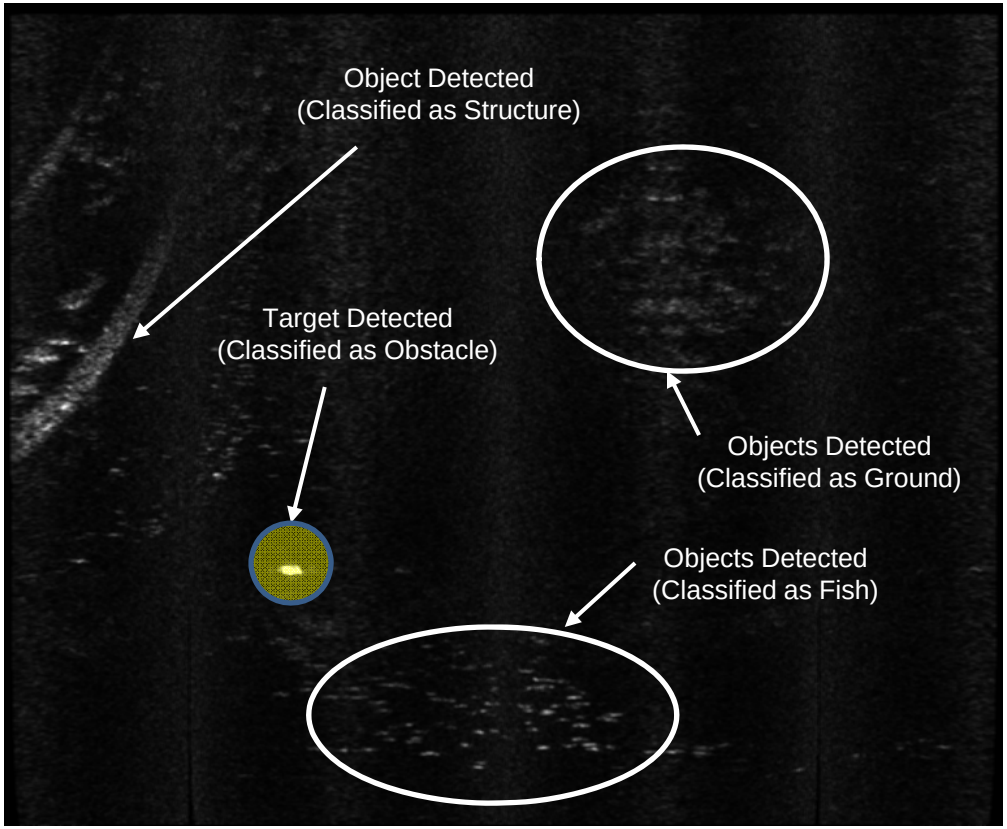
Path Planning

- Search Area Definition
- Automated Path (re) Planning(X,Y,Heading)
- Optimal to ensure high sensor coverage on the structure at all times
- A series of waypoints are defined from the optimal heading/range values

Obstacle Detection/Avoidance



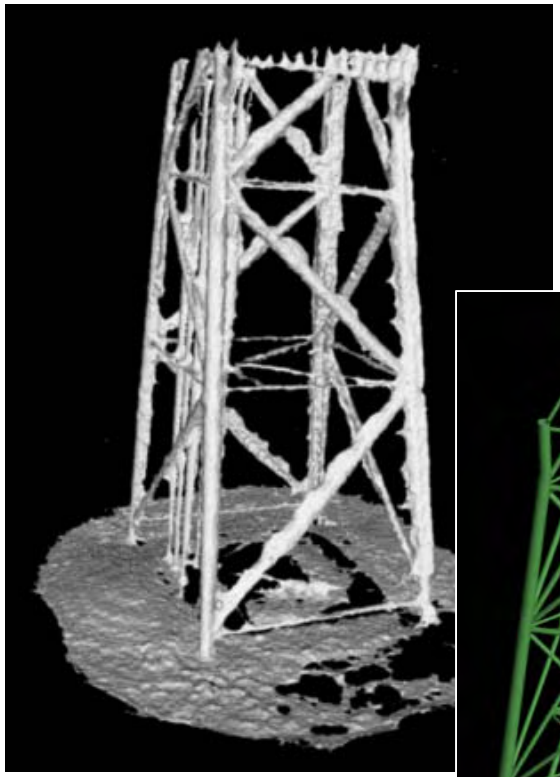
OD / OA Capability Validated
(Local Offshore Testing)

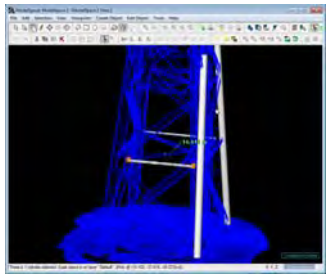


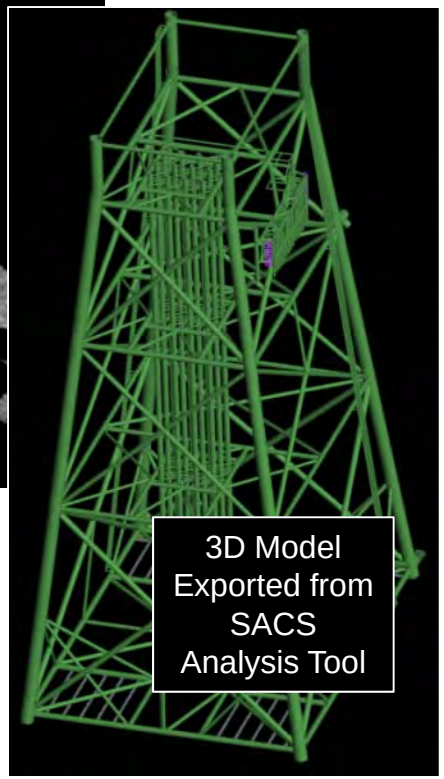
Successful Obstacle Detection / Classification
(Local Offshore Testing)

Demonstrated Obstacle Detection Classification and Avoidance

3D Model Generation and Change Detection

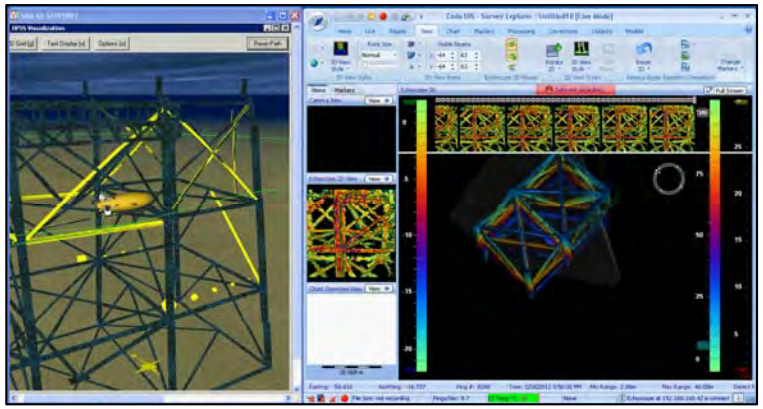




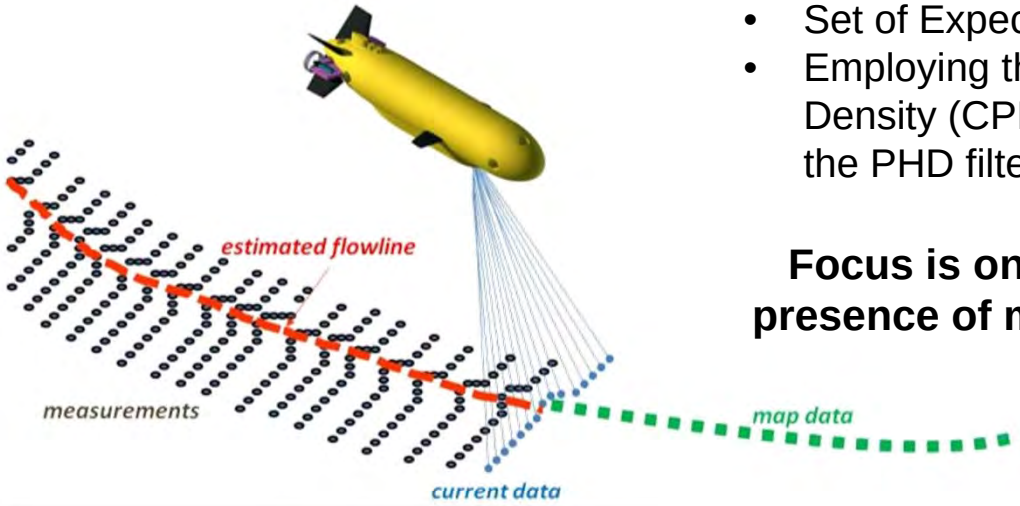


3D Model Exported from SACS Analysis Tool

- **Model-Building Mission:**
  - Speed 2.0 knots
  - Standoff from Structure 15M
  - 100% overlap per depth slice
  - 130 ft. platform surveyed in 41 min. in low visibility conditions
- **Change Detection Mission:**
  - Same mission parameters
  - Real-time change detection against pre-existing 3D model
  - Can employ models from existing "SACS" structural analysis tool

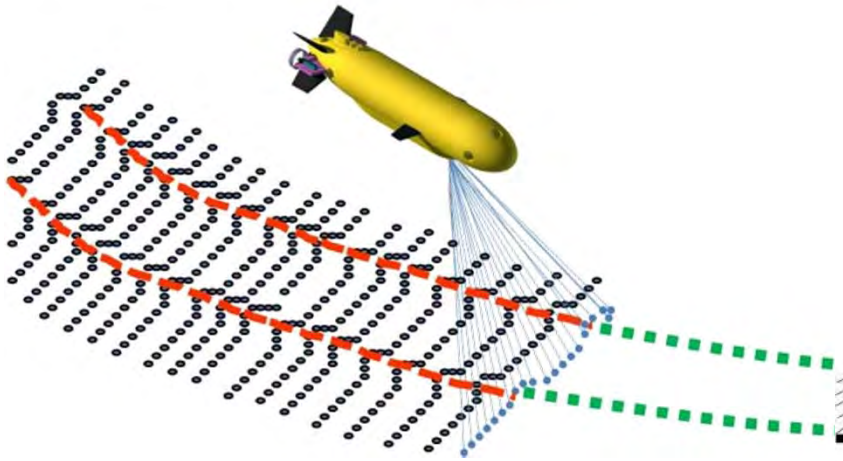


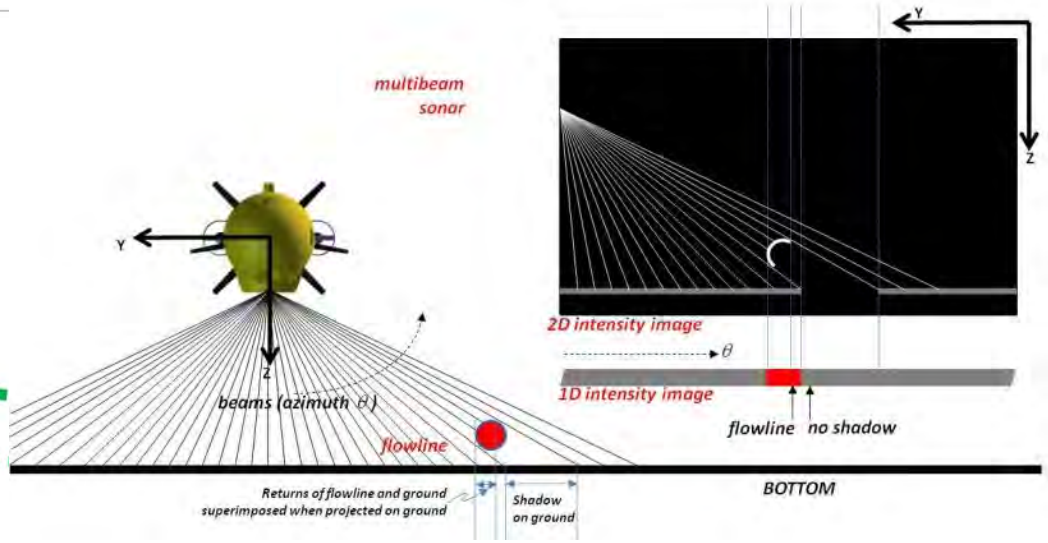
Flowline / Pipeline Tracking



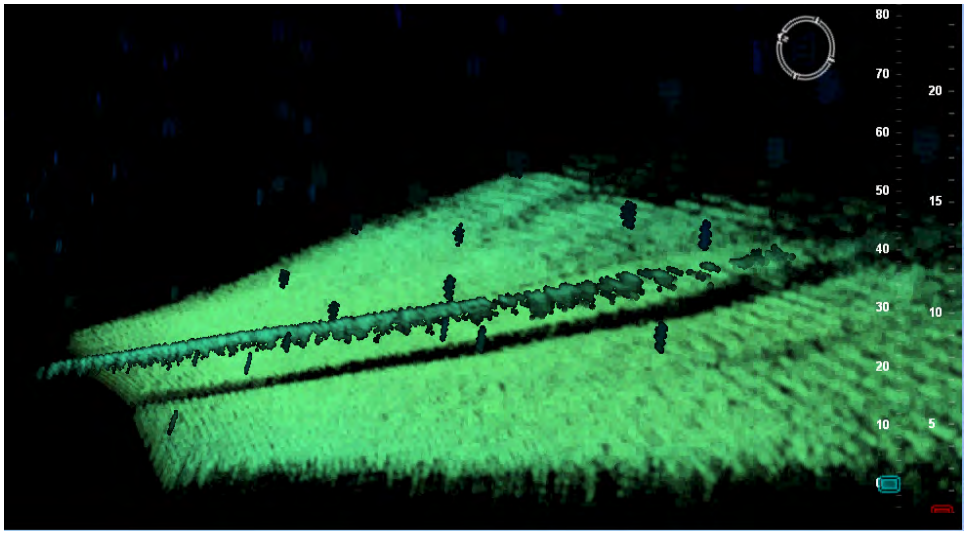
- Set of Flowline “Detections” from sensor data
- Set of Expected Flowline “Detections” from map data
- Employing the Cardinalized Probability Hypothesis Density (CPHD) Filter - Better tracking performance than the PHD filter used in many AUVs

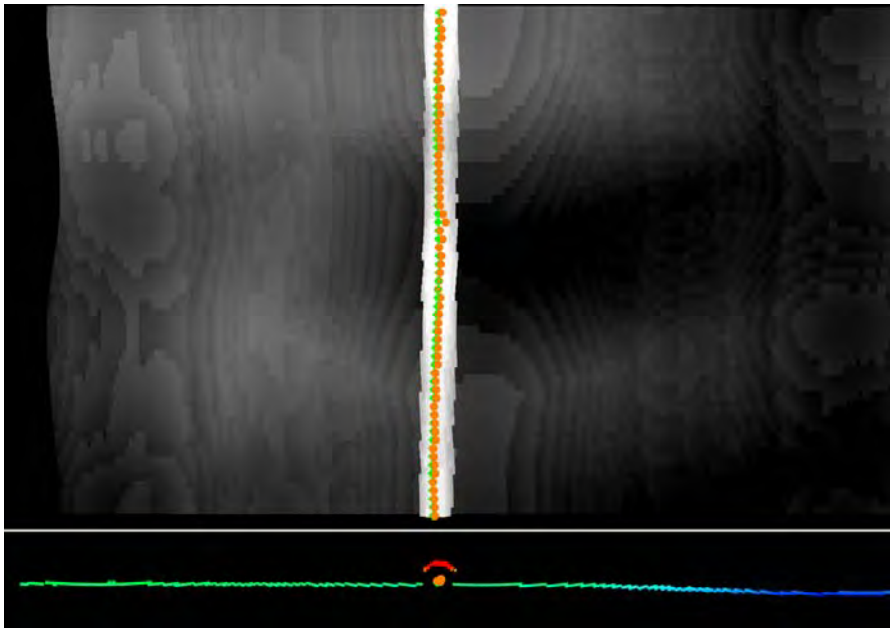
Focus is on achieving tracking robustness in the presence of multiple pipelines, clutter, and unknown / changing environment

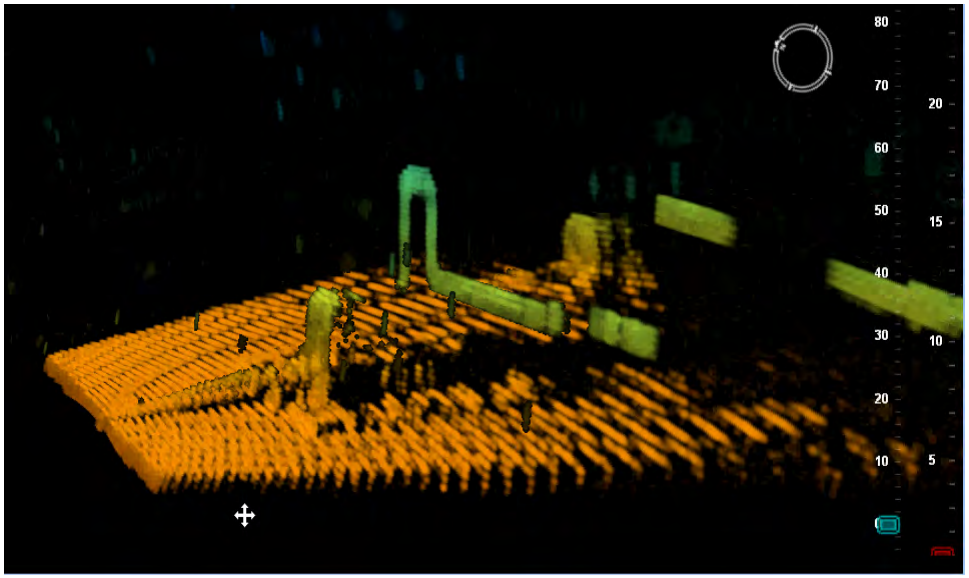


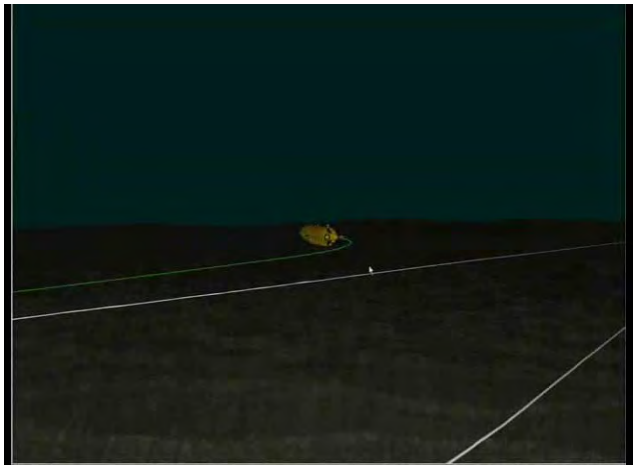


Simulation of 3D Forward Looking Sonar & MBES Tracker









Marlin® Mk3 Payloads

Marlin® Mk3 – 4000M AUV

Variant 1 –

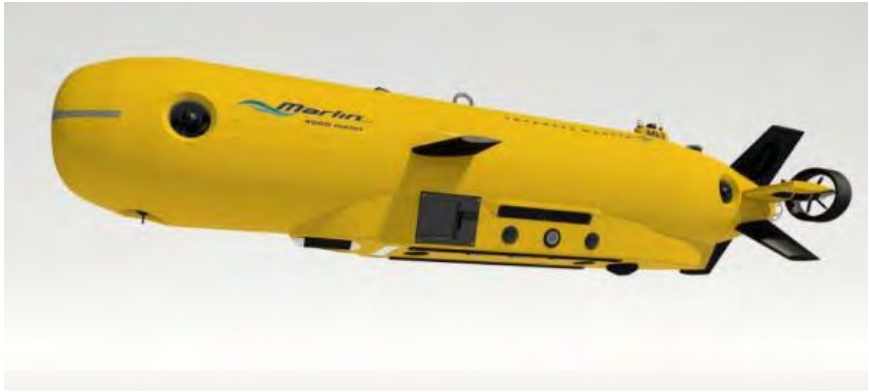
Deepwater Facility/Pipeline Inspection

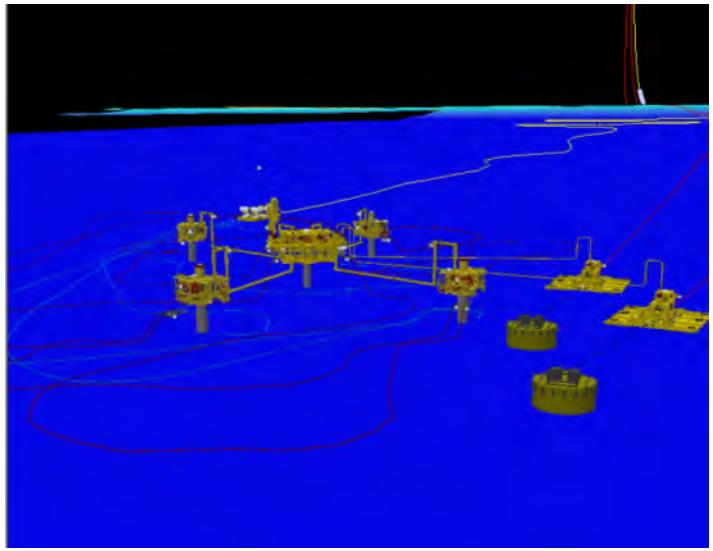
Inspection of Subsea Infrastructure, Pipelines, and Flowlines

Variant 2 –

Deepwater Field Resident

Deployed from Vessel or Facility-Subsea Docking, Recharging, Data Harvesting, Risers, Moorings Inspection



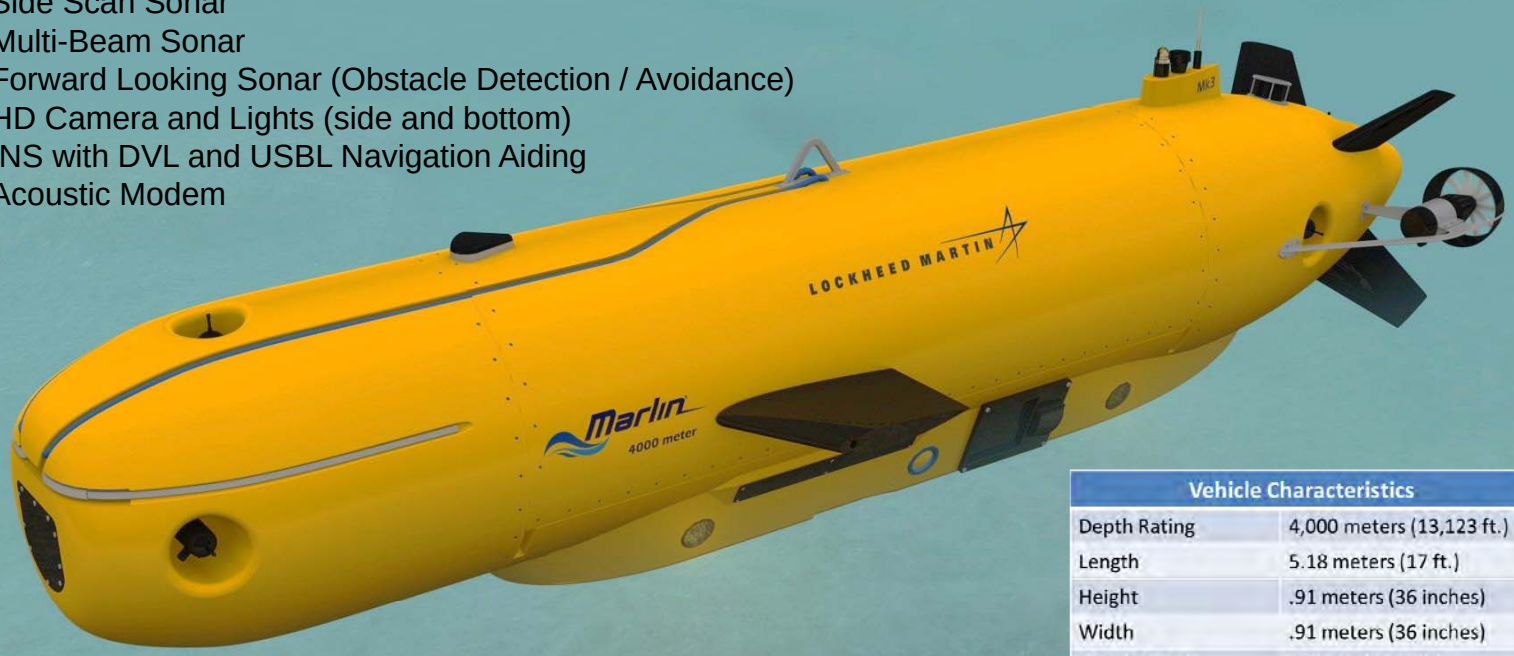


Key Characteristics	
Depth	4000M
Speed	3.5 Kt (5Kt Sprint)
Maneuver-ability	6 Degrees of Freedom (Full Hover)
Endurance Range (3000M)	>20 Hrs 56.9 Nmi (103.8 km) 6 Battery Configuration
Physical	5.2M Long, 2.4 MT

Bringing a Full Range of Infrastructure Inspection Capabilities to Deepwater Fields

Marlin ® Mk3 Overview

Key Sensors:
- 3D Sonar
- Side Scan Sonar
- Multi-Beam Sonar
- Forward Looking Sonar (Obstacle Detection / Avoidance)
- HD Camera and Lights (side and bottom)
- INS with DVL and USBL Navigation Aiding
- Acoustic Modem



Vehicle Characteristics	
Depth Rating	4,000 meters (13,123 ft.)
Length	5.18 meters (17 ft.)
Height	.91 meters (36 inches)
Width	.91 meters (36 inches)
Weight (Dry)	2495 kg (5500 lb)
Auto functions	6DOF (AUV Mode)
	5 DOF (Hovering Mode)
Max Operating Speed	5 knots
Battery Capacity	44 kWh
Endurance	> 20 hours
Range	> 100 km
Payload (Wet)	159 kg (350 lb)

Key Capabilities
- Modular and Expandable Energy Section
- Mission Package is Interchangeable
- 4000M Depth Rating
- > 100 KM range at 3 knot Operating Speed
- Vertical and Lateral Thrusters for Hover and Station Keeping
- Utilizes proven Marlin® Launch and Recovery System

Advanced Capabilities & Modular Design To Support Future Missions

Marlin® Mk 3 Modular Mission Package

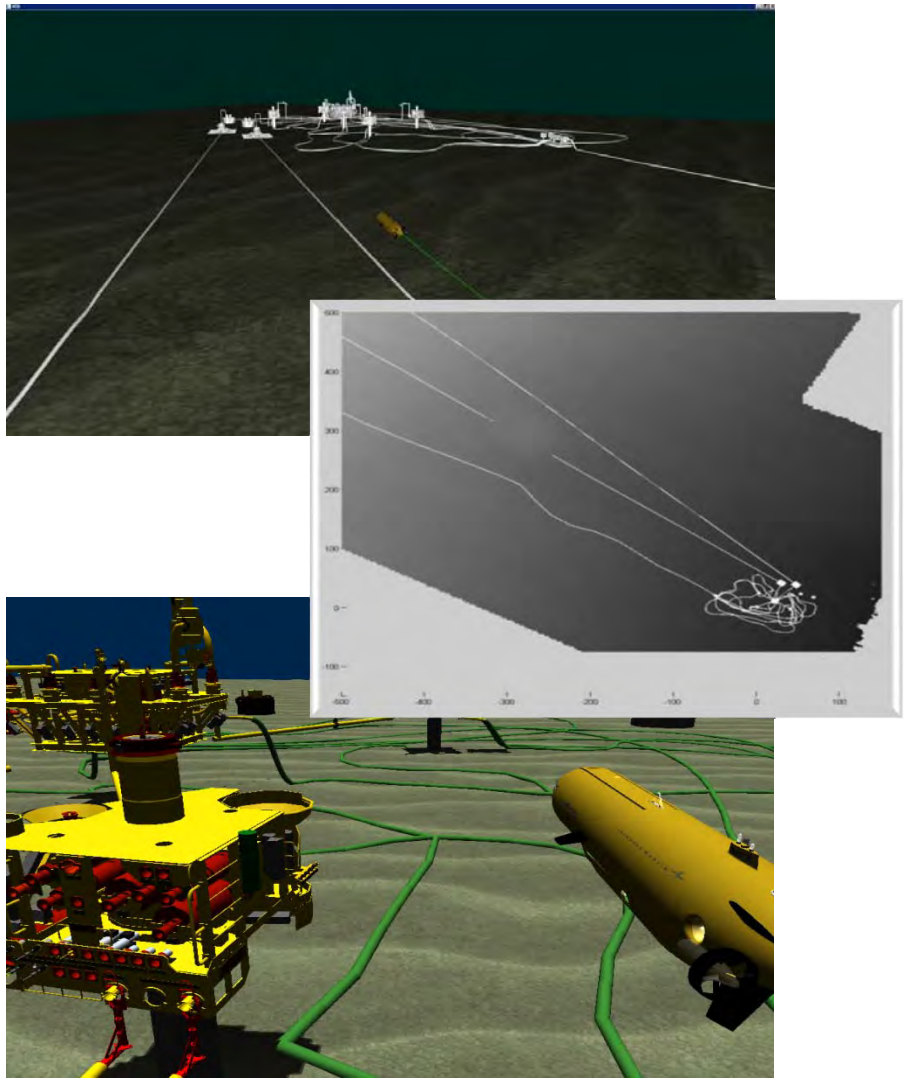
Rapid Change-out of Payloads as the Mission Evolves:

- Mk3 V1: Pipeline Inspection / Facilities Inspection
- Mk3 V2: Field Resident Applications
  - Add High Bandwidth Comms as required
  - Add Plume Detection, Tracking, and Localization
- Modular Design facilitates Payload / Energy tradeoffs
- Future Applications:
  - Geotechnical Survey
  - Seabed Mining

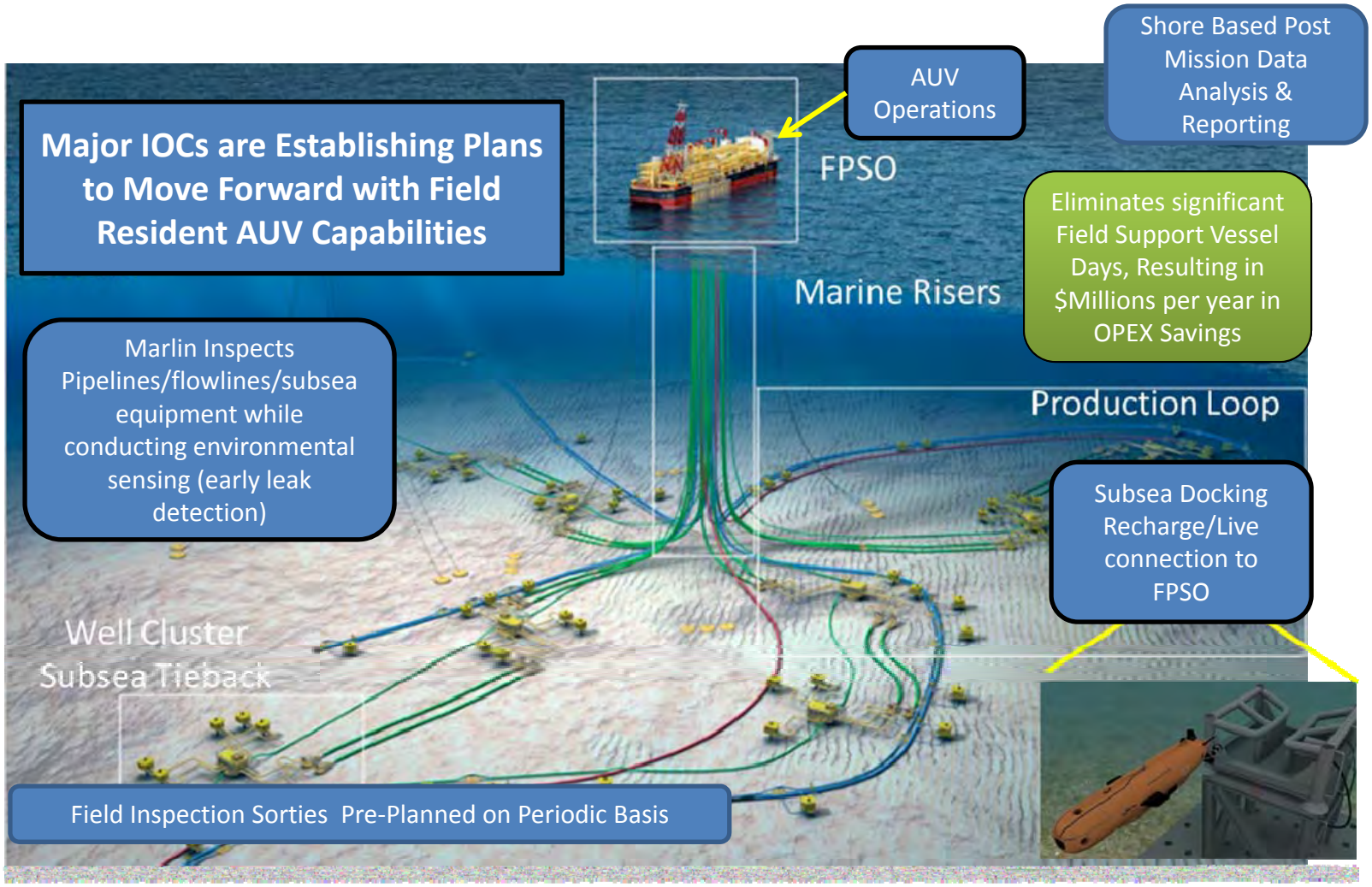
The Marlin Mk3 Payload Module Can be Reconfigured for Many Missions

Marlin® Mk3 V1 – Pipeline / Facilities Inspection Planned Mission Capabilities

- Operate autonomously in deepwater fields up to 4000m
- Perform bathymetric / seabed surveys
- Perform pipeline / flowline inspections
- Perform inspections of deepwater facilities



Marlin® Mk3 V2 Field Resident AUV



Field Resident AUV System Remains Submerged for Extended Periods

Recent Projects

Autonomous Underwater Inspection Using a 3D Laser

Project Overview

Project Objective

- Develop and demonstrate 3D Modeling and Change Detection using an AUV-based 3D Laser, including:
  - Close-in, high resolution3D laser imaging
  - Generation of high resolution, geo-registered 3D models of subsea structures
  - Detection of changes against a priori models

4 Phase Project Plan:

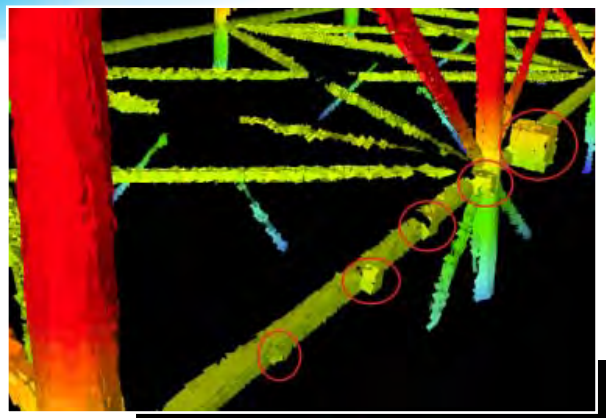
- Requirements / Interface Definition
- Hardware / Software Design & Build
- Onshore Integration & Testing
  - 3D Laser FAT
  - Simulation Laboratory Integration & Testing
- Offshore Prototype Testing

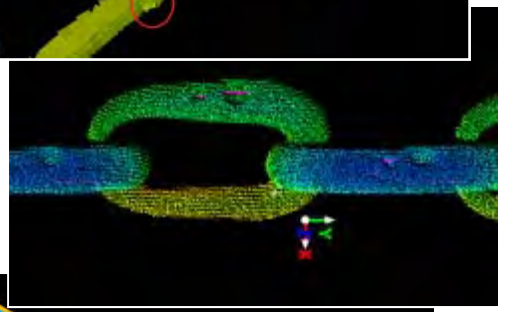
Potentially dramatic cost reductions and improved operating efficiencies can be achieved if high-accuracy inspections can be performed with an AUV

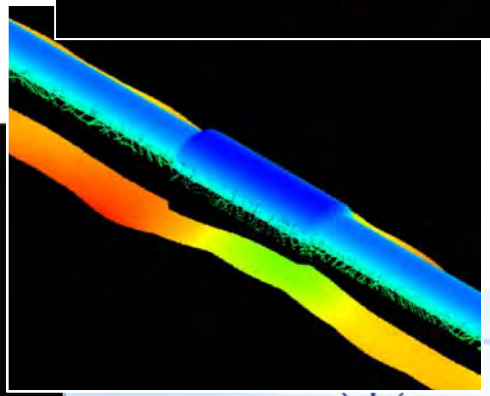
RPSEA
Research Partnership to Secure Energy for America

Laboratory Simulation Conclusions

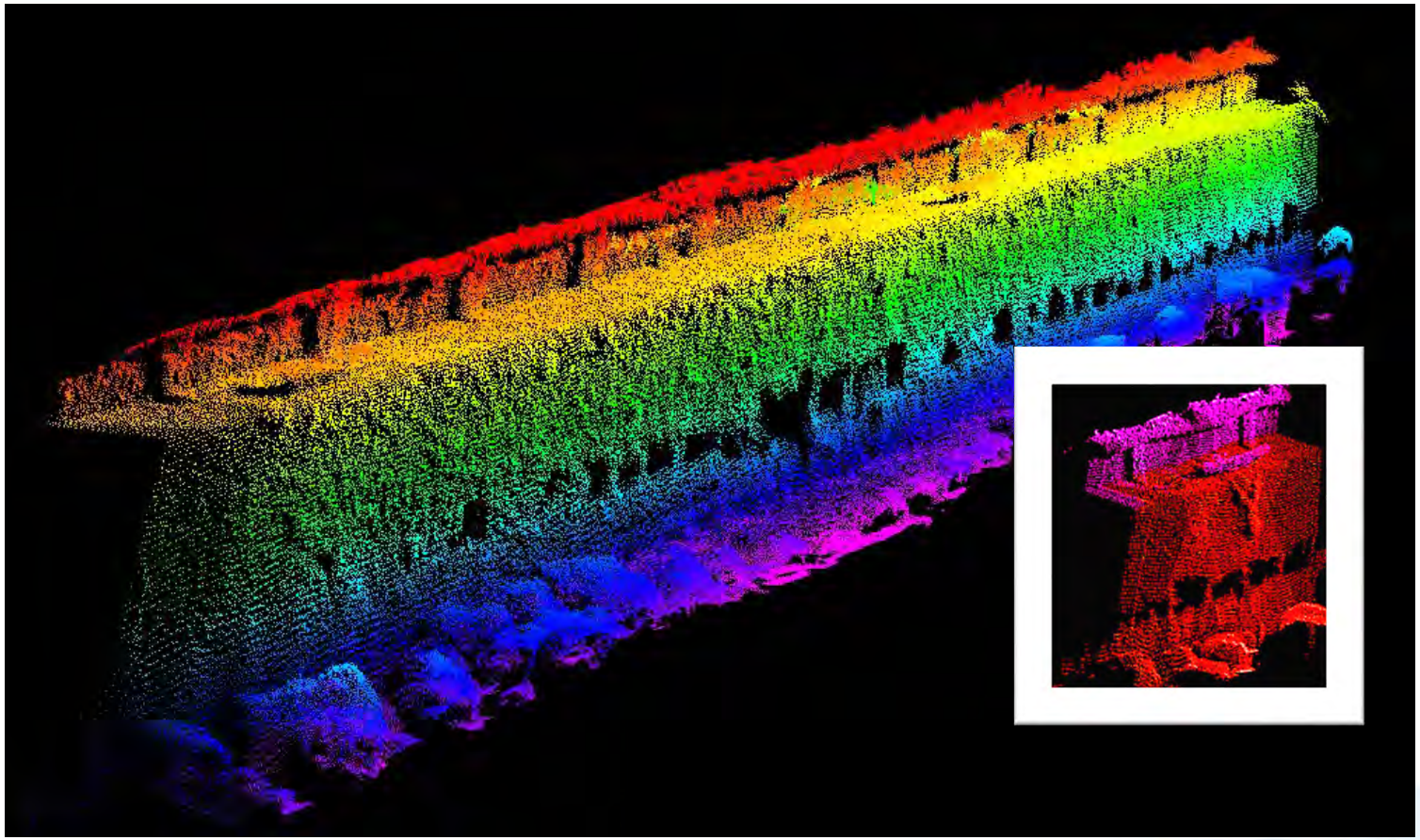
- Excellent Results for Some Test Cases:
  - Wellhead Verticality: < 0.08 degrees angular error
  - Jumper Metrology: < 0.5% length / elevation error
  - Anode Depletion: < 2% to 10% dimensional errors
  - Spoils Volume < 2% volumetric error
- Additional Work Required to Assess / Optimize Other Test Cases:
  - Pipeline Dent / Pit / Concrete Coating Damage Detection and Measurement
  - Mooring Chain Pit / Wear Damage Detection and Measurement







Offshore Test Results: Downed Barge

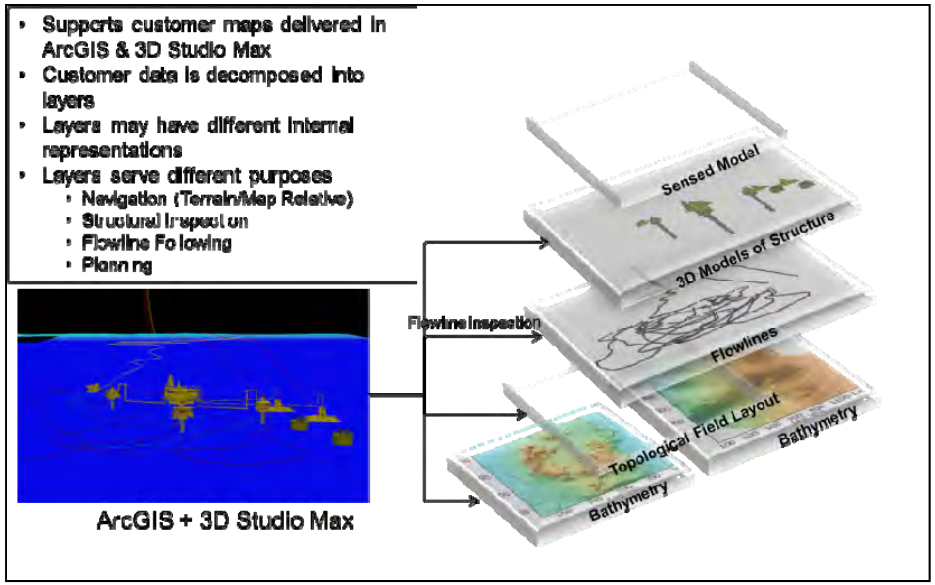


- Single pass scan by AUV at approximately 1 knot and 5.25 meter standoff range
- Scanned barge structure is approximately 72 ft. in length; scan completed in ~ 45 seconds
- Consistent with Simulation Lab results for a single pass at a 5 meter standoff

RPSEA
Research Partnership to Secure Energy for America

Terrain Aided Navigation

- Incorporating “best practices” in navigation from across Lockheed Martin
- Focused on Correlation of Multiple Navigation Sources:
  - Multiple map layers employed to derive “elevation map”
  - Multiple sensor inputs employed to derive altitude and position
  - Application of correlation algorithms, filters, position-aiding and SLAM technologies



Objective: Common Terrain-Aided Navigation Capability Across All Platforms

FOR MORE INFORMATION, PLEASE CONTACT:

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