Unmanned Maritime Vehicle (UMV)Test & Evaluation Conference

Held in Conjunction with
Autonomous Underwater Vehicle (AUV) Fest 2005

"Accelerating Deployment of Unmanned Maritime Vehicles Through Advancements in Test & Evaluation"

Keyport, WA

14-16 June 2005

Agenda

Tuesday, 14 June 2005

Navy Keynote, by Dr. Paul Lefebvre, Undersea Warfare Analysis and Assessment Product Area Director, Naval Undersea Warfare Center
Industry Keynote, by Mr. Chris von Alt, Chairman, Hydroid, Inc.

Technical Session 1 - UMV T&E Experiences

- Design and Testing of the Spartan USV Mine Warfare Module, Dr. Robert Mons, Sr. Advisory Engineer, Northrop Grumman Corporation
- Simulation and In-water Testing of the Mid-Sized Autonomous Research Vehicle (MARV), Mr. Thomas Fulton, Naval Undersea Warfare Center
- Surveillance Buoy, Dr. Daniel D. Morris and Dr. Franklin D. Snyder, Northrop Grumman Corporation and Mr. Eric C. Hansen, Naval Surface Warfare Center
- Underwater Robotics, Dr. Promode R. Bandyopadhyay, Naval Undersea Warfare Center

Wednesday, 15 June 2005

Technical Session 2 - Improved UMV T&E Systems and Techniques

- High Bandwidth Wireless Networks for Unmanned Maritime Vehicle Communications, Mr. Sean Kragelund, Naval Postgraduate School
- Improving "Ground Truth" Measurement & Stimulation for Unmanned Maritime Vehicle T&E, Mr. Troy D. Kelley, Naval Undersea Warfare Center
- Advanced Surface Launcher (ASL), Mr. Dave Lussier, SEA CORP and Mr. Michael Connelly, Naval Surface Warfare Center

Technical Session 3 - Advances in Land-Based and Laboratory T&E

- Multi-vehicle Collaborative Autonomous Control Under Difficult Communications Conditions, Mr. Robert W. Chalmers, Johns Hopkins University Applied Physics Laboratory, National Security Technology Department
- An Experimentation Framework to Support UMV Design and Development, Dr. Roger Neill, Dr. Francis Valentinis and Dr. John Wharington, Maritime Platforms Division, Austrialian Defence Science and Technology Organisation
- Out-of-Water Test Methods to Accelerate Implementation of Autonomous Rendezvous in the NPS ARIES AUV, CAPT J.W. Nicholson, Ph.D., United States Naval Academy
- Naval Undersea Warfare Center Division Keyport, Mr. Gary Zook, Naval Undersea Warfare Center

Technical Session 4 - Distributed UMV T&E and Testing with Training

- Successes in Combining Testing with Training in the Modular Mission Package (MMP) Program, Mr. Mark Connolly, Naval Surface Warfare Center, Panama City
- Collaborative Test/Training, Experimentation/Evaluation Capability (CTEC) – The NUTEC Engine for USW Live, Virtual, & Constructive Joint Exercises, Mr. Reid Johnson, Naval Surface Warfare Center
- Out-of-Water Test Methods to Accelerate Implementation of Autonomous Rendezvous in the NPS ARIES AUV, CAPT J.W. Nicholson, Ph.D., United States Naval Academy
- Enabling Effective & Efficient Fleet UMV Operational Training through Distributed USW Test & Training Technology Enabling Effective & Efficient, Mr. Michael Kelf, Science Application Internation Corporation and Mr. G. Michael Hewitt, SONOALYSTS, Inc.
- AUV Fest 2005 Demonstrations: Technologies

Thursday, 16 June 2005

Plenary Session:

- Naval Postgraduate School, VADM Roger F. Bacon, USN (ret), Chair, Professor Undersea Warfare, Naval Postgraduate School
- Naval Oceanography: Experimenting into the future…, Mr. Ed Gough, Deputy Commander, Naval Meteorology and Oceanography Command
- Distinguished Visitors Day Touring & Demos, Mr. Steve Stuart, AUV Fest 2005 Event Manager, Naval Undersea Warfare Center
- AUV Fest 2005: Highlights, Col William Schopfel, USMC (Ret), Officce of Naval Research Test Director

Panel Discussion:

- Panel Members
  - Office of Naval Research: Science & Technology, Dr. Thomas Swean, Office of Naval Research
  - Future Technology Development and Assessment for UUV Acquisition, Mr. James Griffin, Naval Undersea Warfare Center, Autonomous Systems and Technology Department
  - Graduate Education for Unmanned Vehicles and Undersea Warfare: NPS Teaching, Research and Partnership Strategies, Dr. Don Brutzman, Undersea Warfare Academic Group, Center for AUV Research Naval Postgraduate School (NPS)
  - Customers: Fleet Operators, CDR Jon Wood, Naval Special Clearance Team One

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Autonomous Underwater Vehicle (AUV) Fest 2005

"Accelerating Deployment of Unmanned Maritime Vehicles Through Advancements in Test & Evaluation"

AUV Fest 2005
June 7 - 16, 2005

UMV T&E Conference
June 14 - 16, 2005

Event #5330

National Unmanned Undersea Vehicle Test & Evaluation Center (NUTEC)

Keyport, Washington

Sponsored by:

The Office of Naval Research

Naval Undersea Warfare Center

Naval Meteorology and Oceanography Command

and

NDIA's Test & Evaluation Division

NDIA Unmanned Maritime Vehicle (UMV) Test & Evaluation Conference

June 14-16, 2005 Naval Undersea Museum Keyport, WA

A G E N D A

Tuesday, June 14, 2005

7:15 a.m. **Conference Check-In and Continental Breakfast**
Naval Undersea Museum Lobby

P L E N A R Y S E S S I O N

8:00 a.m. **Call to Order**
Mr. C. Samuel Campagna, Director, Operations, NDIA

8:05 a.m. **Presentation of the Colors and National Anthem**
N*avy Band of the Northwest* and *U.S. Navy Color Guard*

8:10 a.m. **Welcome**
CAPT Daniel J. Looney, USN, Commander, Naval Undersea Warfare Center Division, Keyport

8:15 a.m. **Navy Keynote**
Accelerating Deployment of Unmanned Maritime Vehicles Through Advancements in Test & Evaluation Capabilities
Dr. Paul Lefebvre, Undersea Warfare Analysis and Assessment Product Area Director, Naval Undersea Warfare Center

8:45 a.m. **Industry Keynote**
Test & Evaluation Needs, Challenges, and Successes in Accelerating Delivery of UUV Systems to the Fleet
Mr. Chris von Alt, Chairman, Hydroid, Inc.

9:15 a.m. **Break and Refreshments in Display Area**

9:15 a.m.-5:00 p.m. **Display Area & Remote AUV Fest 2005 Display Center Open**
Naval Undersea Museum Display Area and AUV Fest 2005 Remote Display Viewing Center

TECHNICAL SESSION 1 – UMV T&E EXPERIENCES

10:15 a.m. **Opening Remarks**
Mr. Richard R. Peel, Conference Chairman, Naval Undersea Warfare Center

Design and Testing of the Spartan USV Mine Warfare Module
Dr. Robert Mons, Northrop Grumman Corporation

Simulation and In-water Testing of the Mid-sized Autonomous Research Vehicle (MARV) to Support USCG Homeland Security Applications
Mr. Thomas Fulton, Naval Undersea Warfare Center

Testing Automatic Ship Detection and Classification with EO Data
Dr. Daniel Morris, Dr. Franklin Snyder, and Mr. Eric Hansen, Northrop Grumman Corporation

Development of an Automated Biorobotic Marine Vehicle
Dr. Promode Bandyopadhyay, Naval Undersea Warfare Center

12:00 p.m. **Lunch**

1:00 p.m.- **AUV Fest 2005 Demonstrations**
5:00 p.m. Shuttle bus transportation to/from the Keyport waterfront

5:30 p.m.- **Opening Reception**
7:00 p.m. Naval Undersea Museum

Wednesday, June 15, 2005

7:15 a.m. **Conference Check-In and Continental Breakfast**
Naval Undersea Museum Lobby

TECHNICAL SESSION 2 – IMPROVED UMV T&E SYSTEMS AND TECHNIQUES

8:00 a.m. **Session Chairman's Opening Remarks**
CDR Roy Barnes, USN, Operational Test and Evaluation Force

High-Bandwidth Wireless Networks for UMV
Mr. Sean Kragelund, Naval Postgraduate School

Improving "Ground Truth" Measurement & Stimulation for UMV T&E
Mr. Troy D. Kelley, Naval Undersea Warfare Center

Advanced Surface Launcher (ASL)
Mr. David Lussier, SEA CORP and *Mr. Michael Connelly,* Naval Undersea Warfare Center

9:45 a.m. **Break and Refreshments in Display Area**

9:45 a.m.- **Display Area & Remote AUV Fest Display Center Open**
5:00 p.m. Naval Undersea Museum Display Area and AUV Fest 2005 Remote Display Viewing Center

TECHNICAL SESSION 3 – ADVANCES IN LAND-BASED AND LABORATORY T&E

10:15 a.m. **Session Chairman's Opening Remarks**
Mr. Jim Griffin, Naval Undersea Warfare Center

Multi-vehicle Collaborative Autonomous Control Under Difficult Communications Conditions
Mr. Robert Chalmers, Johns Hopkins University Applied Physics Laboratory

A Framework to Support UMV Design and Evaluation
Dr. Roger Neill, Australian Defence Science and Technology Organisation

Out-of-Water Test Methods to Accelerate Implementation of Autonomous Rendezvous in the NPS ARIES AUV
CAPT John Nicholson, USN, United States Naval Academy

Durability Assessment Using Accelerated Life Testing
Mr. Gary Zook, Naval Undersea Warfare Center

12:00 p.m. **Lunch**

TECHNICAL SESSION 4 – DISTRIBUTED UMV T&E AND TESTING WITH TRAINING

1:00 p.m. **Opening Remarks**
Dr. Thomas Swean, Office of Naval Research

Testing and Training for the Modular Mission Package Program
Mr. Mark Connolly, NSWC Panama City

Collaborative Test, Training, Experimentation, & Evaluation Capability (CTEC) – The NUTEC Engine for USW Live, Virtual, & Constructive Joint Testing
Mr. Reid Johnson, Naval Undersea Warfare Center

Enabling Effective & Efficient Fleet UMV Operational Training through Distributed USW Test & Training Technology
Mr. Brian J. Williams, SAIC; *Michael A. Kelf*, Naval Undersea Warfare Center

2:20 p.m.- **AUV Fest 2005 Demonstrations**
5:00 p.m. Shuttle bus transportation to/from the Keyport waterfront

Thursday, June 16, 2005

7:15 a.m. **Conference Check-In and Continental Breakfast**
Naval Undersea Museum Lobby

PLENARY SESSION
DISTINGUISHED VISITORS DAY

8:00 a.m. **Call to Order**
Mr. C. Samuel Campagna, Director, Operations, NDIA

8:05 a.m. **Presentation of the Colors and National Anthem**
U.S. Navy Color Guard and *Kitsap Chordsmen*

8:10 a.m. **Welcome and Opening Remarks**
Mr. Donald F. McCormack, Jr., Technical Director (Acting), Naval Undersea Warfare Center

8:20 a.m. **Plenary Session Introduction**
Mr. Jim O'Bryon, Chairman, NDIA Test and Evaluation Division

8:35 a.m.	**NDIA Perspectives** *Lt Gen Lawrence Farrell, USAF (Ret)*, President & CEO, NDIA
8:50 a.m.	**Future Littoral USW With Unmanned Systems - An Integrated Warfare View** *VADM Roger Bacon, USN (Ret)*, Naval Post Graduate School
9:05 a.m.	**Naval Oceanography - Experimenting in to the Future** *Mr. Edward Gough,* Technical Director, Naval Meteorology and Oceanography Command
9:35 a.m.	**Overview of Activities for Distinguished Visitors Day** *Mr. Steve Stuart*, AUV Fest 2005 Event Manager, Naval Undersea Warfare Center
9:45 a.m.	**Break and Refreshments in Display Area**
10:15 a.m.	**Highlights of AUV Fest 2005 Demonstrations** *Col William Schopfel, USMC (Ret)*, Office of Naval Research Test Director
11:00 a.m.	**Panel Discussion** *Senior UUV Community Leaders from Government, Academia, and Industry*
12:10 a.m.	**Closing Remarks** *CAPT Daniel J. Looney, USN*, Commander, Naval Undersea Warfare Center Division, Keyport
12:15 p.m.	**Lunch**
12:15 p.m.-5:00 p.m.	**Display Area & Remote AUV Fest 2005 Display Center Open** Display Area and AUV Fest 2005 Remote Display Viewing Center (Lower Level)
1:30 p.m.	**Waterfront Vehicle Area Tours & Viewing of Live UMV Demonstrations** Shuttle bus transportation to/from the Keyport waterfront
5:30 p.m.	**Salmon Bake** Keyport Lagoon Picnic Area

AUV Fest 2005

National UUV Test & Evaluation Center

NUTEC

National UUV Test & Evaluation Center

http://kpwawao.kpt.nuwc.navy.mil/NUTEC

NDIA Unmanned Maritime Vehicle Test & Evaluation Conference

"The Department of Defense finds that this event meets the minimum regulatory standards for attendance by DoD employees. This finding does not constitute a blanket approval or endorsement for attendance. Individual DoD component commands or organizations are responsible for approving attendance of its employees."

Privacy Act Waiver Notification

Your participation in this event subjects each participant, their employees, agents and assignees to photography. By participation in this event, each entity, employee, agent, or assignee hereby agrees to waive any rights to still and or video images taken by NUWC Division, Keyport. Moreover, each participant acknowledges that NUWC Division, Keyport may use any data, photography, or other information gathered in this event without limitation.

NPS
PRAESTANTIA PER SCIENTIAM
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POSTGRADUATE
SCHOOL

NDIA Unmanned Maritime Vehicles T&E Conference Presentation

Roger F. Bacon
Vice Admiral, USN (ret)
Chair, Professor Undersea Warfare
Naval Postgraduate School

16 June 2005 Naval Base Kitsap, NUWC Keyport – Undersea Museum

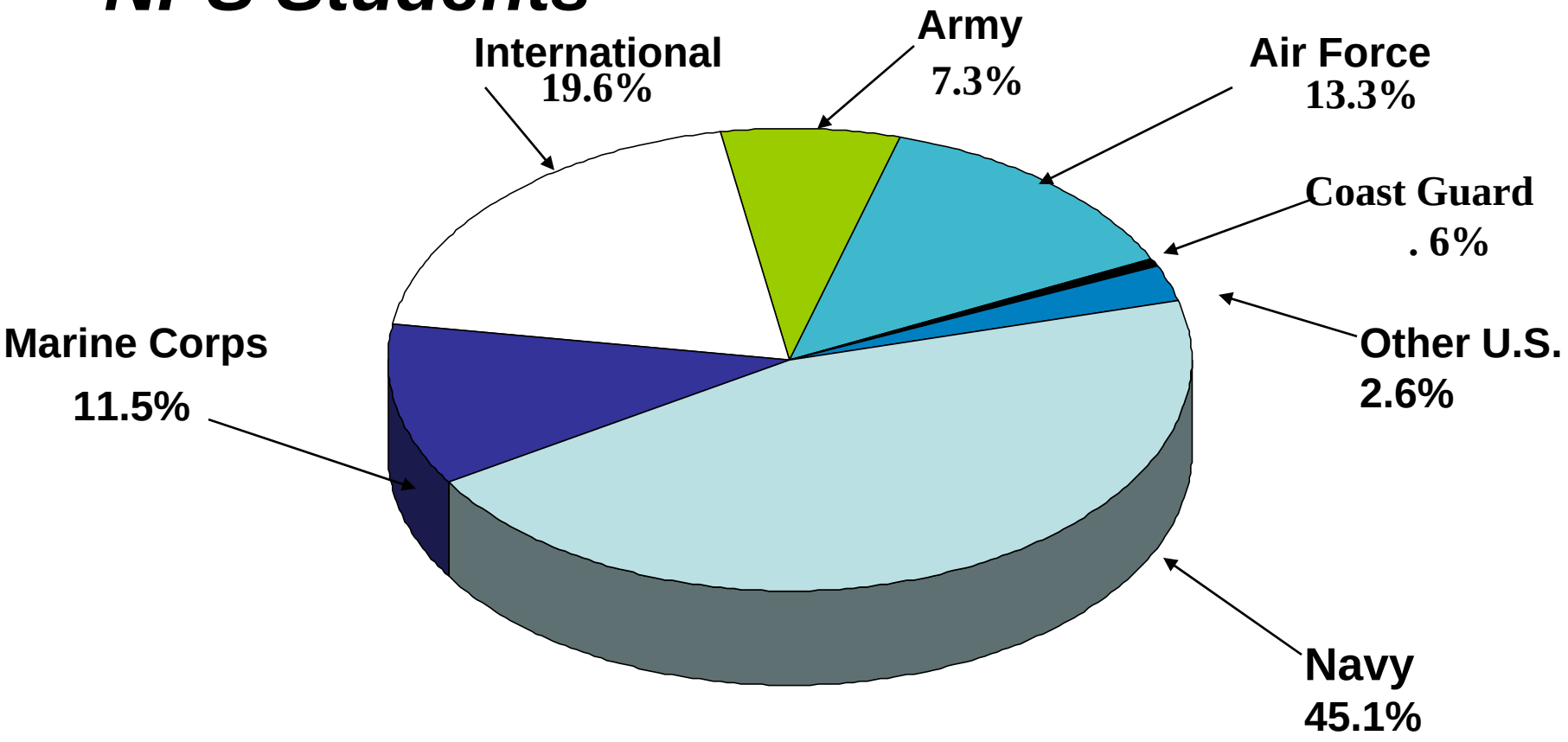
Naval Postgraduate School Mission

- *Relevant and unique advanced education and research programs*

- *Increase the **combat effectiveness** of U.S. and Allied armed forces*

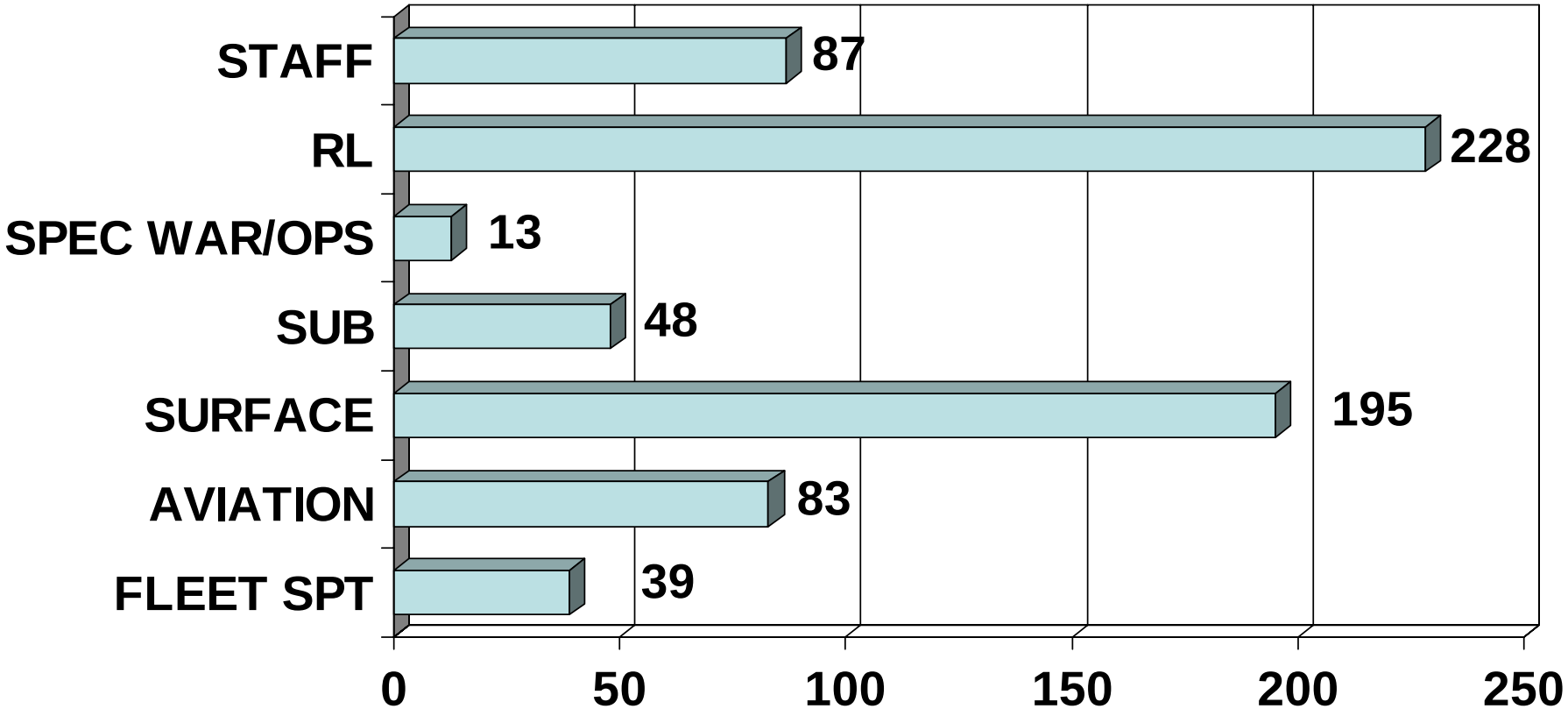
- *Enhance the security of the United States.*

NPS Students



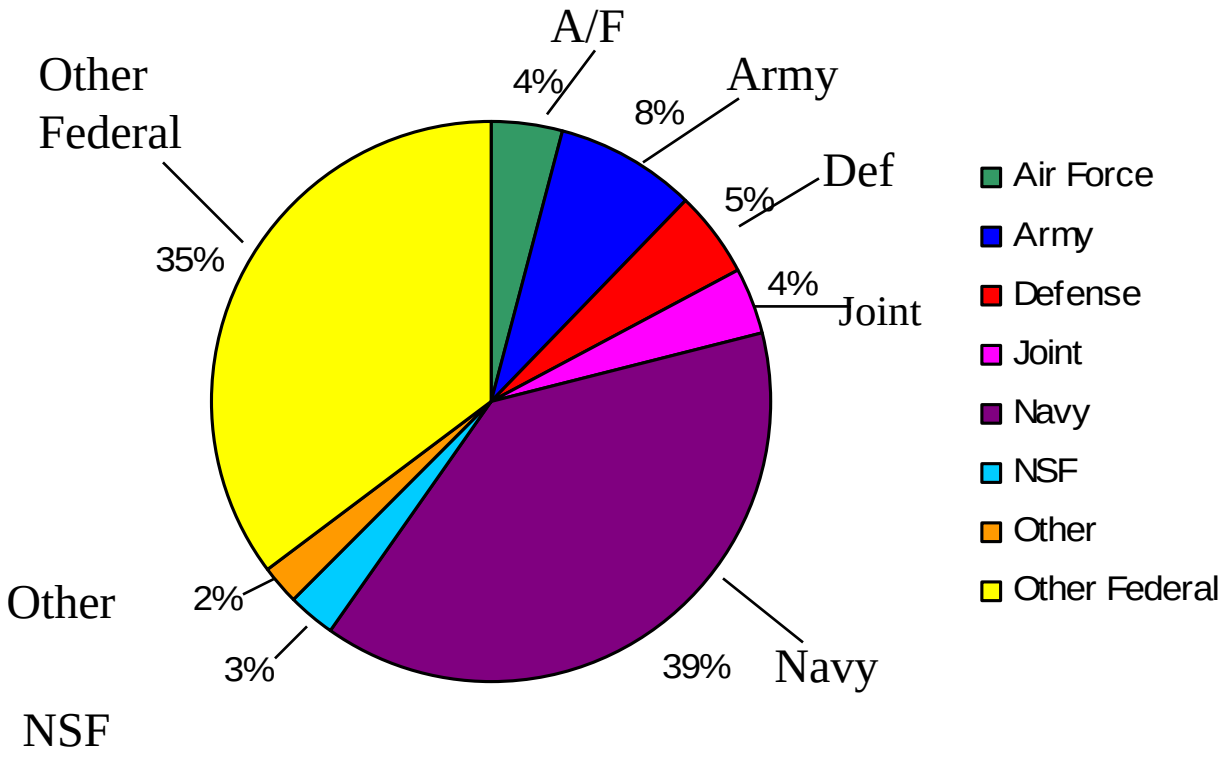
Current Enrollment: 1544 plus 715 in Non-Resident Programs

Navy Resident Student Population



QTR 2 FY 05

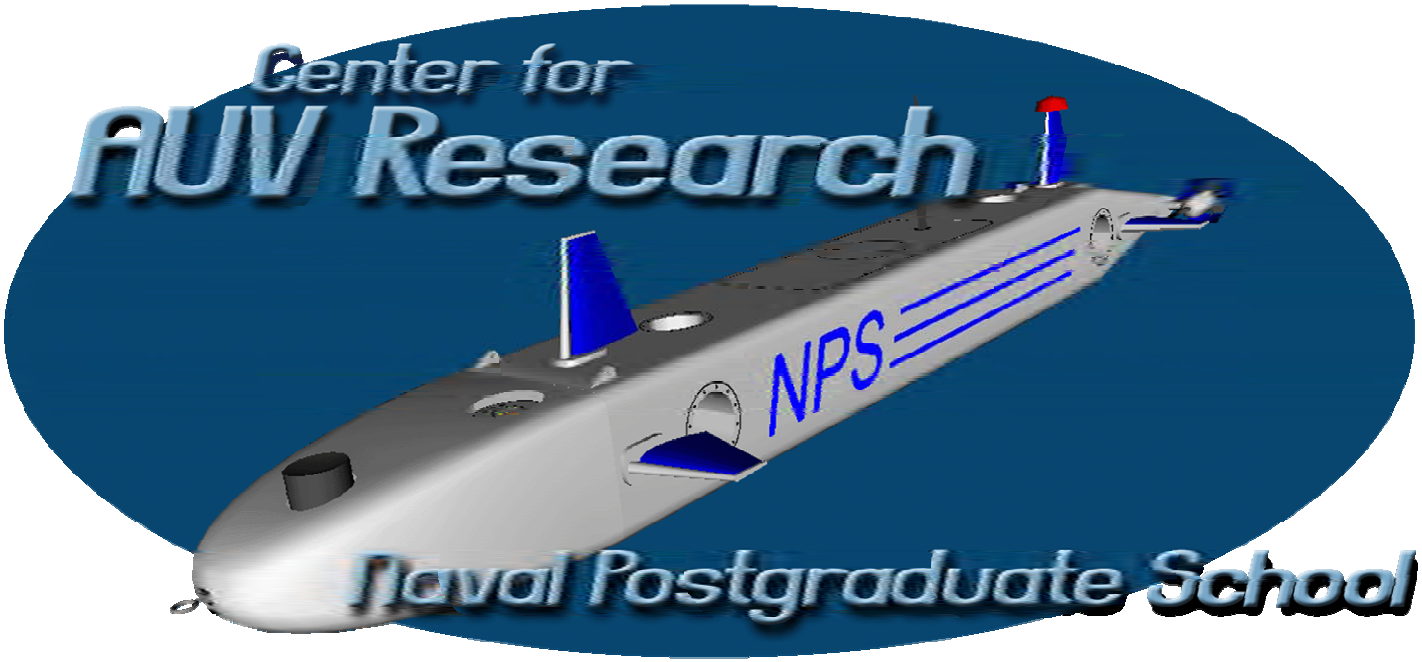
FY04 Sponsored Research Programs Research And Education



Total: $83.7M

Unmanned maritime vehicles- Naval Postgraduate School Since 1986

NPS Center for AUV Research



Dr. Anthony Healey Distinguished Professor
Naval Postgraduate School

Chairman of Mechanical and Astronautical Engineering department

Director , Center of AUV Research at Naval Postgraduate School

ONR support : Mr. Tom Swean

120 Theses in AUV technology , 5 PhD students since 1986

Mission Statement

- **The primary goal of the NPS Center for AUV Research is to educate Navy and USMC officer students in the development and use of technologies needed for unmanned underwater vehicles through coursework, thesis and dissertation research.**

- **The secondary goal of the Center is to advance Naval UUV operations by providing:**

  1. **Support to the Fleet, Navy Labs and Program Offices**
  2. **Testing and Experimentation of Advanced Technologies**
  3. **Independent Verification and Validation of UUV Concepts**
  4. **Innovative Concept Development**

AUVFEST 05 - Keyport Big Picture

- **AUV /UUV Small Vehicle Programs Have Successfully Demonstrated Organic Mine Countermeasures Capabilities. Examples are here at the Demonstrations.**

- **Larger Vehicles are now being developed with greater autonomy for more complex missions such as ISR and ASW.**

- **ASW is a current and near term focus.**

- **Persistent Presence and Surveillance is needed over larger areas.**

- **Technical Challenges lie in greater autonomy and coordination of information gathering from various assets.**

- **Think about what can be done by using the available real estate on Trident Submarines for deployment and recovery of large numbers of AUV / UUV vehicles!**

The future

UUV FEST 2005 WITH OVER 130 DEMONSTRATIONS HAS PROVEN THE SCIENCE AND TECHNOLOGY OF UNMANNED MARITIME VEHICLES IS ADVANCING RAPIDLY

HOW WILL COMBATANT COMMANDERS EMPLOY IT?

TWO OBVIOUS WARFARE AREAS:
MINE WARFARE AND ANTI-SUBMARINE WARFARE

SYSTEMS ENGINEERING AND ANALYSIS STUDENTS AT WAYNE E. MEYER INSTITUTE Naval Postgraduate School ARE WORKING ON IT

EIGHTH INTEGRATED WARFARE PROJECT SEA8 -FOR OPNAV

INTEGRATED WARFARE PROJECT FOR SEA 8

Anti-Submarine Warfare in the Littorals in 2025 will present a major challenge for the United States.

Quieter and more capable submarines operating in the littoral environments will continue to challenge the Navy as it assures access.

The Navy is developing programs to assure the continued capability to establish undersea superiority.

SEA-8 Problem Statement

Develop a System-of-Systems (SoS) Architecture to:

- conduct Undersea Warfare
- in the littorals
- during the 2025 timeframe
- consistent with the CNO's ASW CONOPS for the 21st Century.

Littorals Defined

SEA8

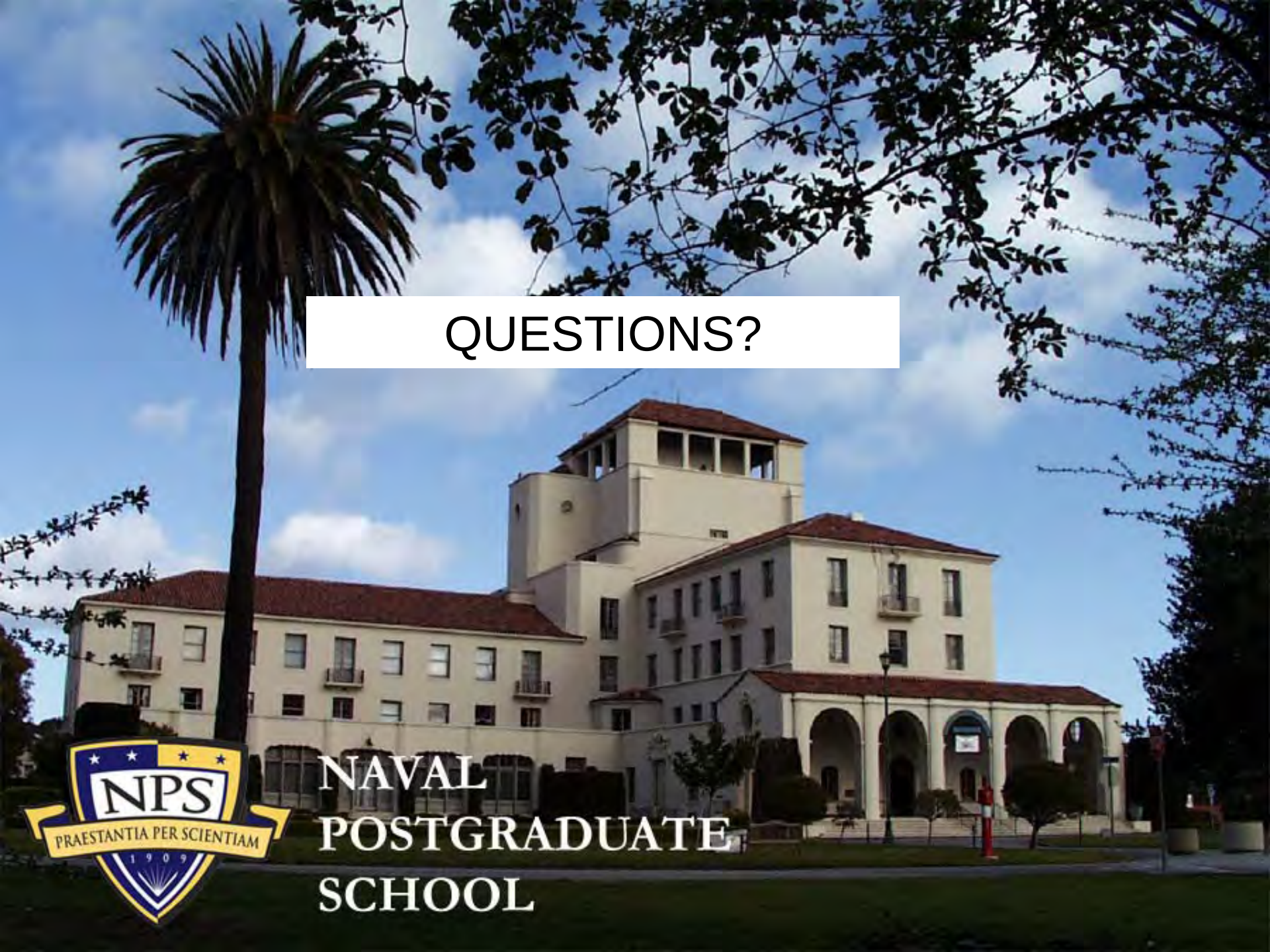
The SEA8 team which will use campus wide support will develop this project over the next six months and

Intend to use Unmanned Maritime vehicles/systems as a major force in Antisubmarine warfare in the littorals in the next 25 to 20 years.

They will report this out in December 2005

SEA 8

SEA 8 is tasked with designing a system that renders enemy under water vehicles (Submarines and UUVs) incapable of preventing U.S assets from operating within the littoral region during the 2025 timeframe.


QUESTIONS?
NPS
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SCHOOL

Backup

CNO TASK FORCE ASW WARFIGHTING STRATEGY

FOUR FORCE ATTRIBUTES:

Pervasive awareness – integrated undersea domain awareness from sensors to networks

Speed – warfighter will have ability to attack immediately with precision and decisive force

Persistence – persistent detection and cueing of sub threats will initiate a detect-to-engage sequence that holds enemy submarines at risk and enables their destruction

Technological Agility – State-of-the-art and state-of-the-practice technologies will facilitate the rapid introduction and fielding of new capabilities

CNO - ASW WARFIGHTING PRINCIPLES

Battle space preparation and monitoring

nb Precise **environmental characterization: historical, predicted and in-situ**

Persistent detection and cueing

- Deployable surveillance and monitoring, **network distributed surveillance**

Combined Arms prosecution

High Search and Kill rates

Non-conventional and non-traditional methodologies

- Reconfigurable manned and **unmanned vehicles**

Defense in depth and force self-protection

USW CURRICULUM Naval Postgraduate School AND SUBMARINE FORCE FUTURE CAPABILITY VISION Ref COMNAVSUBFOR 24 Jan 2005 JOINT LETTER

5 Technology vectors:

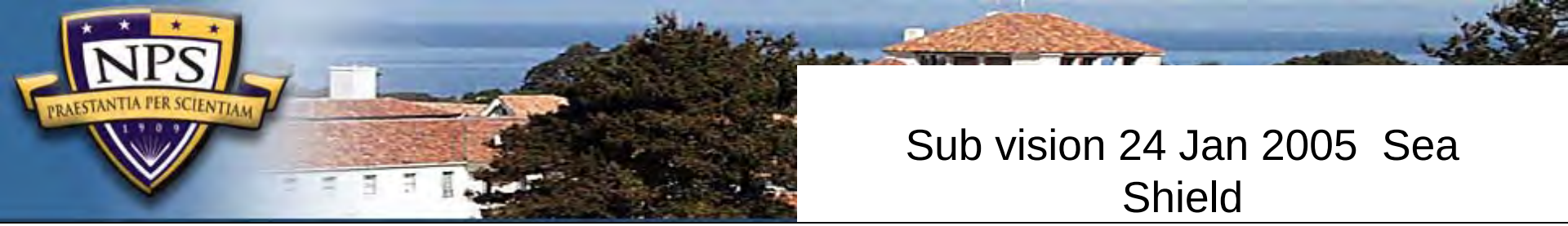
Payload: **increase in sub payload volume and a wide and varied range of off-board vehicles, sensors, and weapons are key to expanding the submarine's sphere of influence. -sea shield and sea strike elements SP 21.**

Modularity : **adapting new weapons and sensors - using modular approach – do quickly and inexpensively**

Connectivity: improved connectivity between submerged submarines, off-board vehicles and emerging shore and sea-based networks is required to better integrate submarines with the joint force.

Computing and Automation: Tactical displays and decision support systems, must be improved to make situational awareness more intuitive and less dependent on experience.

Integrated Electrical Systems: **need simplified and integrated power and propulsion systems**



Sea Shield – Clandestine ASW, SUW and MIW enabled by submarine stealth and access are vital to Joint Battle space preparation and combat success against an ever improving adversary

***Among these improvements*:**

Advanced acoustic hull arrays to enable covert localization and tracking of quiet diesel submarines

- **A submarine –deployable cueing sensor system that will allow a single submarine in the hostile littoral to monitor and prosecute tactically significant areas**
- **These efforts will:**
- **Build on Acoustic Rapid COTS Insertion/Advanced Processing Build improvements**

Mine warfare:

- **Revolutionary new submarine capabilities are required to localize and neutralize mines in order to enable safe passage of a submarine platform through an enemy minefield within a period of a few days.**
- **This capability will require novel sensors and CONOPS and will employ off-board payloads and sensors such as UUVS.**

NPS: Responding to an Evolving World

Center for Homeland Security

- *Dept. of Homeland Security/Dept. of Defense sponsored program*
- *Resident study and distance learning*

Center for Stabilization and Reconstruction Studies

- *Strategies, plans, organizational arrangements, and operational doctrines for post-conflict stabilization operations and reconstruction*
- *Civil-military professionals from US government, allies and NGOs*

NATO Partnership for Peace (PfP) Training Center

- *Only NATO training center in the United States*
- *NPS is the DoD graduation education choice for all of NATO*

USW CHAIR FUNCTIONS

Review USW curriculum for appropriate content relative to undersea and anti-submarine warfare principles and technology applications

Ensure curriculum meets educational standards for post-graduate degrees and requirements for sub-specialty codes.

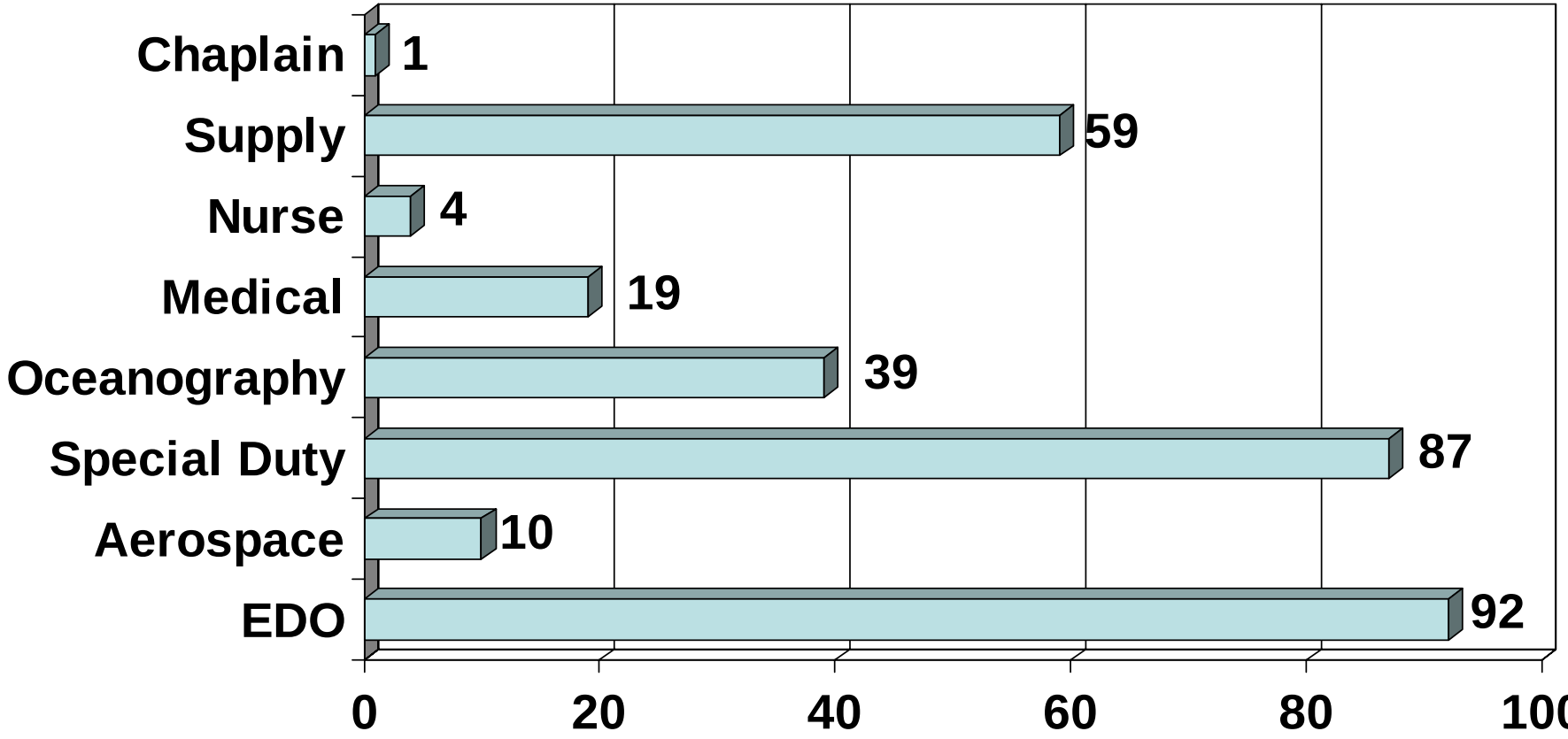
Revise and refine USW curriculum to reflect new curriculum sponsor initiatives

Liaison with Navy Laboratories, acquisition program managers, program sponsors, and operational commands to identify prioritized needs for research topics in USW areas.

Arrange for funds to support thesis work on these research topics.

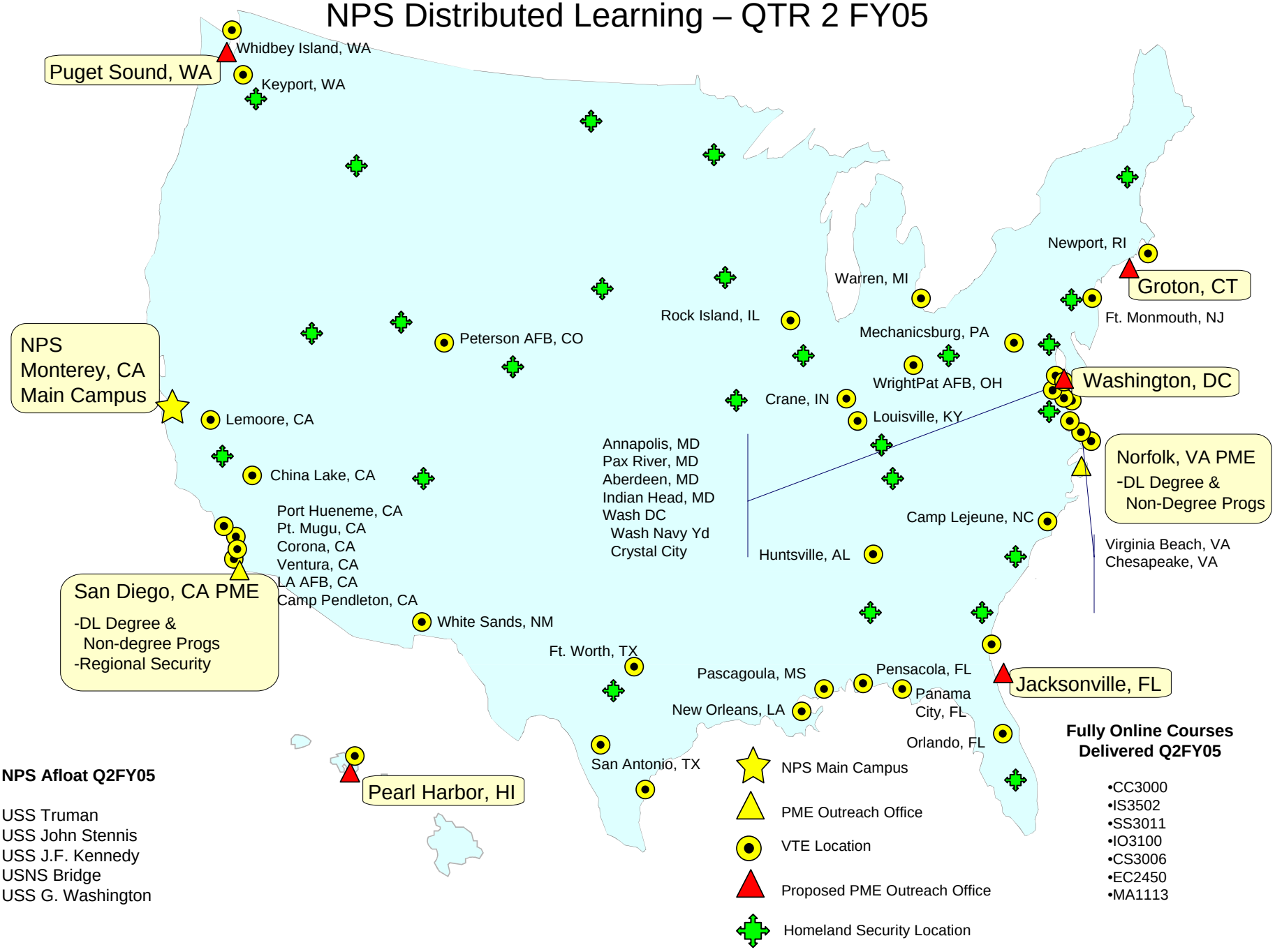
Arrange for thesis Professors and thesis student participation on these research topics.

Navy Staff and RL Student Population



QTR 2 FY 05

NPS Distributed Learning – QTR 2 FY05



NPS Afloat Q2FY05

USS Truman
USS John Stennis
USS J.F. Kennedy
USNS Bridge
USS G. Washington

Fully Online Courses Delivered Q2FY05

- CC3000
- IS3502
- SS3011
- IO3100
- CS3006
- EC2450
- MA1113

Underwater Robotics

Promode R Bandyopadhyay, Ph D
Naval Undersea Warfare Center
Newport, RI

NDIA
June 14, 2005

Sponsors:
ONR 342 (Dr. Thomas McKenna) & NUWC ILIR (Mr. Richard Philips)

Team

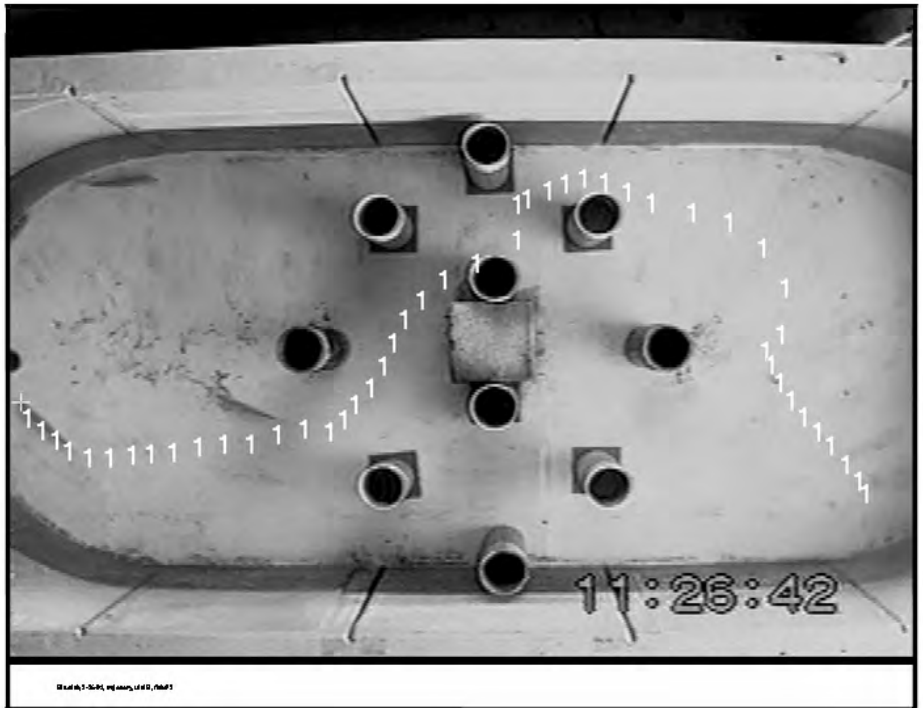
- Dr. Alberico Menozzi (Control)
- Mr. Henry Leinhos (Control)
- Mr. Jason Gaudette (Control)
- Mr. Albert Fredette (EE)
- Professor Anuradha Annaswamy (MIT: Theo Control)

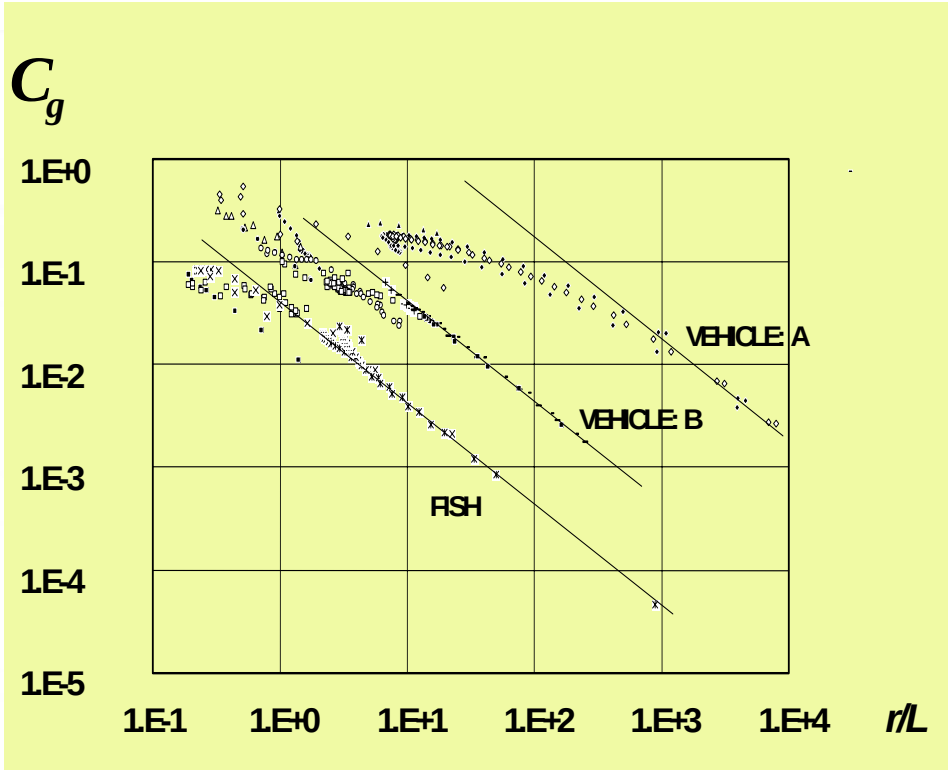
- Dr. David Beal (Hydro)
- Mr. William Nedderman (Design)

- Dr. Stephen Forsythe (Sonar)
- Mr. Thomas Fulton (MARV & Sonar)

- Walter Boober (Noise)

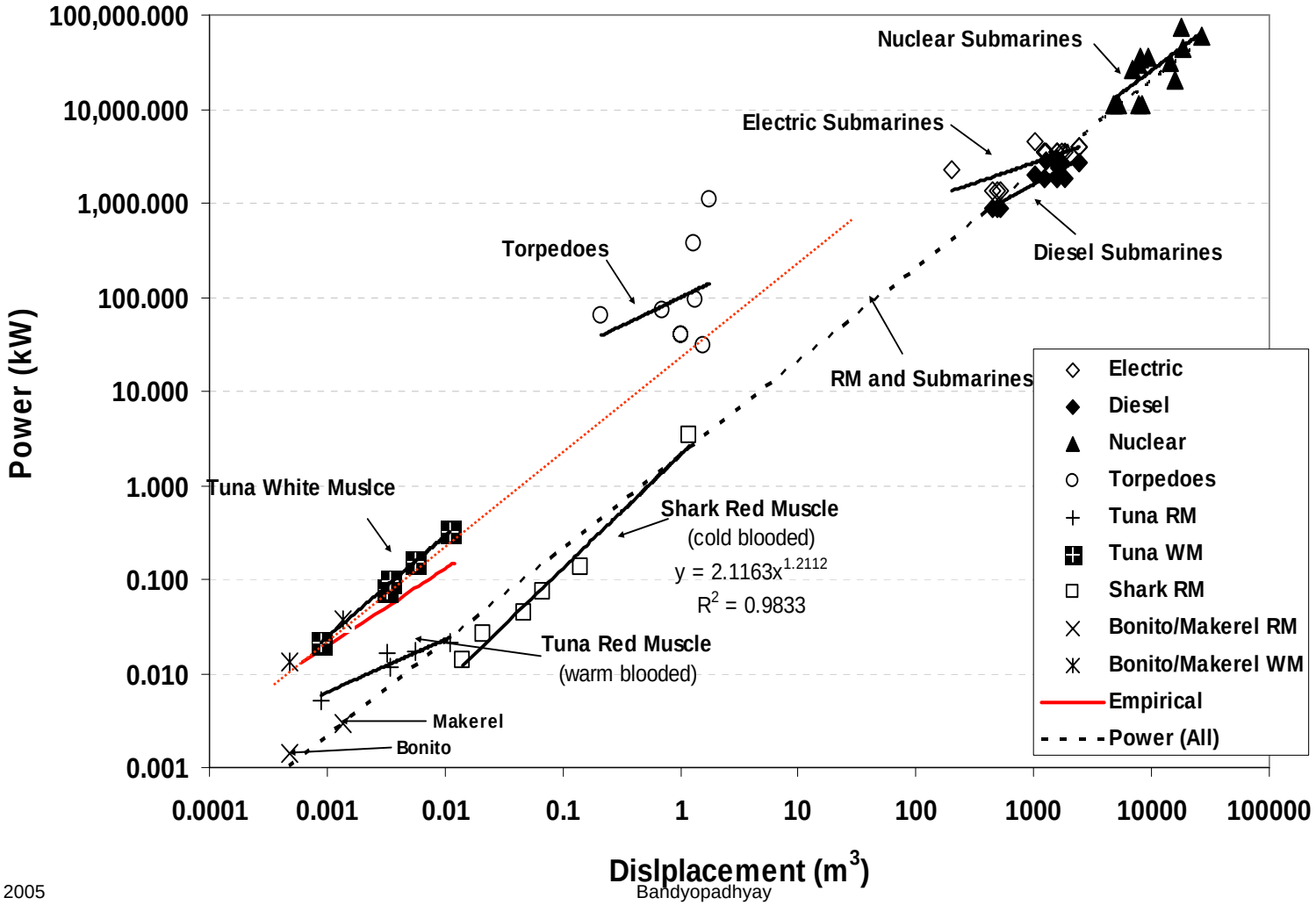
Maneuvering in Nature & in Engineering





- **In turning radius, nature is still ahead of engineering although the gap is narrowing**

Nature & Man Made

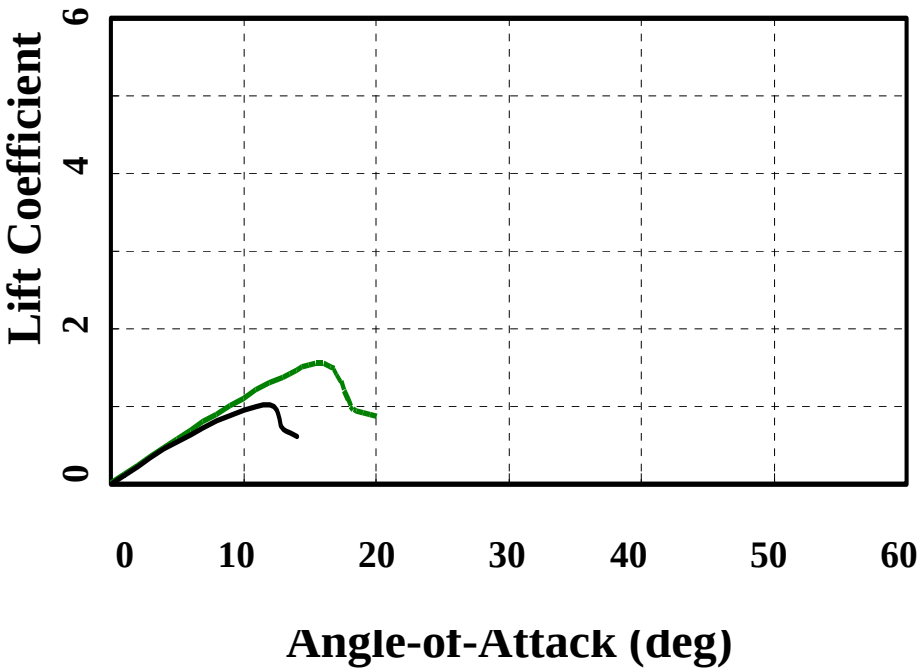


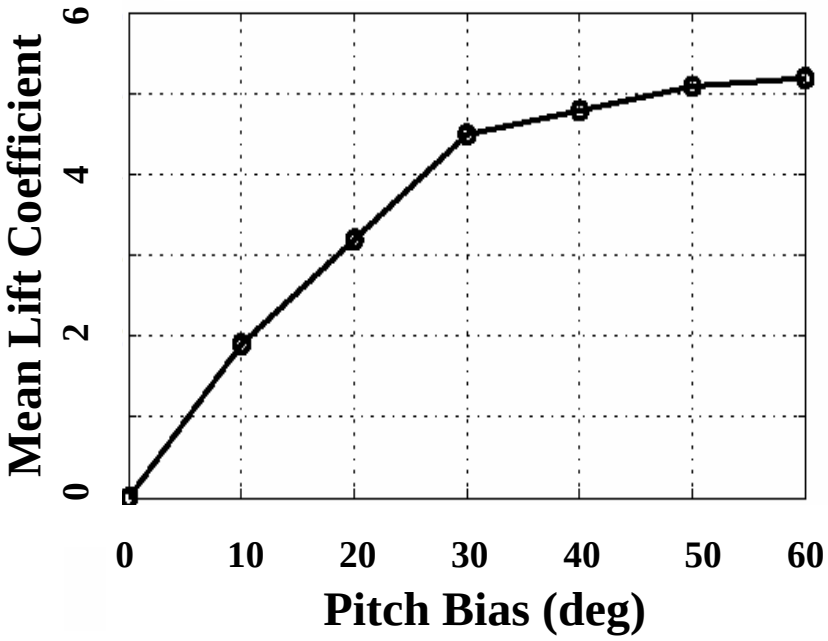
Nature and Man Made

- There is convergence in cruise
- But, Nature is still ahead in Maneuvering

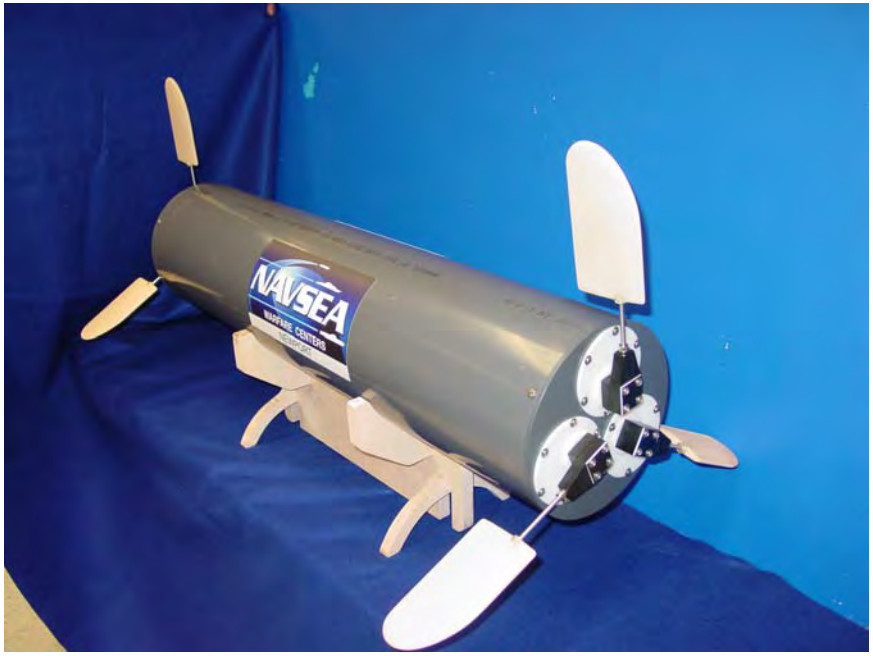
- What science principle is behind nature's superiority that engineering has not implemented?

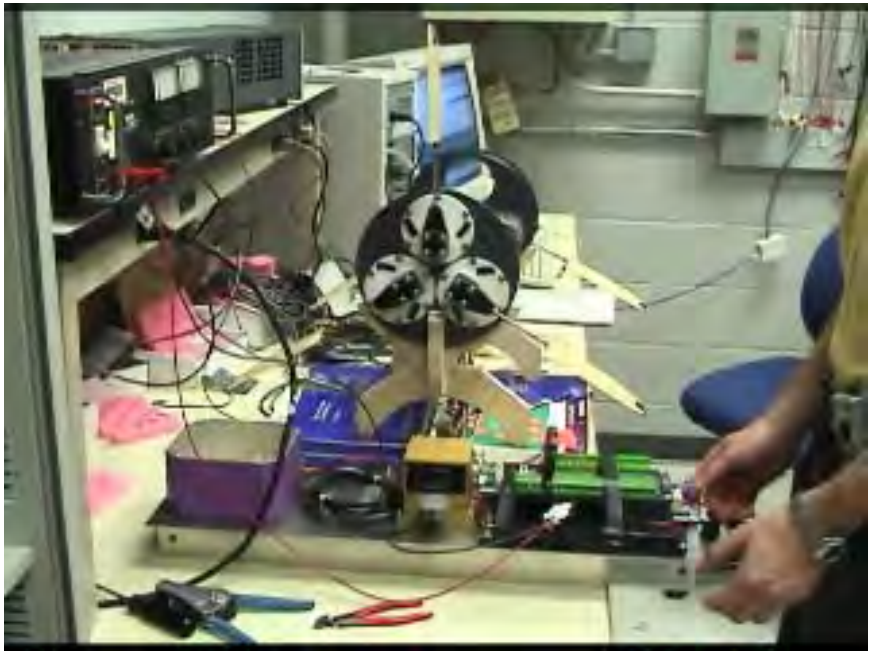
High-Lift Principle



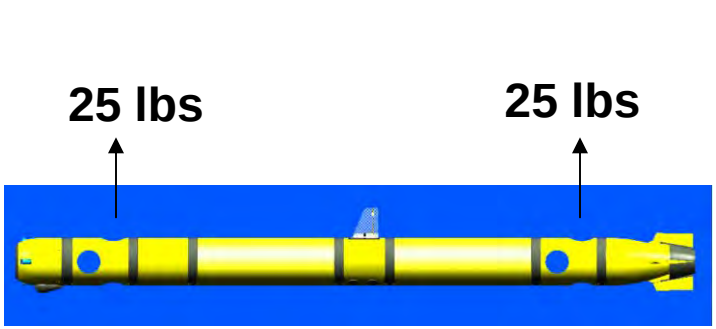


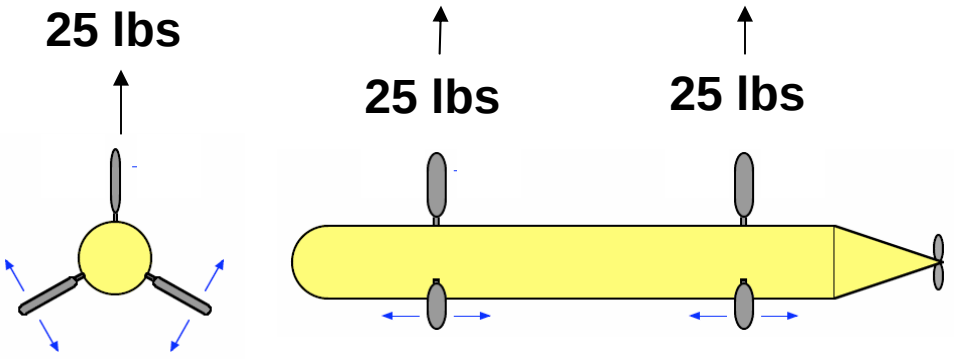
The Proposed Vehicle





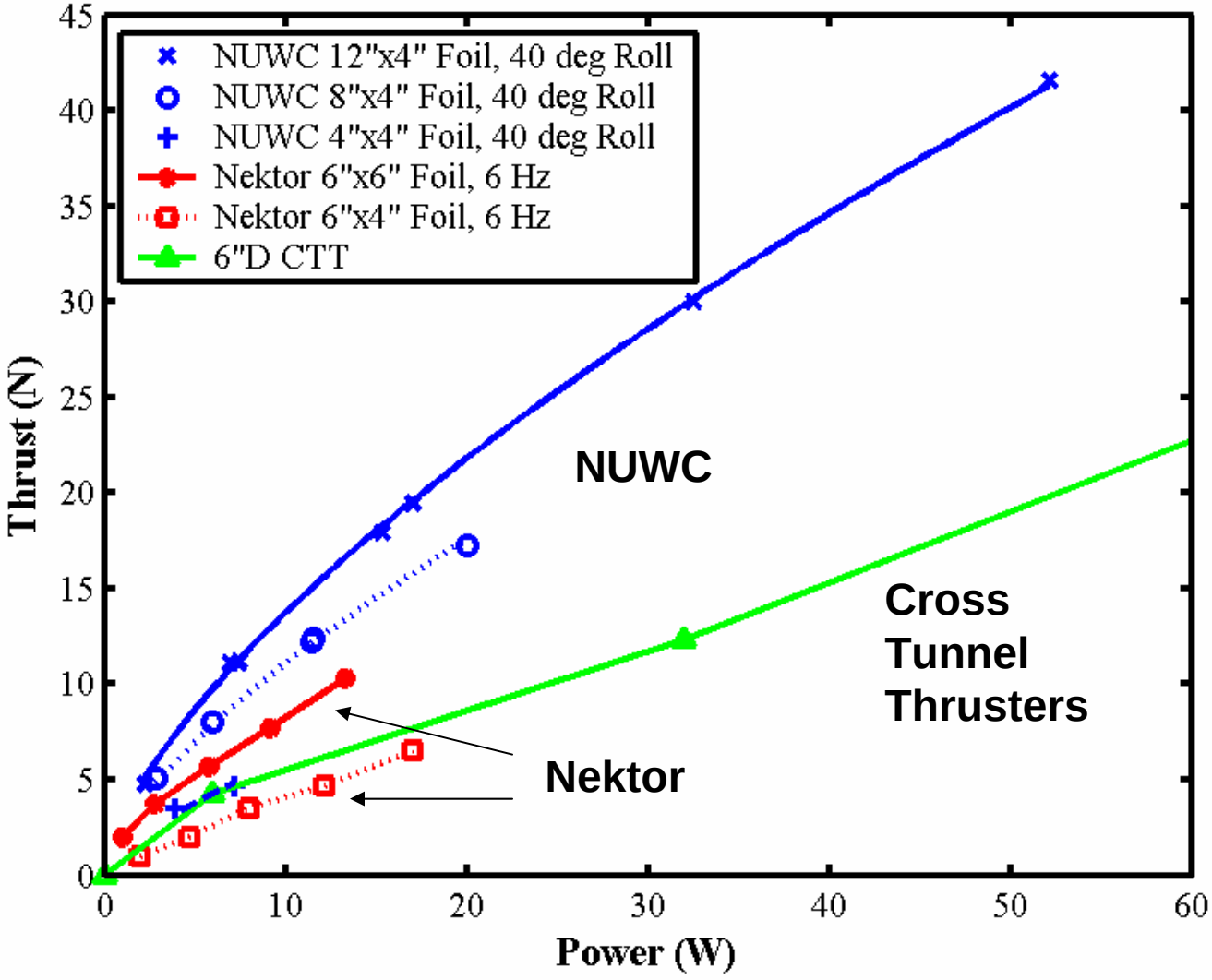
Actuator Power Saving Over Cross Tunnel Thrusters





- **For upward translation, 4 foils do the work of 2 CTT @25lbs each**
  - **Lift-based (12” span): 440W Foils vs. 1078W CTT**
  - **Lift-based (8” span): 540W Foils vs. 1078W CTT**

NUWC Biorobotic Foils Have the Best Power Saving Performance Over CTT & Nektors



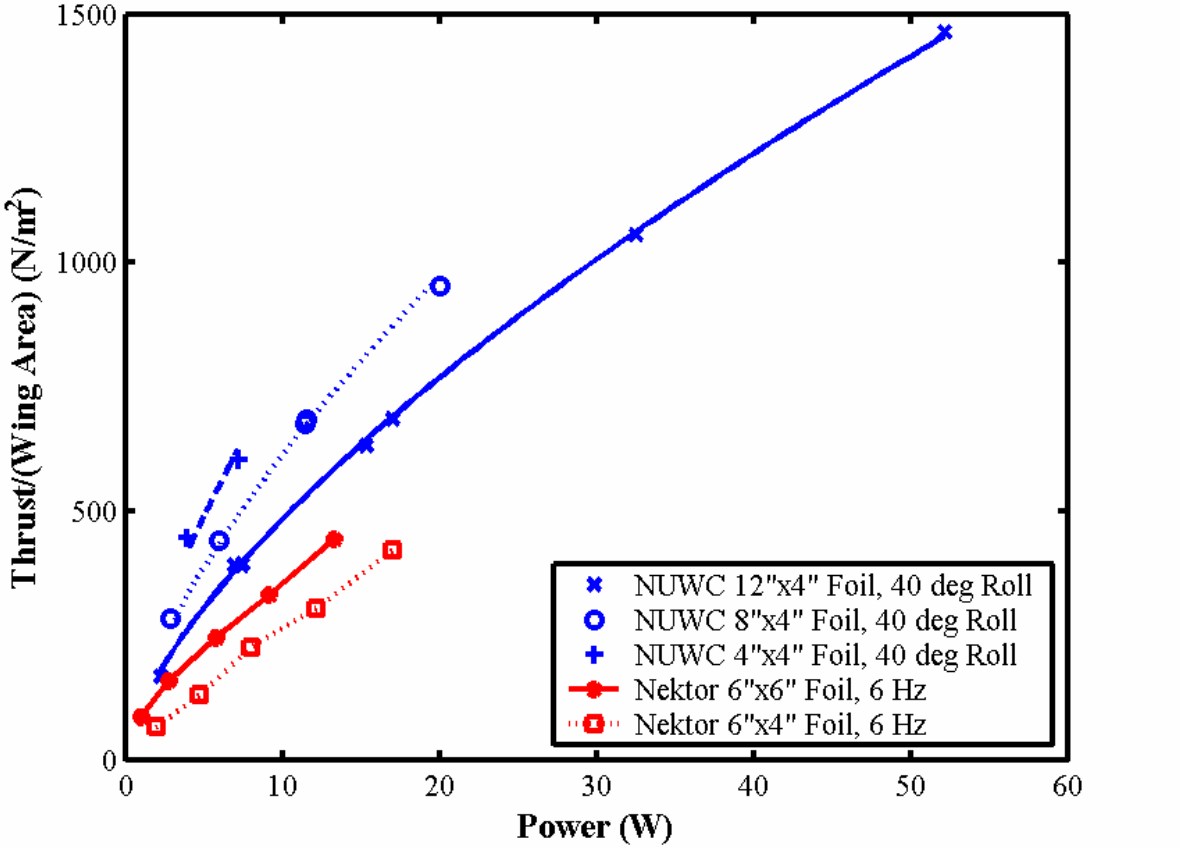
NUWC Foils are more efficient and more scalable over Nektors

Example for 420 N/m^2 Thrust, the hydro power used by 6” x 6” Nektor is:

50% greater compared to NUWC 12” foil

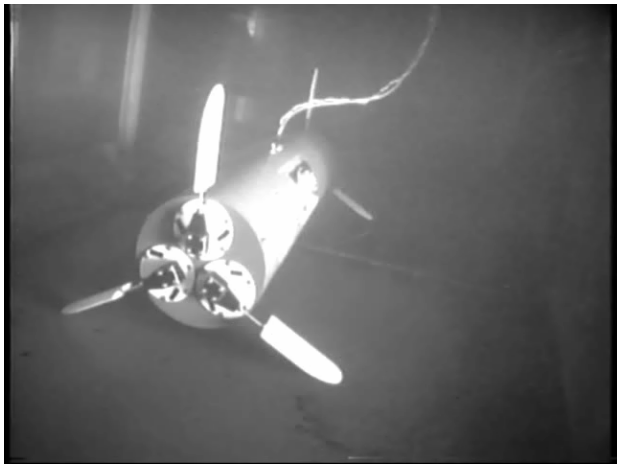
100% greater compared to NUWC 8” foil, and

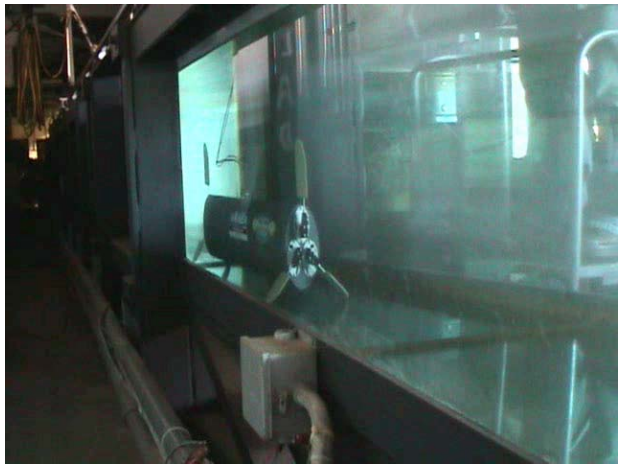
200% greater compared to NUWC 4” foil



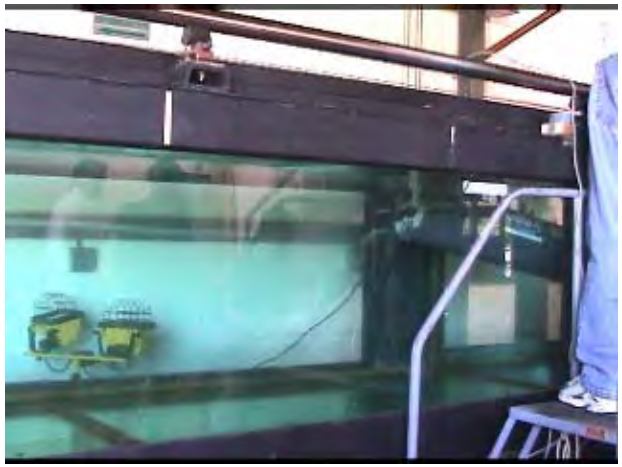
Swimming in Acoustic Test Facility

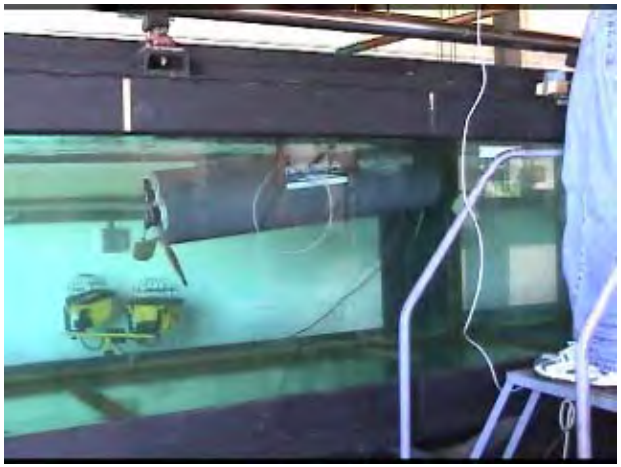
Low Speed Maneuvering





Low Speed Maneuvering





Low Speed Maneuvering

Subneuron: A Robust Orbit Generator

Inferior Olive

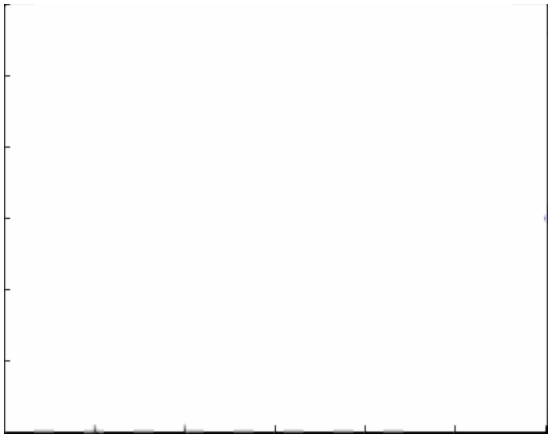
$$\frac{dz}{d\tau} = f(z) - w \qquad \frac{du}{dt} = \frac{1}{\varepsilon_{ca}}[f(u) - v]$$

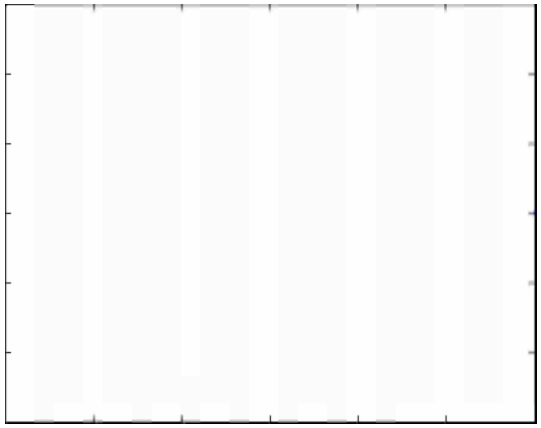
$$\frac{dw}{d\tau} = \varepsilon_{ca}[z - I_{ca} - I_{ext}] \qquad \frac{dv}{dt} = u - (z - I_{ca}) - I_{Na}$$

$$x = w - w_0 \qquad \omega = \sqrt{\varepsilon_{ca}}$$

$$\ddot{x} + g(x)\dot{x} + \omega^2 x = 0$$

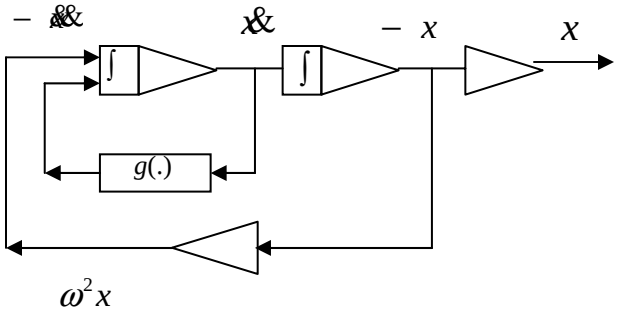
$$g(y) = a_0 + a_1 y + y^2$$

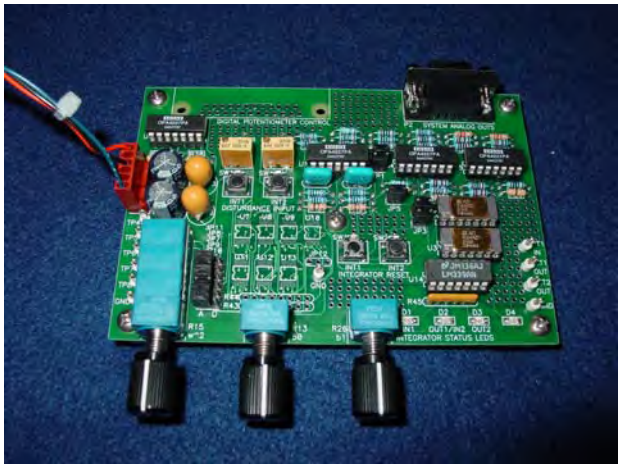




Frequency, amplitude, bias, and general shape can be varied through a_0, a_1 and ω

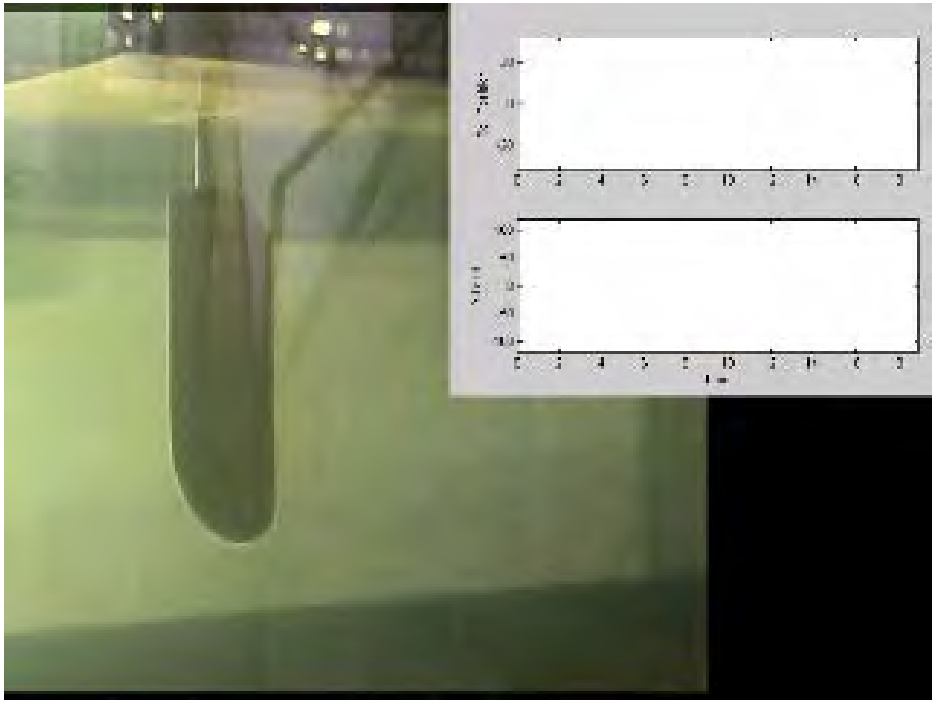
PCB-analog implementation:

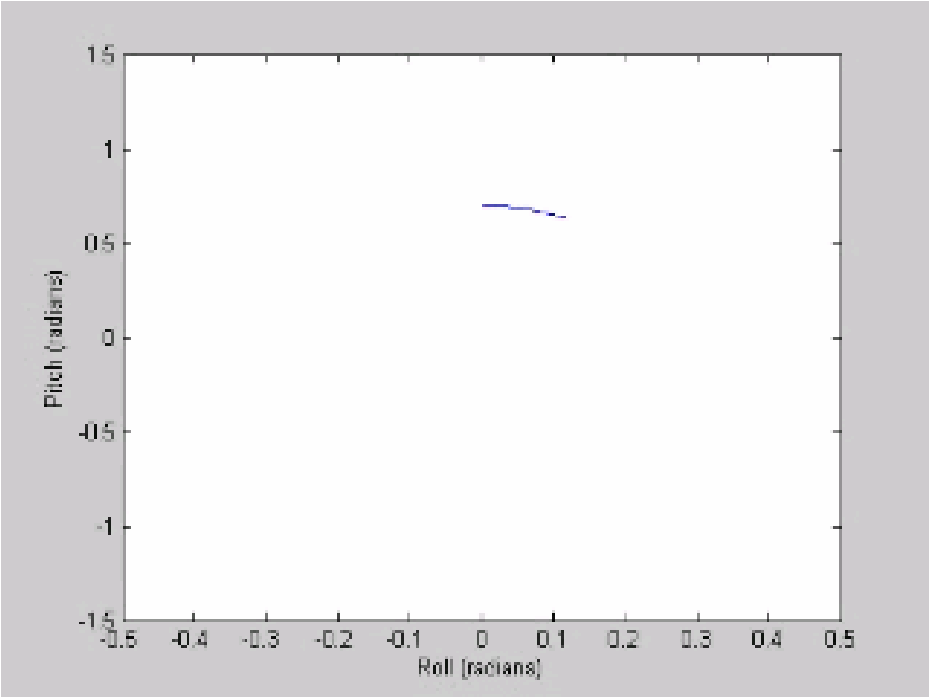




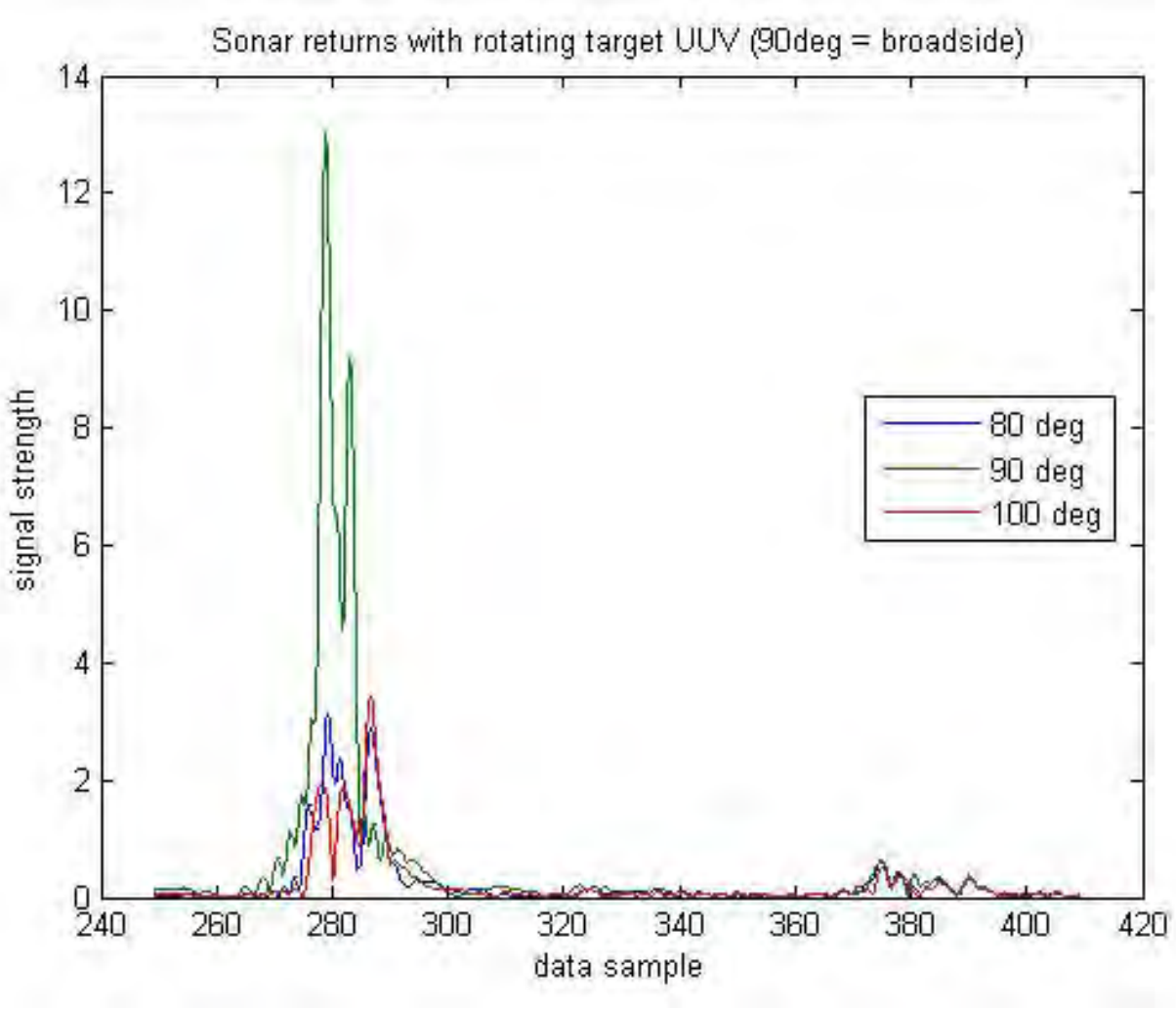
Local Autonomy of Actuators

Roll & Lift



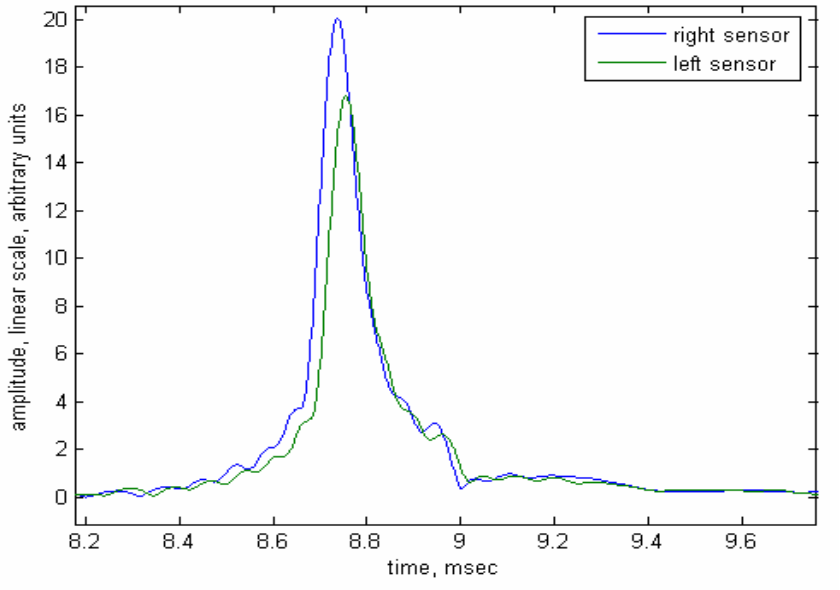


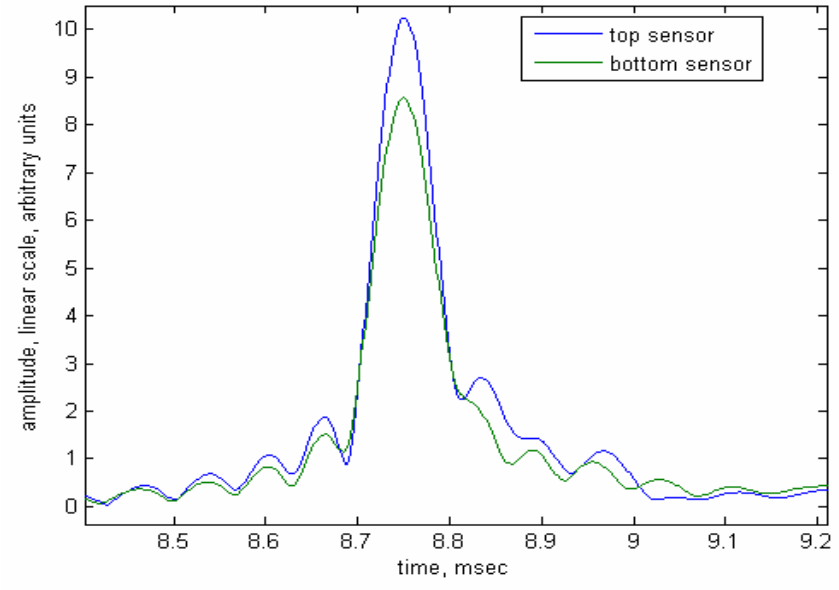
Sonar: x3 Drop in 10 deg Yaw



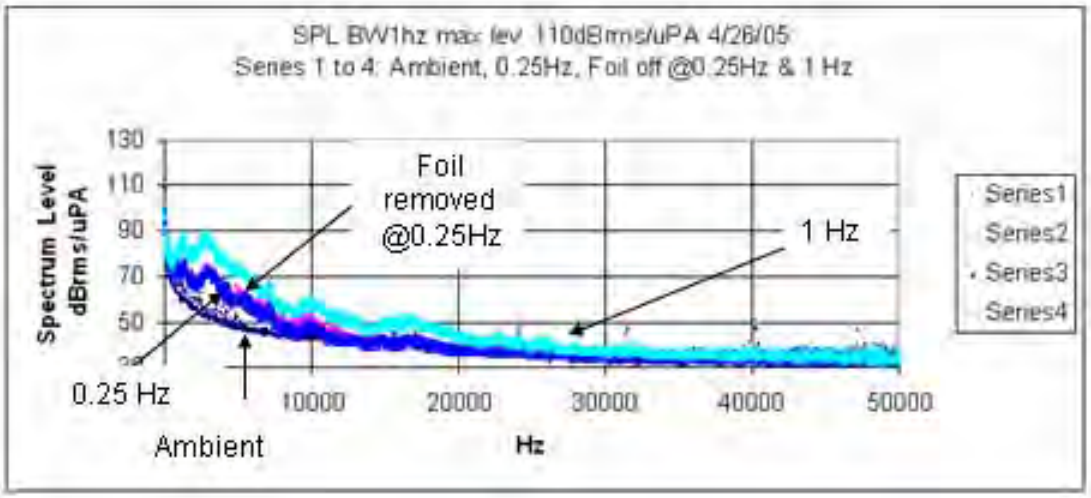
Interaural Arrival Times

Observe different arrival times between left and right ears, but equal arrival times between top and bottom ears





Noise


SPL BW1hz max lev 110dBrms/uPA 4/26/05
Series 1 to 4: Ambient, 0.25Hz, Foil off @0.25Hz & 1 Hz
Spectrum Level dBrms/uPA
130
110
90
70
50
Foil removed @0.25Hz
1 Hz
0.25 Hz
Ambient
10000
20000
30000
40000
50000
Hz
Series1
Series2
Series3
Series4

Linear Actuation of Foils

Usefulness

- Hovering
- Power Efficiency
- Station Keeping
- Docking/Recovery
- Stealth

Graduate Education for Unmanned Vehicles and Undersea Warfare

NPS Teaching, Research and Partnership Strategies

Don Brutzman

Undersea Warfare Academic Group, Center for AUV Research
Naval Postgraduate School (NPS)

16 June 2005

Topics

- NPS
- Undersea Warfare curricula
- Unmanned Systems research
- Partnerships with industry
- Exemplar projects

Naval Postgraduate School (NPS)

- U.S. Navy's University
  - Mission: graduate education + relevant research
- Numerous curricula, most sciences & engineering
  - 2-year masters degrees with thesis
  - Ph.D. research
- Joint, allied and civil-service students, faculty
  - USN, USMC, USA, USAF: ~1300
  - International student officers: ~350
  - Faculty ~300
- Research efforts significant
  - FY2004 reimbursables: $100M

USW Curriculum http://www.nps.navy.mil/usw

- Multiple masters degrees (*not* a USW degree)
  - Physical Oceanography
  - Electrical Engineering – Signal Processing
  - Physics – Engineering Acoustics
  - Operations Research – TDAs, search etc.
  - Proposed: MSES Unmanned Systems
- Each major typically a 2-year program
  - 29 students on board, plus 7 graduating tomorrow
  - 2 dozen interdisciplinary faculty
  - Special 1-year Immediate Grad. Ed. Program (IGEP)
  - *Must have*: masters thesis of directed independent work

Critical curriculum components

- Accredited hard-science degrees
- Apply learning to real research challenges
  - Masters thesis, doctoral dissertation
- Cross-disciplinary exposure
  - Academic disciplines
  - Tactical communities for “team-sport” USW: aviation, surface, subsurface, environmental
- Apply naval-officer student expertise

NPS ASW Certificate

- Four courses offered via distance learning
  - Correspond to initial courses in USW curriculum
  - Offered quarterly, cross-disciplinary subjects
  - Some prerequisites necessary
- Various mechanisms for distance-learning delivery: Web, video teleconferencing, etc.

- Naval officers and civil servants eligible
- Looking for students and sponsorships

Partnerships with industry

- Joint work, use of equipment, software
- Cooperative Research and Development Agreements (CRADA)
- Key players at NPS:
  - USW Chair VADM Roger Bacon USN Ret.
  - MIW Chair RADM Rick Williams USN Ret.
- Unparalleled cross-disciplinary faculty
  - Cover full range of scientific and engineering disciplines
  - Leaders: please send us your list of too-hard problems
- Industry and government welcome to use our work
  - Visiting engineers and scientists also welcome

We operate vehicles every week

- Center for Autonomous Underwater Vehicle (AUV) Research
  - Tony Healey, Principal Investigator
  - 3rd-generation ARIES vehicle, also one REMUS
  - Over 120 M.S., Ph.D. graduates since 1987
- UAV center also established
  - Multiple airframes, nearby airport
  - 23 Km range to surfaced AUV with 802.11G
- USV center being proposed
  - Have applied for SeaFox USV, others welcome

Associated exemplar NPS efforts

SeaWeb Acoustic LAN

- Communications at speed and depth
- Synthesis of acoustics and networking
- Bandwidths are not becoming huge, but steady connectivity is possible
- Ongoing series of demonstrations including Pacific Fleet TASWEX fall 2005

usw-xml Working Group

- The usw-xml working group is improving Undersea Warfare (USW) interoperability using Extensible Markup Language (XML) tagsets for system data interchange.
- Cooperative collaboration between many stakeholders is needed for interoperability.
  - No one community can solve this in isolation
- Sponsored by NAVSEA PEO IWS
  - Perhaps first tactical DoD Community of Interest
- NPS and NUWC Newport lead this effort

MOVES Institute

Modeling, Virtual Environments and Simulation (MOVES)

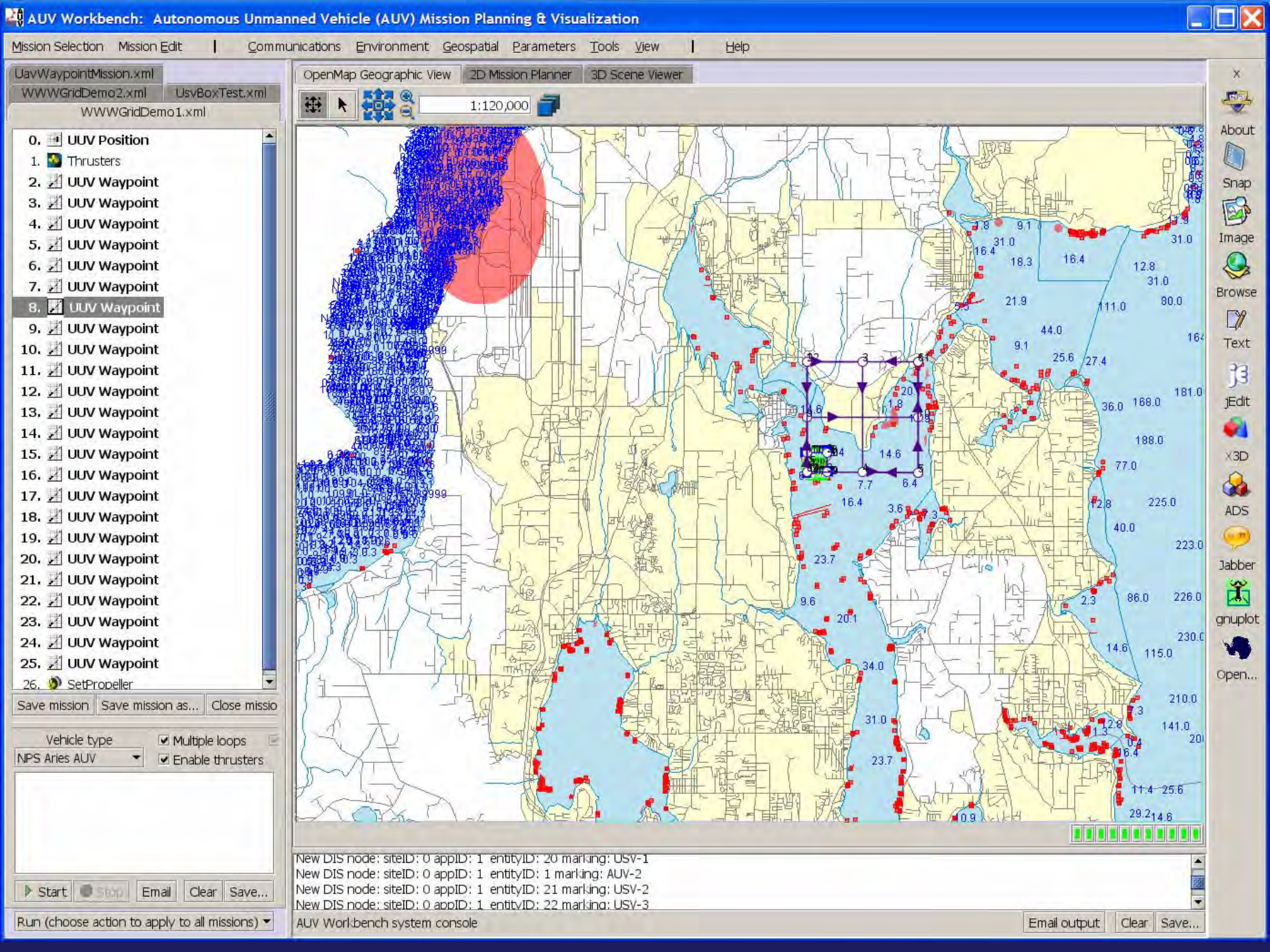
- Our mission is research, application and education in the grand challenges of modeling, virtual environments, and simulation.

Research Directions

- The research product directions include
- 3D visual simulation and networked virtual environments
- Computer-generated autonomy, computational cognition
- Human-performance engineering, immersive technologies
- Game-based simulation, understanding, and analysis
- Combat modeling and analysis

AUV Workbench

- Underwater, air, surface unmanned vehicles
- Build scientific TDA with full-fidelity physics
  - Rehearsal: mission planning
  - Reality: real-time tasking and monitoring
  - Replay: playback telemetry
- Multiple sponsors & partners: NAVO/NRL, NUWC Newport, NAVAIR, Sonalysts, et al.
- Open source, open standards, new tech
  - Extensible 3D Graphics (X3D) for large worlds
  - XML, binary compression for GIG Web Services


AUV Workbench: Autonomous Unmanned Vehicle (AUV) Mission Planning & Visualization
Mission Selection
Mission Edit
Communications
Environment
Geospatial
Parameters
Tools
View
Help
UavWaypointMission.xml
WWWGridDemo2.xml
UsvBoxTest.xml
WWWGridDemo1.xml
0. UUV Position
1. Thrusters
2. UUV Waypoint
3. UUV Waypoint
4. UUV Waypoint
5. UUV Waypoint
6. UUV Waypoint
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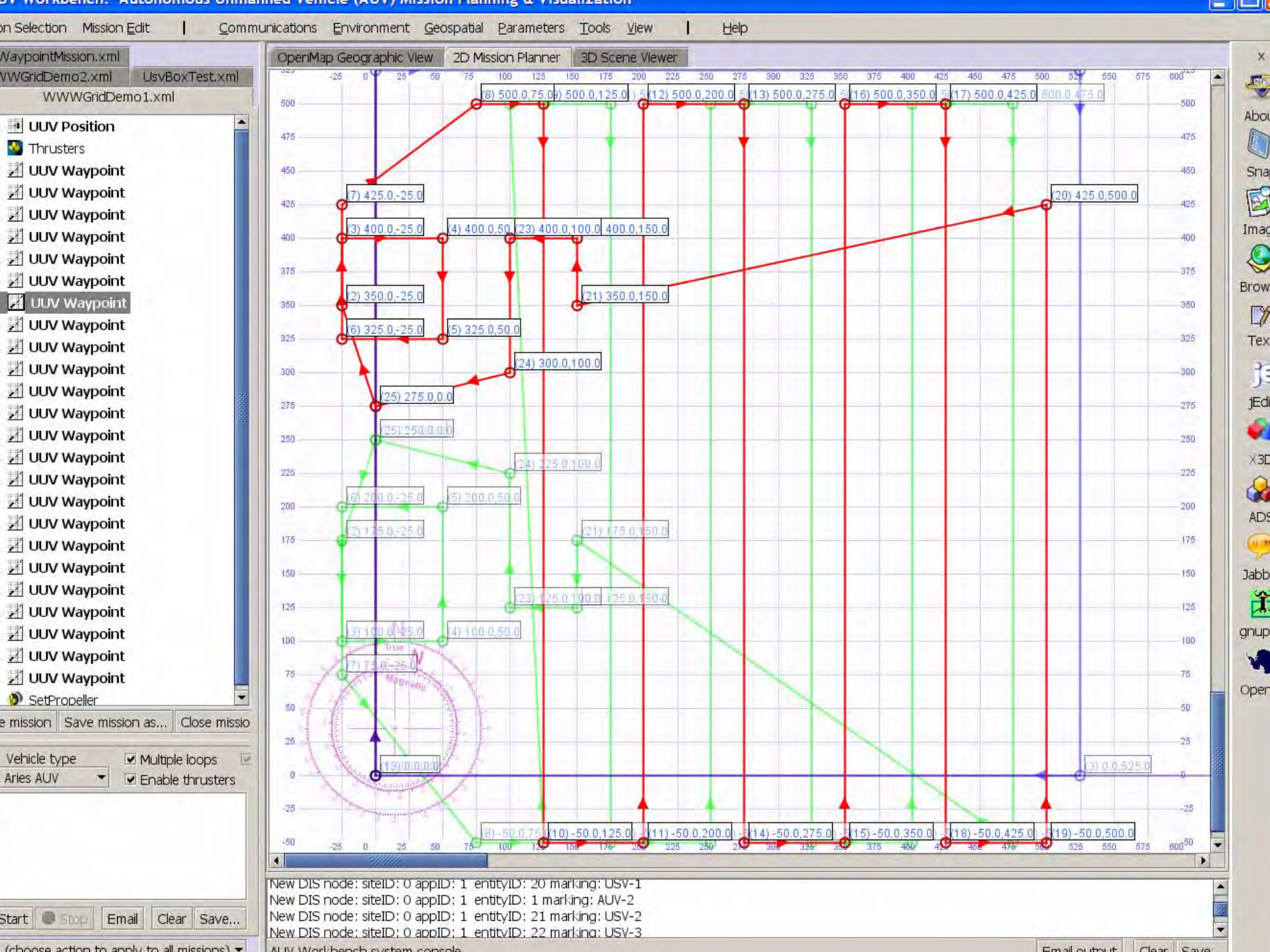
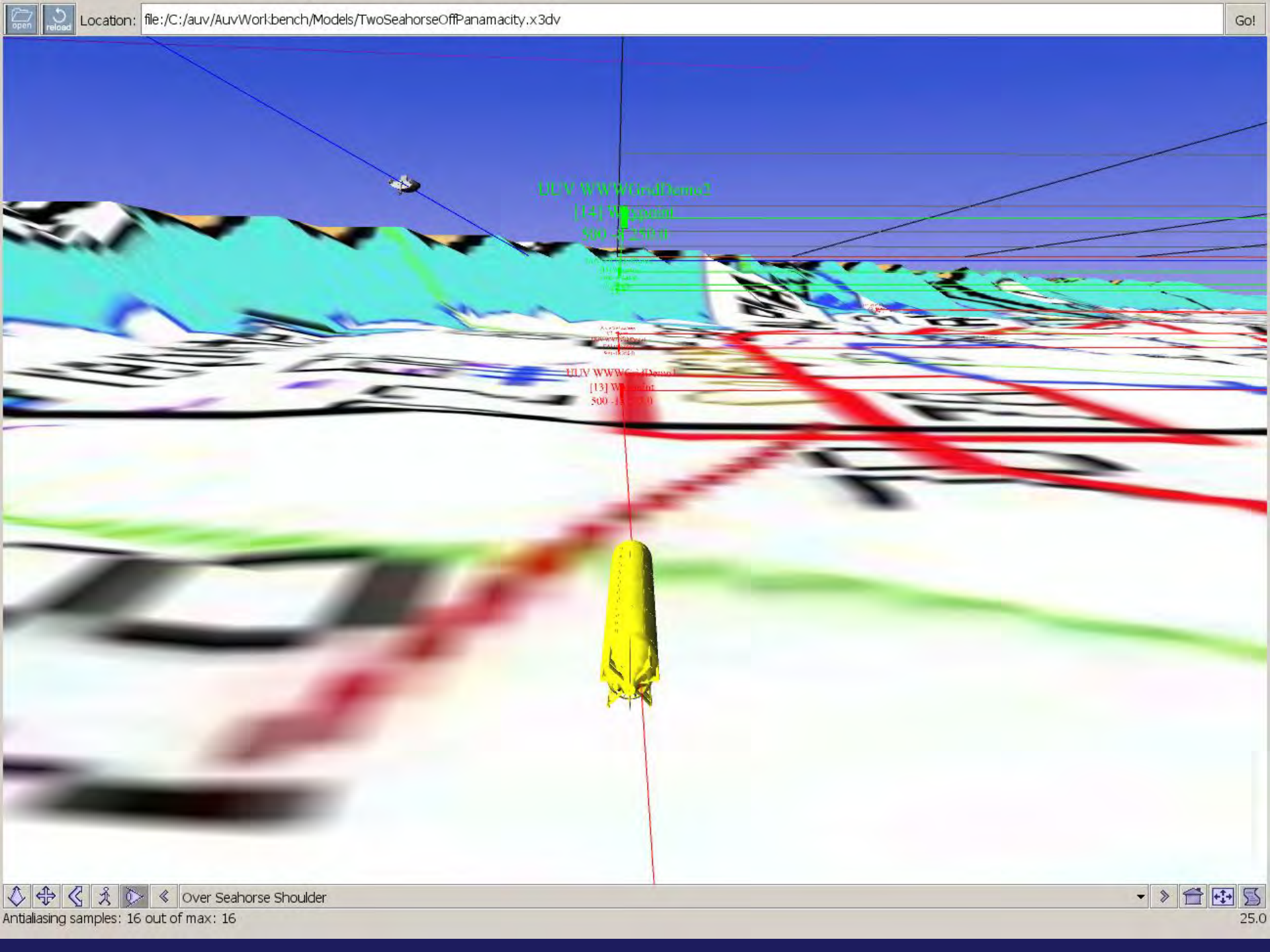
20. UUV Waypoint
21. UUV Waypoint
22. UUV Waypoint
23. UUV Waypoint
24. UUV Waypoint
25. UUV Waypoint
26. SetPropeller
Save mission
Save mission as...
Close missio
Vehicle type
NPS Aries AUV
Multiple loops
Enable thrusters
Start
Stop
Email
Clear
Save...
Run (choose action to apply to all missions)
OpenMap Geographic View
2D Mission Planner
3D Scene Viewer
1:120,000
New DIS node: siteID: 0 appID: 1 entityID: 20 marking: USV-1
New DIS node: siteID: 0 appID: 1 entityID: 1 marking: AUV-2
New DIS node: siteID: 0 appID: 1 entityID: 21 marking: USV-2
New DIS node: siteID: 0 appID: 1 entityID: 22 marking: USV-3
AUV Workbench system console
Email output
Clear
Save...
About
Snap
Image
Browse
Text
jEdit
X3D
ADS
Jabber
gnuplot
Open...


Selection
Mission Edit
Communications
Environment
Geospatial
Parameters
Tools
View
Help
WaypointMission.xml
WWGridDemo2.xml
UsvBoxTest.xml
WWWGridDemo1.xml
UUV Position
Thrusters
UUV Waypoint
SetPropeller
Save mission as...
Close missio
Vehicle type
Aries AUV
Multiple loops
Enable thrusters
Start
Stop
Email
Clear
Save...
OpenMap Geographic View
2D Mission Planner
3D Scene Viewer
(8) 500.0,75.0
(9) 500.0,125.0
(12) 500.0,200.0
(13) 500.0,275.0
(16) 500.0,350.0
(17) 500.0,425.0
(7) 425.0,-25.0
(20) 425.0,500.0
(3) 400.0,-25.0
(4) 400.0,50.0
(23) 400.0,100.0
400.0,150.0
(2) 350.0,-25.0
(21) 350.0,150.0
(6) 325.0,-25.0
(5) 325.0,50.0
(24) 300.0,100.0
(25) 275.0,0.0
(10) -50.0,125.0
(11) -50.0,200.0
(14) -50.0,275.0
(15) -50.0,350.0
(18) -50.0,425.0
(19) -50.0,500.0
New DIS node: siteID: 0 appID: 1 entityID: 20 marking: USV-1
New DIS node: siteID: 0 appID: 1 entityID: 1 marking: AUV-2
New DIS node: siteID: 0 appID: 1 entityID: 21 marking: USV-2
New DIS node: siteID: 0 appID: 1 entityID: 22 marking: USV-3
Email output
Clear
Save


open
reload
Location: file:/C:/auv/AuvWorkbench/Models/TwoSeahorseOffPanamacity.x3dv
Go!
Over Seahorse Shoulder
Antialiasing samples: 16 out of max: 16
25.0

Summary themes

- NPS is the Navy's corporate university
- Solid graduate education is essential for naval officers and civilian engineers

- USW (ASW + MIW) robotics are hard
- Cross-disciplinary interoperability is the key to solving next-step challenges

- Test & evaluation are essential throughout

Contact

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http://web.nps.navy.mil/~brutzman

Code USW/Br, Naval Postgraduate School
Monterey California 93943-5000 USA
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1.831.656.7599 fax

Multi-vehicle Collaborative Autonomous Control Under Difficult Communications Conditions

Robert W. Chalmers
Johns Hopkins University Applied Physics Laboratory
National Security Technology Department

The Swarming Autonomy “Theme Bug”

Our MVC Vision

Unmanned Vehicles as a Ubiquitous Service for the Warfighter

Underwater MVC Challenges

- UUVs need Collaborative MVC that is
  - » Effective under Poor Communications Environments
  - » Effective in Dynamic and/or Intractably Complex Conditions
  - » Rapid in Response to Perturbations in the Environment or the Objectives
  - » Robust and Survivable

Bottom Line

We Have Achieved Robust Militarily Useful Behaviors Reactively and Emergently

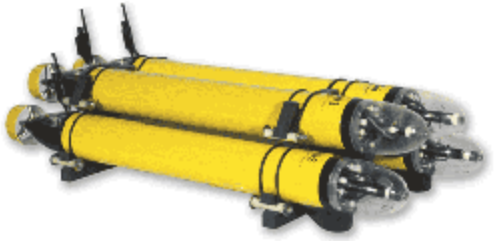
Generated Behaviors

	Fields Generated by		
	Targets	Peers	Area Effects
Patrol		✓	✓
Track & Trail	✓	✓	✓
Survey & Map	✓	✓	✓
Path Finding	✓	✓	✓
Formation Flying		✓	
Recruitment	✓	✓	✓
Comm Link		✓	
Resource Allocation ‣ Vehicle Damage ‣ Objective Change ‣ Environmental Change	✓	✓	✓

Emergent Swarming

Emergent Swarming IS…

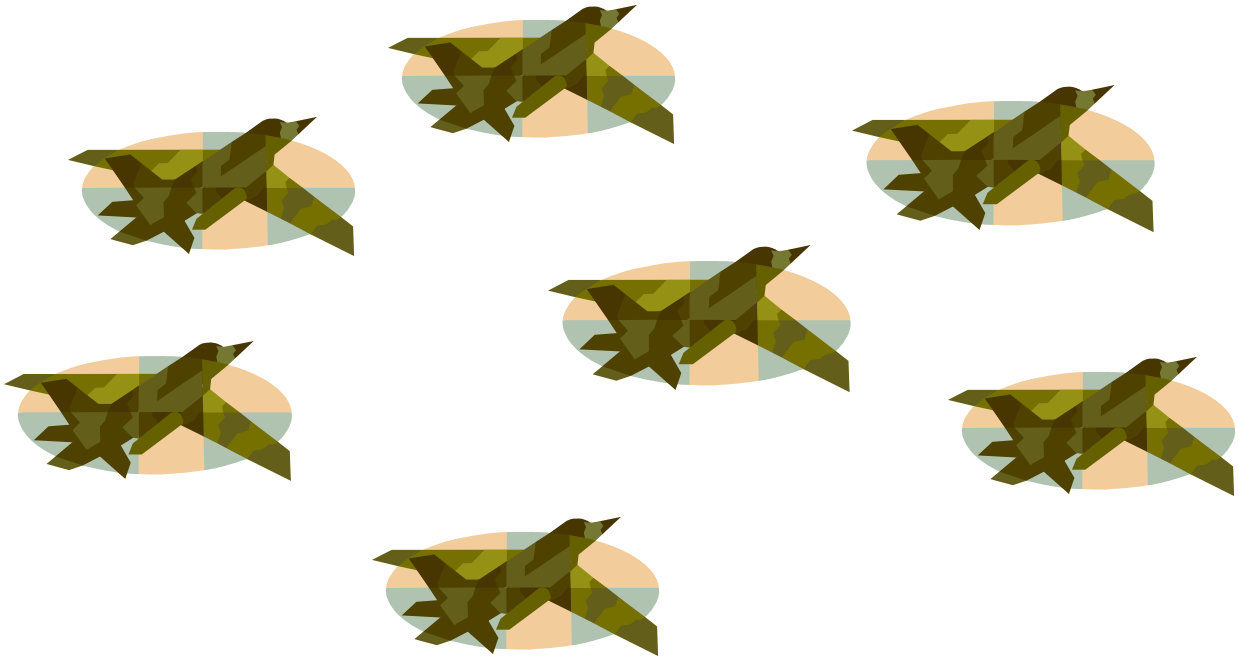
Locally-Executed Control Algorithms That Provide Globally Self-Organizing Behavior Amongst Cooperating Vehicles



Emergent Swarming IS…

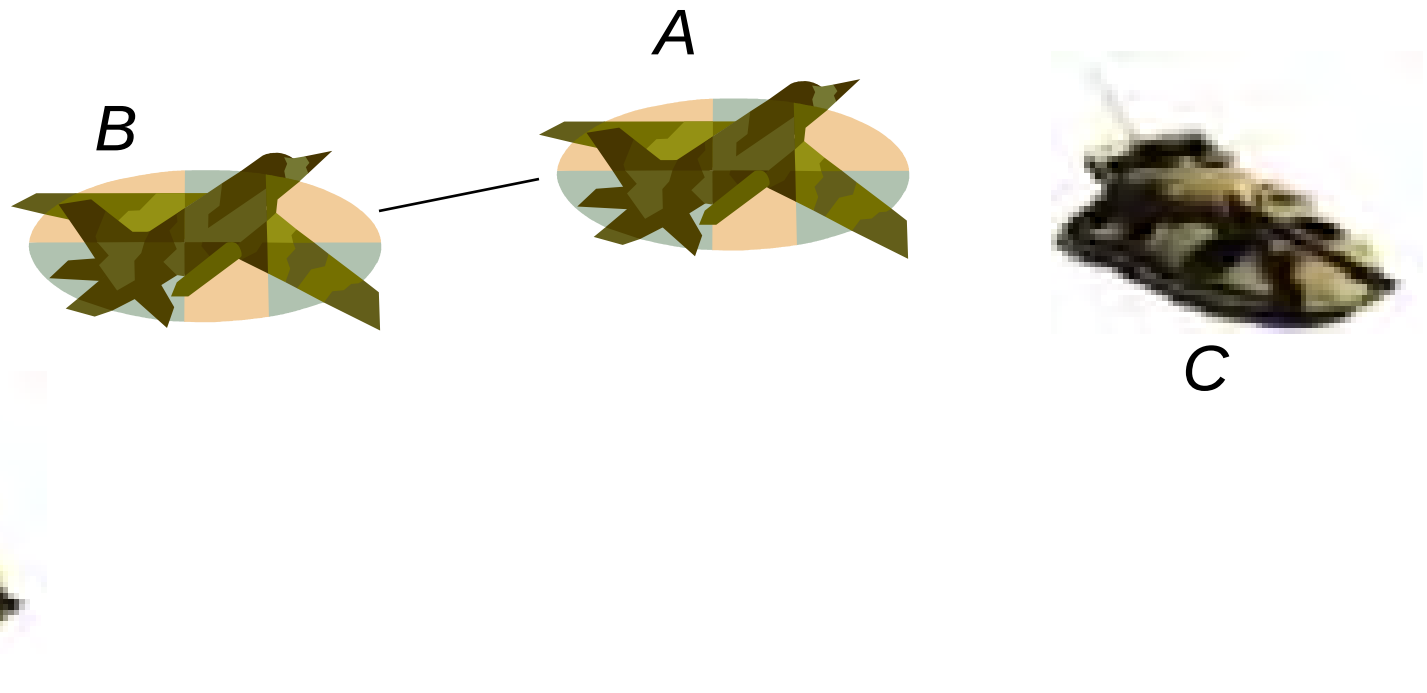
Locally Controlled:

Individual Decision Makers (Agents) on Each Platform



Emergent Swarming IS…

NOT Deliberative:



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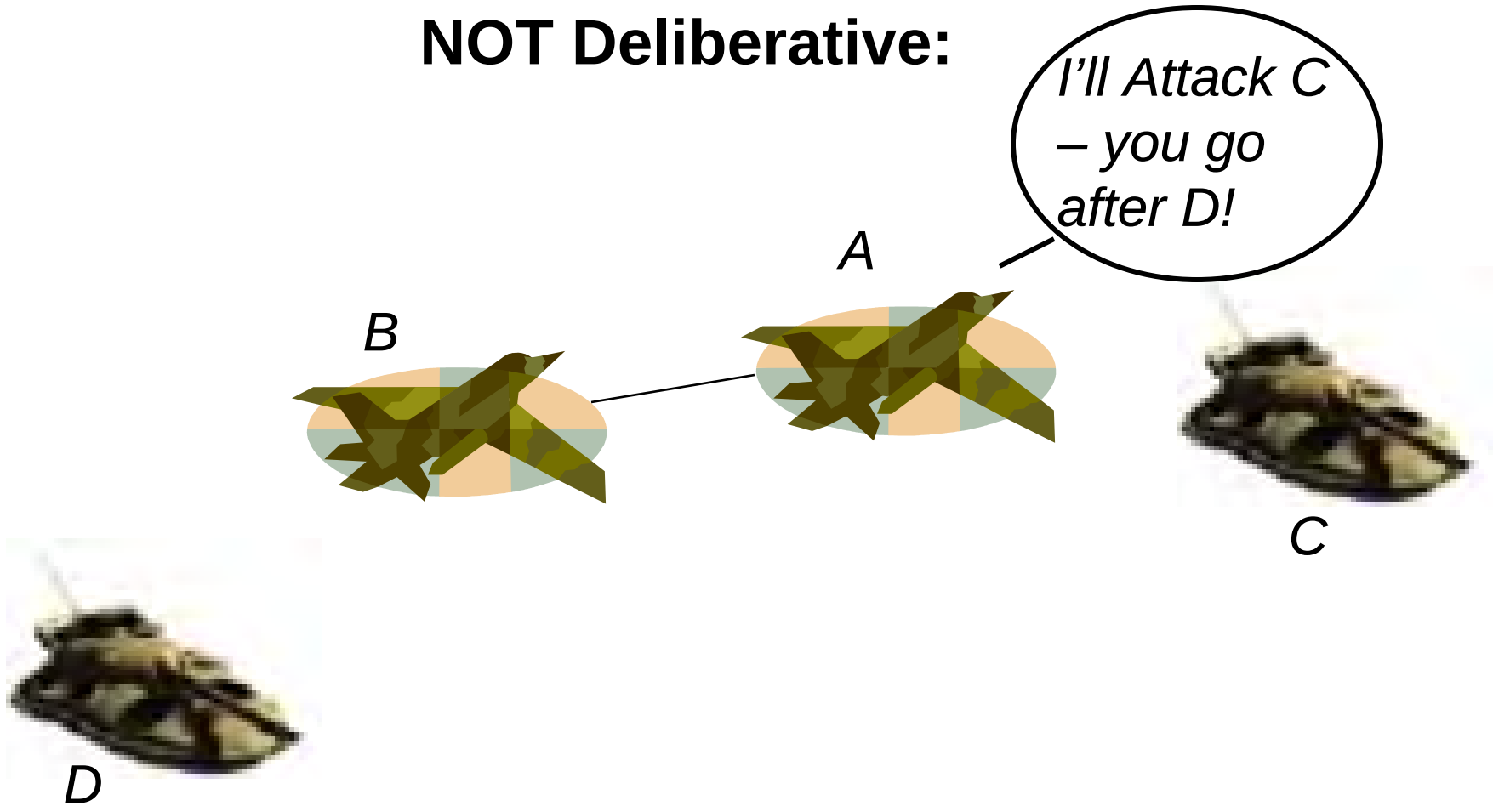

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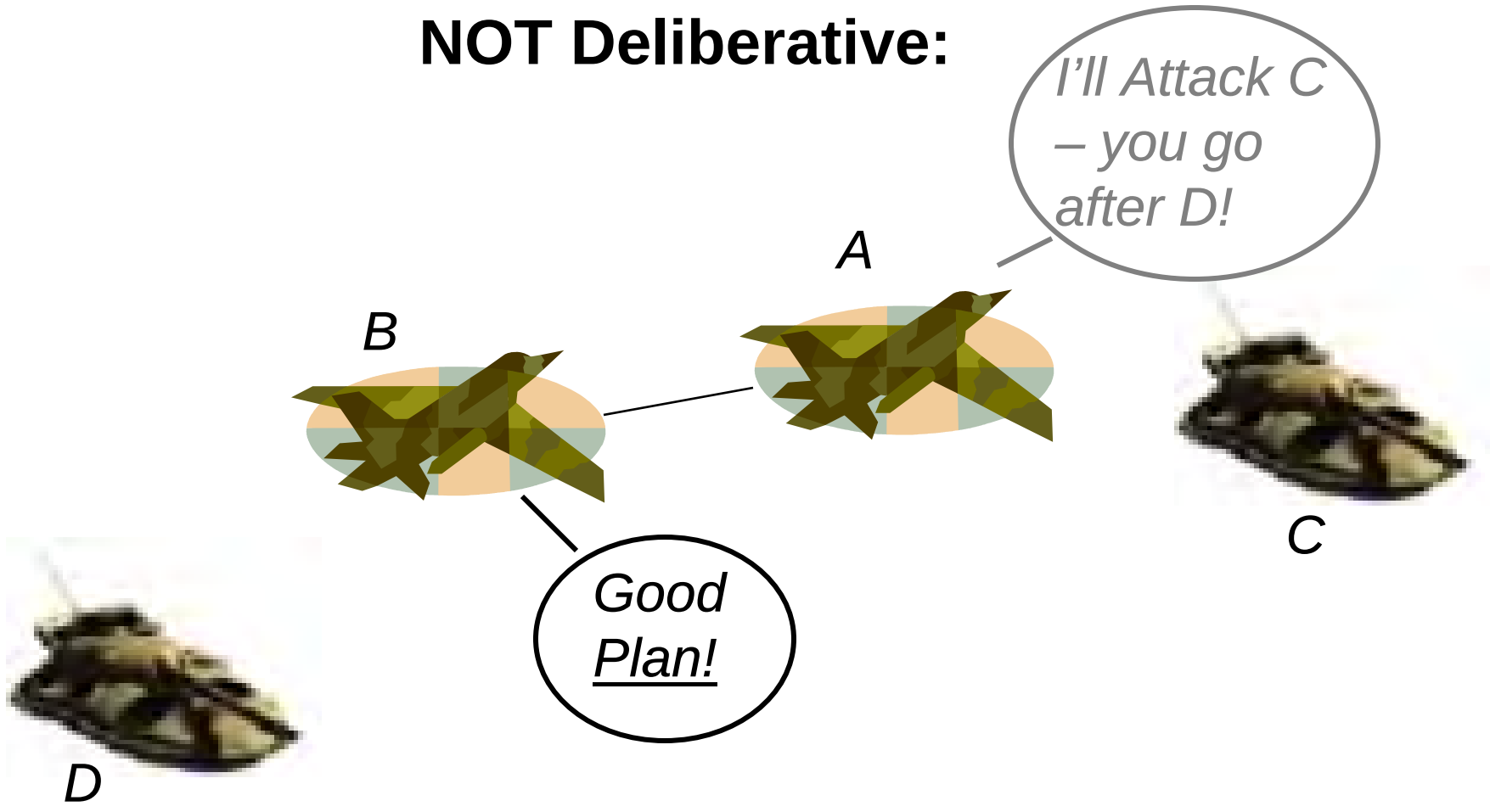
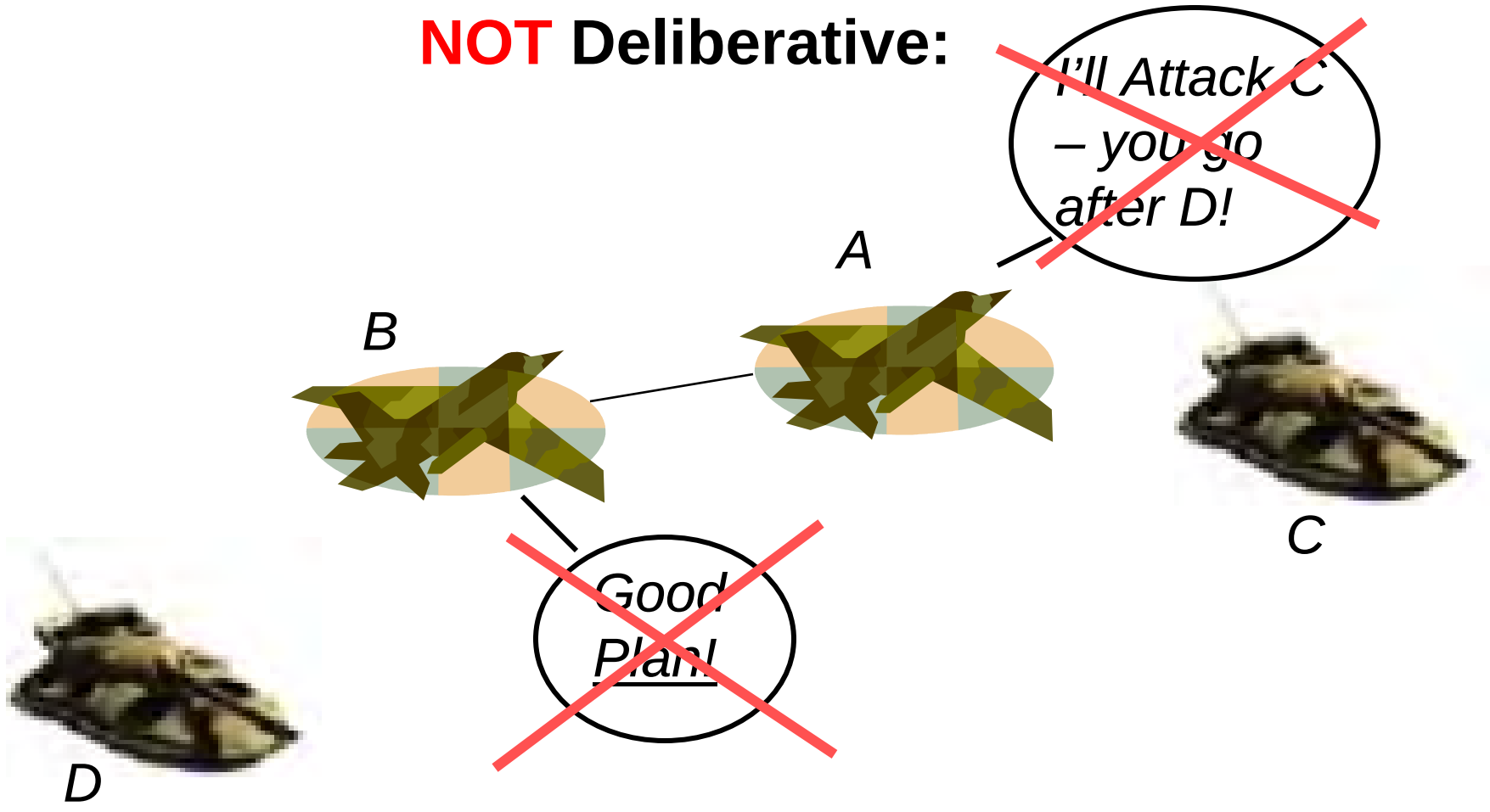


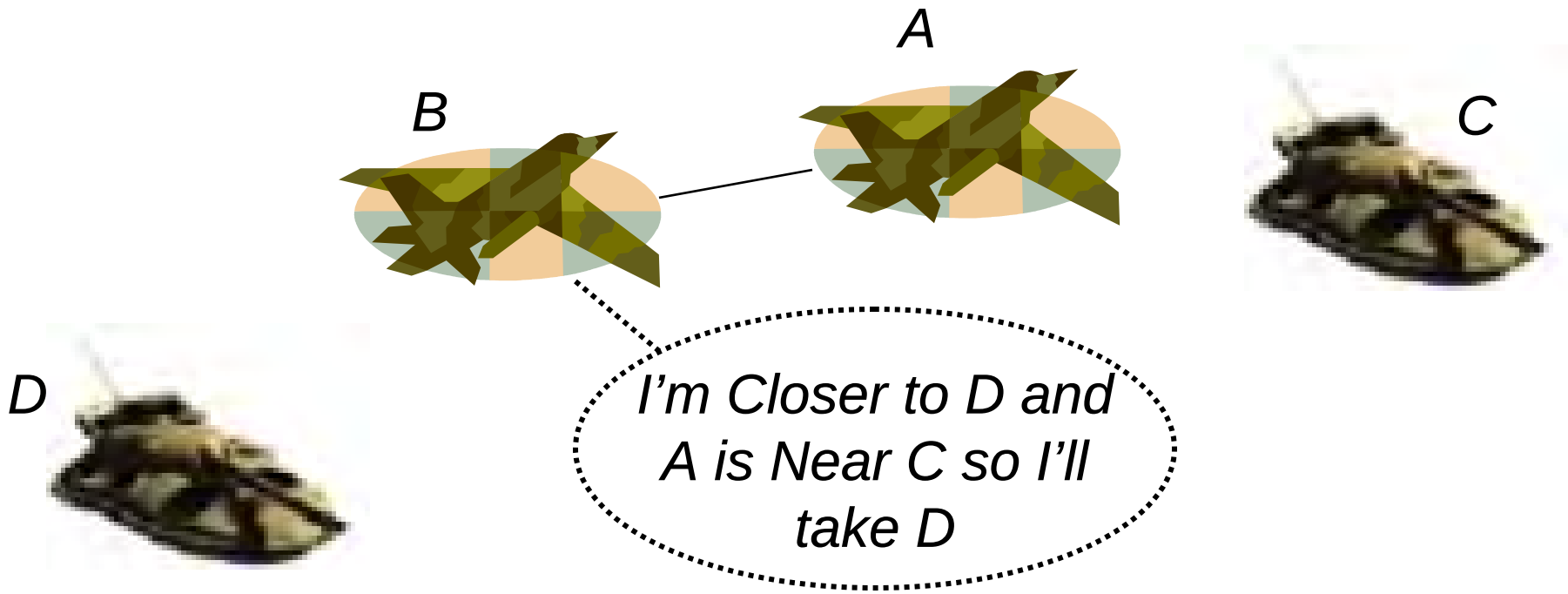
Emergent Swarming IS…

NOT Deliberative:



Emergent Swarming IS…

NOT Deliberative:



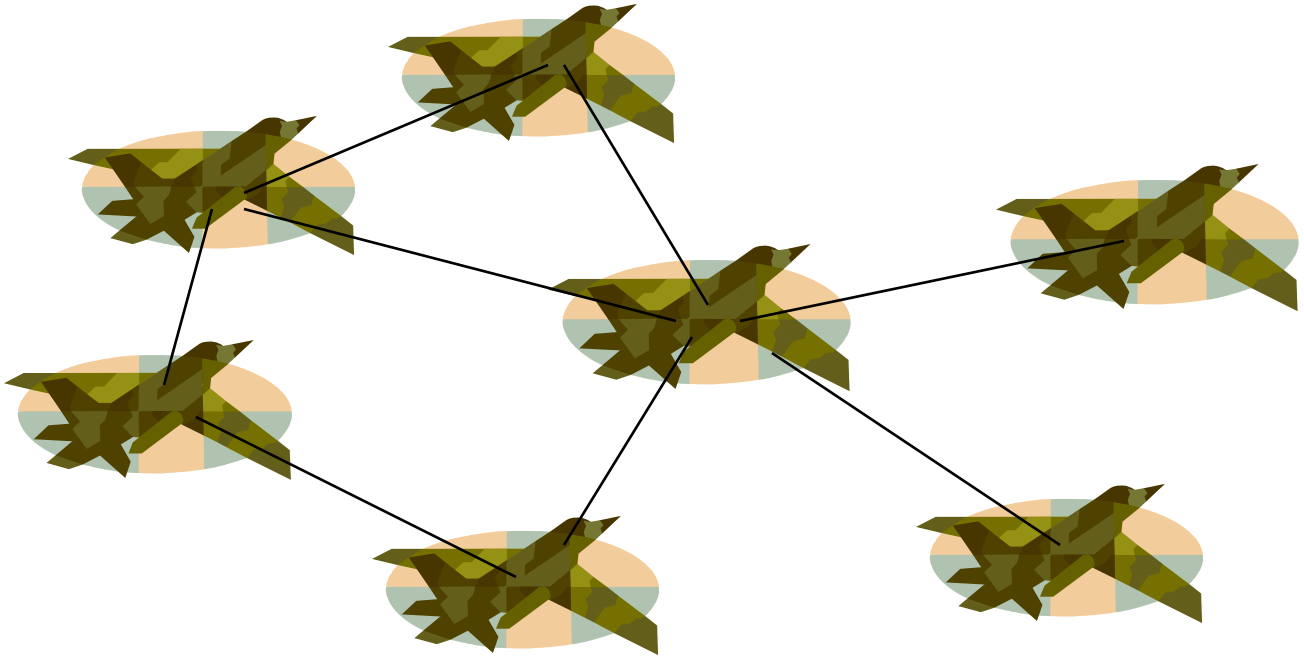
Coordination *Emerges* from Sympathetic Decision Processes and Shared Knowledge

Emergent Swarming IS…

Heterarchical:

An Unstructured Network of Cooperating Peers

No dedicated leaders* ever!



(*single points of vulnerability)

With a Flat Communications Topology any one Swarming Element can be Sufficient to Communicate any End User/Decision Maker

There's no single point of vulnerability, and no particular pre-determined critical path to get information back to the operator.

The nature of the swarming system is such that it can adapt and reshape itself until the requirements are met. This isn't commander Cicada – just the Cicada that was handy and happened to be close enough to relay the relevant information.

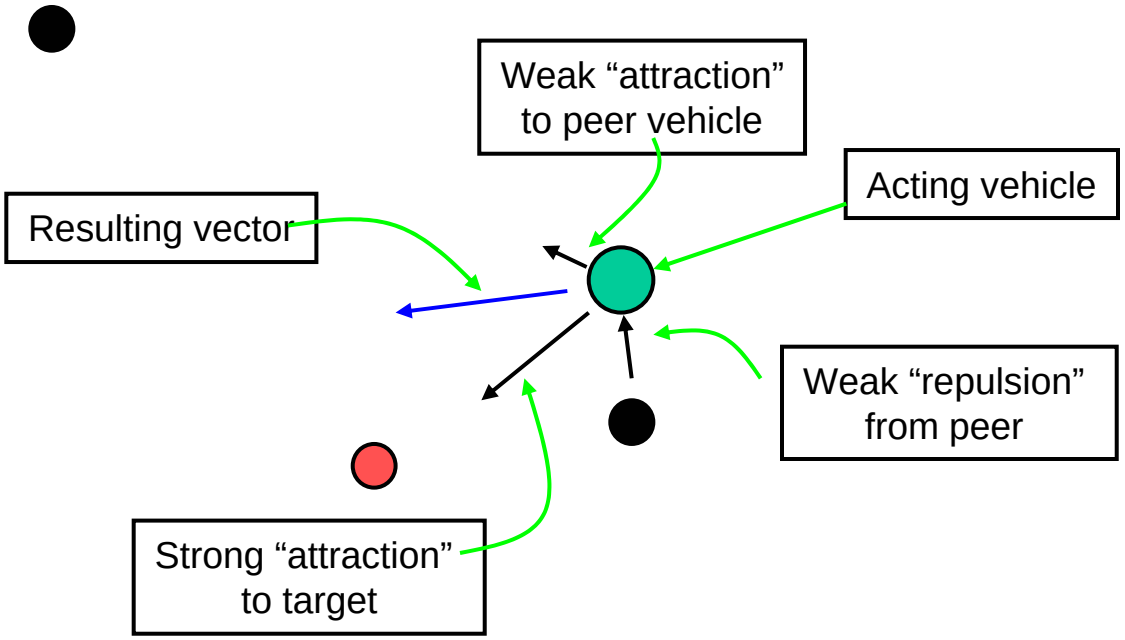
Swarming Models

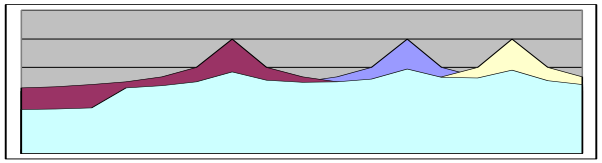
Many Exist, mostly patterned off of natural systems, major themes are:

- Physicomimetic – Pattered after sub-atomic particle interactions
- Biomimetic – patterned after social animals
  - » Flocking Behavior
  - » Ant Colony Behavior
  - » Termite/Wasp Nest Building
  - » Wolf-Pack Hunting
  - » Mold Growth

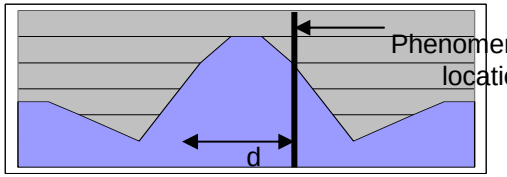
CO-FIELDS BEHAVIORS

Generating Behavior by associating fields with a movement vector.





An Influence Co-field (light blue) Derived from Three Influence Fields



Co-fields Generated by a Single Phenomena may be Used to Keep a Distance “d” from the Phenomena.

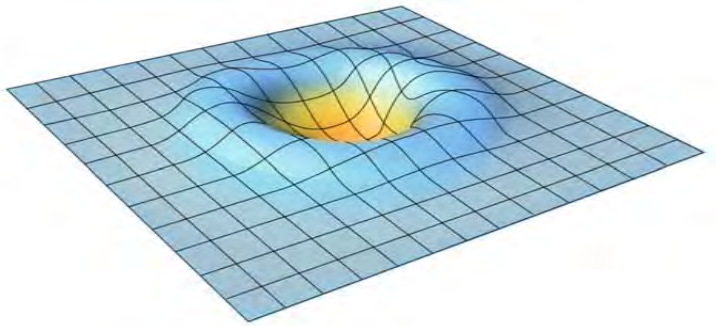
Co-Fields: Towards a Unifying Model for Swarm Intelligence Letizia Leonardi, Marco Mamei, Franco Zambonelli

JHUAPL Innovation: Dynamic Co-Fields

Dynamic Co-Fields Extends Co-Fields by Allowing Individual Fields to Change as a Function of Time

Dynamic Influences May be Generated by:

- Historical Observations
- Introducing Temporal Decay To Knowledge
- Using Observations as an Impetus for Formula Modifications
- Using Field Strengths as an Impetus for Formula Modifications
- **Generating One's Own Field**



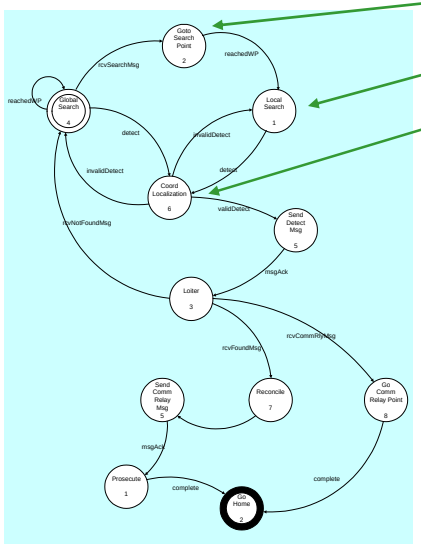
This Allows Vehicles to:

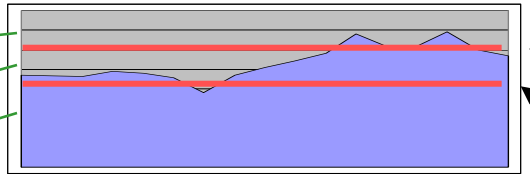
- Patrol
- **Avoid Local Minima**
- Limit Oscillatory Behavior
- Adapt by Learning
- Manage Uncertainty (Intermittent Contacts or Communications)

Vehicle Actions and Modal Behavior

Movement is Not Enough…

Vehicles need to be able to take actions and change from one behavior to another. For example, shifting from patrolling to tracking when a target is detected.





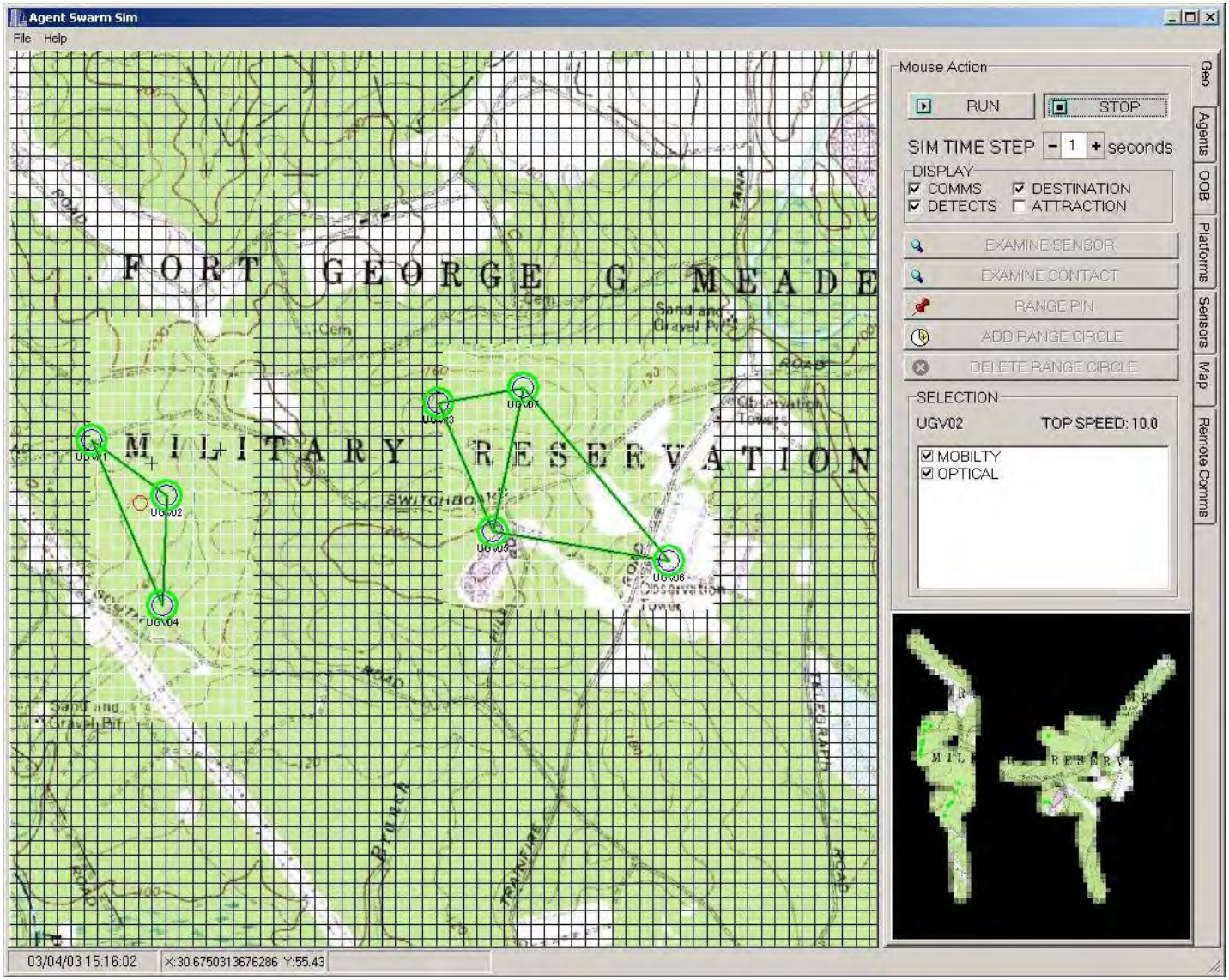
Above this Threshold "flee" the Area

Below this Threshold Take Action

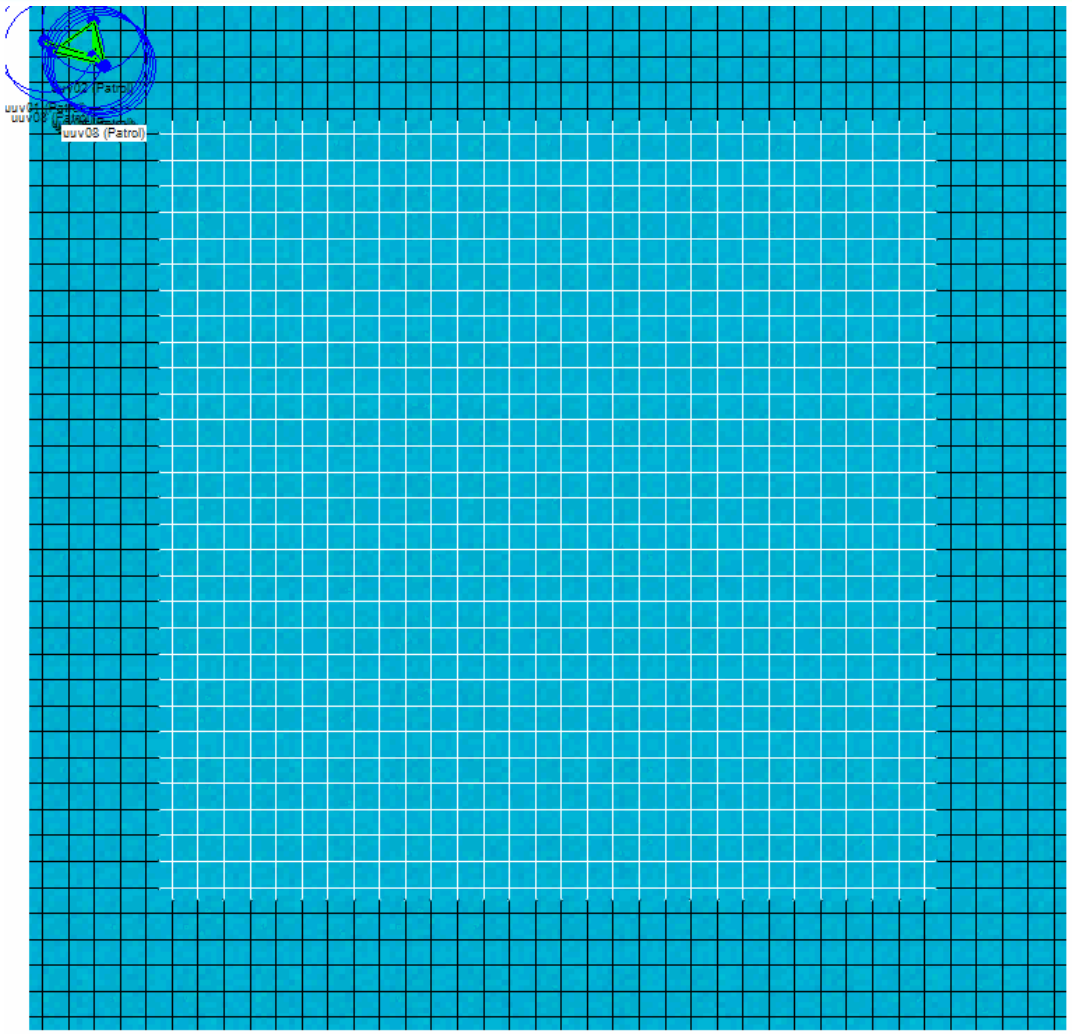
Field Thresholds may be Used to Adjust Behavior in Response to Phenomena

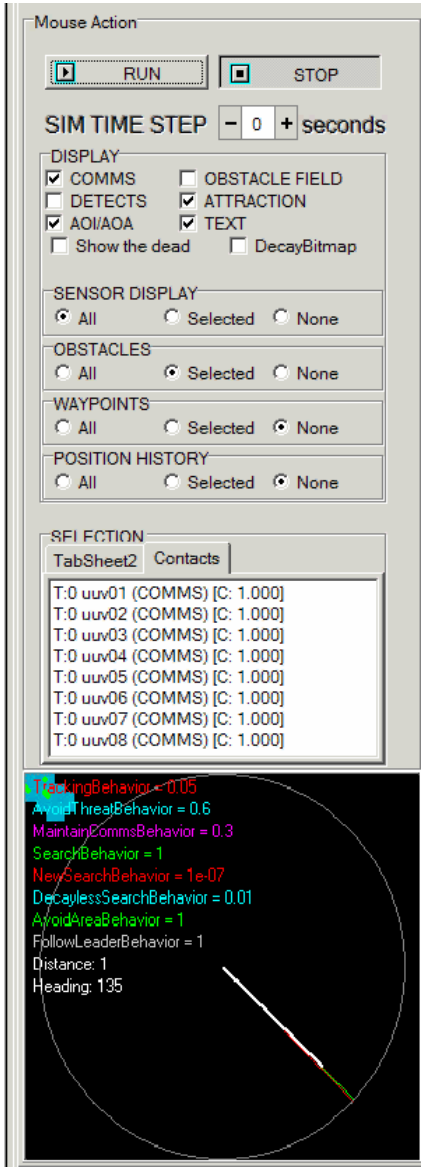
Mode Transitions and Transitory acts may be Precipitated by Applying Thresholds to Co-field Magnitudes

Simulator for Autonomous Agents

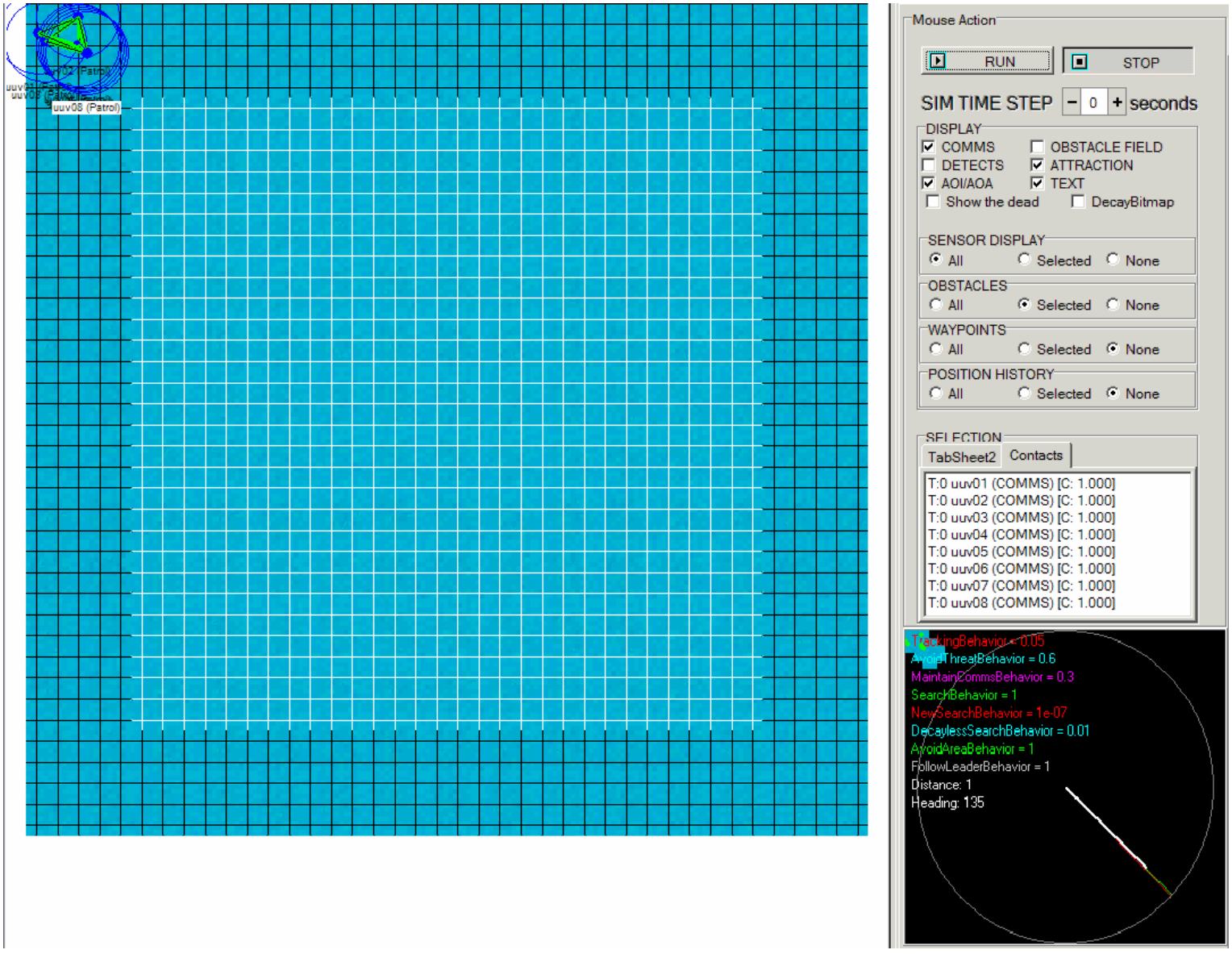


Cooperative Search (weak comms)

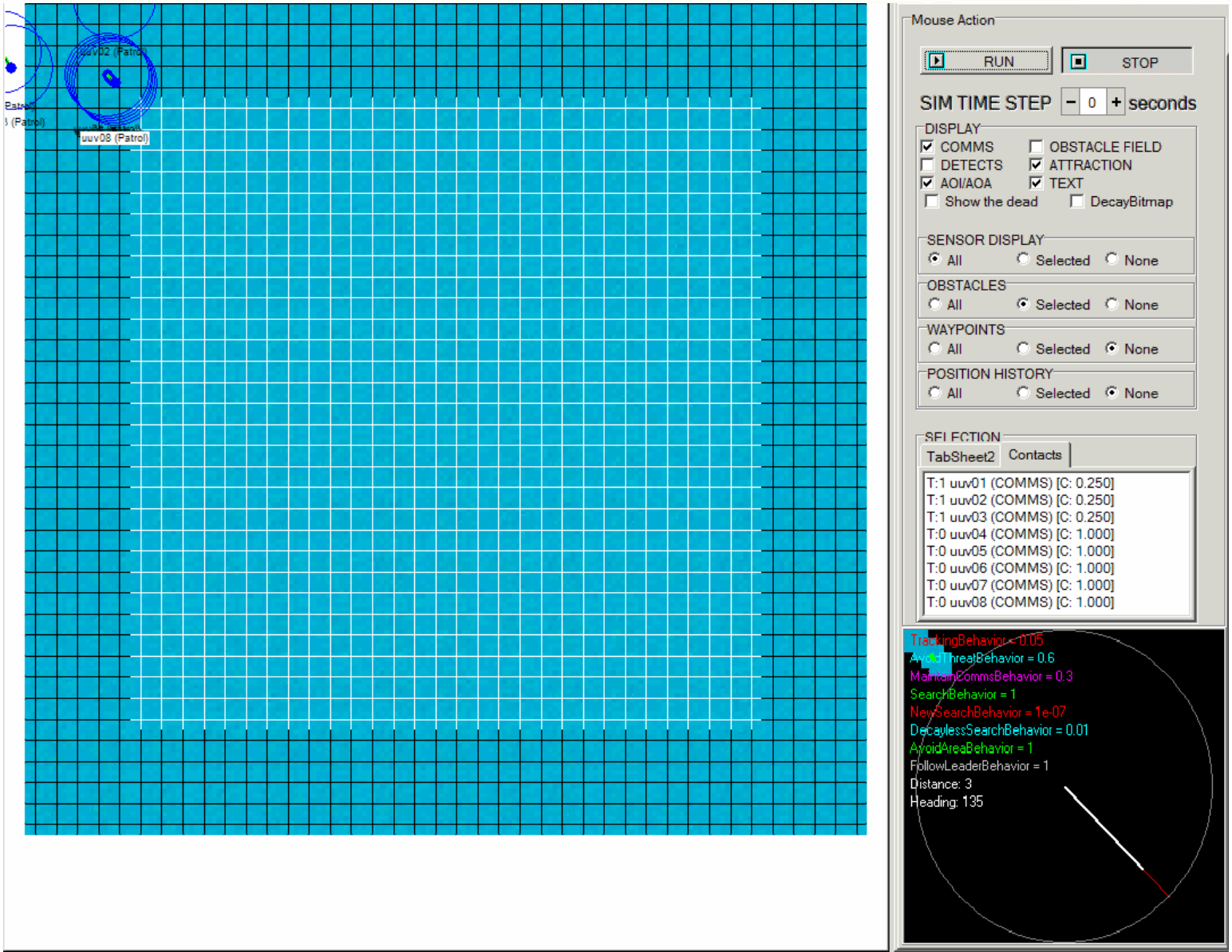




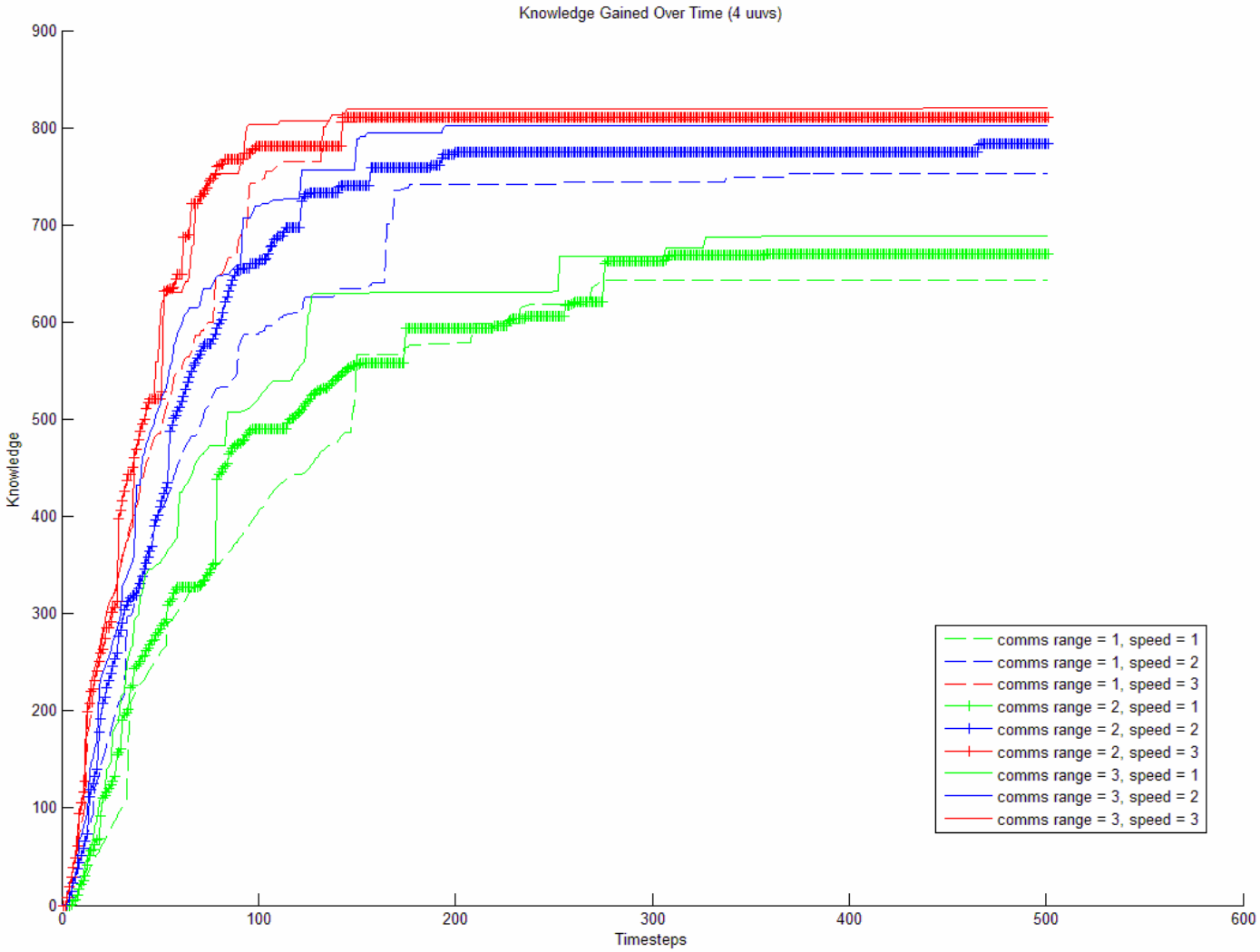
Cooperative Search (longer comms range)



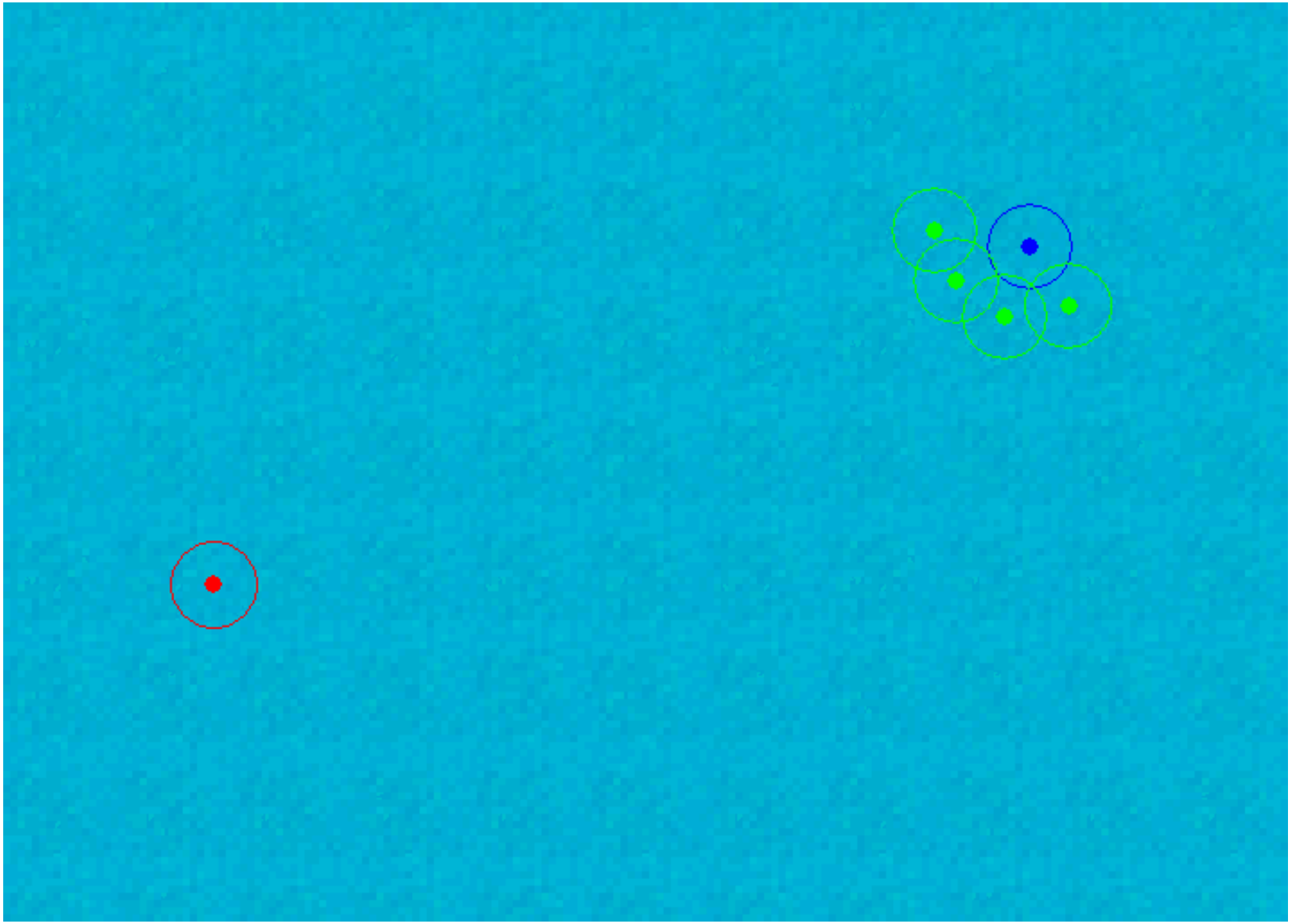
Cooperative Search (faster UUV)



Comms vs. Speed Results



Mode Transition to Comms Chain



Swarming Autonomy Benefits

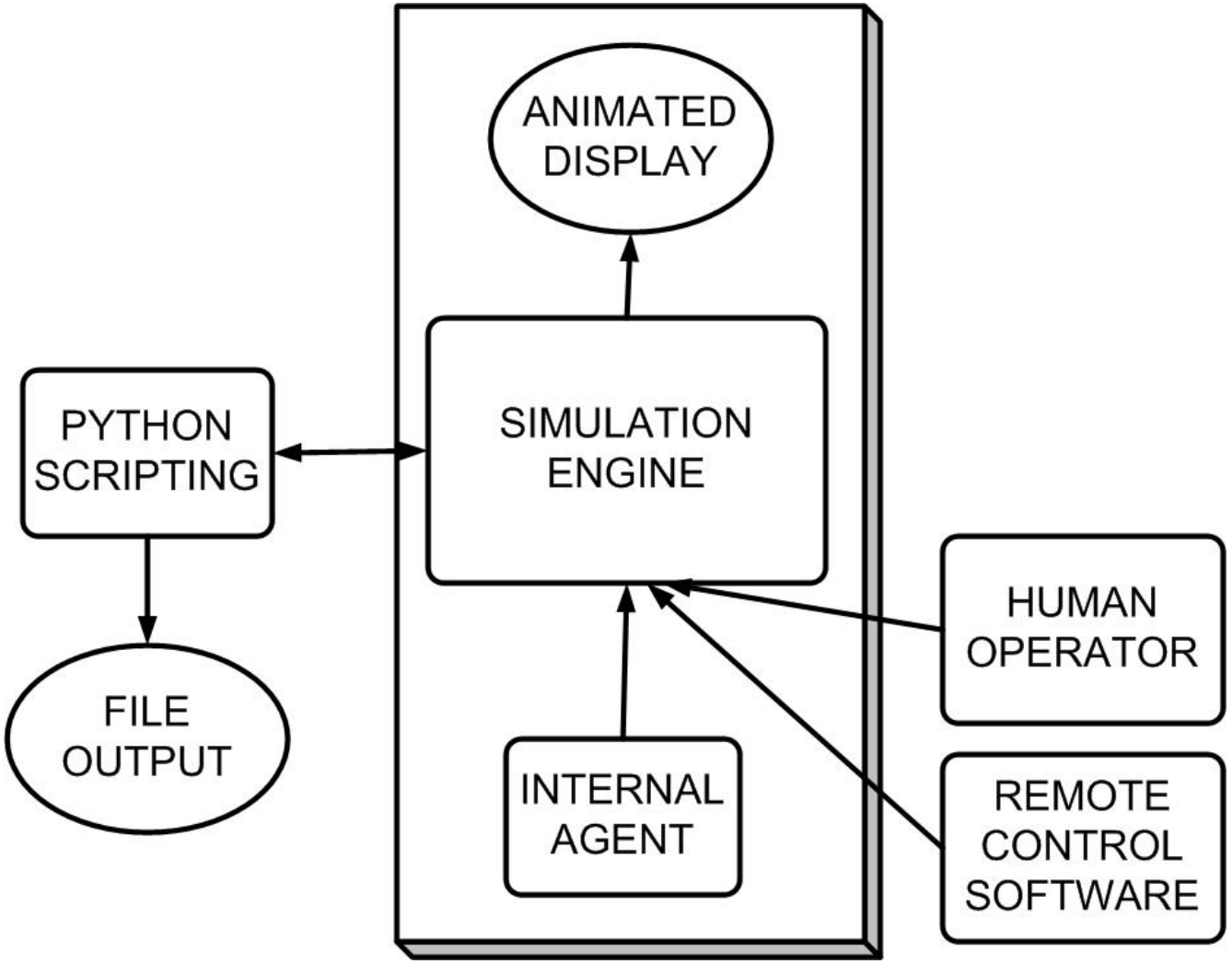
1,000,000,000,000 Cicadas Can’t Be Wrong!

Thank you!

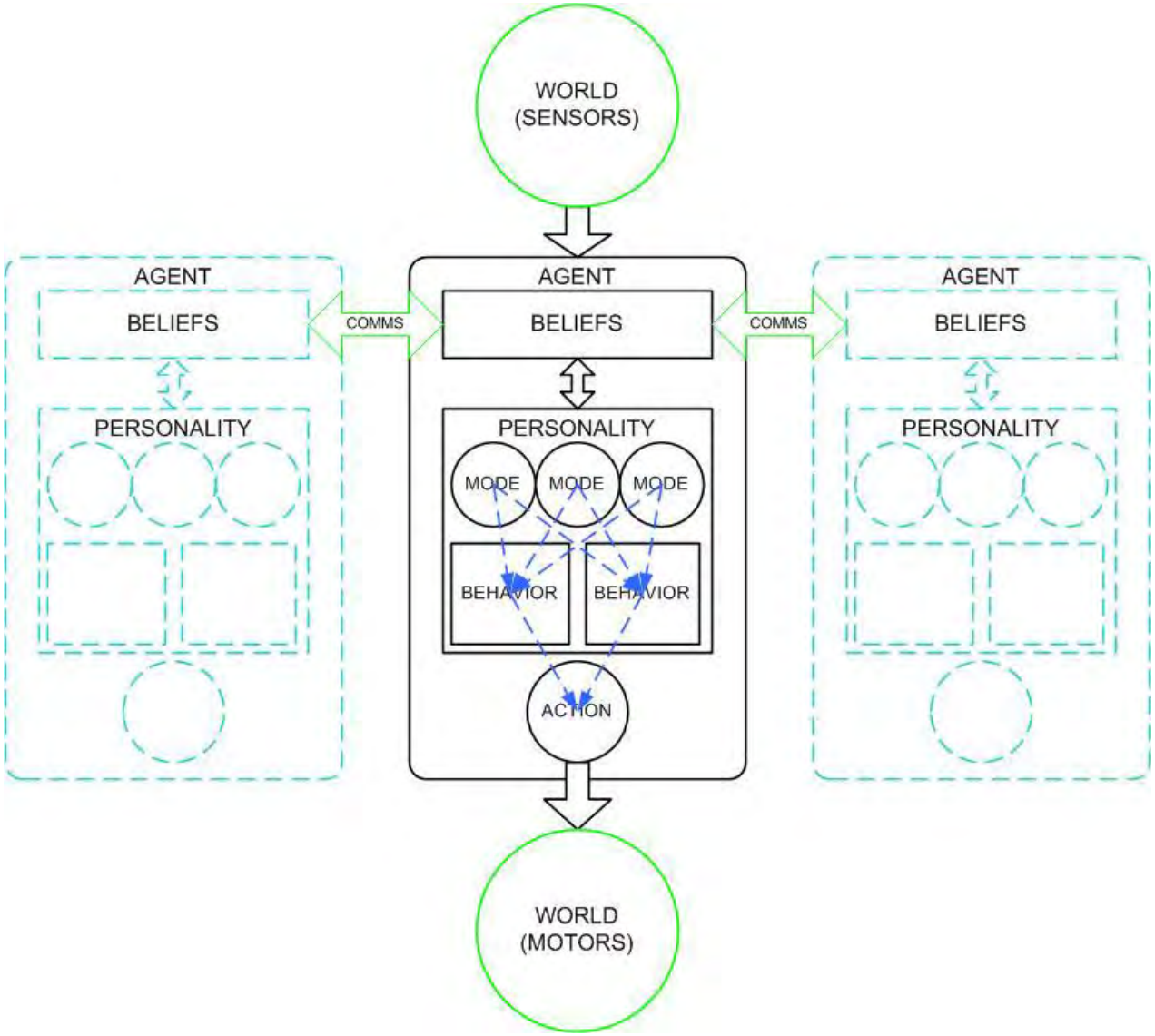
robert.chalmers@jhuapl.edu
(and David H. Scheidt)

BACKUP SLIDES

Swarming Engagement Simulator Input/Output



Agent Architecture

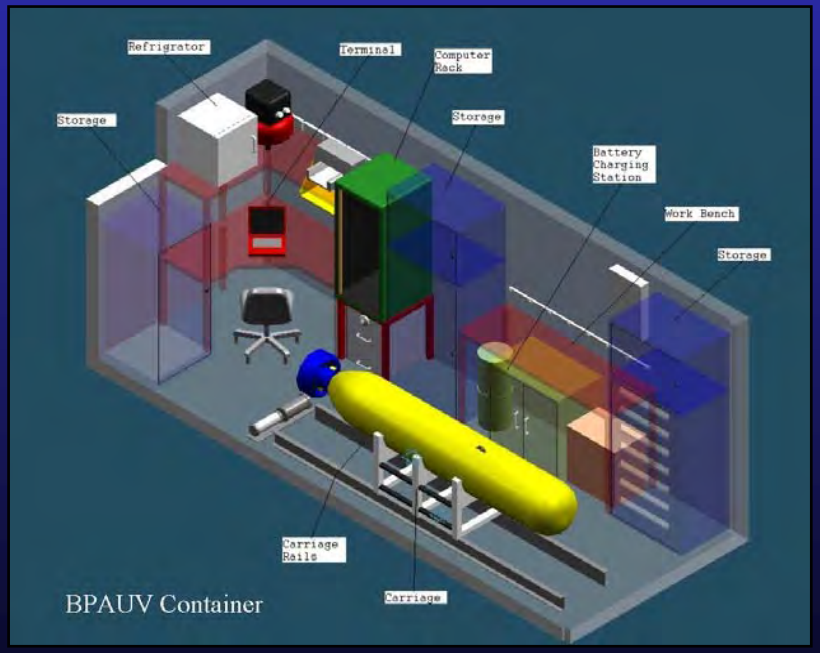


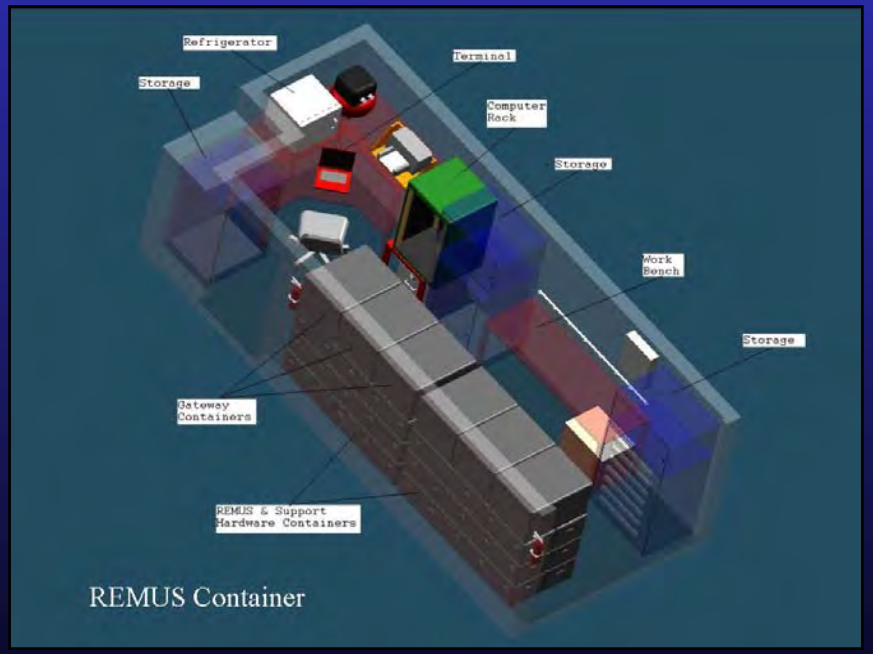
Successes in Combining Testing with Training in the Modular Mission Package (MMP) Program

Mark Connolly

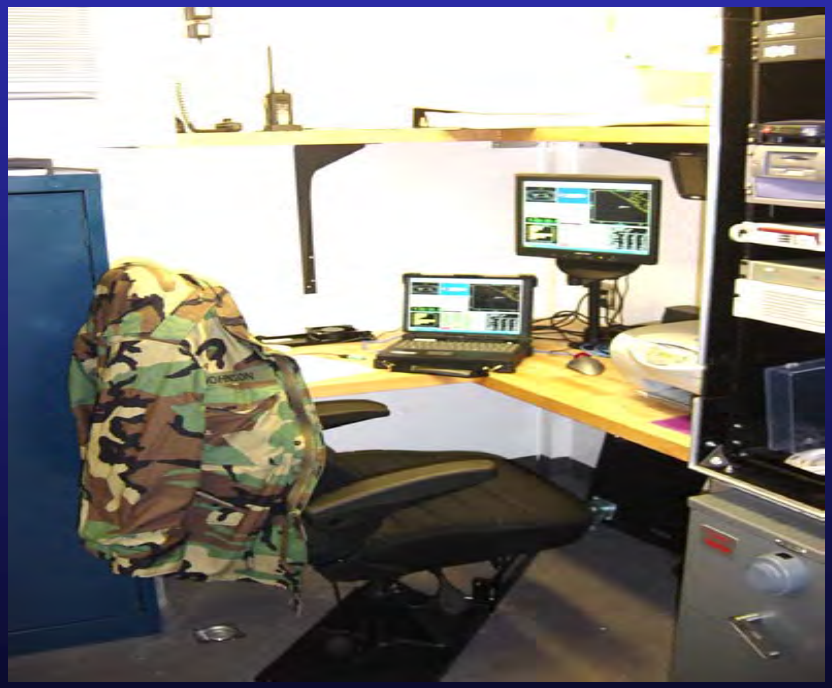
Naval Surface Warfare Center Panama City

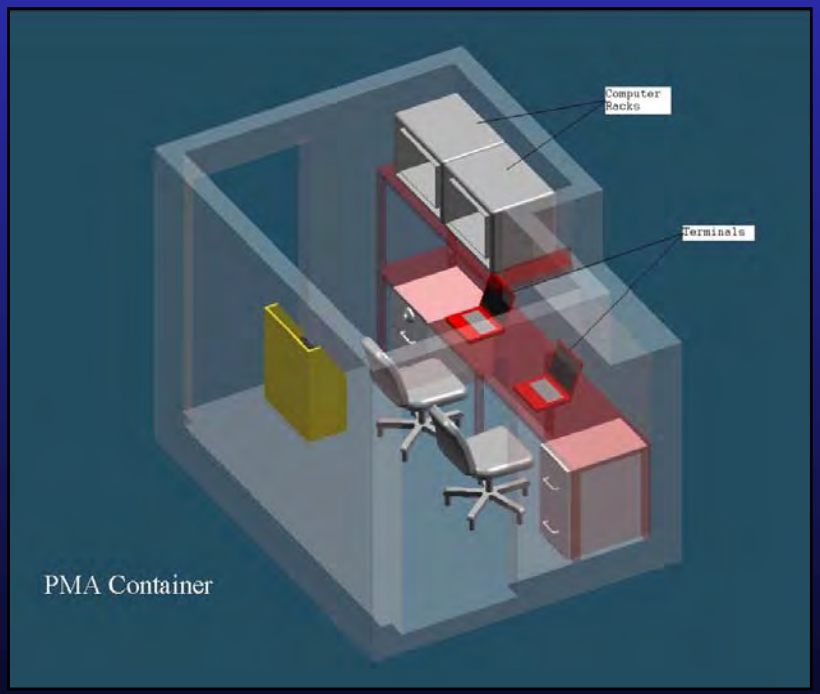
The Modular Mission Packages are milvans which house REMUS and BPAUV vehicles, and the equipment required to support missions.





The milvans are easily embarked and debarked from the host ship, and are adaptable to most ships.





Bringing Together the Military and R&D Cultures

What military operators like:

- The instruction and training aids provided on how to prepare the UUVs for a mission, and how to conduct Post-Mission Analysis (PMA) of the data.
- Being provided with a “window on the future” of new Navy technology.

Bringing Together Cultures, con't

What military operators dislike:

- The tendency of R&D personnel to tinker:
  - o Software development done on the fly.
  - o Vehicles constantly being reconfigured.
  - o Each reconfiguration requires a time consuming navigation recalibration.

What R&D personnel like:

- Initially, R&D personnel prepared, launched and recovered the UUVs. Now, military operators have taken over the responsibility.

- They are developing procedures and hardware for BPAUV L&R on various platforms.

•REMUS vehicles are lifted over the side of the host ship and deployed from a RHIB.

- Military operators provide a seamless interface, from MCM tasking to reporting contacts to the MCM Commander via MEDAL.

What R&D personnel like, con't:

- The Navy takes responsibility for providing target fields with mine-like targets. This gives R&D personnel a means of quantifying improvements made to the UUVs as an MCM tool.
- Military operators focus on Tactics, Techniques and Procedures (TTP), such as:
    - Mission Profiles
    - Time Management
    - Manning Requirements

Improvements Made Based on Military Operators Recommendations:

- The operator interface has been simplified, with one task per window and less jargon.
- Improved battery management, particularly during “standby” time when vehicles are powered up and awaiting orders to deploy.
- Real-time tracking of the vehicles with an Over-The-Horizon communications link has been provided.

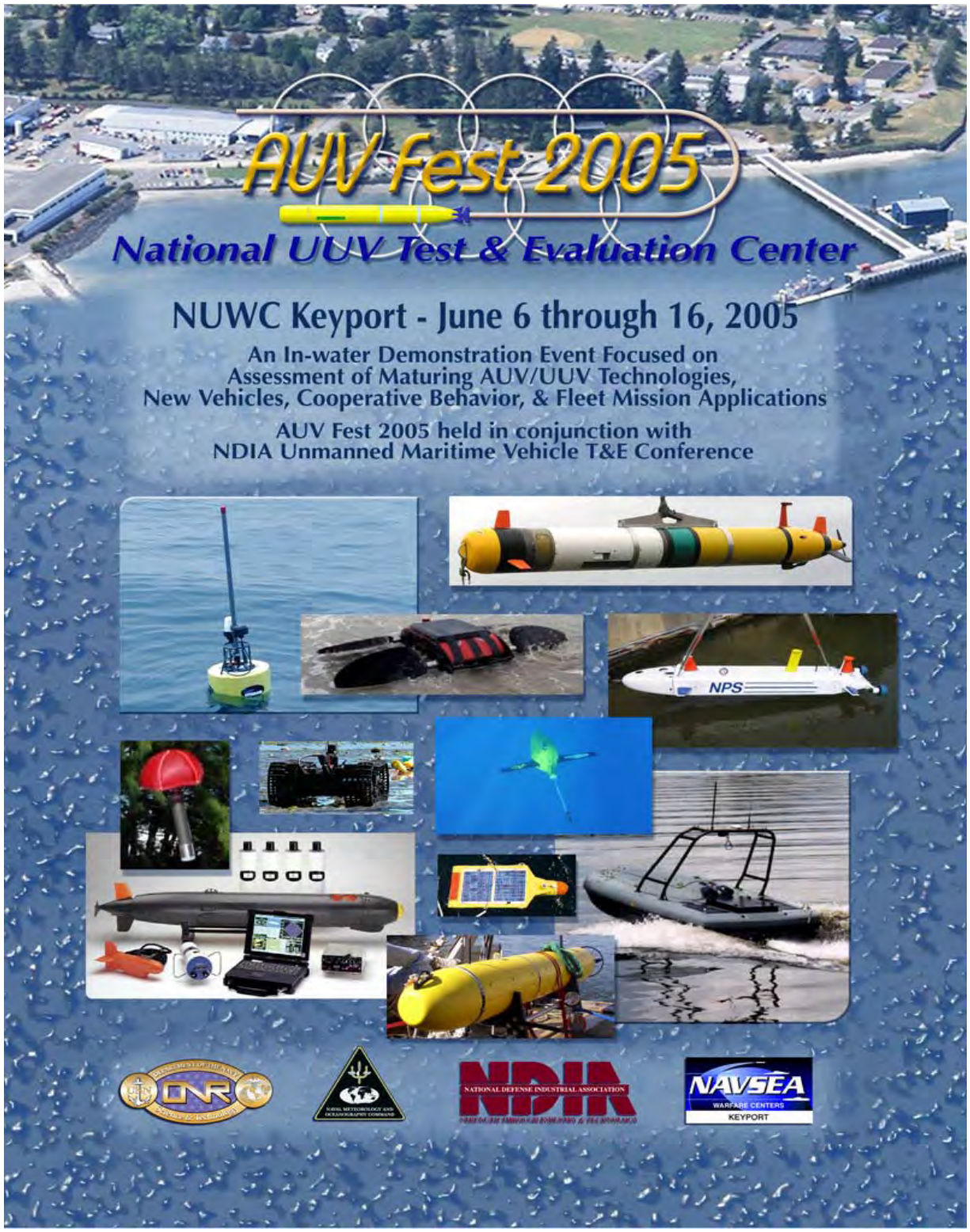
Improvements, con't:

- Maintenance levels have been defined, specifying which repairs can be done in the field and which require factory support.
- The ergonomic design of the milvans has been improved, with more efficient use of storage space and the ability to secure equipment during high sea states.

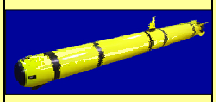
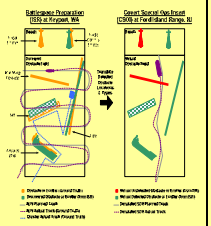
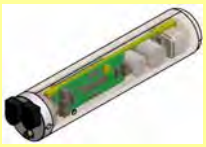
Recent Training and Exercises

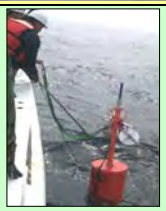
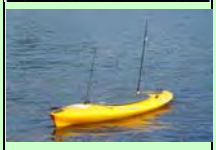
- REMUS training, Panama City, 2/04
- BPAUV training, Panama City, 3/04
- Blue Game, Norway, 4/04
- CJTFEX, North Carolina, 6/04
- BPAUV training, Panama City, 7/04
- RIMPAC (Hawaii), 8/04
- REMUS training, Panama City, 11/04
- GOMEX (Florida), 12/04
- BPAUV training, Panama City, 2/05
- REMUS training, Panama City, 4/05

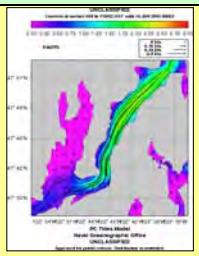
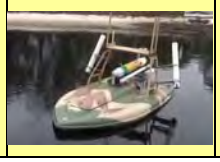
Questions?



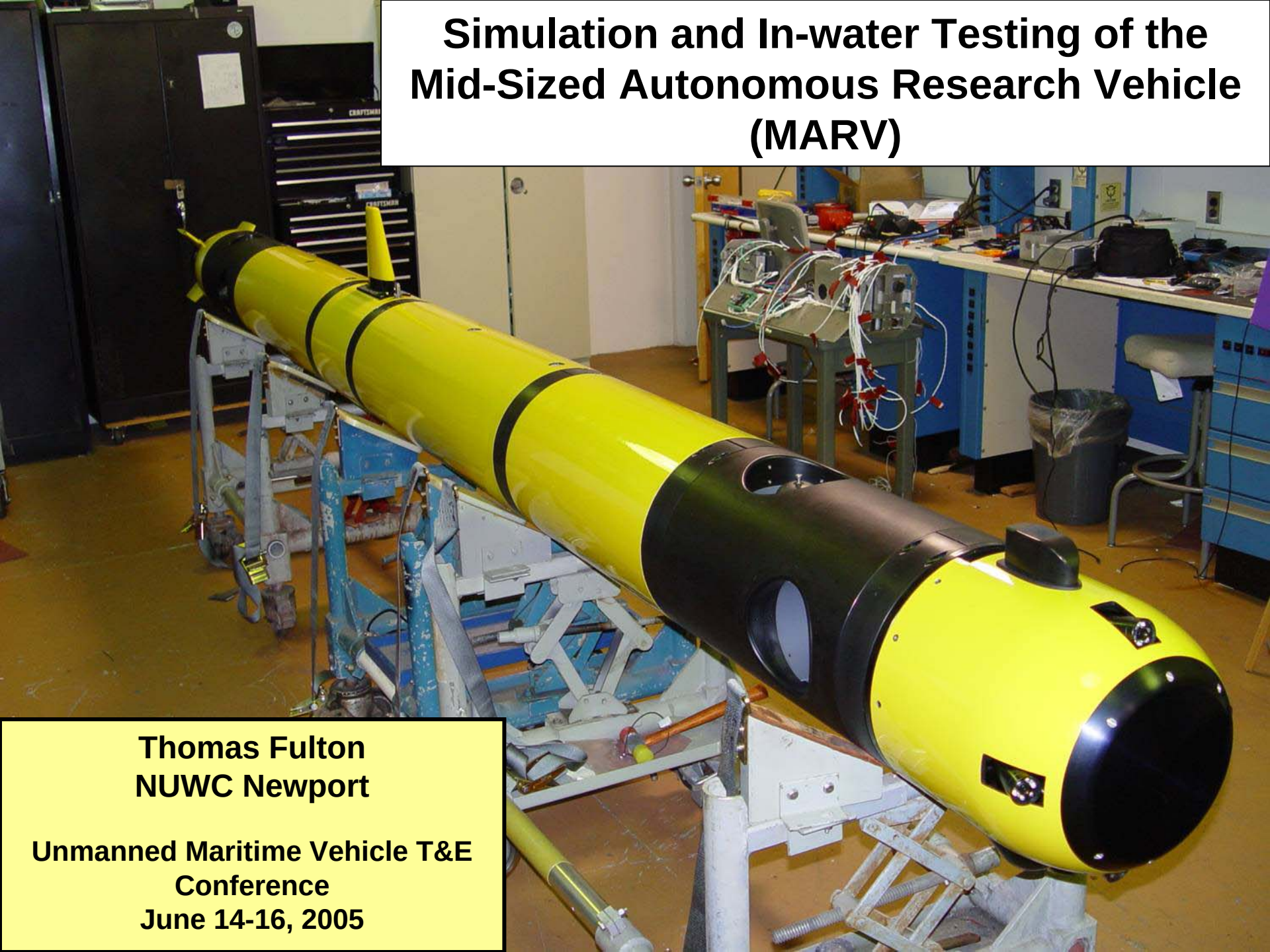
AUV Fest 2005: Technologies

Project Info	Picture	What it Does	How it Works	Standout Talent
REMUS-600 UUV [Remote Environmental Monitoring Units] Woods Hole Oceanographic Institution		Very long range search, survey, and target identification, with the ability to localize proud and buried targets.	**REMUS-600**: 5 kW rechargeable Li-Ion Battery, Inertial Navigation, 600 meter depth rating, acoustic modem, wireless network and Iridium communications, GPS, Doppler Velocity Log.	**REMUS-600:** Endurance, Navigation, and reliability. Ease of operation is similar to field proven REMUS-100. Stability control is ideal for SAS imaging.
SSAM [Small Synthetic Aperture Minehunter] installed on a REMUS-600 UUV **NSWC Pan. City**	 SSAM: A specialized payload of the REMUS-600, above	Combines synthetic aperture sonar (SAS), CAD/CAC and UUV technologies to detect, classify, and localize proud and buried targets.	System records high frequency (HF) and broadband low frequency (BBLF) SAS data while executing predefined UUV search patterns. Post mission, the data is retrieved and processed to generate very high-resolution HF and BBLF underwater imagery. The imagery is then fed into CAD/CAC algorithms for automated detection, classification, and localization of proud and buried contacts.	The **SSAM** system provides underwater imagery resolution previously nonexistent in its size class.
MARV [Mid-sized Autonomous Research Vehicle] **NUWC Newport**		Serves as a research platform for various payloads undergoing testing	Conducts a search pattern over an area of interest using various payloads to satisfy mission or testing requirements. Payloads include chemical sensors and color video. Capable of communicating with other vehicles and conducting joint exercises.	Payload flexibility allows execution of multiple missions
CETUS II [Composite Endoskeleton Testbed UUV System] Lockheed Martin		Conducts survey missions to collect images that can be viewed by operators. Capable of conducting Reacquire, Identify and Neutralization missions.	Hovers near target using thrusters; gathers data and, if appropriate, latches onto the target to deliver a neutralizing payload.	The smallest hovering AUV; hovering ability provides data collection capability not found in other AUVs.
CTEC-ISR Scenario [Collaborative Test and Evaluation Center - Intelligence, Surveillance, and Reconnaissance Scenario] **SAIC Keyport, NUWC Keyport, NUWC Newport**		Live, remote, virtual Intelligence, Surveillance, and Reconnaissance (ISR) information support to SEAL Delivery Team -1 (SDVT-1), providing Command and Control linkage w/SEALs in Hawaii. Goal is to integrate environmental and intelligence data, real and simulated AUV/UUV assets, and operational units in a battlespace preparation and mission planning test, training and evaluation (TT&E) exercise taking place over 8 days and at multiple locations. Demonstrates remote and distributed T&E capability, a precursor to CTEC.	Day 1: Naval Oceanographic Office (NAVO) and Joint Intelligence Center (JIC) will give an environmental and mock intelligence briefing on the scenario site (OP area A). Day 2: **NCST-1 Hydroid REMUS** will survey underwater obstacles. Day 3: **MARV** will take underwater video to verify obstacles; **SAUV** will survey chemical plumes. Day 4: MARV and **SAUV,** and then **MARV** alone, will survey chemical plumes. Day 5: **HUSCy** will further survey obstacles, using different sensors than **REMUS.** Days 6-8: **21-UUV**, simulated from NUWC Newport, will survey shore-based RF transmitters. **(MARV** and **SAUV** will also be active in the chemical mission on days 6-8. All chemical detections will be simulated.) **SDVT-1** in Hawaii will receive briefings and analyzed data daily, assess the emerging battle-space picture, and develop a mission plan.	Demonstrate CTEC and NUTEC capability to support distributed, live-virtual-constructive (LVC) TT&E Satisfies National Capabilities Requirement
Crawlers **NSWC Panama City**		In the Very Shallow Water (VSW) environment, reacquires targets, identifies them, and neutralizes them. In the surf zone, crawlers survey and map potential approach lanes.	Crawls autonomously. Using its sonar, the object is reacquired and imaged using a camera and neutralized using explosive charges carried onboard. Crawlers can carry many different payloads in support of different missions.	Crawlers operate in breaking surf, strong surge, and currents, and they can perform missions from VSW up onto the beach.
Gateway Buoy **Florida Atlantic University**		Self-Mooring and air-deployable Gateway Navigation and Communications Buoy for support of littoral AUV missions	Takes acoustical communications from Woods Hole Oceanographic Institute (WHOI) and Florida Atlantic University (FAU) modems and transmits them using RF Freewave to shore. Can provide navigational information to the AUV via Acoustical Communications (**ACOMMS**). Capable of Global Positioning System (GPS) self-location.	Rapidly deployable from the air or a fast boat
REMUS Very Shallow Water AUVs [Remote Environmental Monitoring Units] Woods Hole Oceanographic Institution		Search, Classify, and Map (SCM) Mines in very shallow water areas (depth < 100 ft). Communicates with, and provides autonomous redirection to, other vehicles.	Using a variety of sensors including Side Scan Sonar (SSS), Forward Looking Sonar (FLS), video cameras, and various oceanographic sensors. **REMUS** sweeps an area, looking for mine-like objects.	**REMUS** is able to work in very shallow water with other vehicles to Search, Classify, and Map mine-like objects. Proven as a most effective vehicle for this duty.
ACOMMS [Acoustic Communications] **Woods Hole Oceanographic Institution**		Provides acoustic networking for MCM AUVs including **REMUS, Bluefin, CETUS** and **Crawlers.** The acoustic network provides command and control information to vehicle operators ashore.	This modem uses a time-division protocol to allow acoustic transmissions at data rates from 80 bps to 5700 bps. Packets are broadcast so that every node in the network has a full picture of the mission as it proceeds.	The use of standard message formats by all underwater vehicles enables a real-time picture of underwater operations as they progress.

Project Info	Picture	What it Does	How it Works	Standout Talent
COIN [Common Operator Interface] ARL Univ. of Texas, Naval Special Clearance Team -1, SPAWAR		COIN is a software application that provides mission planning, execution, analysis and reporting with a common and consistent graphical user interface among the Naval Special Clearance Team-1 (NSCT-1) Mine Countermeasures (MCM) supported systems.	COIN gathers data from a variety of vehicles and sensors and allows this data to be displayed in one software application.	COIN makes planning, execution and analysis much easier because it can be done in one standard environment.
REMUS Shallow Water [Remote Environmental Monitoring Units] Hydroid Inc.		Large area/long duration Search, Classify, and Map (SCM) missions as well as high-resolution sidescan and/or video Reacquisition and Identification (RI) in the shallow-water environment (10'-300')	Uses dual frequency sidescan sonar to conduct Search and Map (SM) and RI surveys. Also uses Computer Aided Detection/Computer Aided Classification (CAD/CAC) processing: Inertial Navigation System, GPS and 600kHz DVK/Acoustic Doppler Current Profiler-aided navigation; and an acoustic modem and Iridium communications provide in-mission monitoring, redirection, and command interface.	Small and lightweight, with versatile mission adaptive capabilities satisfying both SCM and RI missions in shallow waters.
ACDS [Acoustic Communication and Data Storage Unit] Naval Research Laboratory		Long-term unattended recording and storage of underwater acoustics with point-to-mobile-point channel characterization in shallow and very shallow water environments.	Bottom moored **ACDS** units, with 8-channel receive arrays, collect ambient noise and periodically transmit probe signals to other ACDS units as well as receive various AUV sources of opportunity for acoustic channel characterization. Acoustic data is processed and relayed to shore station via WiFi for monitoring and further analysis.	Ability to record 360 GB of data and operate unattended for extended 7-day durations. Provide empirical measures of shallow water and very shallow water acoustic channel adversity for AUV ACOMMS users.
Nekton Ranger [VSW MCM] Nekton Research		An expendable autonomous vehicle used for Very Shallow Water (VSW) Reacquire and Neutralize (RN) mine countermeasure missions.	Commanded by RF or acoustic link to execute mission. Navigation assisted by GPS. Homes to mine intercept using Blazed Array sonar. Ranger has been designed to support a 10 lb mine neutralization payload.	Small size (A-size hull diameter) is ideally suited for easy single-operator deployment, which is critical in rapid-response situations.
Transphibian Nekton Research		Hunts mines in hazardous areas where control is difficult such as the surf zone or choppy waters around piers.	Paddles using four oscillating fins that mimic sea creature locomotion. It can sink to the bottom and crawl to the mine for neutralization.	It's the only AUV that can swim and crawl, returning itself to the ocean if washed ashore.
SAUV [Solar AUV] Falmouth Scientific and Technology Systems, Autonomous Undersea Systems Institute		A solar powered vehicle that conducts Intelligence, Surveillance, and Reconnaissance (ISR) missions from the surface or submerged.	Swims in cooperative groups of SAUVs, maintaining continuous operations while other SAUVs recharge. Communicates and reports results in real time via RF or satellite link. Capable of providing gateway communication services with other types of AUVs via ACOMMS.	Solar powered system allows for extended persistent surveillance in excess of one year. Using Autonomous Underwater Systems Networking (AUSNet) to provide network capability over ACOMMS
SCOUT [Surface Craft for Oceanographic and Undersea Testing] Massachusetts Inst. of Tech.		Low cost platform using COTS hardware. Provides navigation assistance to AUVs. Cooperative behavior. Autonomous operation.	Uses WiFi, RF and acoustic modems, GPS, and a compass to create a scaleable network of "location aware" assets that assist subsurface vehicle operations.	Low Cost and low manpower operations. Rapid deployment, flexible, robust architecture. Behaviors developed with surface craft will be transitioned for use in AUVs.
ARIES [Acoustic Radio Interactive Exploratory Server] Naval Postgraduate School		Demonstrates obstacle detection and avoidance behavior and collects data for further avoidance algorithm development.	Uses Blazed Array Forward Looking Sonar (FLS) to map area in front of vehicle. Will adjust course and altitude based on processed sonar images.	FLS can "see" sea mounts and other undersea obstacles and avoid them.
Gavia AUV Hafmynd ltd. Naval Special Clearance Team -1, SPAWAR		Performs both SCM and RI tasks for MCM missions.	Uses GPS and inertial navigation to provide over the horizon deployment capability. Modular construction allows for rapid configuration changes with payloads tailored to meet mission needs. Payloads have included Side Scan Sonar and video surveillance.	Modular configuration for rapid mission tailoring and quick vehicle turn around.
Sea Lion Bluefin-9 Naval Special Clearance Team -1, SPAWAR, Naval Support Activity-Pan. City		Search, Classify, Map (SCM) Mine-like objects. Capture video for Reacquire and Identification (RI) missions.	Uses GPS and inertial navigation to provide over the horizon deployment capability along with SCM mission capabilities without transponders.	Can change program mission quickly at sea, as well as the battery.

Project Info	Picture	What it Does	How it Works	Standout Talent
Sea Glider **Applied Physics Laboratory, Univ. of Washington**		Acquires and telemeters ocean water column property data between surface and 1000 m depth with scientific precision and can be commanded remotely via Iridium to fly to desired waypoints and/or station-keep. Ocean parameters measured: conductivity, temperature, optical scattering, fluorometry, and dissolved oxygen. Computed onboard: depth-averaged and surface ocean currents, salinity, and sound speed. Demonstrated capabilities: 1800+nm horizontal range, 190+days continuous operation.	Employs a buoyancy engine for vertical thrust, and a hydrodynamically efficient shape and a mass-shifter element (glider's battery pack) to achieve controlled flight. Command and waypoint files are downloaded and data uploaded from the glider with each profile using an Iridium link.	Persistent, autonomous battlespace characterization platform.
Noise Mapping (Slocum) Glider **Alaska Native Technologies, SPAWAR**		Acoustic noise mapping. Collect acoustic (ambient noise) and environmental (Sound Velocity Profile (SVP)) data.	Operate in shallow coastal waters (as shallow as 5m) where high maneuverability is necessary. Collect acoustic (ambient noise) and environmental (SVP) data and transmit these data over a broadband link for display at a shore site. With appropriate sensors it can monitor acoustic activity, communications, Nuclear, Biological, and Chemical (NBC) activity, report as required.	Inexpensive Resource for Denied Area Surveillance. Autonomous, high endurance operations. Autonomously establish a barrier patrol for denied areas (homeland defense). Relatively inexpensive, recovery not required.
HUSCy [Hydrographic Unmanned Survey Craft] **NAVOCEANO Sea Robitics**		Tactical hydrographic and environmental data gathering in shallow to very-shallow water environments	Freewave UHF data link to enable remote mission monitoring. GPS to navigate remotely or autonomously to areas of interest. Uses Side Scan Sonar, Acoustic Doppler Current profiler, CTD, transmis-someter, and an echo sounder to gather hydrographic and oceanographic data.	Low cost, autonomous shallow water littoral warfare environmental data gathering system.
R-I UUV **WHOI REMUS** **Naval Special Clearance Team -1,** **SPAWAR**		Reacquires and Identifies (R-I) mines in the very-shallow water regime.	Uses high-frequency side scan sonar and video camera for the identification mission. Also has on board Computer Aided Classification/Detection software for Classification missions.	Original dual-frequency side scan sonar vehicle, currently undergoing a User Evaluation with Naval Special Clearance Team-1 and Concept of Operations development with SPAWAR.
REMUS SCM **Hydroid** **Naval Special Clearance Team -1,** **Naval Support Activity-Pan. City, SPAWAR**		Performs Search-Classify-Map (SCM) missions in the very shallow water regime.	Uses side scan sonar, video cameras, transponder and GPS navigation for SCM Missions.	Vehicle is being evaluated for the 2nd generation UUV system at Naval Special Clearance Team-1.
Environmental Post Mission Analysis (PMA) **Naval Oceanographic Office**		Environmental Intelligent Preparation of the Battlespace (EIPB) that aids mission planning, mission execution, and sensor performance prediction, reducing tactical timelines and minimizing risks to the warfighter.	Use environmental knowledge to process and analyze on-scene vehicle sensor data, such as acoustic imagery, currents, inherent optical properties, and sound velocity profiles, to provide rapid turn-around of derived relevant operational products.	Flexible capability to process and fuse data from different sensor/vehicle systems and provide environmental information to Mine Warfare Environmental Decision Aids Library (MEDAL). Provides an interface to NAVOCEANO tidal current forecasts and historical environmental databases.
BAUV [Biorobotic Autonomous Underwater Vehicle] **NUWC Newport**		Prototype platform which can hover or transit laterally, vertically, forward, and reverse, enabling stealthy low-speed maneuvers in energetic environments.	Uses six heaving and pitching flapping fins to control vehicle in six degrees-of-freedom.	Provides six degree-of-freedom low speed maneuverability with efficiency and stealth in a scalable platform.
RDUST [Remote Delivery of Unmanned Systems Technology] **NSWC Pan. City**		Removes the warfighter from the area of risk when deploying autonomous underwater mine hunting vehicles. Provides communications to the mine hunter from well outside the threat area being searched. Provides UUV location and allows in-stride redirection.	Provides semi-autonomous positioning for UUV launch from beyond 10 miles distance. Allows surface awareness through infrared and color camera video feeds.	This speedy vehicle can greatly extend the reach and safety of the warfighter.

Simulation and In-water Testing of the Mid-Sized Autonomous Research Vehicle (MARV)



Thomas Fulton
NUWC Newport

Unmanned Maritime Vehicle T&E Conference
June 14-16, 2005

Agenda

- MARV overview
- MARV as a T&E platform for UUV payloads
  - chemical sensor
  - color video cameras
- Computer simulation of MARV missions before in-water runs
- Post-run evaluation of MARV missions

NAVSEA
WARFARE CENTERS
NEWPORT

MARV
Mid-sized Autonomous Research Vehicle

12.75" OD

Performance Specifications

- **Operating Depth**
  - Surface to 1500 feet
  - Minimum water column depth: 20 feet
- **Operating Speed**
  - 2 - 5 knots forward/reverse (baseline configuration)
  - 0 - 1 knot forward / reverse / vertical / lateral / spar buoy (in thruster configuration)
- **Endurance**
  - 2.5 kWh available lead-acid, 6 kWh Li-Ion
  - Baseline transit/survey mode (@ 3 knots or 1.5 m/sec)
    - Distance: 30-72 nautical miles
    - Duration: 10-24 hours
  - High AOA hover mode
    - Duration: Variable, ~7-14 hours
- **Navigational Accuracy**
  - 0.05% Distance traveled median error (CEP 50) @ speed & depth
    - Equates to 5meter/hr drift at 5 knots
  - Position resets via surfacing for DGPS fix
    - 1 ~ 2 meter accuracy after approx. I minute
- **Connectivity**
  - Through-air LOS wireless r.f. communication link (11 MBits/sec)
    - TCP/IP & UDP protocols
  - Through-water (2 km) acoustic communication link (100 Bits/sec)
- **Tracking System**
  - Portable Self Tracking
  - Absolute Track w/ GPS Accuracy
- **Present Payloads (FY05)**
  - Chemical / TNT Analyzer
  - Color cameras
    - For Future Video Mosaicing, Vision Based Nav.
- **Future Payloads (FY05-06)**
  - Two High AOA Thruster Stations (fore & aft)
  - DIDSON Imaging System
  - Obstacle Avoidance / Bathymetric Sonar

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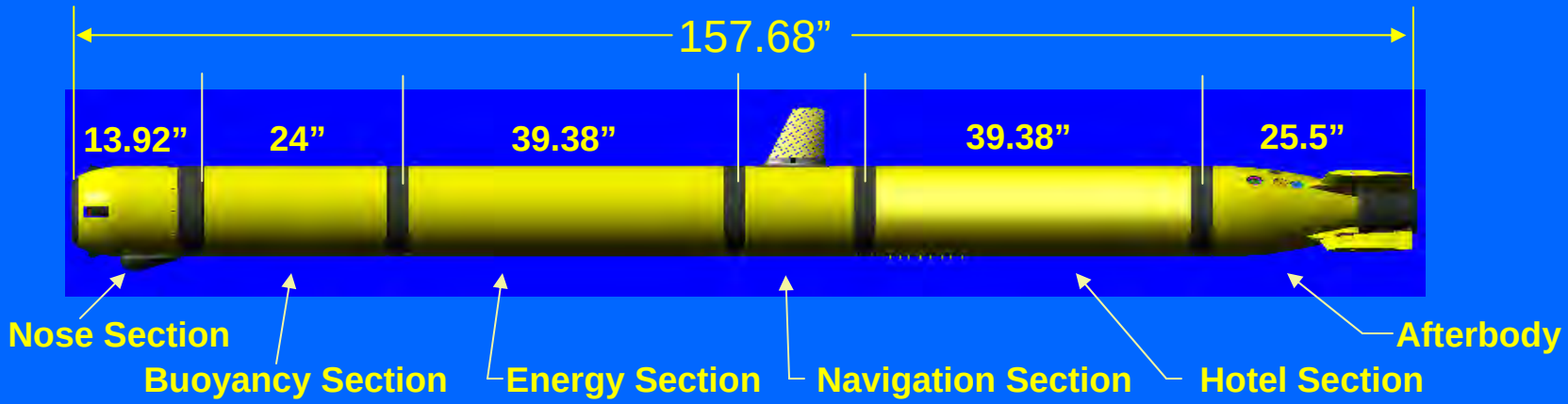
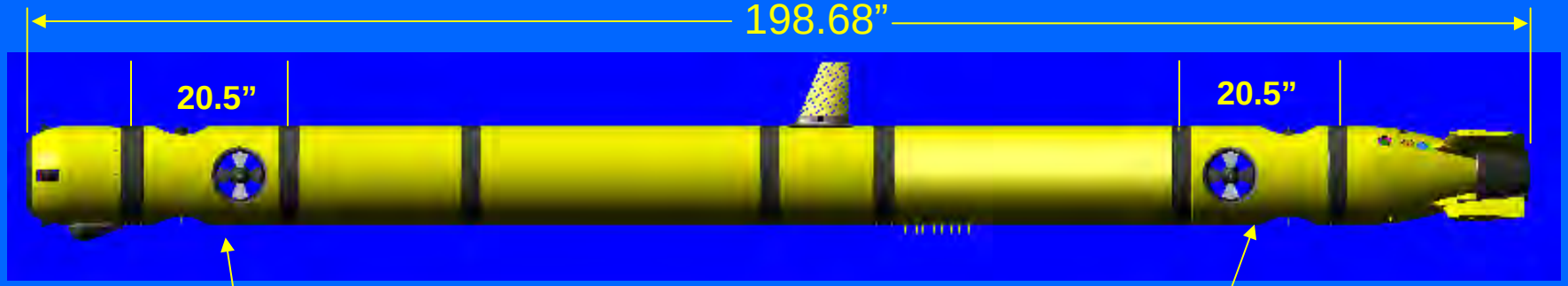
UUV Layouts

Baseline Configuration, 652.45 lbs, 10.24 ft^3



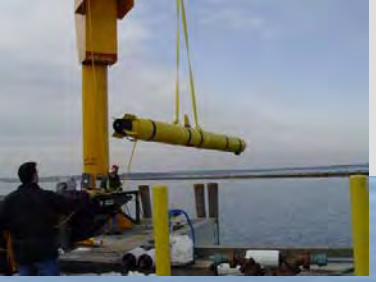
Thruster Configuration, 860.37 lbs, 13.44 ft^3

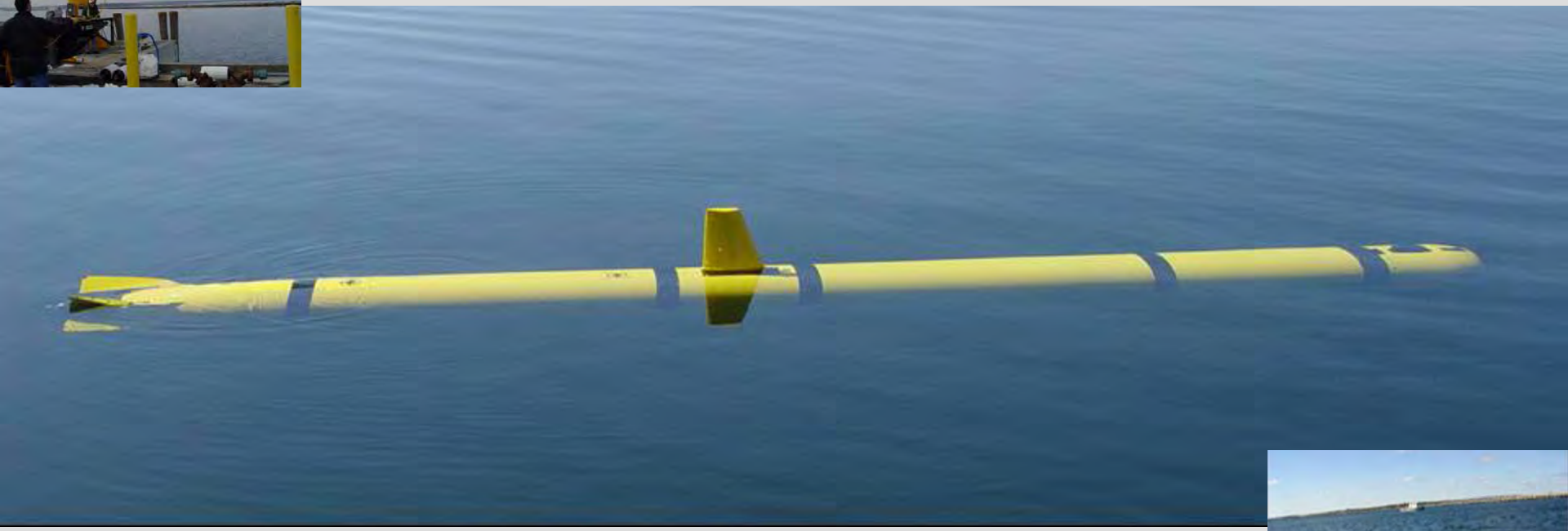


MARV Payload Integration Capability

- Voltage: 2-95 VDC
  >95 VDC with vehicle modifications
- Power: Up to 100W Standard
  Additional Power in 100W increments (300W available, additional may require vehicle mods)
- Connectivity:
  - 10/100 Base-T Ethernet standard
  - RS-232/422 optional through addition of serial servers
- Payload Data Storage:
  - Local storage within the payload
  - Via the vehicle controller if the data volume and throughput is low
  - Vehicle time and navigation data is provided to payload if needed
- Payload Data Retrieval:
  - Low volume/low throughput data can be transmitted during a run via ACOMMS
  - Larger data sets can be transferred via 11 Mb/sec RF Ethernet when on the surface or in lab
  - Manual retrieval via media removal or umbilical to payload
- Physical dimensions: 24” section available now (1.4 cuft); 39” sections or larger possible
- Future integration with MARV Autonomous Controller allows vehicle to make mission and navigation decisions based on real time payload sensor data

In-Water Test Status



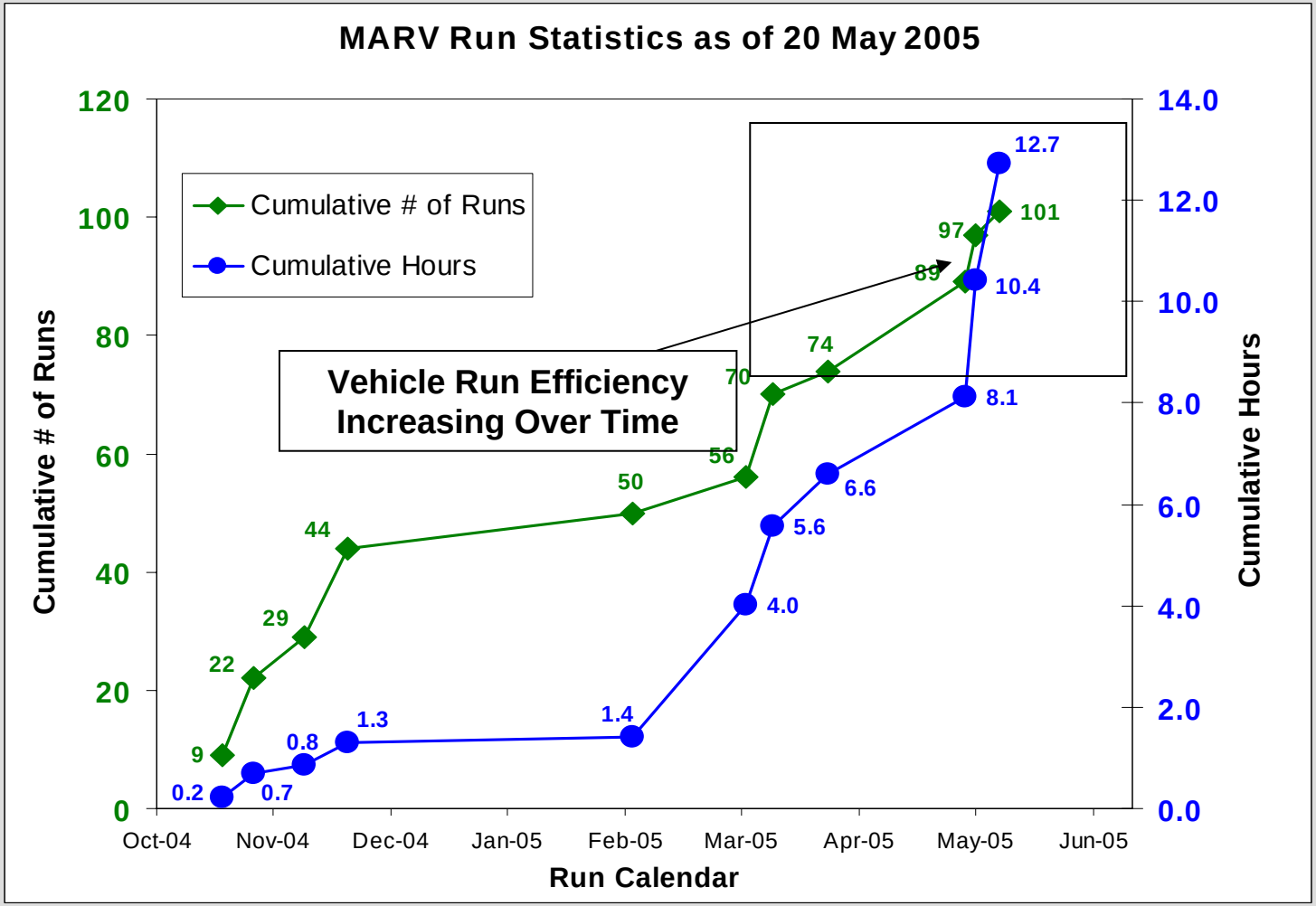


- Accomplishments to Date (11 Days of Operations)
  - 101 In-Water Dynamic Missions Completed
    - Surface and Sub-surface Operations (In-Flight)
    - autopilot control verified
    - Low speed (≤3 knots) control coefficients optimized
  - Vehicle Powered In-Water Over 80 Hours (On-Surface & In-Flight)
  - Camera system successfully demonstrated
  - Chemical Analyzer successfully demonstrated
  - Depth-mode and over-bottom navigation mode (terrain-following) waypoint navigation successfully demonstrated
  - Benthos acoustic modem tested to range of 1.2km
  - Forward and Reverse dive maneuvers successfully demonstrated

In-water Testing and Evaluation

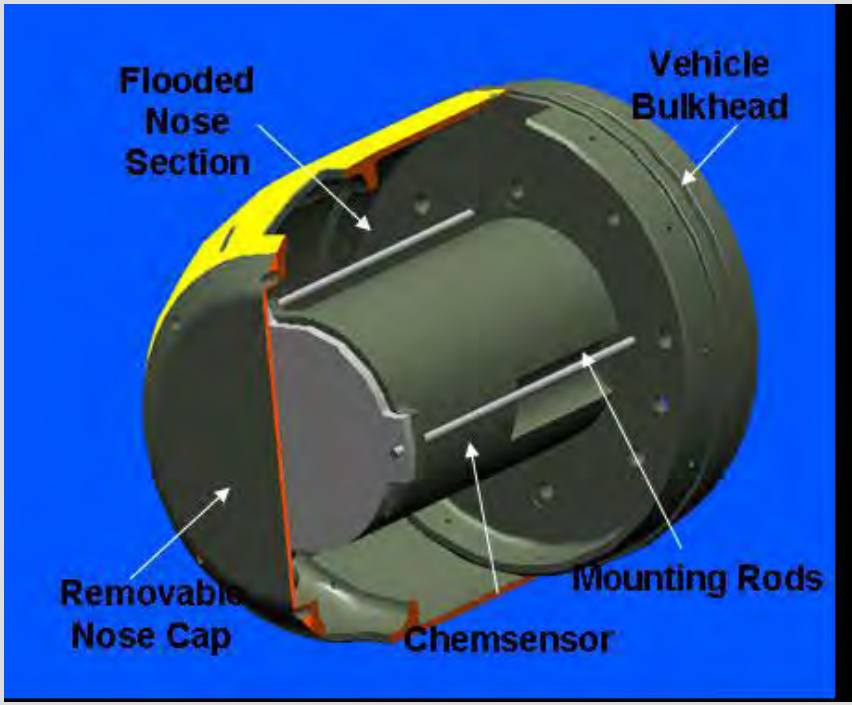
- Iterative cycles of
  - bench tests
  - in-water runs
  - troubleshooting fixes

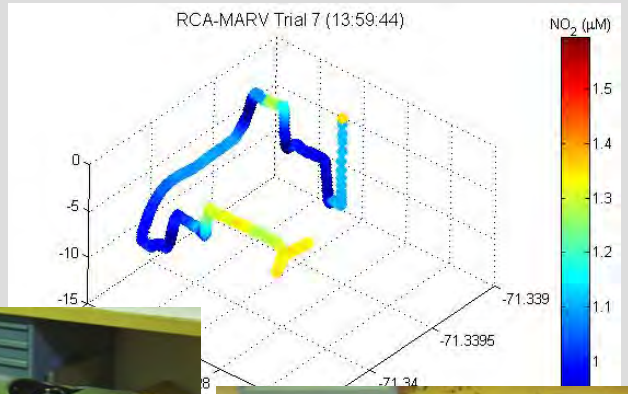
  have led to highly reliable vehicle
- Initial UUV troubleshooting is complete, vehicle missions in excess of 2 hours have been performed



MARV Chemical Sensor Integration

- Four channel chemical analyzer made by SubChem Systems, Inc.
- Chemsensor has been completely integrated to MARV and tested.
- Mounted inside of MARV's flooded nose section. This allows for easy access to the sensor without opening the vehicle.



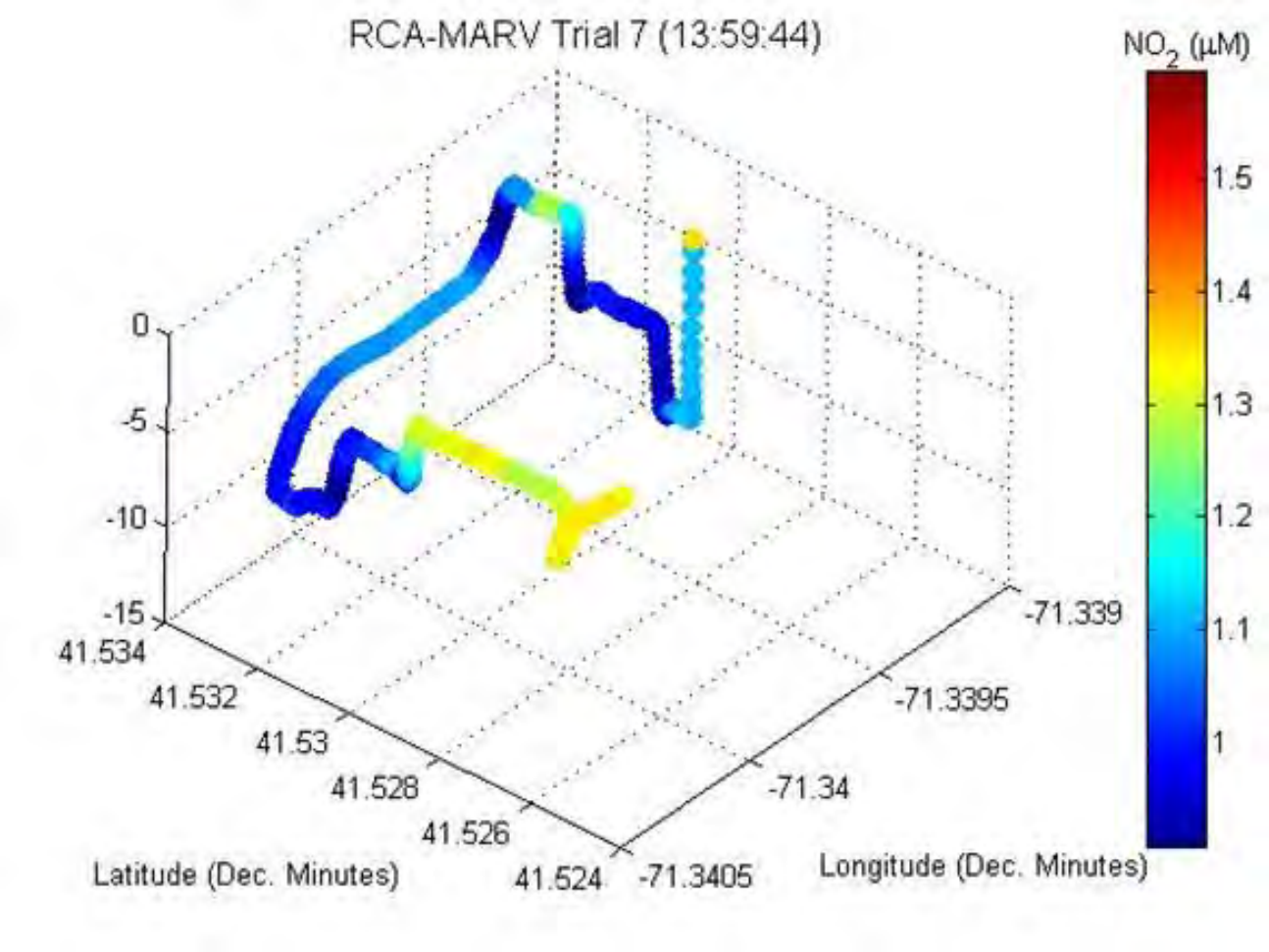


SubChem Systems, Inc.

Narragansett Bay Mission April 5, 2005

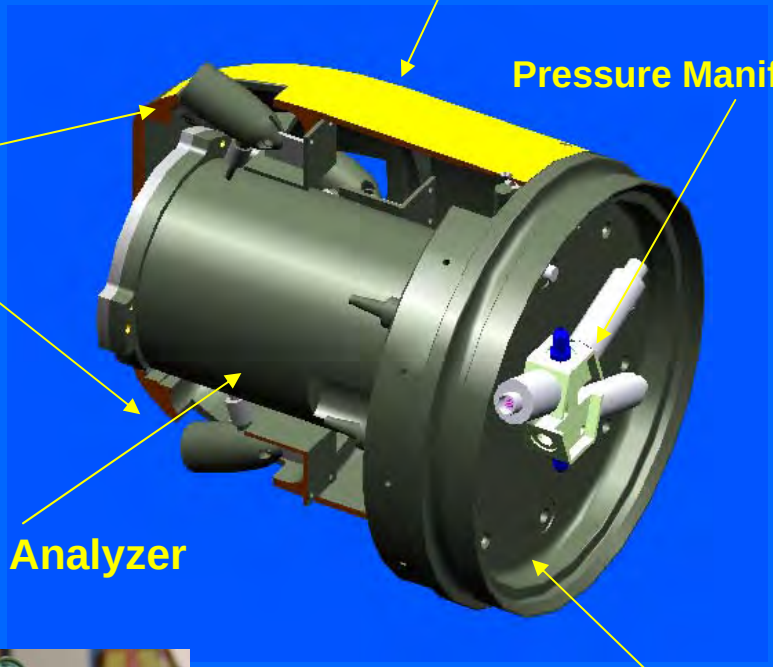
Nitrite measured from natural runoff

- **Higher nitrite levels seen in fresh-water layer on surface**
- **Sensitivity of sensor exhibited in small change of nitrite levels with depth**



Video Camera Integration – Nose Section

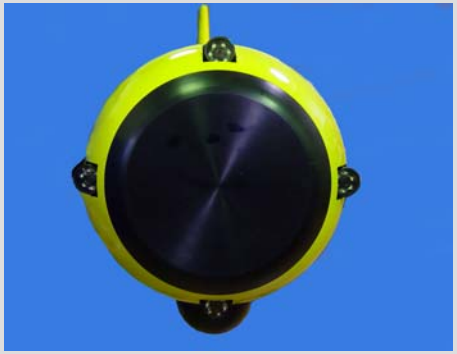
- Free Flooded Modified MK46 Nose Housing
- Up to four high resolution Underwater Cameras with up to 45° of pivoting
- Cameras equipped with LED array for lighting
- Tracking Transducer from ORE
- Pressure manifold adds multiple ports for pressure transducers and pressure switches
- Large Payload Area for:
  - Flooded Forward Looking Array
  - Homing and Docking Sensor
  - Acoustic Electronic Package
  - Chemical Analyzer



Hull Inspection UUV System Overview

Camera Details

- Atlantis Model AUC-5600



- Four color cameras
- 380 TV line resolution
- Infrared 0 lux night vision
- 270,000 pixel resolution with a 75^{o} field of view

- At zero ambient lighting, optional Infrared lighting provides 12-25 ft. visibility
- Requires 12 VDC power supply

Video Camera Integration – Nose Section

Port camera image of RHIB boat propeller

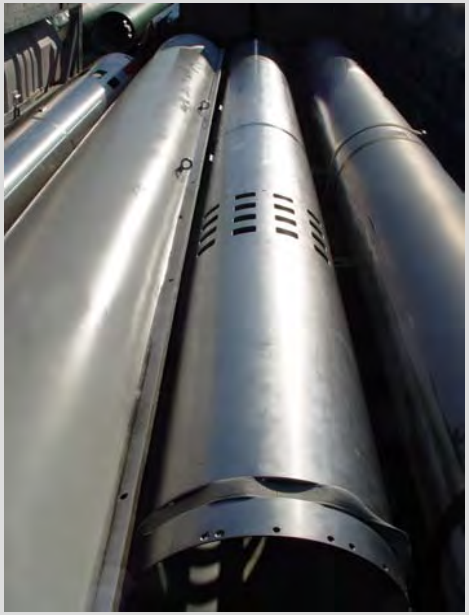
Aloft camera image of WB30 boat

Aloft camera image of hand and rope

T&E : Future concepts

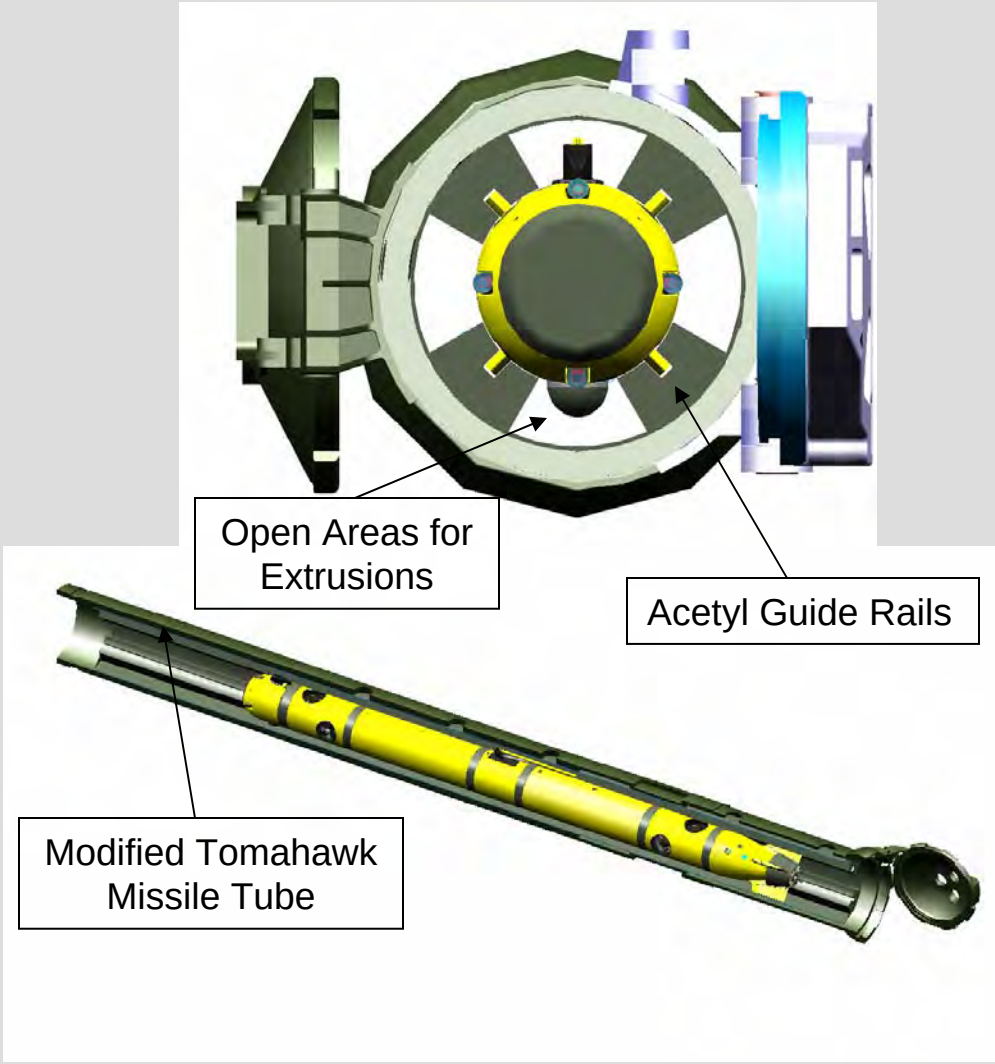
Launching out of Torpedo Tube

- **MARV is lightweight torpedo size in diameter but Torpedo tubes are designed for Heavyweights.**
- **Sleeve must be developed for MARV to be launch capable**
- **Two possible options have been researched:**
  - **- Sea Lance Capsule**
  - **- Tomahawk Missile Tube**



Tomahawk Missile Tube

- **A sleeve built to launch Tomahawk missiles out of submarine torpedo tubes.**
- **Missile tubes are available and commonly used in the fleet.**
- **Since missile tubes inner diameter are sized to fit a Tomahawk missile it can accommodate all of MARV's extrusions.**
- **Missile tubes are made of Stainless Steel which makes them corrosive resistant and easy to modify.**
- **Modifications would include simple guide rails to keep MARV centered.**

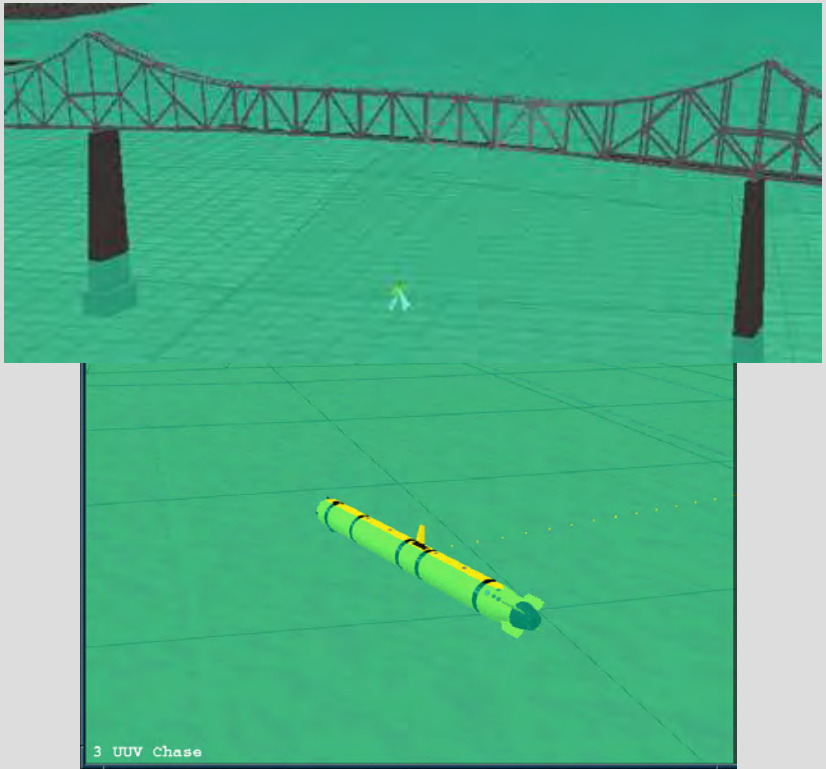


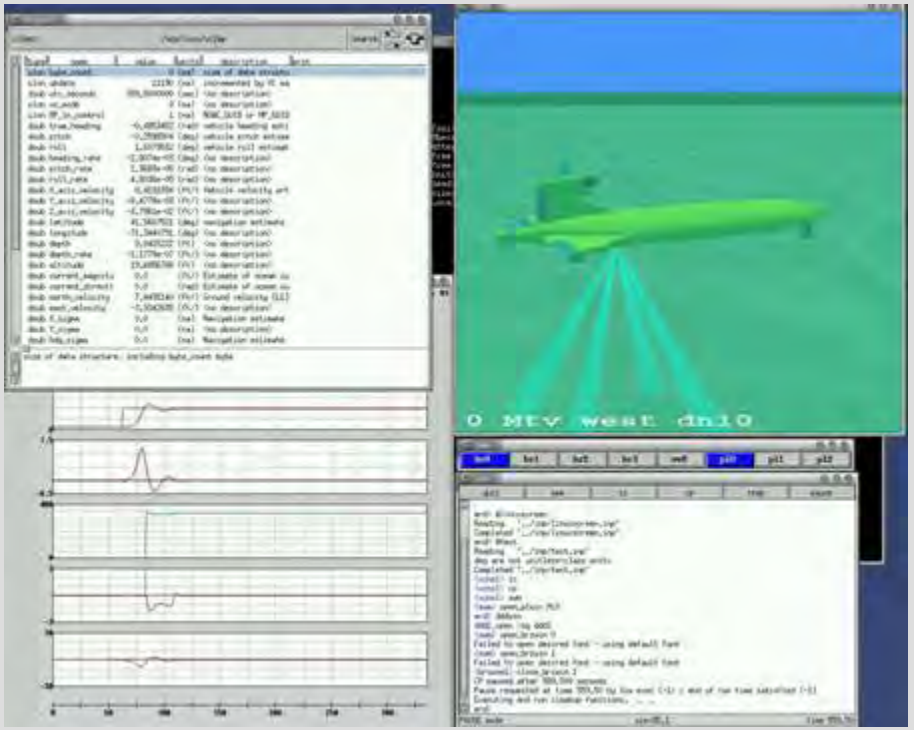
Computer Simulation

- 6 DOF vehicle simulation
  - MARV
  - 21UUV
  - MTV
- Equations of motion
- Vehicle physical properties

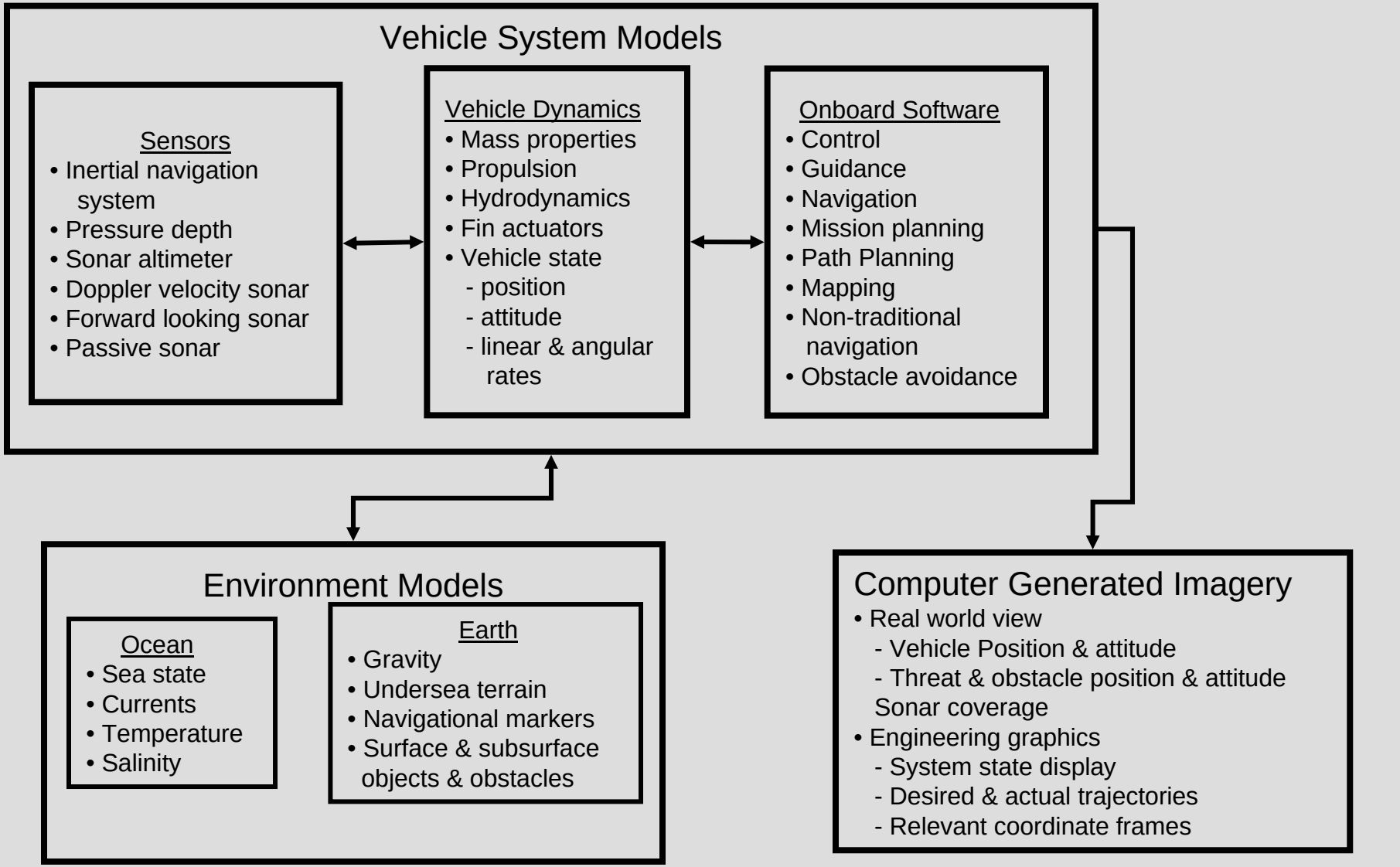
- **Subsystem models**
  - **Doppler Velocity Sonar**
  - **Inertial navigation system**
  - **Pressure depth sensors**
  - **Sonar altimeter**
  - **Forward looking sonar**
  - **Passive sonar**

- Ocean environment
  - Narragansett Bay
  - FBE-K
- Hardware-in-the-loop Capabilities
- SGI-based graphical displays
  - 3D vehicle dynamics & monitoring
  - Online plotting
  - Online data access





CSIM Architecture



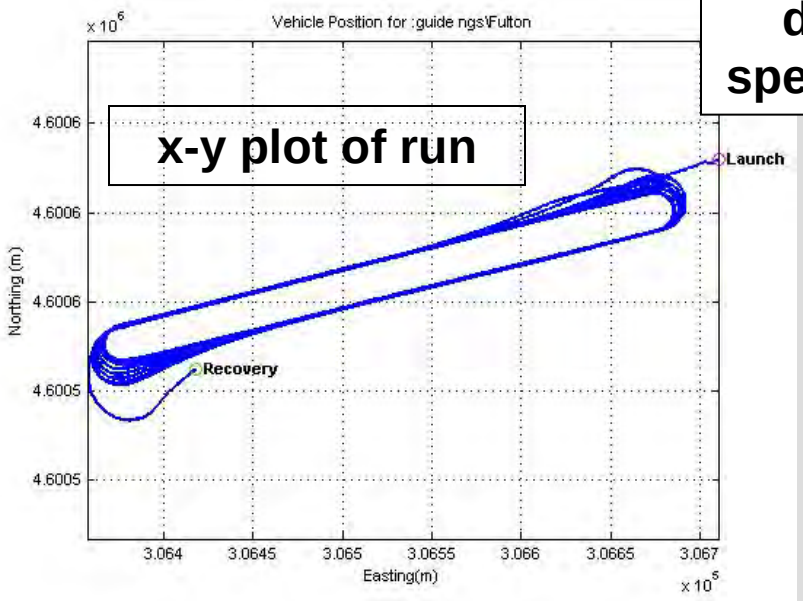
Post-mission run evaluation

- Mission downloaded from Vehicle Controller (VC)
- Mission reviewed in detail in Matlab
  - x-y plot of mission profile, depth, speed over ground, motor rpm, voltage and amperage during mission, fin deflections, pitch, etc.
- Data used to evaluate control of autopilot, navigation accuracy and vehicle stability over run

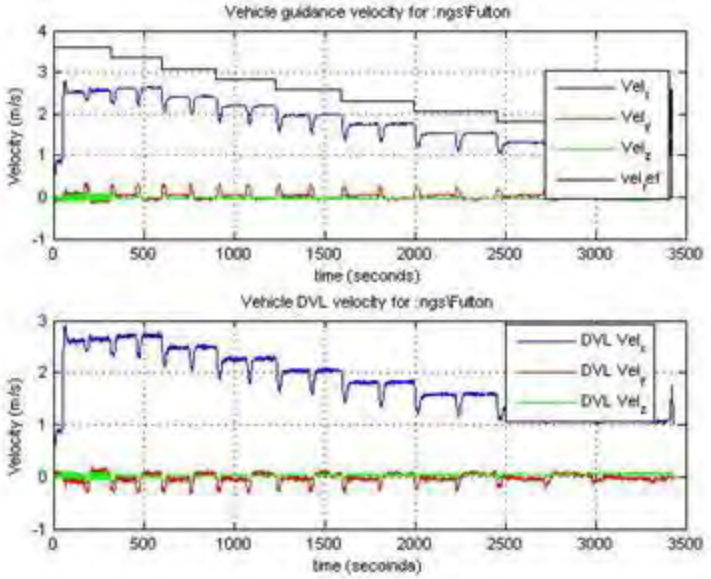
Post run mission evaluation

decreasing speed racetrack

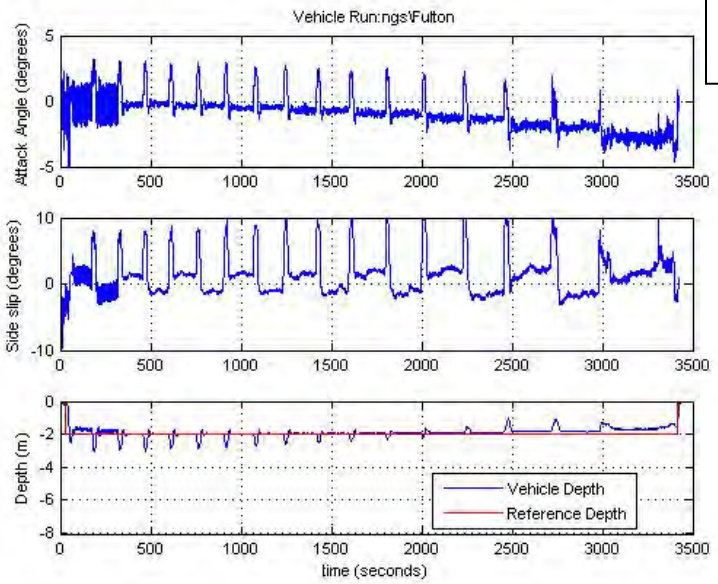
x-y plot of run



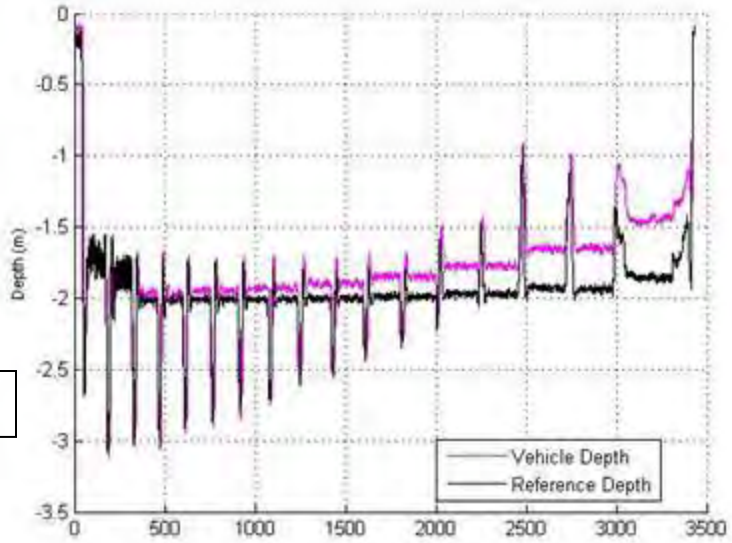
speed over ground, DVL data and controller data



crabbing, pitch and depth



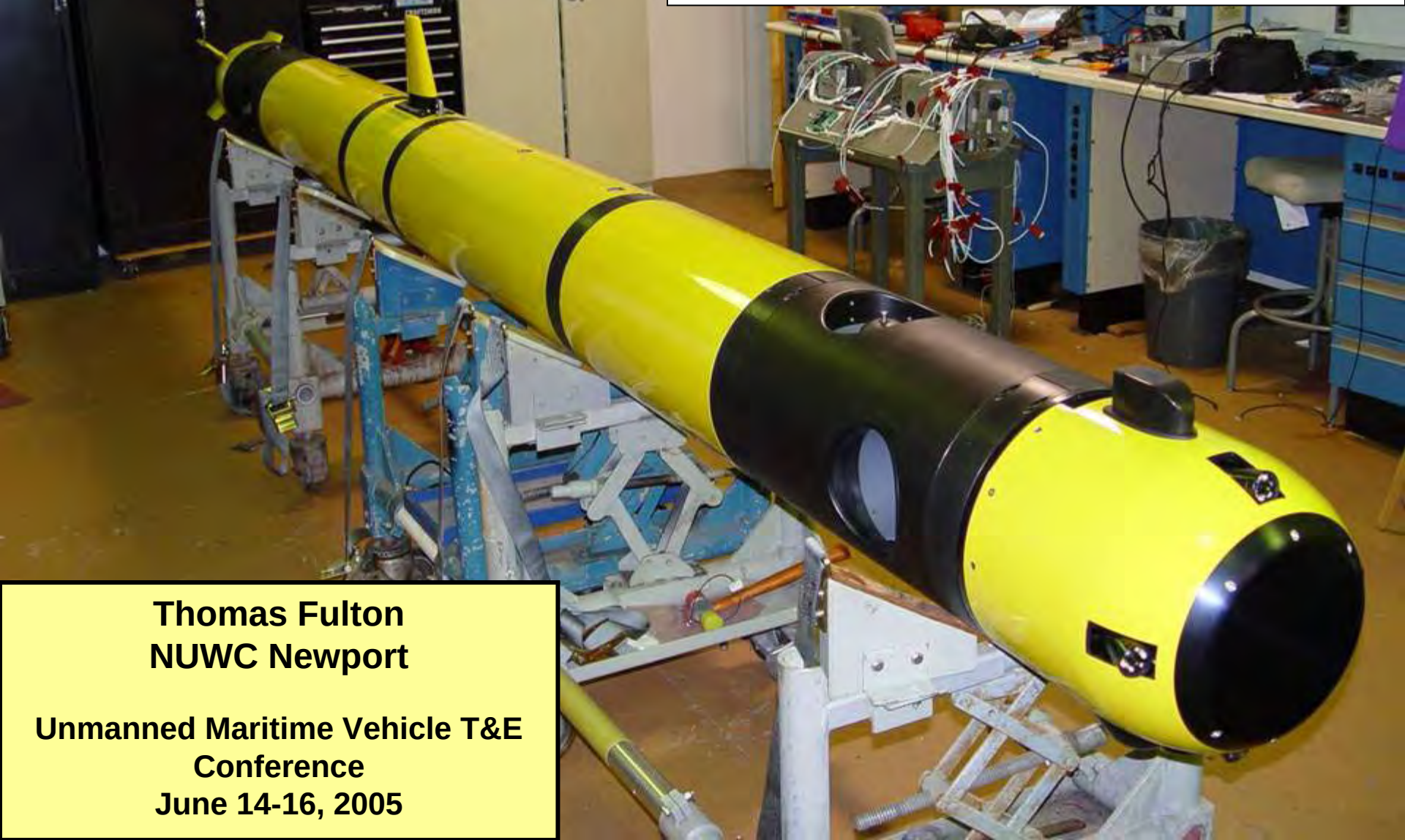
vehicle depth



MARV

Mid-Sized Autonomous Research Vehicle

Questions?



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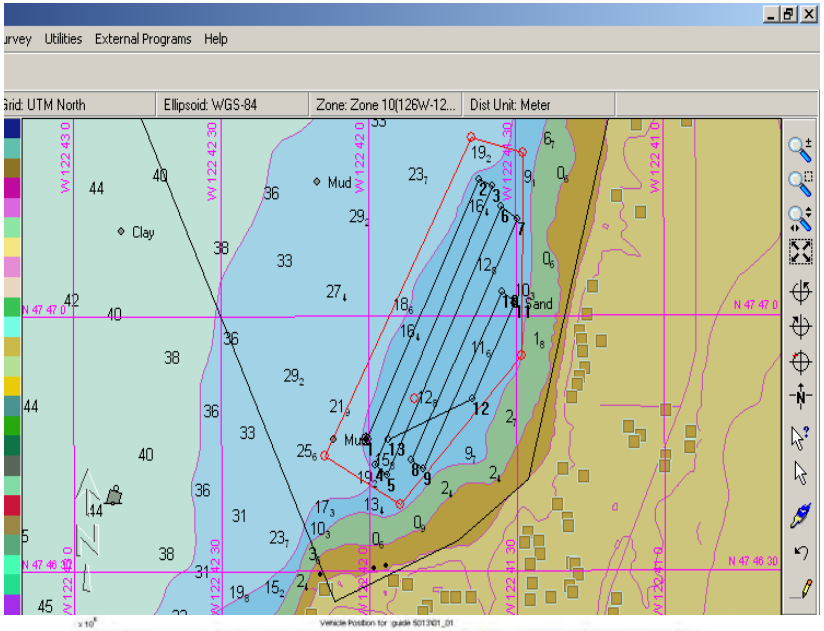
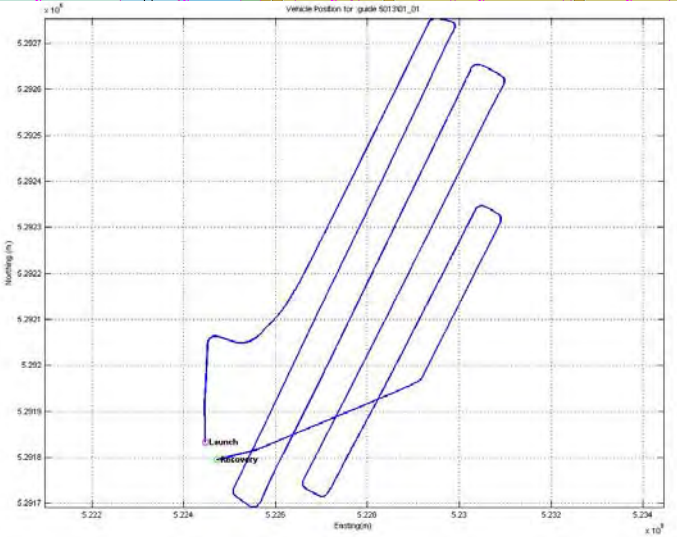
- BACKUP Slides

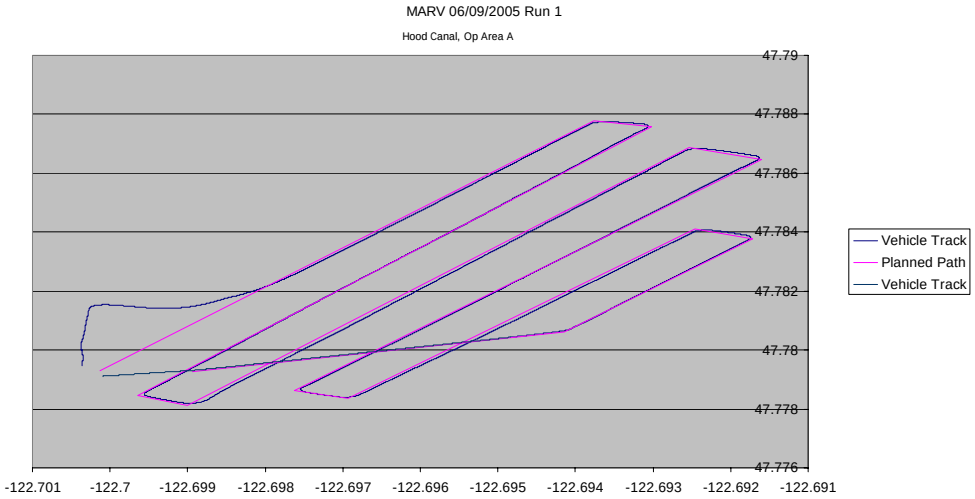
Run data – 6/9/05, run 1





Lawnmower mission, over-bottom tracking with cameras

- Depth limited to 11m
- Speed 3.5 kts



Run data – 6/9/05, run 1

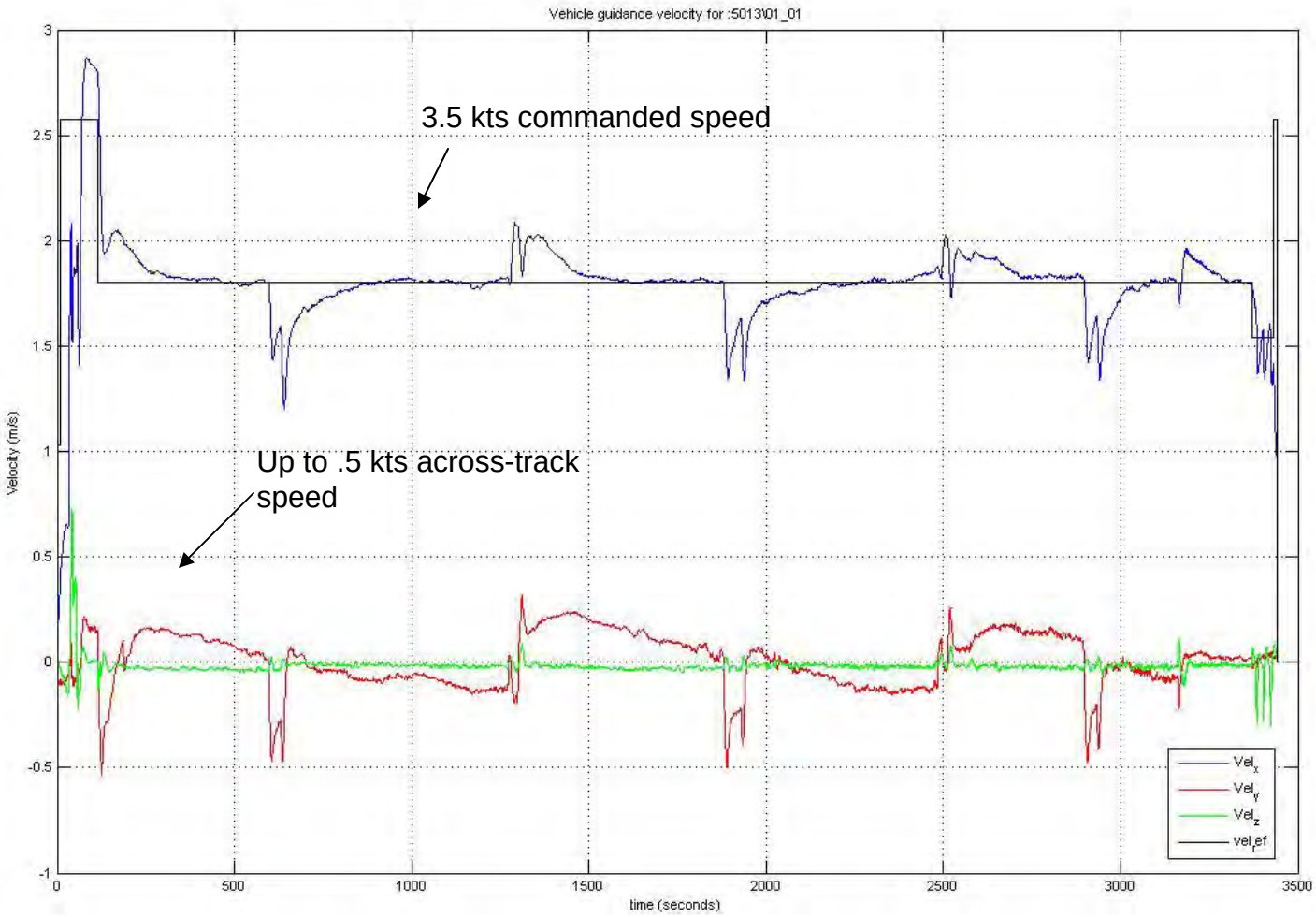
Velocity

Blue = x direction (forward)

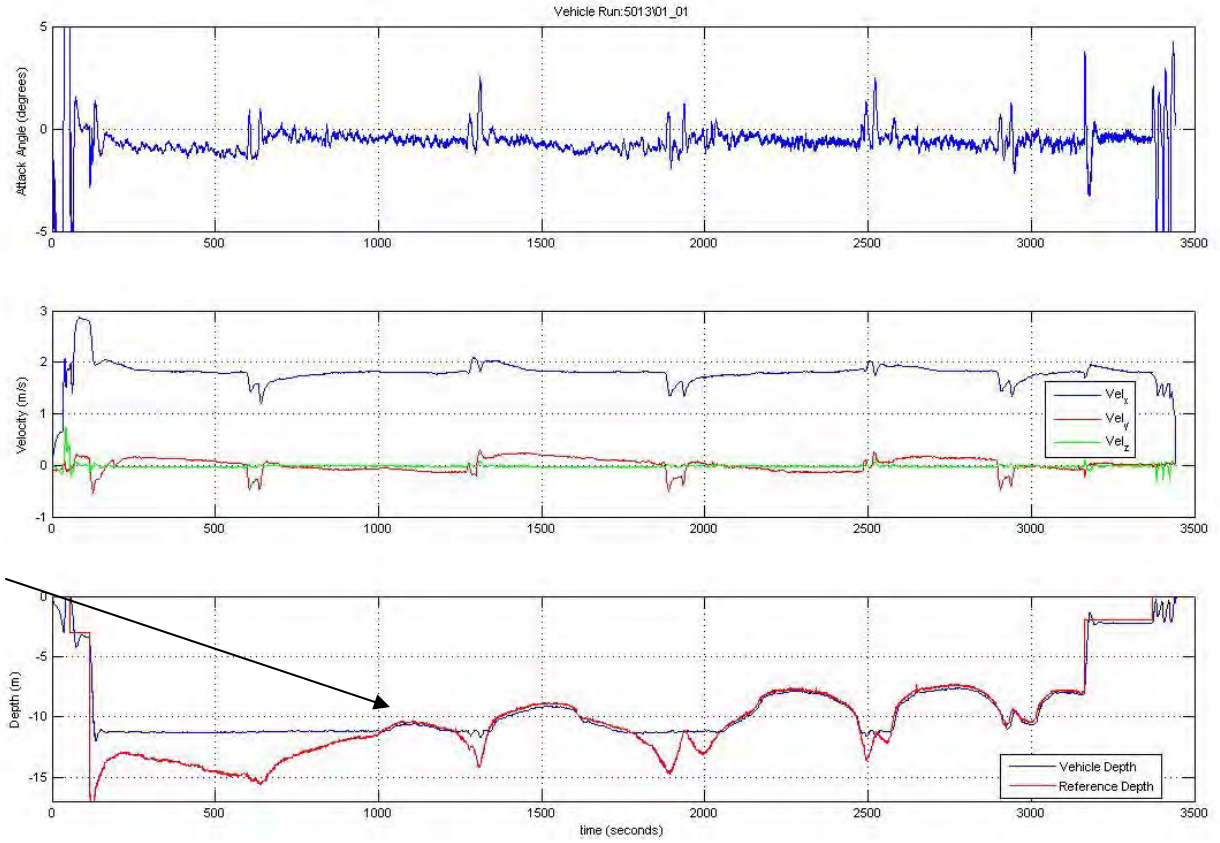
Red = y direction (athwartships)

Green = z direction (vertical)

- Tidal flow and eddies caused vehicle to be pushed at southern end of run legs



Run data – 6/9/05, run 1



Good bottom-following exhibited; floor of 11m is not exceeded during run

Density variations over tide change

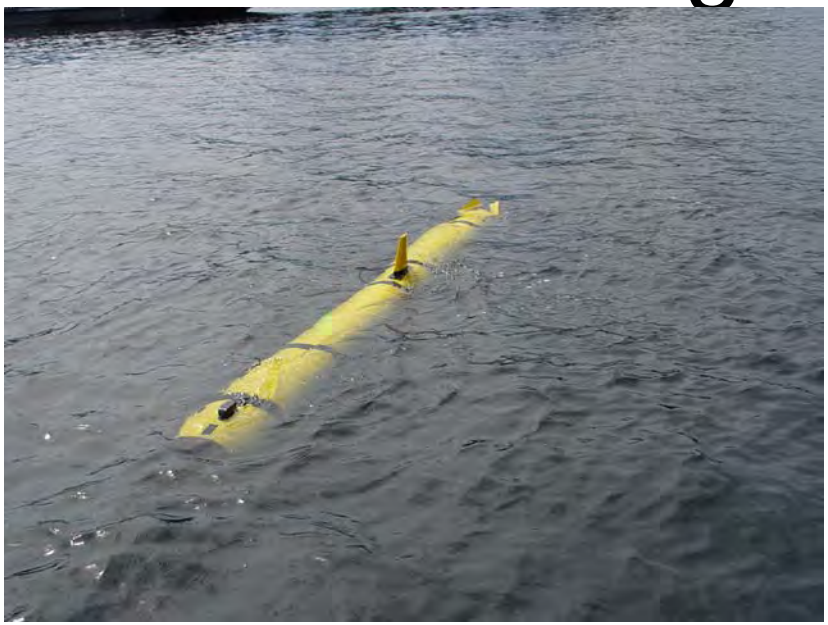
08:40 AM

6/9/05, 8:40 am (3 hours after high tide, Bangor wharf)

MARV trimmed at 1% buoyant in salt water (~6.5 lbs buoyant)

Note bow submerged, including 2” tall acoustic transponder

09:55 AM



6/9/05, 9:55 am (4:15 hours after high tide, Bangor wharf)

MARV on same day, 1h15m later

Note bow and deck forward of antenna above waterline, including 2” tall acoustic transponder

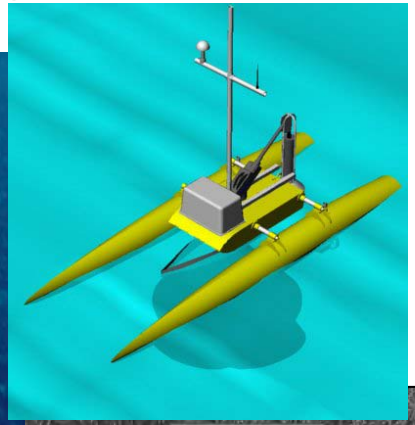
Naval Oceanography

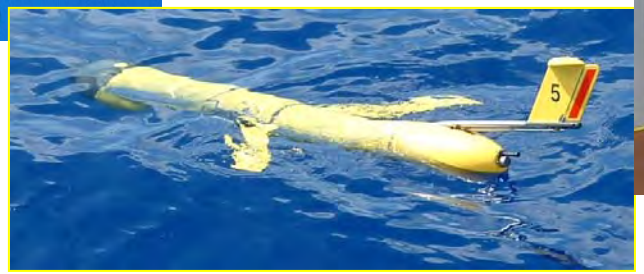
Experimenting into the future…

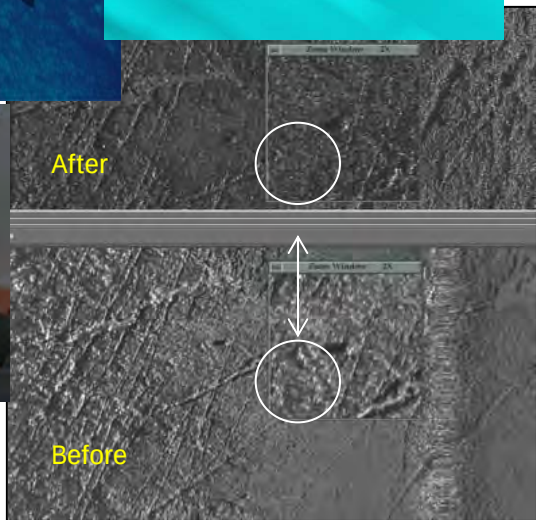
Mr Ed Gough

Deputy Commander

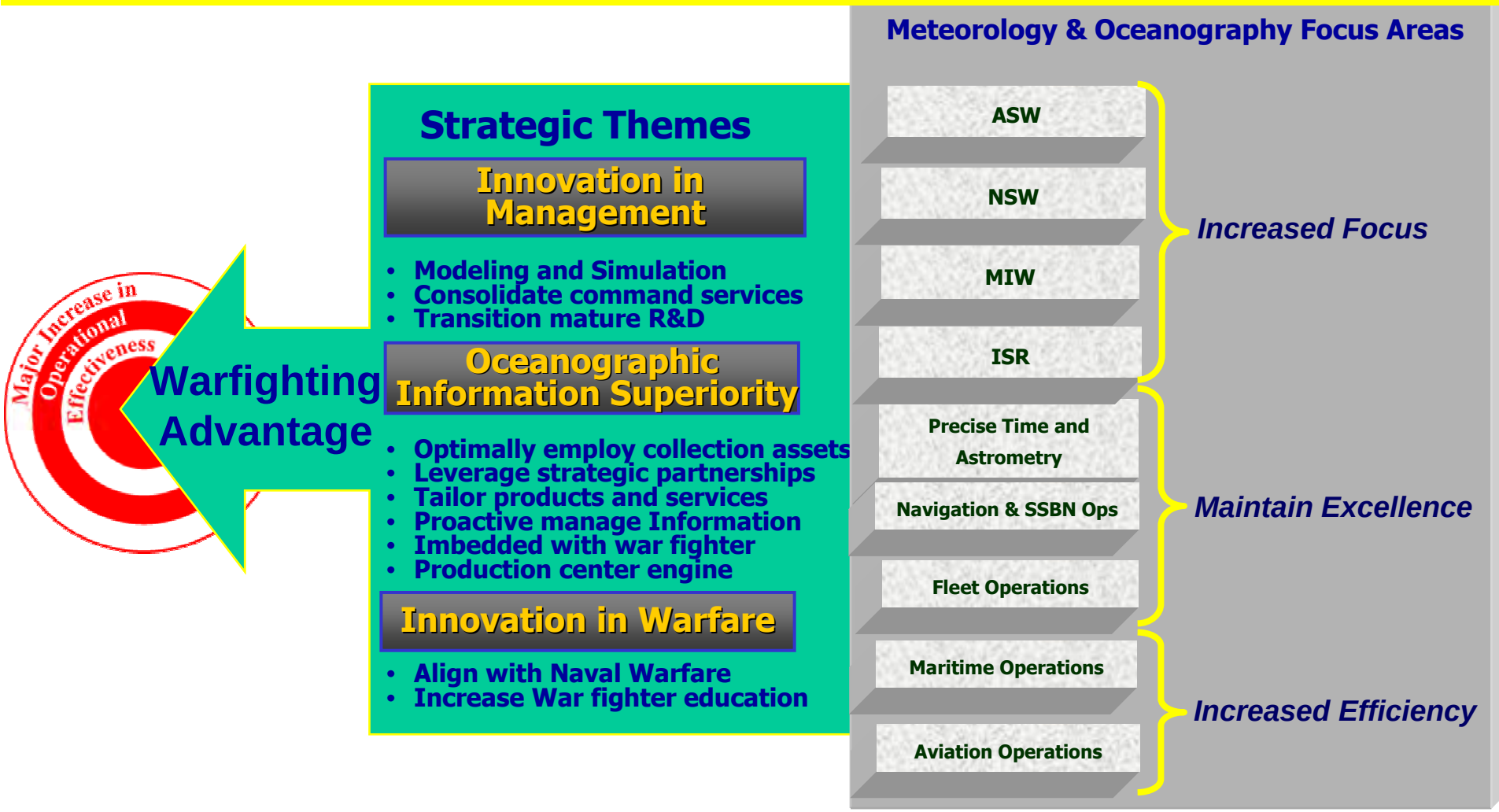
Naval Meteorology and Oceanography Command







Meteorology & Oceanography Strategic Plan



Mission: To provide an asymmetric war fighting advantage through the application of Oceanographic sciences.

Oceanography
Levels of Engagement

Strategic

- White Hull Surveys
- Environmental Database Population
- OPLAN Timelines
- Campaign Analyses
- War game Support
- S&T Partnerships with ONR for future technologies

Operational

- Oceanographic Modeling
- Experimentation for driving CONOPS and TTPs
- Readiness Evaluation Measurement (SHAREM/MIREM)

Tactical

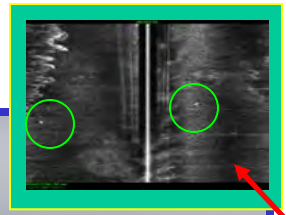
- EIPB for sensor effectiveness and efficiency
- All aspects of planning and execution
- On-scene tactical METOC support
- Go-No Go criteria
- TTS collection and value added product generation

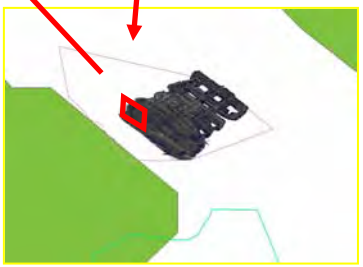
REACHBACK…Continually revise prosecution plan based on in-situ collected information

HydrographicUnmannedSurfaceCrafty

6 months from concept to reality…

- MISSION: Autonomous Tactical Hydrographic and Littoral Warfare Environmental Data Gathering in Shallow, Very Shallow Water and Surf Zone Environments in support of:
  - **Surface Navigation**
  - **Sub-Surface Navigation (UUV/ROV)**





HydrographicUnmannedSurfaceCrafty

- **Hydrographic Sensor Package**
  - Marine Sonics 300 kHz Side Scan Sonar w/ display
  - 235 kHz Sonar Mite Single Beam ES & 215 kHz Single Beam ES
    - Provide sounding depths for hydrographic bathometric charting
- **Oceanographic Sensor Package**
  - RD Instruments 600 kHz Rio Grande ADCP (Acoustic Doppler Current Profiler)
  - RBR CTD (Conductivity, Temp, and Depth)
  - WetLABs Transmissometer

- **Environmental Translation**
  - Seabed profile and clutter
    - Slope
    - Sand waves
    - Ridges
    - Rock patches
    - "Mine like" objects
  - Provide sounding depths for hydrographic bathometric charting
  - Gather current data
  - Track water mass and reflective properties
    - Sound Speed Profile – set optimal active sonar range for detection
  - Water Density -
    - essential for UUV/ROV ballasting or trimming
  - Temperature –
    - SSP, diver gear load-out etc.
  - Visibility –
    - diver vis or bump detection

UUV In-Stride Battlespace Preparation

UUV Platforms

HUSCy

Sea Lion

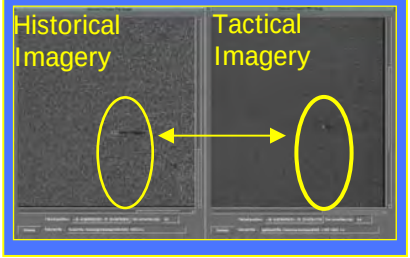
REMUS

NAVOCEANO Bottom Mapping Workstation

- **Multi-sensor processor**
- **Bottom Mosaics**
- **Automated Algorithms**
  - **Clutter Density**
  - **Bottom Roughness**
  - **Mine-Like Contacts**

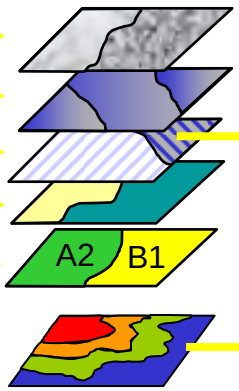
Change Detection

MCM Change Detection is the process of correlating new mine-like contacts found during mine-hunting operations with historical contacts found during peace-time route surveys.

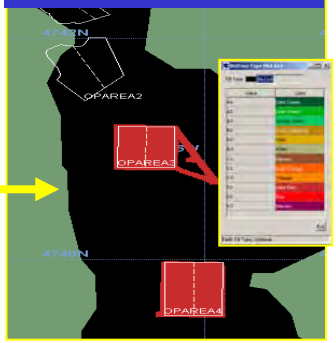


Environmental Products

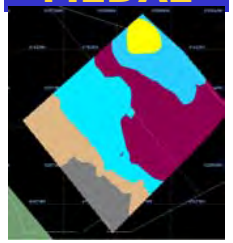
- Sediments
- Burial
- Roughness
- Clutter Density
- MIW Doctrinal Bottom Type
- Bathymetry



MEDAL



MEDAL

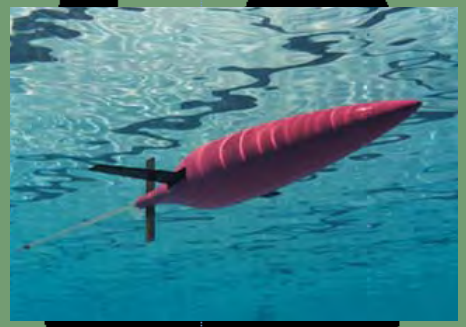


Impact:

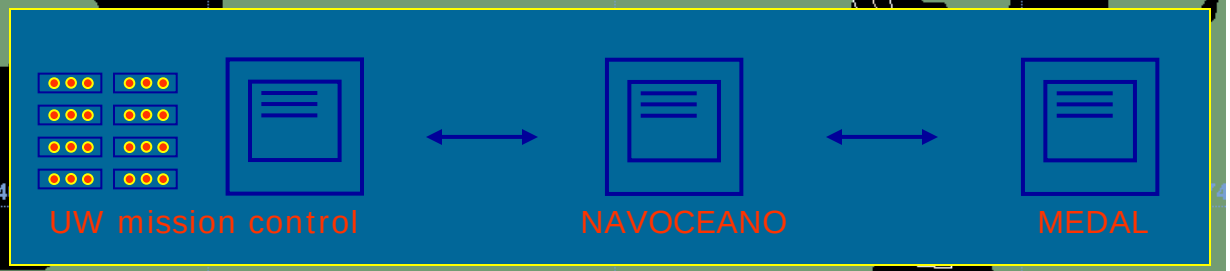
- **Reduction from change detection /battlespace characterization.**
- **More *Accurate* Assessment of Risk to Follow-on Forces**
- ***Speeds* the Detect to Engage Sequence**

UNCLASSIFIED Distribution DoD and DoD Contractors Only

Persistent Sampling Using Gliders in Dabob Bay

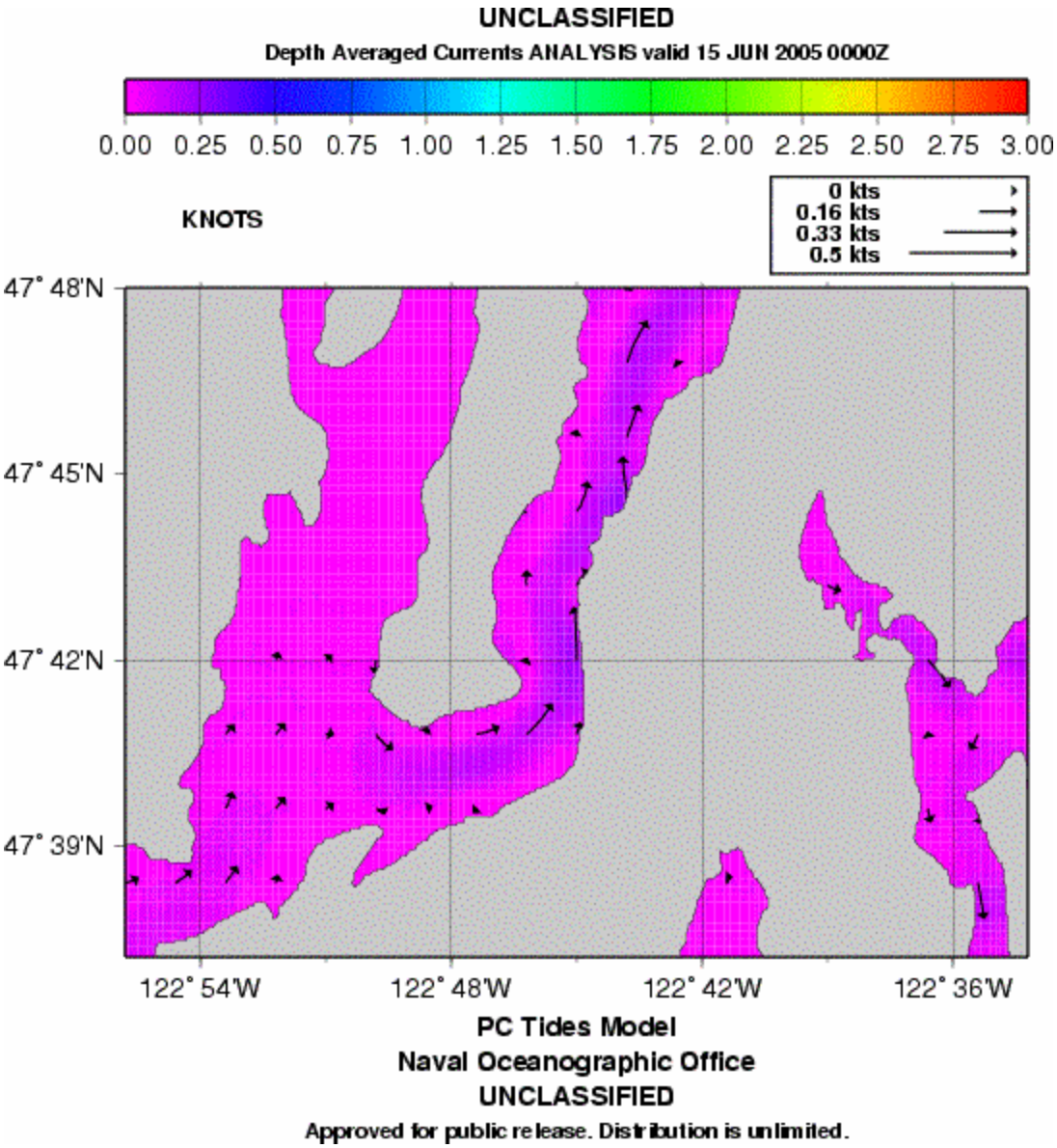


- persistent, autonomous battlespace characterizaton platform
- collects acoustic and environmental data
- ocean parameters measured:
  - temperature
  - salinity
  - optical scattering
  - sound speed
  - depth-avg currents
  - surface currents
- UW Seaglider data sent directly to NAVOCEANO (Stennis Space Center) and imported locally into MEDAL (Mine Warfare Decision Aids Library)



Operational Ocean Forecasting

- **A robust and relocatable forecast system, PCTides, was used for the prediction of tidal currents.**
- **PCTides tactical forecasts, forced by winds provided by FNMOC, were provided for conditions out to 48 hours.**
- **Products were used by vehicle operators and dive teams to minimize the impact of strong currents on operations.**
- **Data collected using bottom-mounted ADCPs and vehicle sensors were used to validate predictions.**



Partnership with S&T

How are UUV's utilized in Naval Oceanography?

We exploit the tactical and non-tactical sensors to characterize the battlespace, utilize or derive the environmental knowledge to create a tactical advantage, and make the warfighter's mission more effective and more efficient.

Fleet Assets

DATA

Applied Oceanographic Knowledge

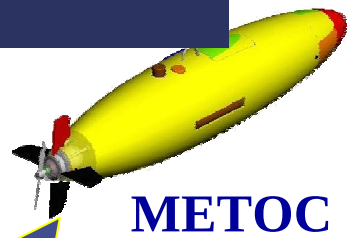
"Navy Corporate Expertise"

Strategic EIPB

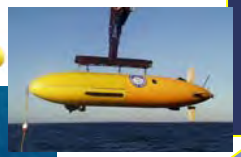
Operational EIPB

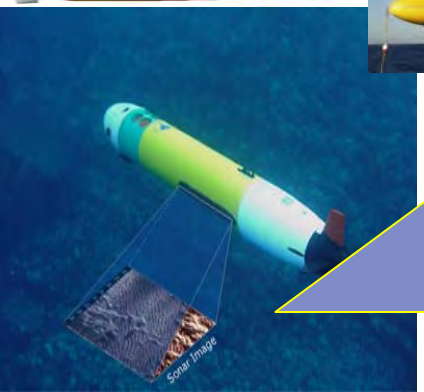
Tactical EIPB

DATA

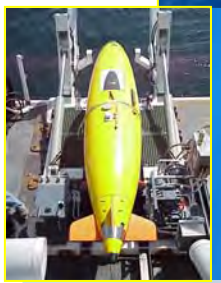


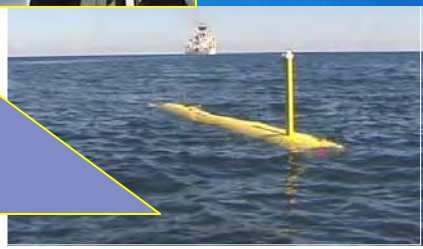
METOC Assets

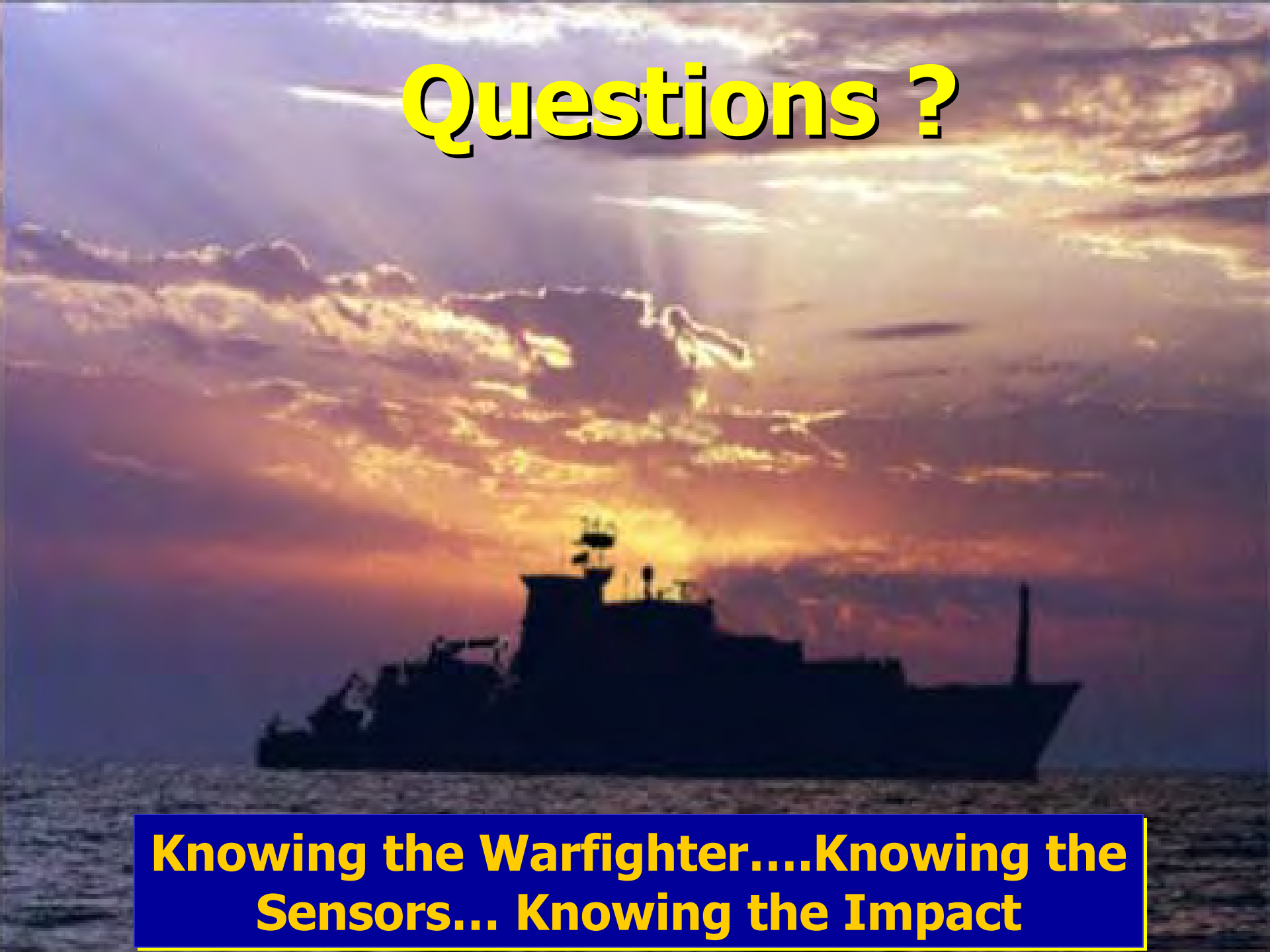




Warfighting Advantage



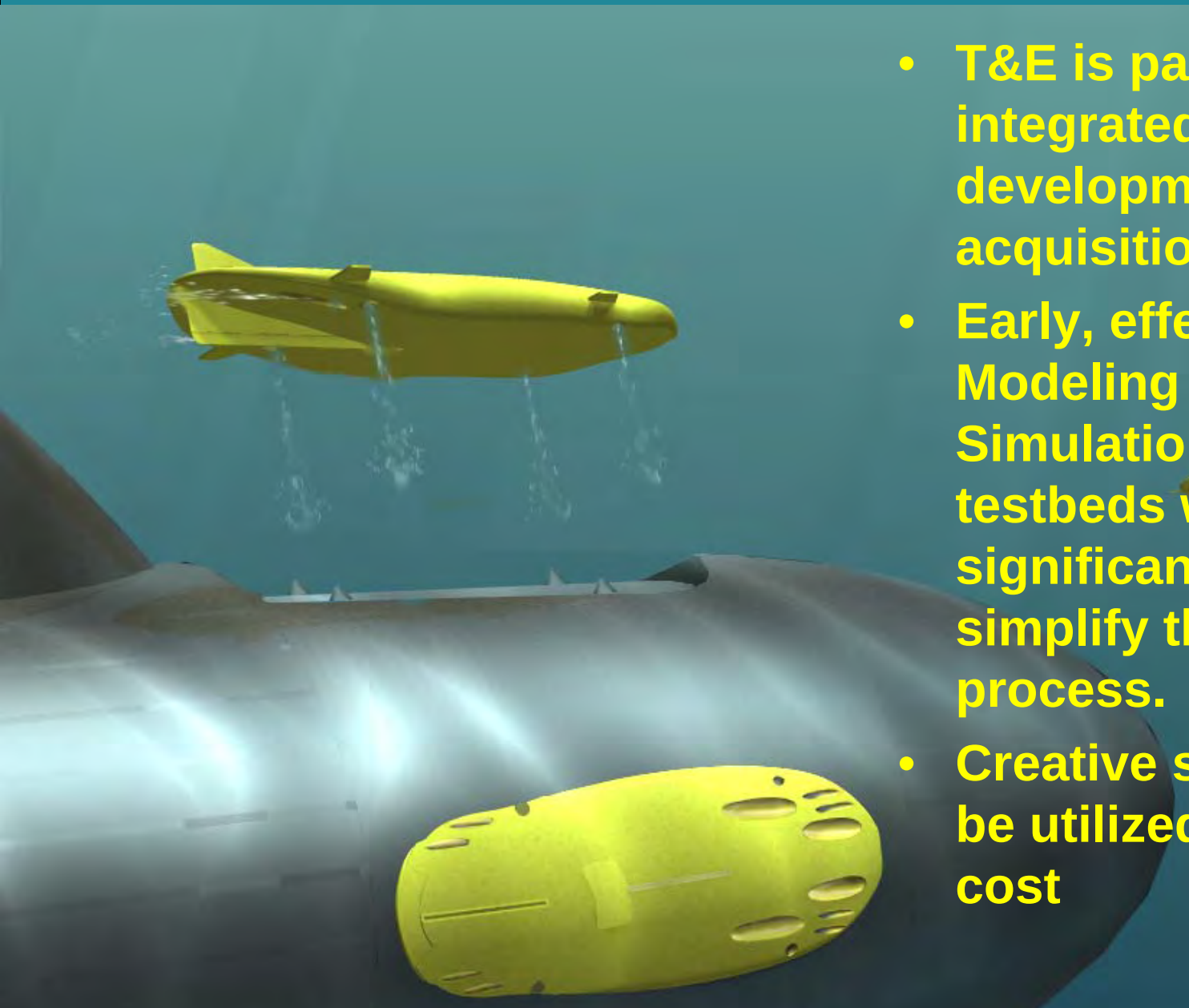



Questions ?
Knowing the Warfighter….Knowing the Sensors… Knowing the Impact

Unmanned Maritime Vehicle (UMV) Test & Evaluation Conference

Future Technology Development and Assessment for UUV Acquisition

James Griffin
NUWCDIVNPT
Autonomous Systems and Technology Department



- T&E is part of an integrated technology development and acquisition strategy
- Early, effective use of Modeling and Simulation and HIL testbeds will add significant “value” and simplify the T&E process.
- Creative solutions can be utilized to reduce cost

Demonstration UUV's

T&E of Payloads on UUV Testbeds

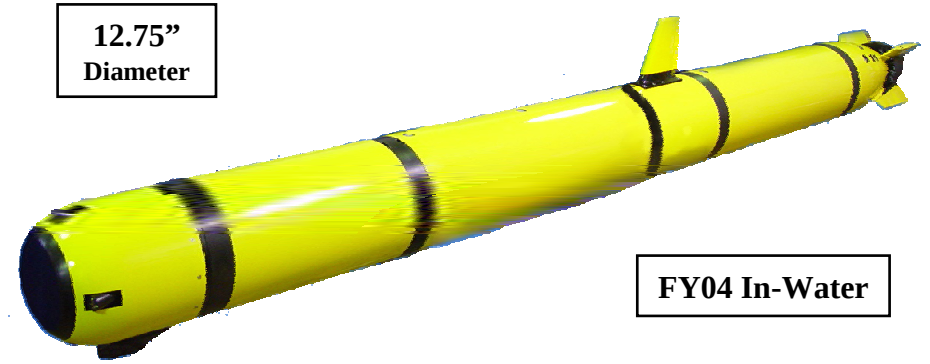
- •Early Awareness of Fleet Integration Issues
- •Common Interfaces and Modular Payloads
- •Applicable UUV Standards

21" Diameter

21UUV

- ~ 200 In-Water Runs
- Acquisition Program Risk Mitigation
- Vision Based Navigation, Camera Suites, Photo Mosaic's
- Side Scan Sonar Imagery
- "Electric Torpedo" Testbed and Weapon Launch from MTV
- Autonomous Controller Experiments

12.75" Diameter



FY04 In-Water

MARV - Mid-sized Autonomous Research Vehicle

- Technology Demonstrations for Various S&T Programs
- Low Speed Control and Hover Payload (Thruster Based) Demonstrations
  - Imaging Sensor Evaluation
  - Homing and Docking Demonstrations

8 Ton Displacement

MTV - Manta Test Vehicle

- **~100 In-Water Runs**
- **Multiple UUV and Weapon Launch**
- **Advanced ISR Suites – RADINT, SIGINT, Optics, IR**
- **Deployed ASW Systems**
- **Advanced Networked Communications**
- **Advanced Autonomy**

UUV M&S Full Spectrum Capability
End-to-End Modeling & Simulation Framework

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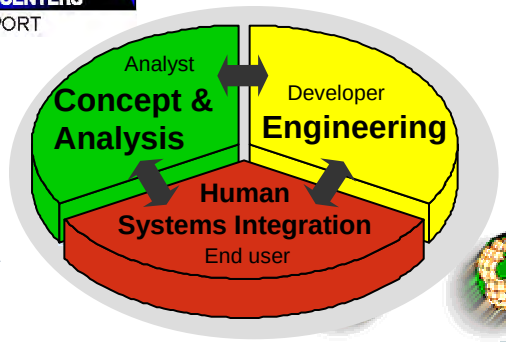
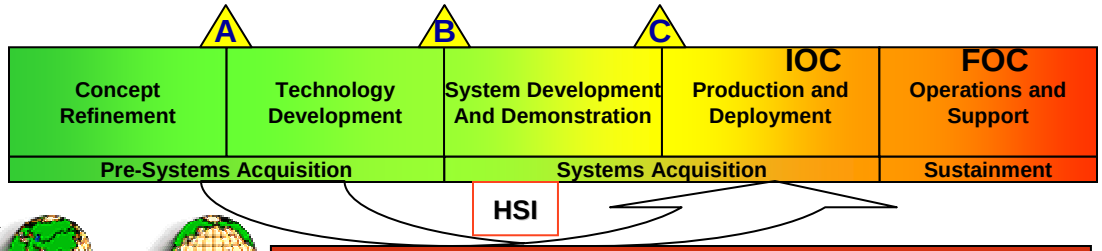
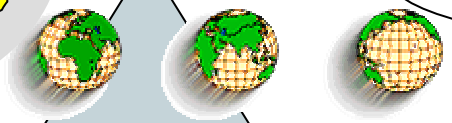


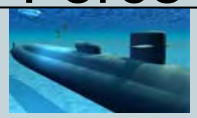
user





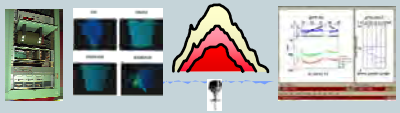
Theater

Force



Platform

System



Engineering

Interoperable
Variable Fidelity

Model re-use

Engineering Level M&S

- Future links to Fleet synthetic training environments
- Enable experimentation and exercise collaboration, distributed networked environments
- Socialization of new technology
- Test & Evaluation in support of Sea Trial.

Capabilitie

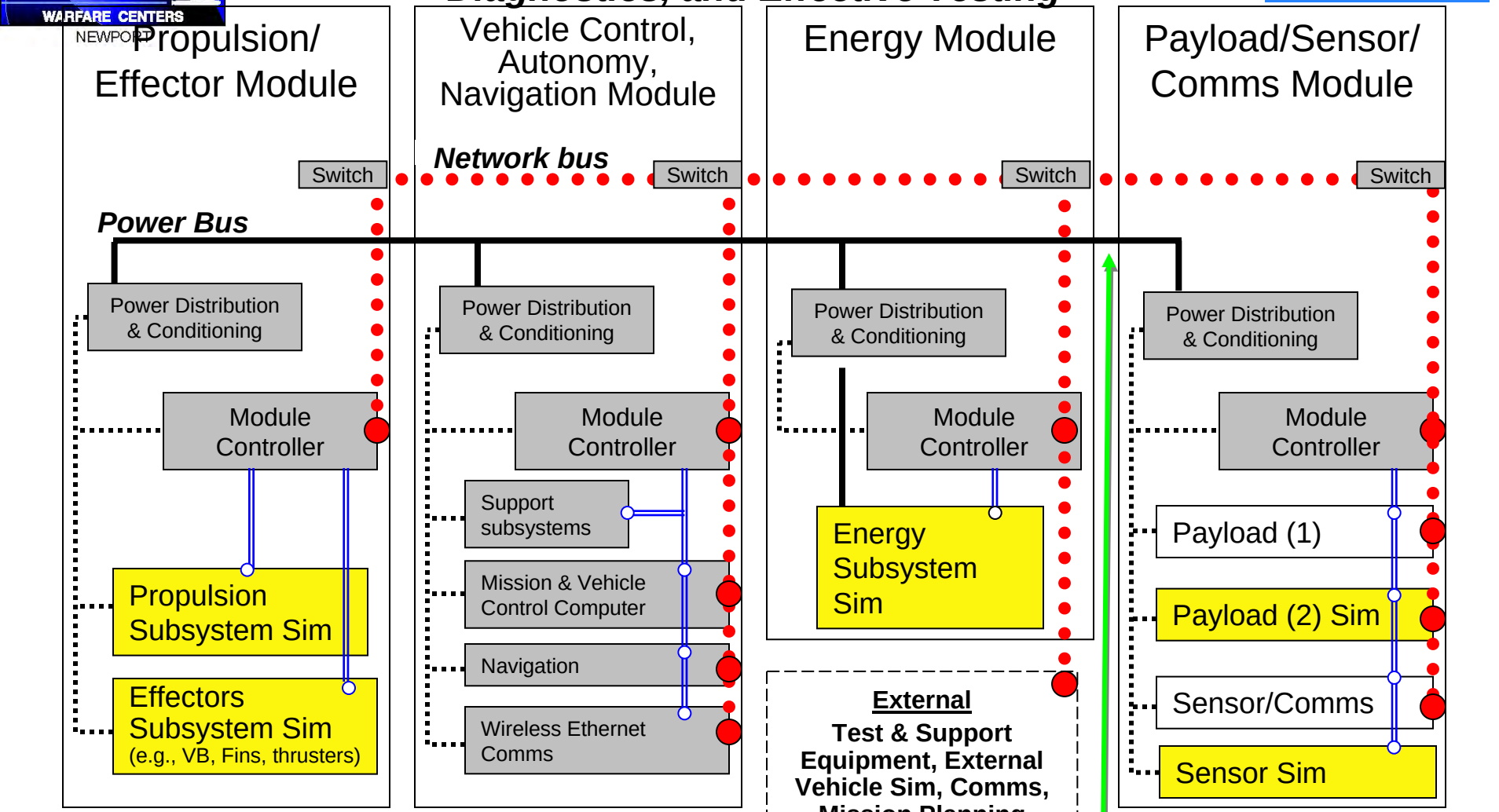
- Assess new concepts and technologies
- Naval & joint CONOPS development
- Provide advanced (TT&Ps)
- Requirements study, analysis of alternatives (AoA)
- Performance prediction, “what-if”, Monte Carlo
- Investment decisions on UUVs.
- Reliability modeling
- Analyze design change impact on program

- Risk Reduction,
- Engineering trade studies
- ICD development & validation
- Contractor system validation
- HWIL/sub-system/end-to-end system simulation

Fleet	Government labs	Warfare Centers	Academia	Industry

Cost-effective	Distributive	Collaborative	Re-usable	Extensible	Composable	Persistent

HWIL Testbed – *Supports Mission Planning, Diagnostics, and Effective Testing*



Key:

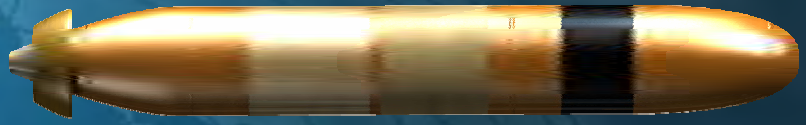
- Discrete I/O, Serial, analog, digital
- 100 base T Data Network
- Vehicle Component
- Main Power Bus
- Simulated Subsystem (hardware or software)
- Conditioned Power lines, specific voltages needed for subsystems, payloads

Note: Support subsystems will be in each section, but will vary between modules. Examples are leak detectors, pressure sensors, pingers, etc.

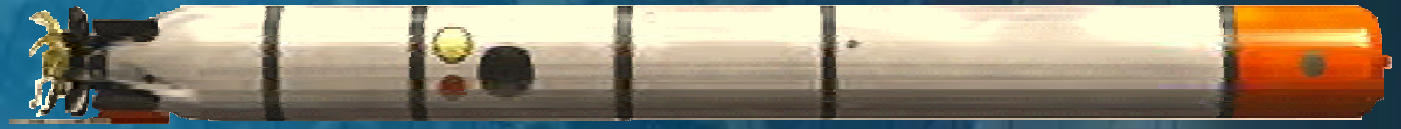
Creative use of Existing Navy Assets: ASW Targets

Partners: EMATT -Sippican Inc.
Mk 30 Mod 2-TBD
Sponsor: PMS404

- **Provided 1073 training events with Mk 39 EMATT for FY 04**



- **Provided 314 training events in support of 446 customers with Mk 30 Mod 1 for FY 04**



- **Received IOC approval letter for Mk 30 Mod 2**

  -Production Contract Awarded (FY05)

Targets as UUV Mission Enablers?

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*Expendable Mobile ASW Training Target (*EMATT)

- State of the Art Electronic Suite
- Dynamics
  - Submarine Realistic Turn Rates
  - Run Speeds: 3-8 Knots
- Autonomous Evasion(AE)
  - AE Cued by Torpedoes, Sonobuoys, Dipper, & Surface Ship
- Range Tracking Pinger Function
  - Addition of Mk 84 Long Ping Format for Shallow Water

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Naval Undersea Warfare Center (NUWC) Division Keyport

Collaborative Test/Training, Experimentation/Evaluation Capability (CTEC) – The NUTEC Engine for USW Live, Virtual, & Constructive Joint Exercises

Reid Johnson
reidj@kpt.nuwc.navy.mil

Briefing for:
NDIA UMV T&E Conference
Naval Undersea Museum
June 13th-16th, 2005

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CTEC Overview

- Strategy
- Technology & Facility Description
- Contribution to AUV Fest 2005
  - COUP (Collaborative Operating USW Picture) using CURATE and Tools
  - Variety of Vehicles and Technologies to Support
  - Complex Data Communications Scenarios
  - Distance Support (ISR Scenario)
- Summary

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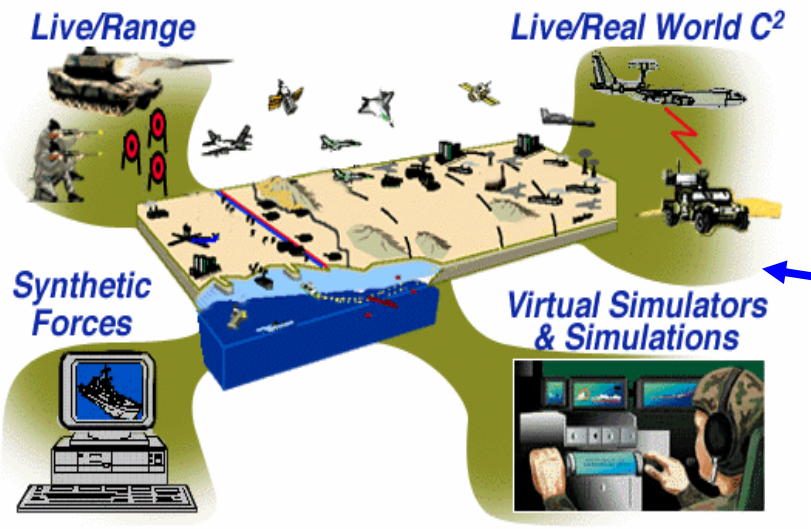
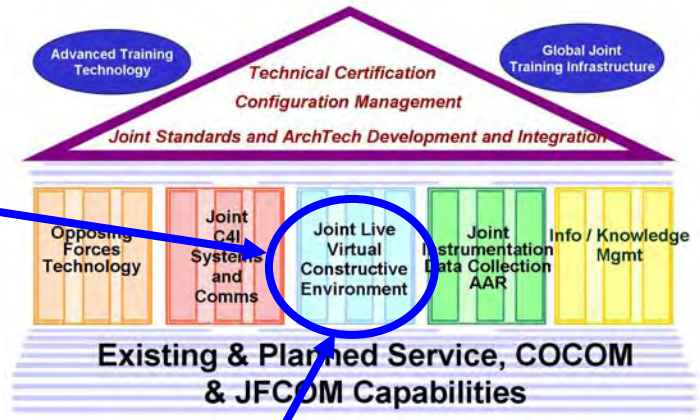
Vector: Integrated, Distributed, Joint L-V-C Environment

Development of Joint synthetic environment (L-V-C*) in support of training and experimentation capability - a persistent network that seamlessly links select ranges and simulation centers throughout the world



JNTC Technical Focus Areas



*** *Live*, *Virtual* and *Constructive* (*"L-V-C"*) Training**

Asset Realization	People	Systems	Environment
Live	Real	Real	Real
Virtual	Real	Simulated	Simulated
Constructive	Simulated	Simulated	Simulated

JNTC *– "The future of T&E is intertwined with training & experimentation …"*
DOT&E *– ".. Test & Training partnership is essential to transformation"*
Sea Trial *– "Integrate war-gaming, experimentation, and exercises to speed development of new concepts and technologies… embrace spiral development… through rapid prototyping and Fleet experimentation"*

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Strategy: T2E2 Transformation

Testing and Training a New Way – Distributed L-V-C Assets at Multiple Locations

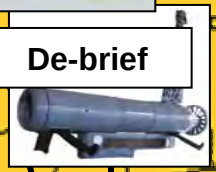
Planning

Execution

CTEC

Analysis

De-brief



Local Operational Network

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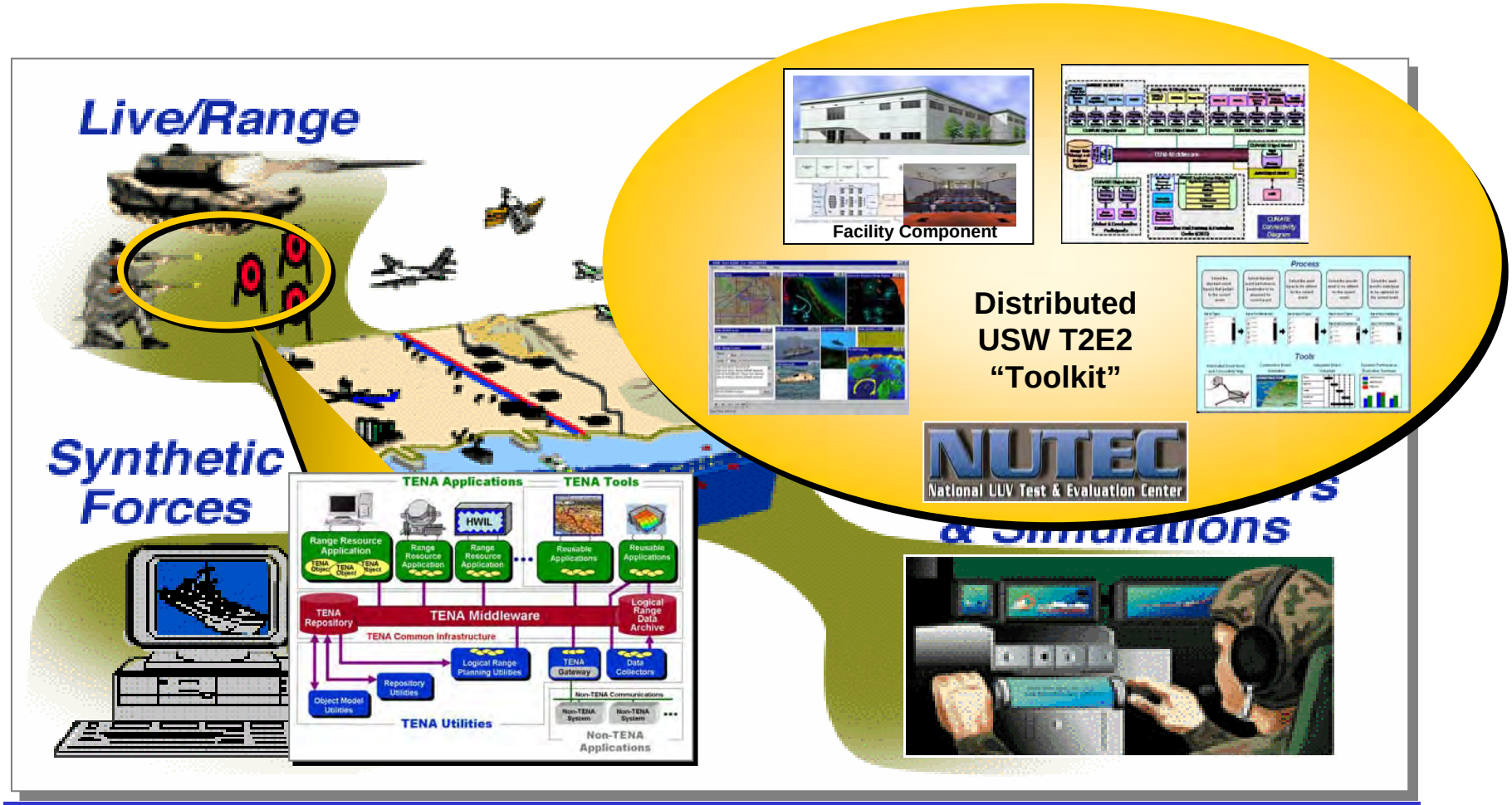
KEYPORT

Strategy: USW T2E2 "Tool Kit"

Focus Area: The Undersea / Littoral Warfare Component

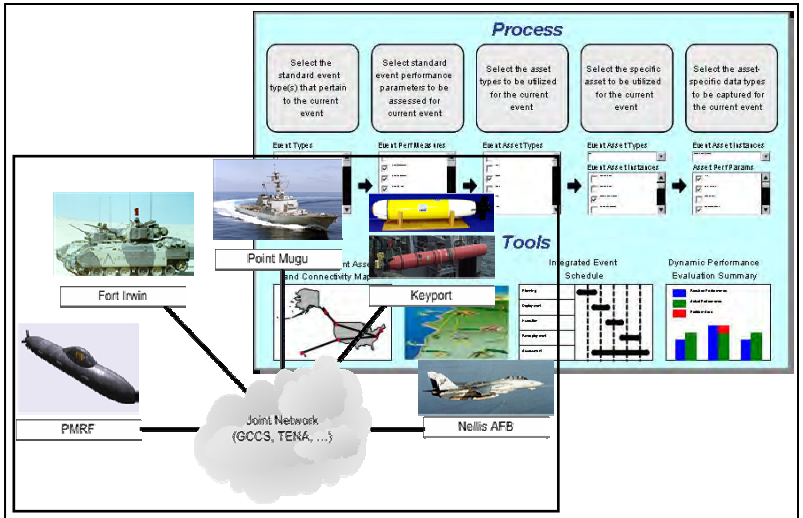


The NUWC Keyport/SAIC IPT is working toward the JNTC capability requirement of distributed and integrated test, training & experimentation for the undersea warfare dimension through specific implementations of TENA and complementary tools.

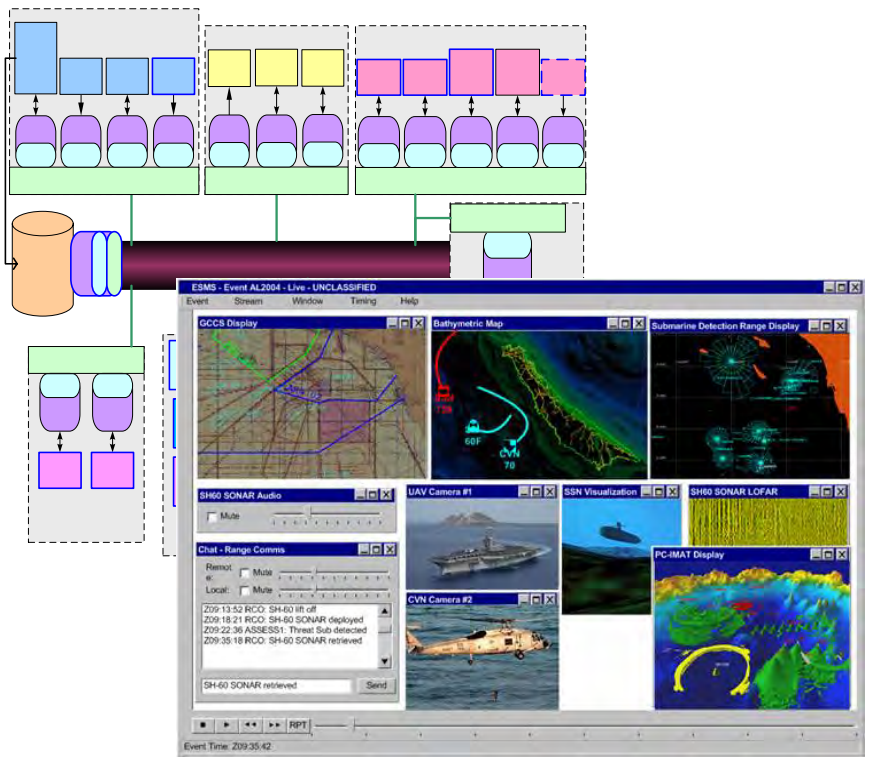
Strategy: CTEC Components

Facility Component

- **CTEC, the *Capability*, is comprised of 3 complementary components:**
  - *Facility*
  - *Organizations & Processes*
  - *Tool Kit*



Organization/Process Components



Tools Component

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AUV Fest '05 PARTICIPANTS

- **MIT**
  - Kayak ASC (Autonomous Surface Craft)
    - Cooperative Navigational Behaviors
- **Nekton Research**
  - Ranger & TransPhibian UUV
    - Re-Acquire & Neutralize Volume Mines
- **NAVOCEANO**
  - HUSCy USV
    - Shallow Water Hydrography / Oceanography
- **Naval Postgraduate School**
  - ARIES UUV
    - Obstacle Avoidance using "Blazed Array" Forward Looking Sonar
- **Naval Research Lab**
  - ACOMMS & Data Storage Buoy
    - Monitor and Record AUV Fest ACOMMS
    - Characterize the Acoustic Sound Channel
- **Naval Special Clearance Team One (NSCT-1)**
  - Sea Lion (Bluefin 9) UUV
    - Transponderless Navigation During MCM
  - REMUS UUV
    - UUV OPS & TACHMEMO Demonstration

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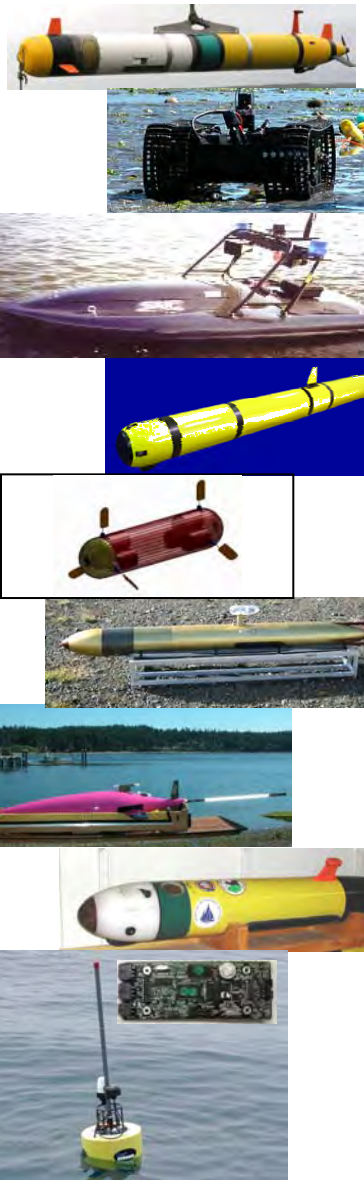
AUV Fest '05 PARTICIPANTS

- **NSWC Panama City**
  - REMUS 600 12-3/4 Inch UUV
    - Small Synthetic Aperture Mine Hunting Sonar
  - TAR & Sea Talon Crawler UGV
    - S-C-M VSW-SZ Target Station Keeping & Vectoring
  - Autonomous Search & Hydrographic USV
    - Remote Delivery of a REMUS UUV From a USV
- **NUWC Newport**
  - MARV 12-3/4 Inch UUV
    - Optical Video Transmission via ACCOMS
    - Chemical (Nitrite) Sensor via ACCOMS
  - Biorobotic AUV
    - Maneuvering Demonstration
- **SPAWAR Systems**
  - Gavia UUV
    - Dual Frequency Side-Scan Sonar for S-C-M / R-I
- **APL, University of Washington**
  - Seaglider
    - Acquire & Relay CTD & Optical Data
- **Woods Hole Oceanographic Institution**
  - REMUS UUV
    - Demonstration of Recent REMUS Upgrades
  - Gateway Buoy
    - Support ACOMMS Demonstrations
    - Conduct MCM Sorties with Bluefin UUVs



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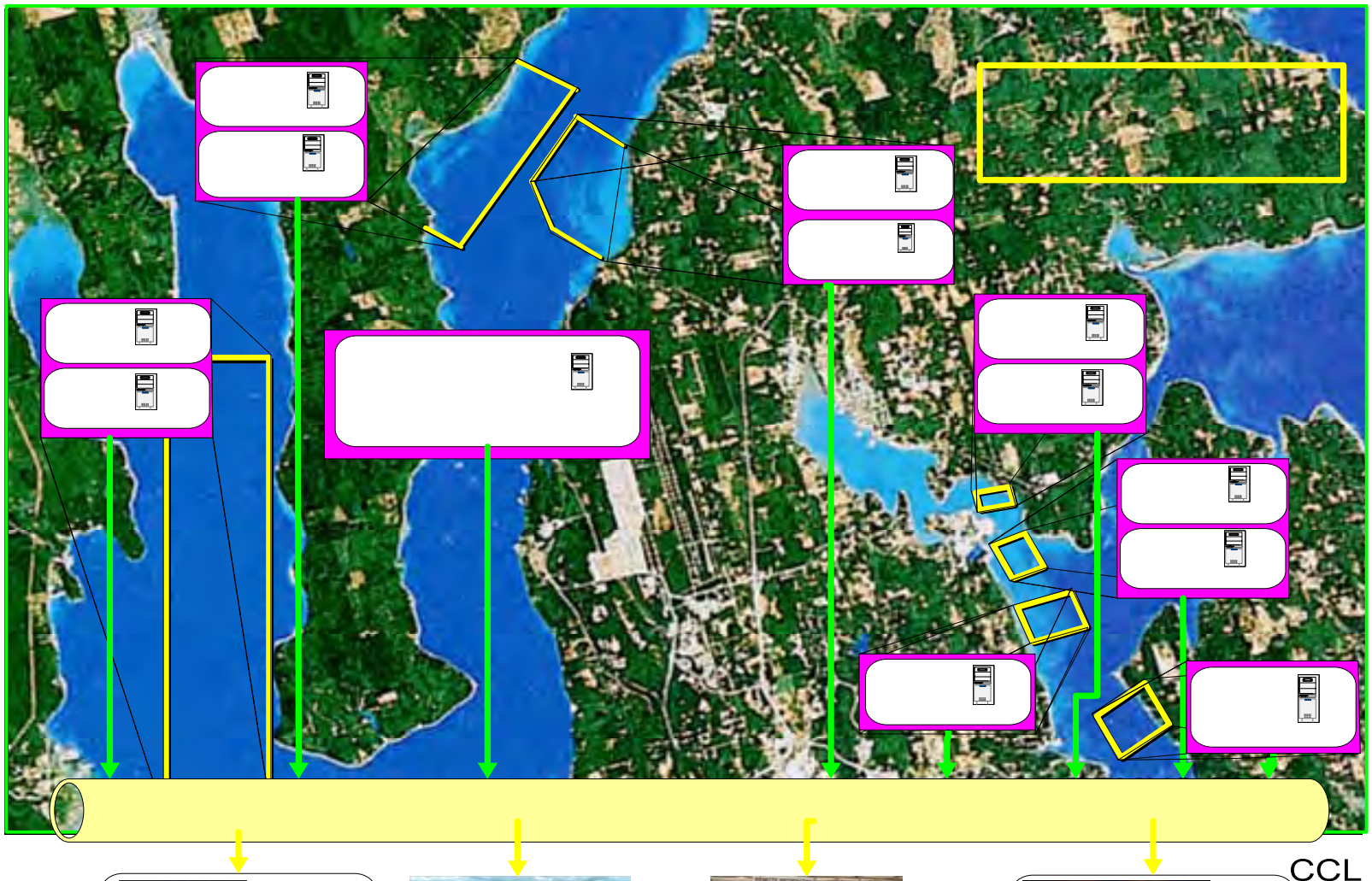
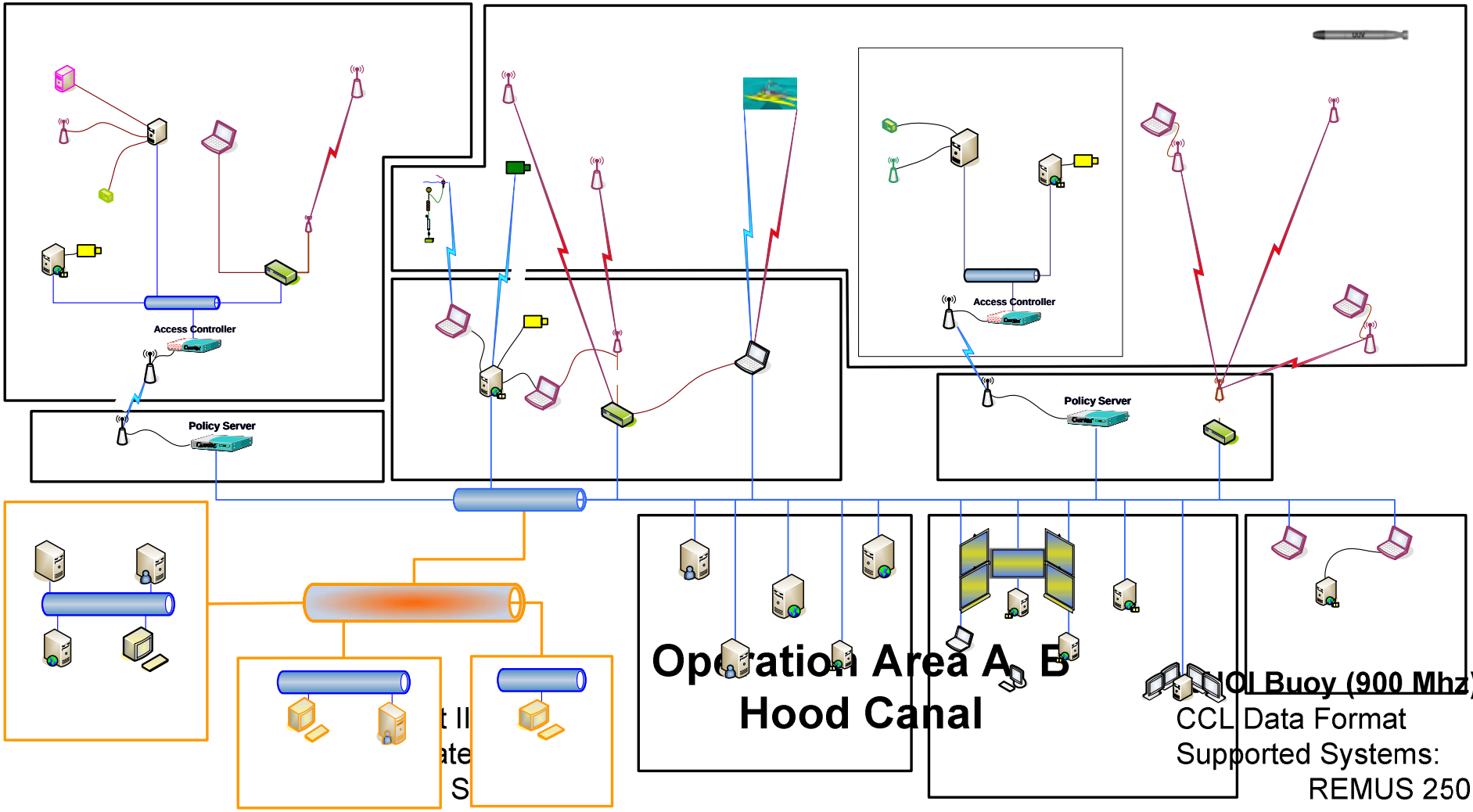
AUV Fest '05 PARTICIPANTS

- **Alaska Native Technologies**
  - **Slocum Glider**
    - Measure CTD & Map Ambient Acoustic Noise
- **AUSI**
  - **Solar AUV (SAUV)**
    - Cooperative Behavior Between SAUV Vehicles
- **Florida Atlantic University**
  - **Air-Deployed Gateway Buoys**
    - Rapid Deployment of Self-Anchoring Gateway Buoys
- **Hydroid Inc.**
  - **REMUS UUV**
    - Find, Localize, & Image Mines
- **Lockheed Martin Perry Technologies**
  - **CETUS II UUV**
    - Interoperability with S-C-M Systems & Crawlers
    - Surface Ship Hull Inspection
    - Close Proximity Maneuvering – Payload Delivery

Collaborative Operating USW Picture (COUP)



COUP Communication & Data Flow Diagram



AUV Fest 2005

Virtual ISR Mission Linking Keyport to Hawaii for SDVT-1 Insertion Mission Planning

Demonstration of the Collaborative Test, Training, Experimentation and Evaluation Capability (CTEC) and NUTEC UUV T&E Center (NUTEC) Assets

NAVSEA KEYPORT
Undersea Warfare Center Division

NUTEC
National UUV Test & Evaluation Center

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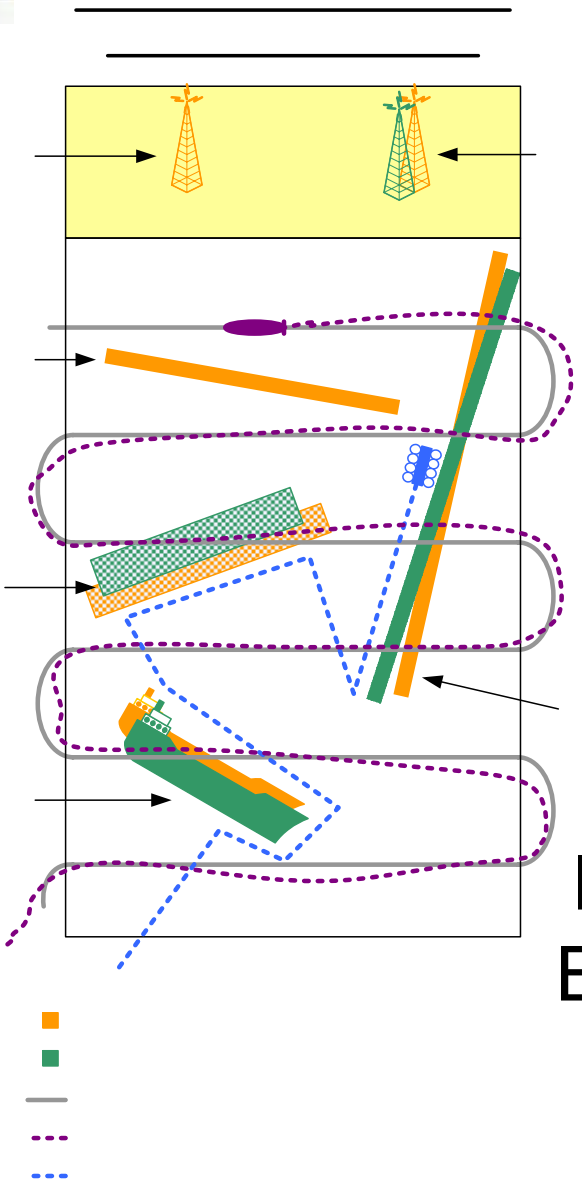
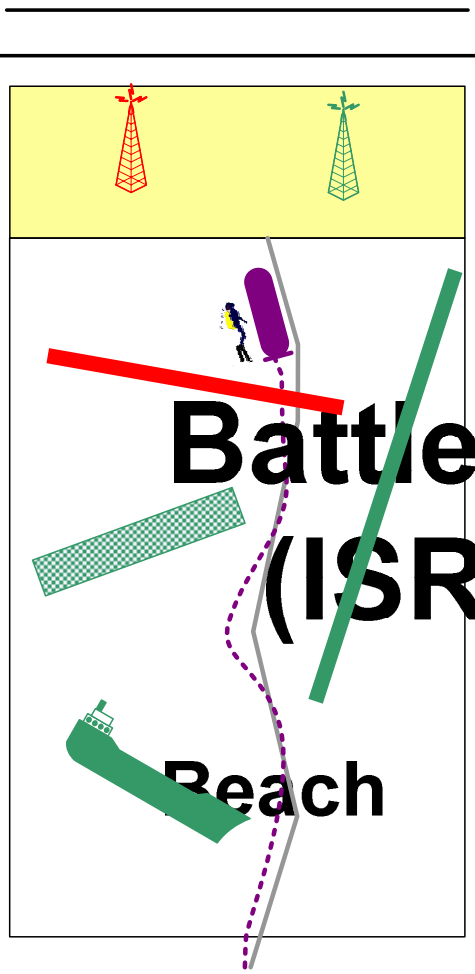
ISR Scenario Objectives

- Demonstrate integration of remote & distributed USW assets (vehicles, range instruments, targets, etc.) during testing, training, and experimental events
- Demonstrate network-enabled dissemination of UUV ISR information for operational benefit
- Demonstrate ability to use Live-Virtual-Constructive (L-V-C)* assets to train, test and evaluate mission planning and execution
- Monitor and assess undersea asset performance during all phases of the event
- Capture all event assessment information for live presentation and for archive and playback
- Assess the overall usefulness of some emerging UUV/ISR capabilities for SDVT-1 mission planning

* L-V-C - see definition on next chart





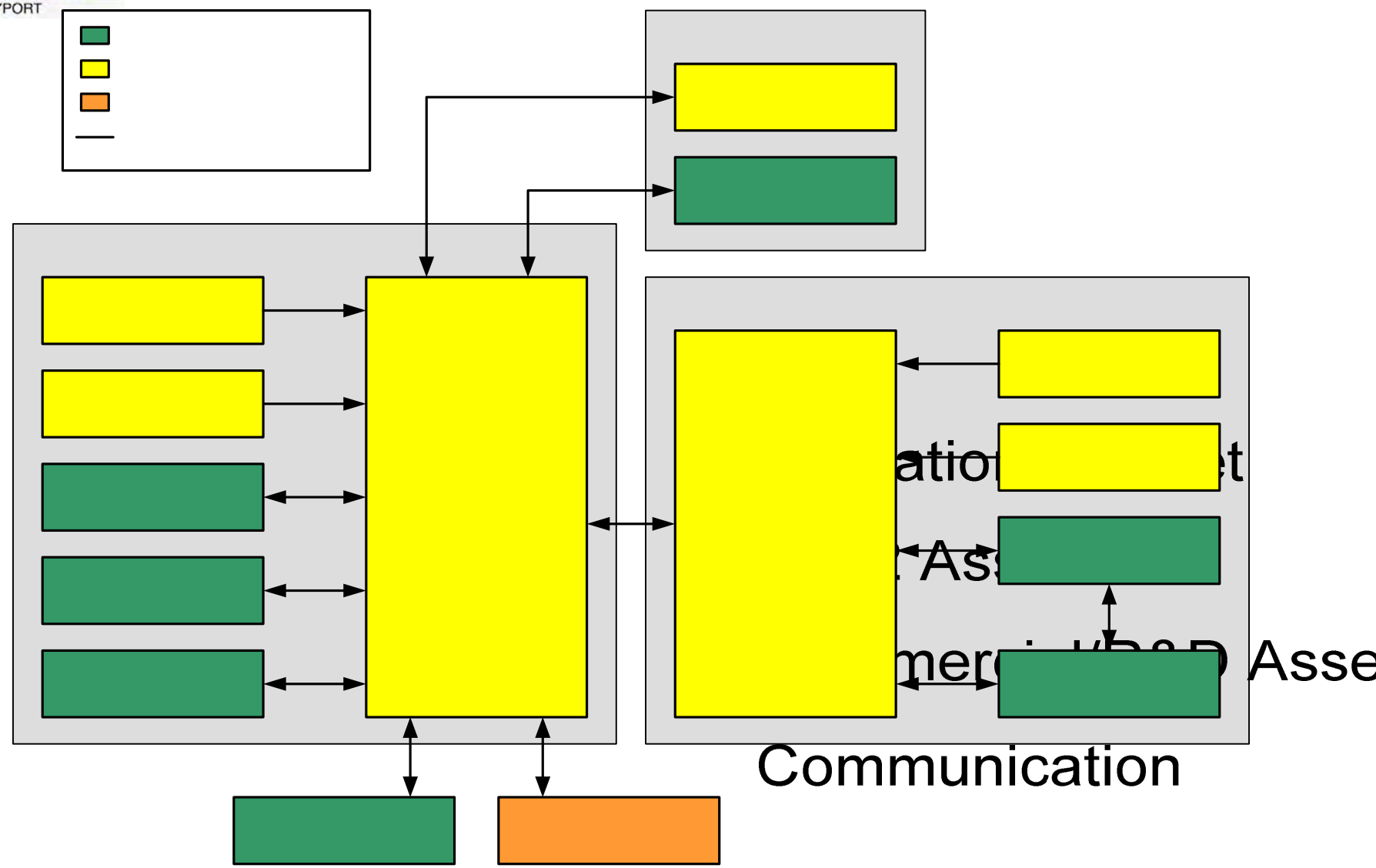
Battlespace
(ISR) at Ke

Beach

Radar
Emitter

Surveyed

Event Systems & Connectivity



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CTEC Summary

- DoD **transformation** is integrating and distributing Testing & Training
- CTEC is a **capability** based on best practices of the Joint DoD community in support of L-V-C (Live-Virtual-Constructive) Testing & Training events
- CTEC, the center, is a **facility** designed to enable and refine the capability
- CURATE (TENA), ESMS, and EPAS are CTEC **tools** being developed to integrate the COUP (Common Operating USW Picture) into a consistent L-V-C Test & Training battle space in support of USW assessment and readiness
- Test & Training **organizations** can leverage CTEC to achieve their objectives for Joint and Fleet forces (Fill the USW "Gap")

Distributed USW T2E2 for Undersea and Littoral Warfare is viable and available through CTEC

For further information regarding CTEC & Distributed USW T2E2

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or

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END

CTEC

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Drill-Down Slides

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COLLABORATIVE T2E2 CENTER (CTEC)

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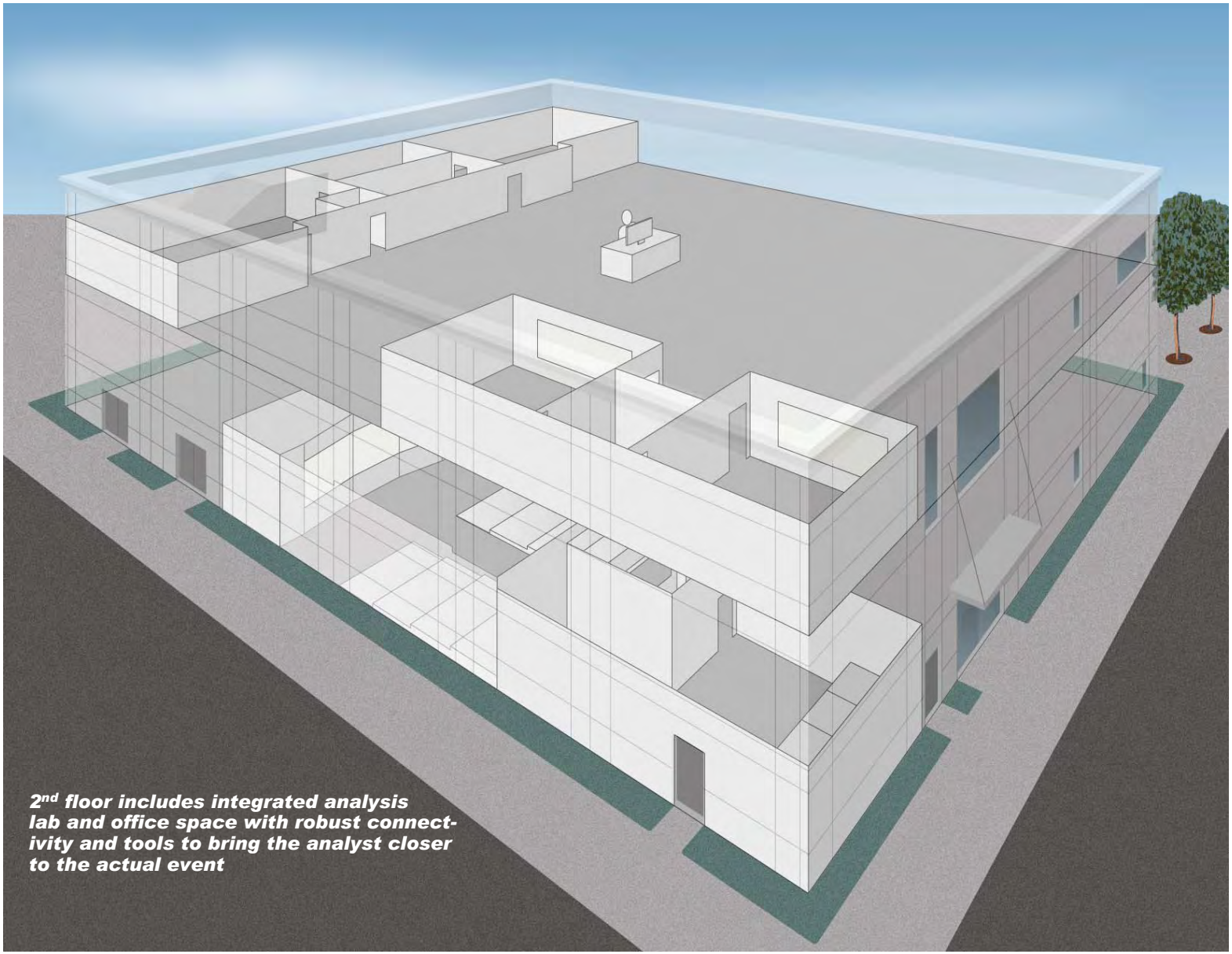
COLLABORATIVE T2E2 CENTER (CTEC)



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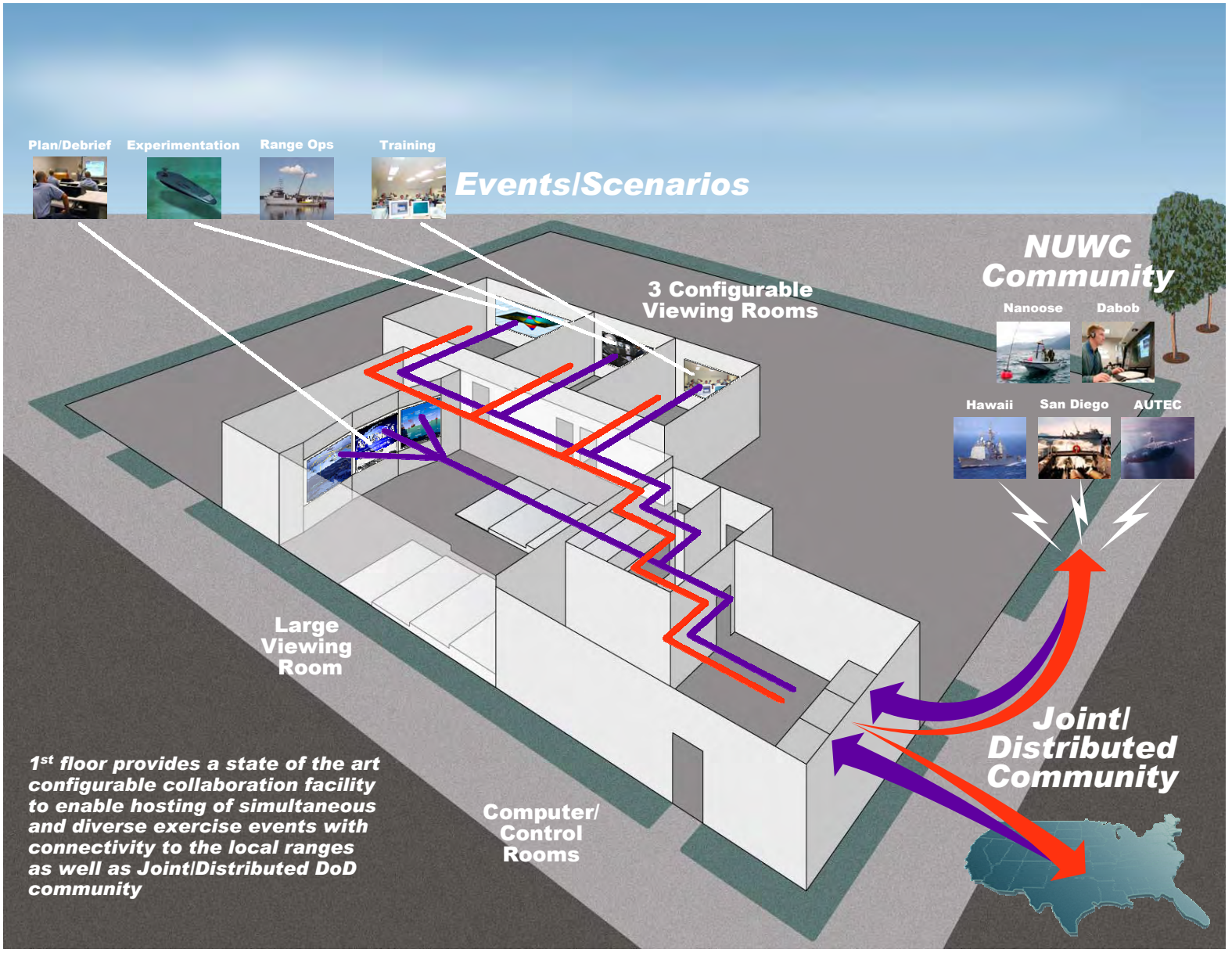
COLLABORATIVE T2E2 CENTER (CTEC)



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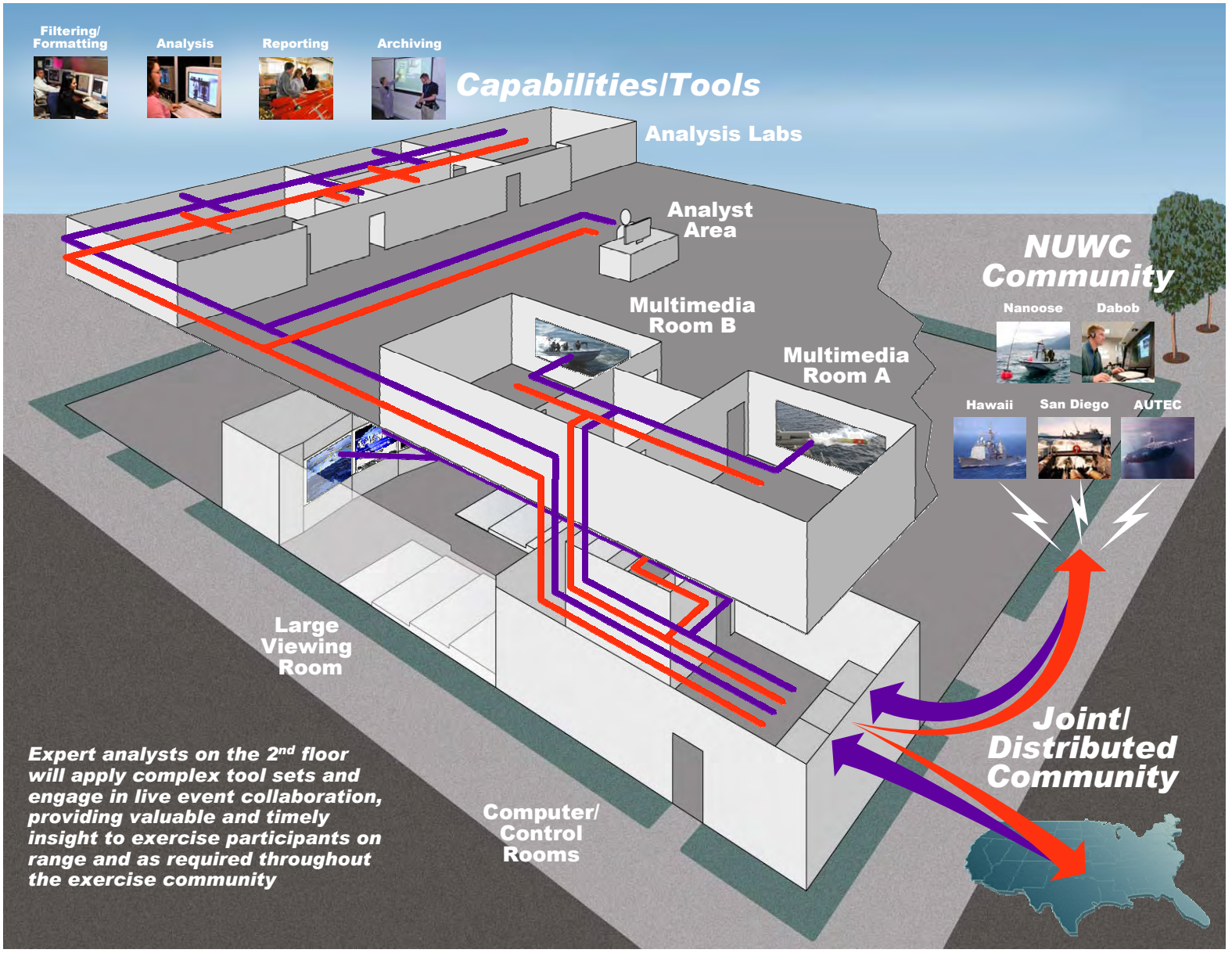
COLLABORATIVE T2E2 CENTER (CTEC)



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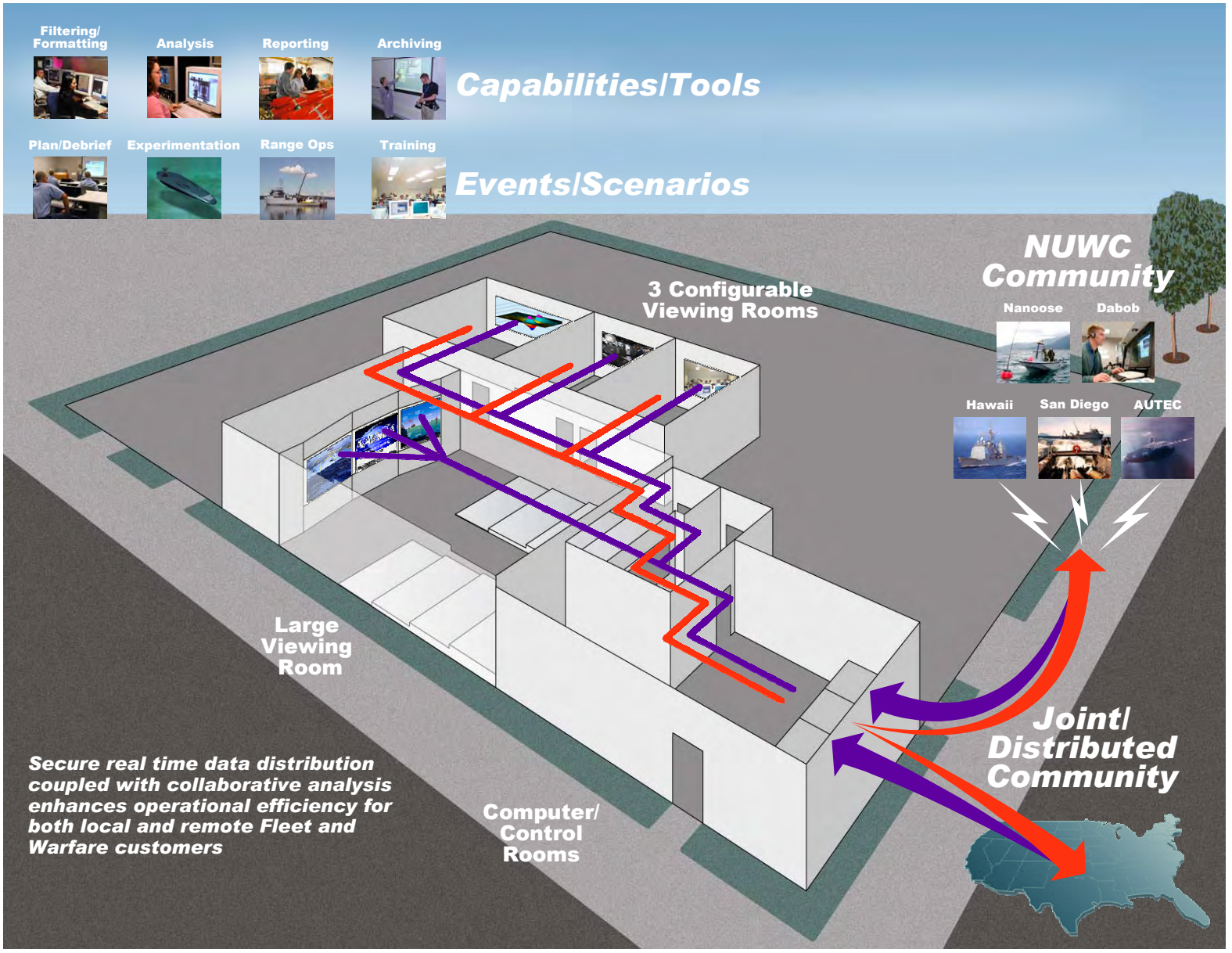
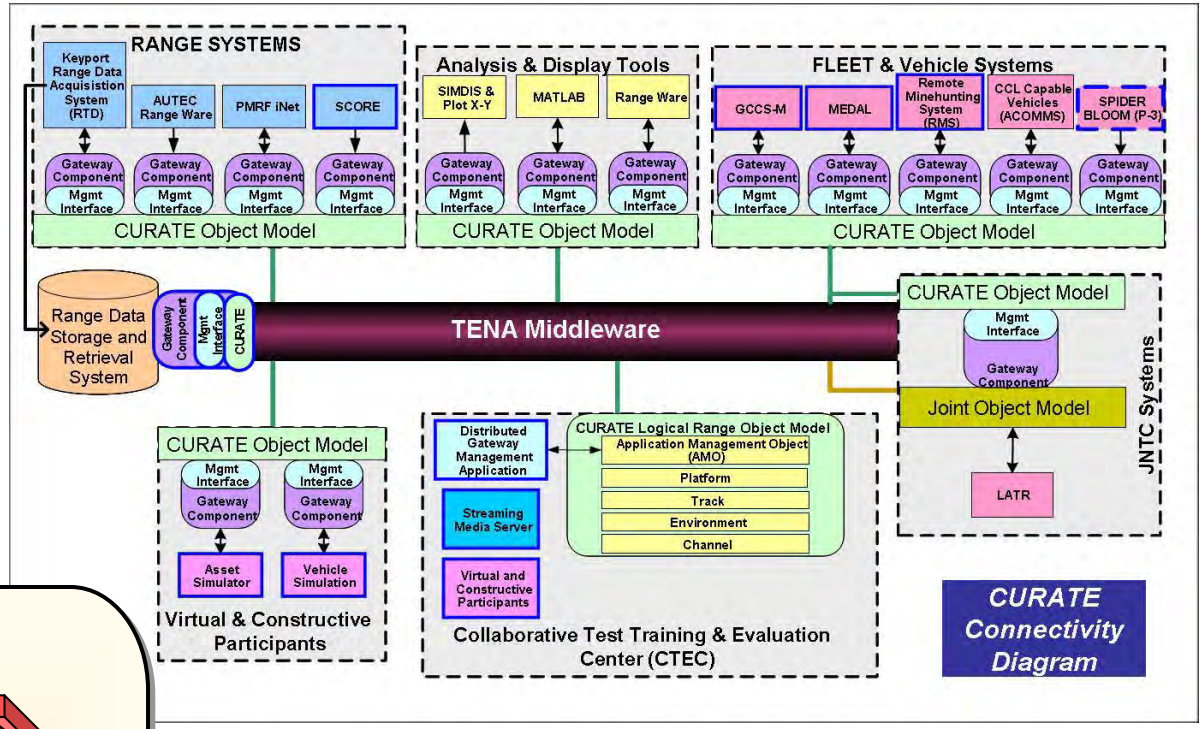
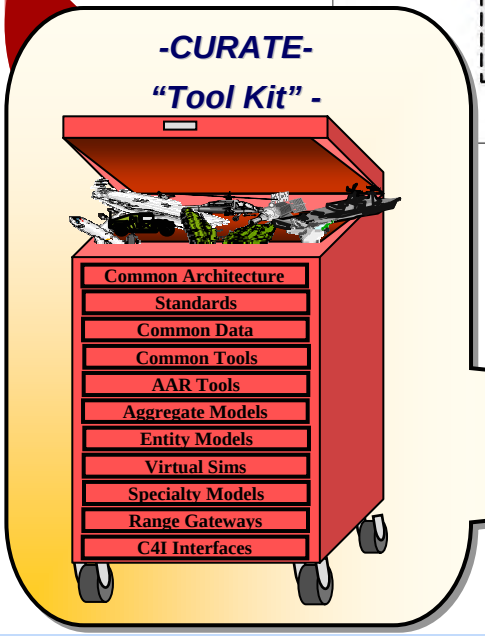
COLLABORATIVE T2E2 CENTER (CTEC)

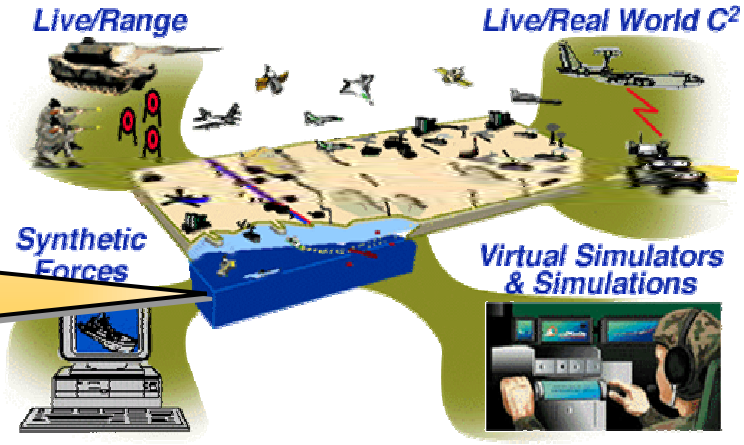


Common Undersea Range Architecture for Distributed T2E2 (CURATE)





Joint USW T2E2 Capability-- Link to Services, JNTC LROM



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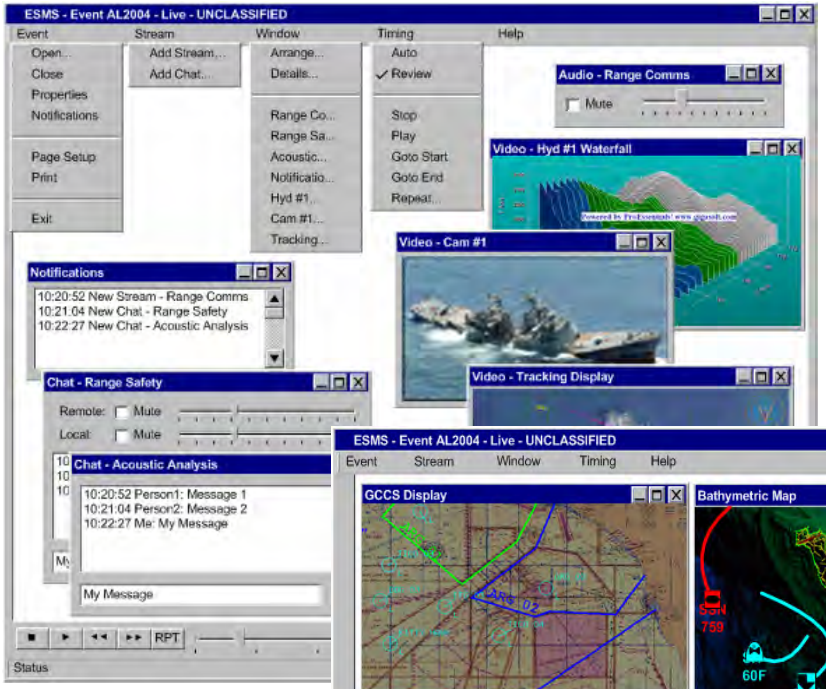
Common Undersea Range Architecture for Test/Training & Evaluation/Experimentation (CURATE)

CURATE is the USW TENA implementation:

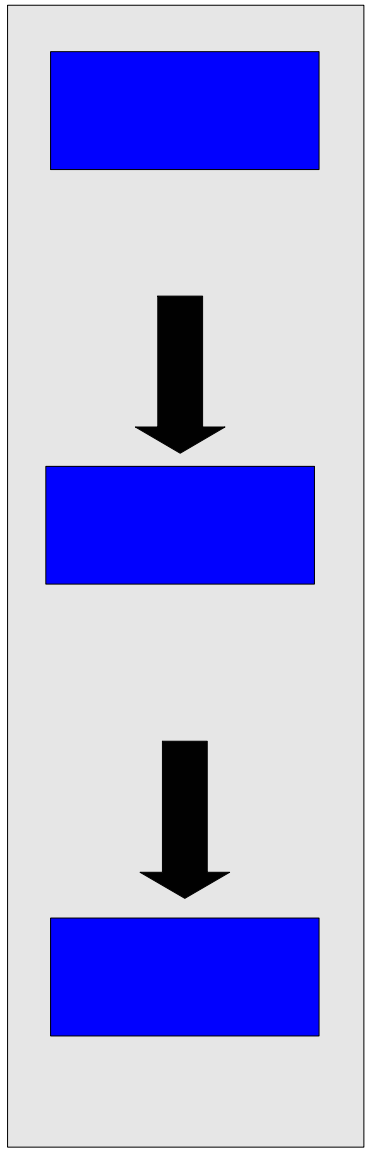
- **Developed as member of OSD sponsored TENA Architecture Management Team. TENA is a funded program (OSD & JNTC).**
- **Supports the "Joint Training Toolkit" goal of JNTC**
- **Supports remote & distributed T2E2 vision, using gateway components for legacy data**
- **Provides a common ASW/USW/MCM data Logical Range Object Model (LROM)**

Event Streaming Media System (ESMS)



Publish/Present Graphical User Interface

Components



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Event Streaming Media System (ESMS)

- **Synchronized event audio, video, & screen capture streams**
  - **Provides event insight to local and remote participants**
  - **Supports live and post-event collaboration capabilities**
  - **Readily scales to support small or large events**
- **Integrates with established DoD and Navy initiatives and architectures (FORCEnet, GIG-ES, TENA, DCTS, NMCI)**
- **Easy-to-use tool for non-technical users**
  - **Familiar web browser based implementation**
  - **Intuitive graphical user interface via Macromedia Flash Player**
  - **Simple capture of stream content**
  - **Automatic deployment/versioning using web server approach**
- **Employs existing, proven, approved technologies**
  - **Adapts COTS (Macromedia Flash) streaming technology**
  - **No specialized hardware needed to capture or present**

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Event Planning and Assessment System (EPAS)

Process

Select the standard event type(s) that pertain to the current event

Select standard event performance parameters to be assessed for current event

Select the asset types to be utilized for the current event

Select the specific asset to be utilized for the current event

Select the asset-specific data types to be captured for the current event

Event Types
- ☐ Amphibious Landing
- ☑ ASW Event
- ☐ MCM Event
- ☐ NEO Event
- ☐ SOF ISR Event
- ☐ SOF Recon Event

→

Event Perf Measures
- ☐ Deployment Time
- ☑ Threat Classificatio
- ☑ Threat ID Success
- ☑ Threat ID Time
- ☑ Threat Kill Success
- ☑ Threat Kill Time

→

Event Asset Types
- ☐ CVN
- ☐ DDG
- ☑ SH-60
- ☐ SSGN
- ☑ SSN
- ☑ P-3C

→

Event Asset Types: SSN

Event Asset Instances
- ☐ SSN 688 (Live)
- ☐ SSN 724 (Live)
- ☑ Newport VSSN (Vi
- ☐ EB Sim SSN (Const

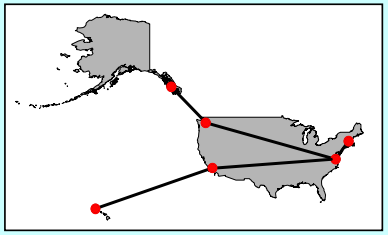
→

Event Asset Instances: Newport VSSN (Virt)

Asset Perf Params
- ☑ TSPI
- ☑ BSY-1 SONAR
- ☐ WAA SONAR
- ☑ Hydrophone Signals

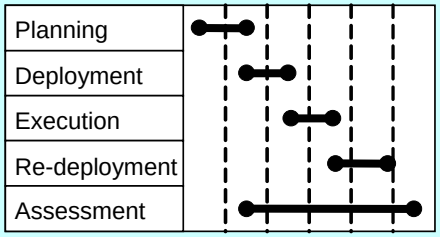
Tools

Automated Event Asset and Connectivity Map

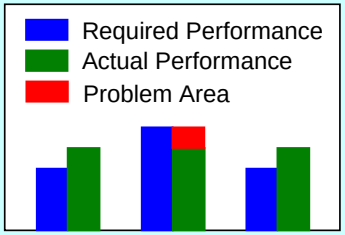


Constructive Event Simulation

Integrated Event Schedule



Dynamic Performance Evaluation Summary



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Event Planning and Assessment System (EPAS)

- **Provides integrated planning and assessment capability for joint Test, Training, Evaluation, and Experimentation (T2E2) events - event definition and asset selection and performance measurement**
- **Utilizes existing (e.g. TENA, HLA) and emergent (FORCEnet, GIG-ES) interoperability mechanisms to provide discovery of specific asset capability and schedule information for planning**
- **Integrates the event planning and assessment process with the data collected during events**
- **Set up event measures of success and to objectively evaluate event and asset performance**
- **Tailor events to meet specific cost and technical objectives through asset selection and simulation**

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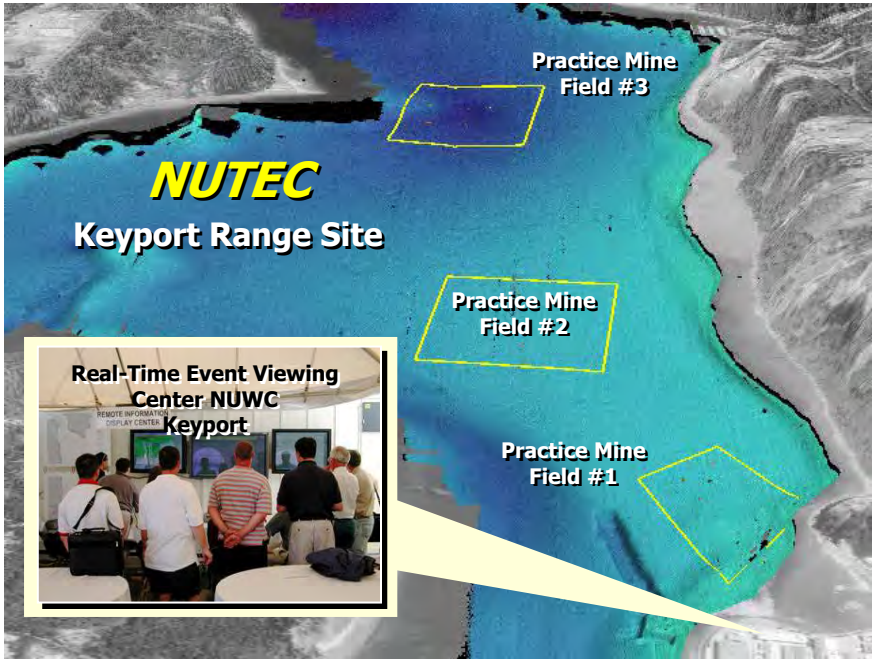
Back-Up Slides

Recent CTEC USW T2E2 Efforts

AUV Fest – 2003

- Initial Demo Of Collaboration Capability At Keyport
- Integration Of Disparate Live UUV Systems Into COP During Mocked Events At Keyport
- Distribution Of Real-time Test & Training Data To Remote Facilities



CJTFEX – 2004

- Remote Use Of Distributed USW T2E2 Infrastructure At Large Scale Training Event
- Integration Of Disparate Live UUV Systems Into COP During Training Events At Camp Lejeune, NC
- Distribution Of Real-time Test & Training Data And Control Capability To Remote Facilities

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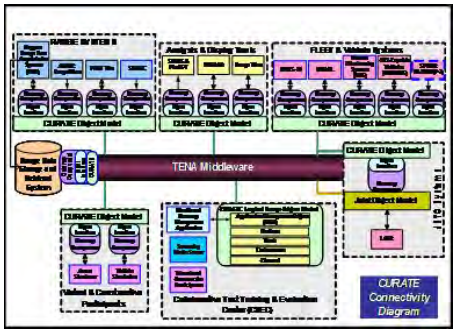
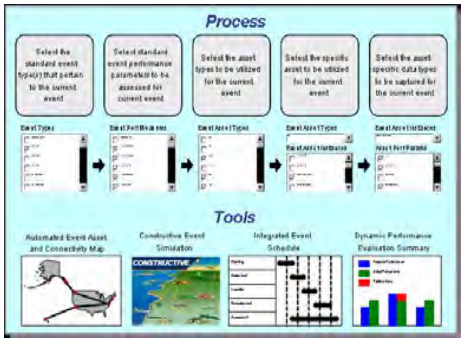
Strategy: Tool & Process Components

- **Common Undersea Range Architecture for Distributed T2E2 (CURATE)**
  - Provides a Common ASW/USW/MCM Data Logical Range Object Model (LROM)
  - TENA Middleware employed to provide rapid, centralized data storage/archiving/playback, as well as controlled live data distribution throughout LROM domain
  - Enables network-enabled, synchronized, distributed T2E2 data to allow collaborative participation in geographically remote locations



- **Event Streaming Media System (ESMS)**
  - Used for distributing event AV streams – Video, Tactical Displays, etc.
  - Provides test, exercise director overall situational awareness
  - Uses COTS Macromedia server products + web browser interface

- **Event Planning and Assessment System (EPAS)**
  - Provides event definition, asset selection, & performance measurement
  - Integrates event planning and assessment process with data collection requirements
  - Sets up event measures of success to evaluate individual and total system performance
  - Tailors events to meet specific cost and technical objectives through asset selection and simulation



Systems Engineering and Development for CURATE, ESMS & EPAS is a Joint Government/ Contractor Effort

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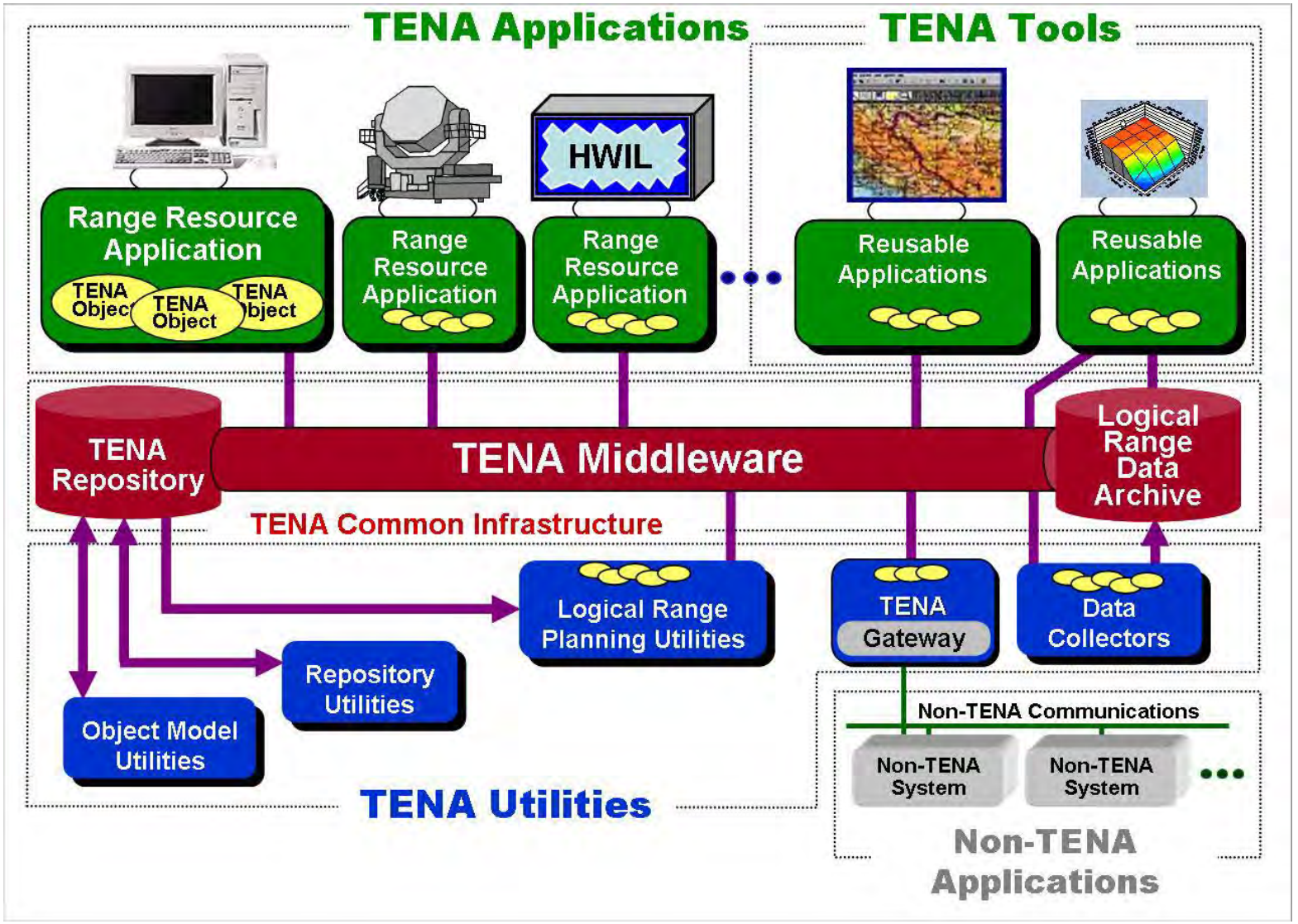
Test & Training Enabling Architecture (TENA)



TENA - Executive Summary

- **TENA supports the implementation of the Joint Vision 2020 by promoting integrated testing and simulation-based acquisition through the use of the concept of a *"Logical Range."***
  - ***A logical range* integrates testing, training, simulation, and high-performance computing technologies, distributed across many facilities, and ties them together with a common architecture.**
  - **In a *logical range*, real military assets can interact with each other and with simulated weapons and forces, no matter where these forces actually exist throughout the world. TENA is designed to make the logical range vision a reality.**
- **A *common infrastructure* through the medium of the TENA object model encodes all of the information that is transferred between systems during a range event. It is the common language with which all TENA applications communicate.**
- **The core of TENA is the *TENA Common Infrastructure*, including the TENA Middleware, the TENA Repository, and the TENA Logical Range Data Archive. TENA also specifies the existence of a number of tools and utilities, including those necessary for the efficient creation of a logical range.**
- ***TENA Gateway applications* allow the integration of TENA applications with non-TENA resources. Gateways communicate with both a TENA logical range (via the TENA Middleware) and another set of applications using some other protocol.**

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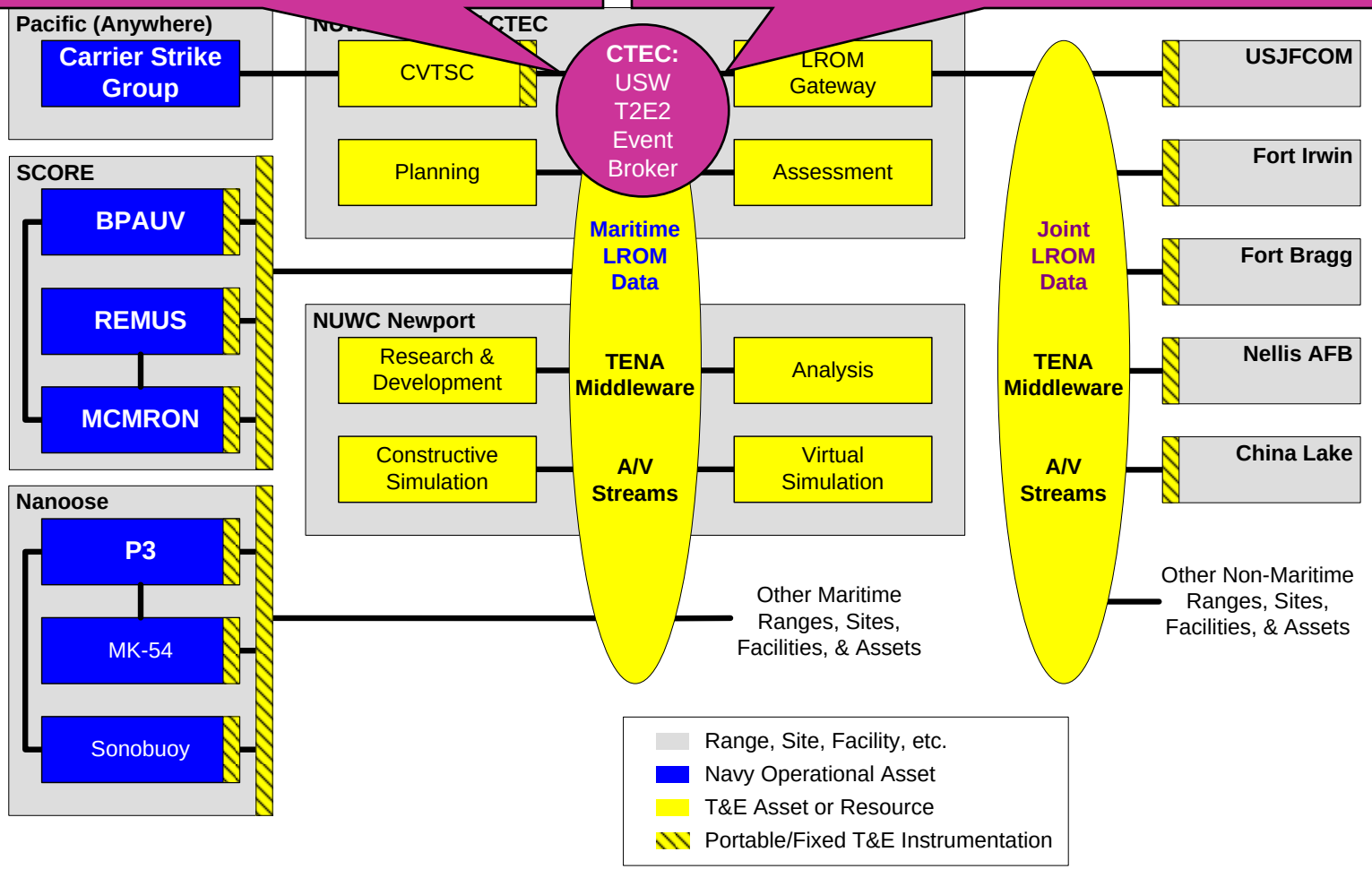
AUV Fest 2005 Demonstrations

SPONSOR / Demonstrator		VEHICLE / TECHNOLOGY	CAPABILITIES TO BE DEMONSTRATED
ONR - Dr. Tom Swean			
	Nekton Research LLC	Ranger	Neutralization of Moored Target with Expendable UUV
	Nekton Research LLC	TransPhibian	VSW-to-Shore Vehicle Demonstration - Swimmer and Crawler Modes
	Lockheed Martin Perry Technologies	CETUS II RIN	Reacquire & ID
	NSWC Panama City / WHOI	REMUS 600 (12.75" UUV)	MCM Applications with REMUS 12.75 Inch UUV with SSAM
			Pictures Along Track Lines / Bathymetric & Environmental Measurements
	NSWC Panama City	CRAWLERS	S-C-M (VSW & SZ) & Acoustic-Communications-Only R-I Mission
			One-on-Many Neutralization with Vehicle to Crawler Vectoring
	Florida Atlantic University	Gateway Buoy	Gateway Communications, Air Deployable / Self-Mooring Buoy
	Naval Postgraduate School	ARIES	Blazed Array Sonar & Obstacle Avoidance
	Woods Hole Oceanographic Institution	REMUS (VSW)	S-C-M / ID - Cooperative, Multi-Vehicle Operations with CETUS II & Crawlers
	Autonomous Undersea Systems Institute	Solar AUV	Cooperative UUV Operations using "Mother Ship" Navigation Concept
	Hydroid, Inc	REMUS (SW)	SW S-C-M/R-I with Dual Frequency Side Scan Sonar, DIDSON, and Video
	NUWC Division Newport	BioRobotic AUV	Demonstrate Precision Maneuvering Capabilities
ONR - Dr. Tom Curtin			
	MIT	CARP	USV Cooperative Behavior with Kayaks
	Alaska Native Technologies	Slocum Glider	Noise Mapping with Gliders
	NAVAIR	Autonomy Software	Simulation/Display of Autonomy Software (Draper)
	APL / University of Washington	Seaglider	Seaglider Operations & Dissolved Oxygen / CTD Profiling
PMS EOD Programs			
	SPAWAR San Diego	GAVIA 8" UUV	Dual Frequency (900/1800 MHz), S-C-M / R-I, Iridium, Obstacle Avoidance
	NSWC Panama City	Bluefin 9 - SEA LION	Bluefin 9 (900 kHz), S-C-M Without Need for LBL Navigation Transponders
	NSCT-1	UUV Operations	UUV Operations and Verification of TACMEMO (Identification)
	ARL:University of Texas	COIN	Demonstrate Interface Between UUV / Diver Tools / Dolphin MCM
NSWC PC			
	NSWC Panama City	REMUS UUV and ASH USV	Remote Delivery of Unmanned System Technology (RDUST) Remote Launch of a REMUS UUV from an ASH USV
NUWC			
	NUWC Division Keyport	HAIL	Spread-Spectrum, LPI, Underwater Communication Systems
	NUWC Division Newport	MARV 12.75" UUV	Accurate Navigation, Color Video, and ACOMMS
	NUWC Division Keyport	CTEC	AUV Fest 2005 Common Operational USW Picture (COUP) & Remote Distribution
			Live, Remote, Virtual ISR Information Support to SDVT-1
			C^2 Linkage with SEAL Delivery Team ONE and NUWC DET in Hawaii
	NUWC Division Newport	ISR Vehicle Simulation	Simulation of an ISR Vehicle - To Show Up in the COUP Display
Other			
	Naval Oceanographic Office	HUSCy (USV)	Demonstrate Shallow Water Hydrography / Oceanography

- Independent Assessment & Evalution
- Assist Test-Training-Experimentation Scheduling
- Translate Requirements to Test/Training Plans
- Optimize Events for Live-Virtual-Constructive
- Integrator

- Optimize L-V-C Asset Selection
- "Referee" Data Flow For Customer (OTD, EX DIR)
- Rapid Event Reconstruction
- Collaboration Setup (Analysts, DMs, Trainees)
- Event Archival for Post Analysis, Lessons Learned



Enabling Effective & Efficient Fleet UMV Operational Training through Distributed USW Test & Training Technology

Michael Kelf

Senior Systems Engineer
Maritime System Solutions Division
SAIC

G. Michael Hewitt

Executive Vice President Navy Submarine Force Training Content & Delivery
SONOALYSTS, Inc.

NDIA Unmanned Maritime Vehicle Test & Evaluation Conference

Keyport, WA

June 14-16, 2005

The Challenge

When a new Unmanned Undersea Vehicle system is ready to go to the Fleet, have we done all we can to assure the sailors will be ready to employ it?

- Typical acquisition cycles for “new” systems result in new products being delivered to the operational community, but leaving that community the responsibility to figure out how to employ it.
- The current Submarine Community approach, is to use “cadres” of specialized operators who take the new, specialized systems to sea and interface with the crew of the host ship in system deployment.
- Shipboard crew members need training because cadres are not expected to provide a long-term ConOps for UUV employment.
- Navy school houses don’t have trainers for teaching operators how to use UUVs, and they probably won’t have them in the near future.

Meeting the Challenge

Spiral Development

- More Challenge: Current military technology development cycle is shorter than traditional DoD acquisition cycle. *However* …
- This also provides another opportunity to gather information on real operations in real environments with new systems to support Fleet training
  - Spiral development and Build/Test/Build strategies generate at-sea and on-range experiments utilizing Fleet platforms and personnel
  - Real-time, hands-on Fleet involvement during actual DT and OT events
  - Virtual, real-time participation by Fleet personnel
  - Employ information from real system operations in real environments to rapidly build and field Fleet training tools
- Information from these experiments which employ Fleet units can enable operational testers opportunity for early assessment of operational effectiveness and suitability

Meeting the Challenge

Training Transformation

Joint National Training Capability (JNTC)

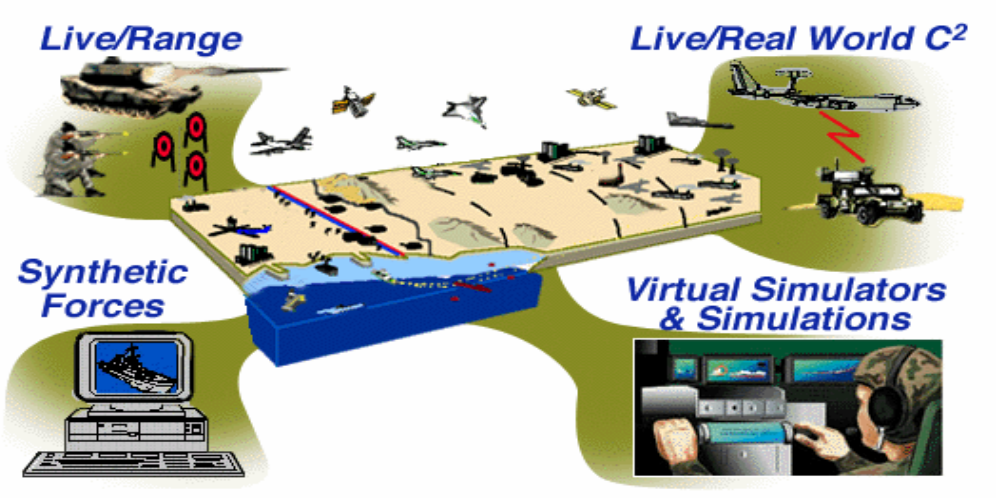
– Future of T&E intertwined w/ Joint Experimentation & Training –

"… a collection of interoperable training sites, nodes, and events that synthesizes Combatant Commander and Service training requirements ...."

"Test and Training Partnership is Essential to Transformation"

Mr. John Bolino, DOT&E

Rapid Evaluation & Analysis to Support a Nation at War



Transformation Drivers - *Navy*

Sea Trial: The Process of Innovation

"… integrate war-gaming, experimentation, and exercises … Embracing spiral development … a process of rapid prototyping and fleet experimentation."

Training Transformation Implementation Plan (T2IP):

JFCOM - Integrate joint experimentation and lessons learned into new training processes and systems

A cost effective, realistic synthetic test & training environment / capability

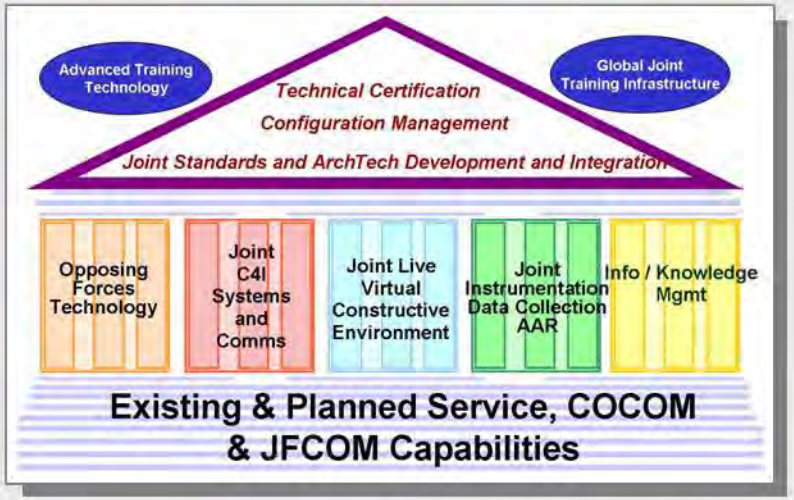
Meeting the Challenge

Joint National Training Capability (JNTC)

JNTC: A National Strategy

Development of Joint synthetic environment (L-V-C*) in support of training and experimentation capability - a persistent network that seamlessly links select ranges and simulation centers throughout the world

JNTC Technical Focus Areas



* *Live*, *Virtual* and *Constructive* ("L-V-C") Training

Asset Realization	People	Systems	Environment
Live	Real	Real	Real
Virtual	Real	Simulated	Simulated
Constructive	Simulated	Simulated	Simulated

Meeting the Challenge

Navy Implementation of National Strategy

Navy Continuous Training Environment (NCTE) … capabilities to conduct *training on demand* … through a persistent network that connects geographically dispersed training simulators and systems with geographically dispersed forces.

- Modeling & Simulation to complement and enhance constrained *Live* training time with *Virtual* training events … in a *synthetic battle space employing tactical training ranges, infrastructure, … joined in a common network for training events*
- Use the Test and Training Enabling Architecture (TENA) standards for training, and operational systems and ranges ...

NCTE - 2009 Goal: Train any audience … a persistent network focused on *joint training, experimentation, testing, education, and mission rehearsal*, by linking command and control, training facilities, ranges, and simulation centers throughout the world.

RADM David B. Hart, Director, Fleet Readiness Division, CFFC
Testimony to HASC March '04

Sea Trial – The Fundamentals

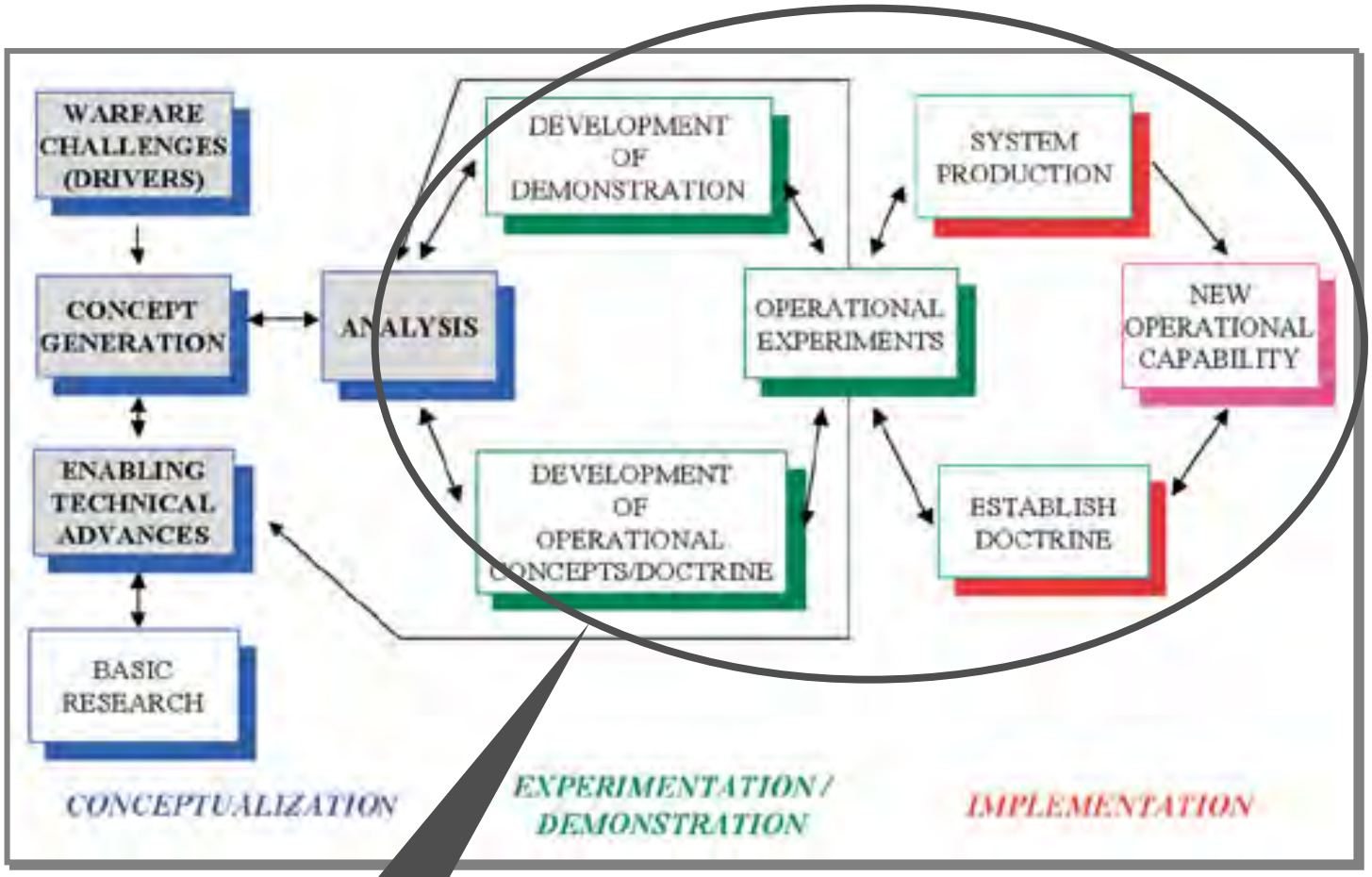
- The Fleet must drive innovation and experimentation.
  - Fleet identifies specific warfighting challenges and the urgency ...
  - ConOps: capitalize on an existing or emerging technology.
  - Experimentation evaluates potential solutions with sufficient analytical rigor.
  - The cycle is complete when the doctrine development, training, and acquisition process reflect those results.

- Active involvement of our operators in the testing and evaluation of the technology … and the tactics and doctrine ...
- Our ships and aircraft will serve as sea-based laboratories, with our operators helping to answer the most pressing question… *"What new ConOps will make the most effective use of existing and emerging technologies?"*

Sea Trial – ADM Robert J. Natter, former Commander, CFFC, October 2003

Meeting the Challenge

The Sea Trial Process – Focus on Capability

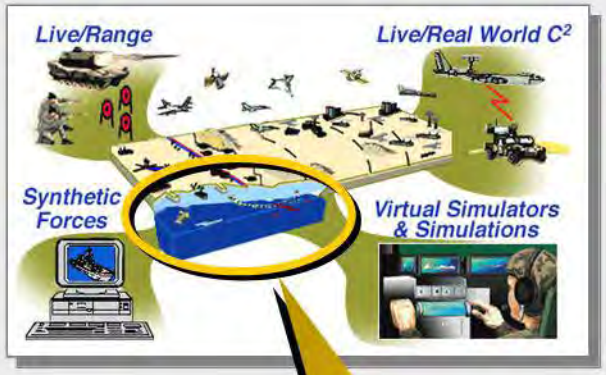


Sea Trial: More than equipment development. New capability necessarily includes the doctrine, tactics, and associated training for Fleet employment.

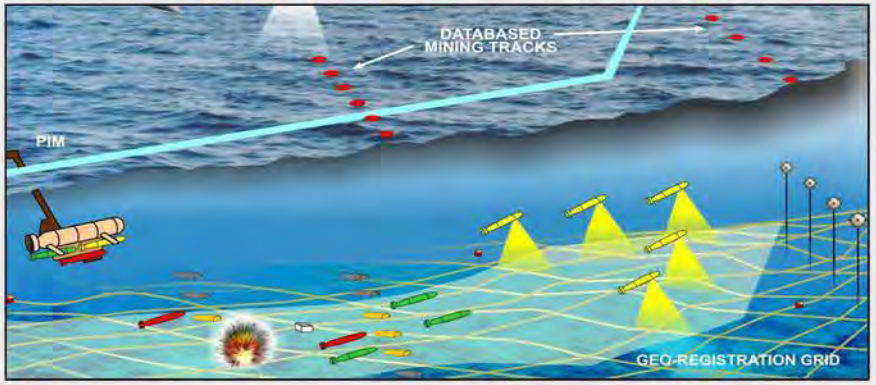
Meeting the Challenge

Distributed USW T2E2 and JNTC

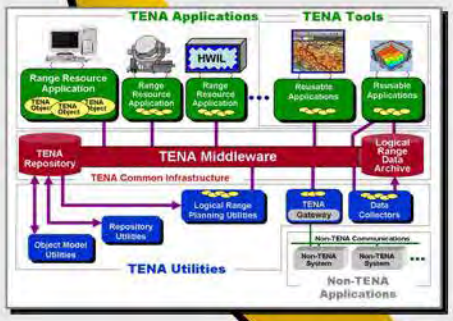
Focus Area: Undersea / Littoral Warfare



Integrating a Live, Virtual, Constructive Synthetic Battlespace for Fleet UUV Training, Testing, Experimentation & Evaluation



TENA

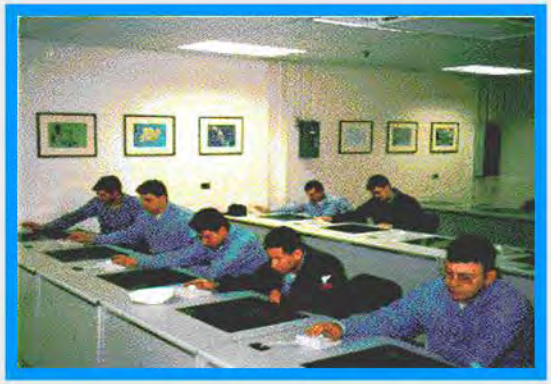


Fully Fielded Safe & Effective UUV-Based Warfighting Capability:

- *System*
- *ConOps & Tactics*
- *Trained Operators*
- *Supportability Products*

Meeting the Challenge

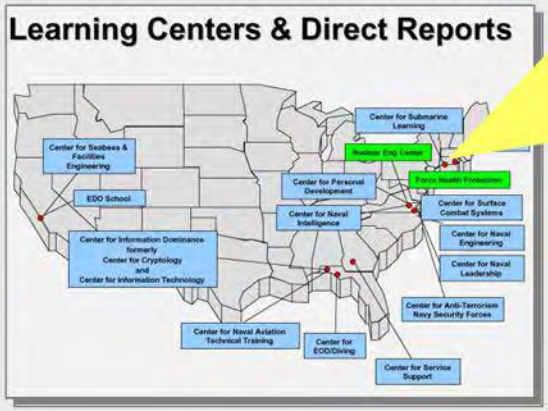
Navy Training Continuum

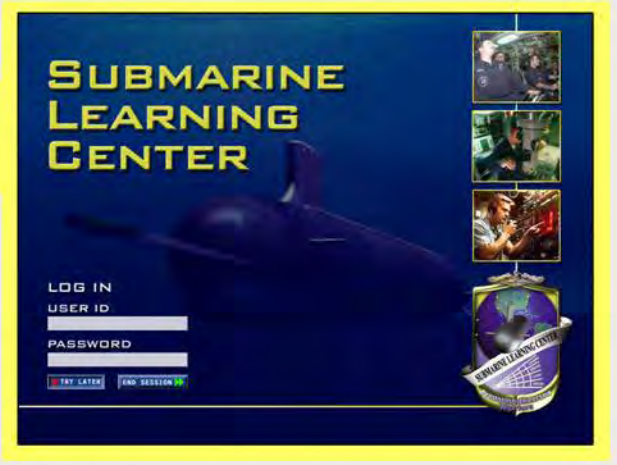


Traditional Schoolhouse Classrooms

PC-based Simulations

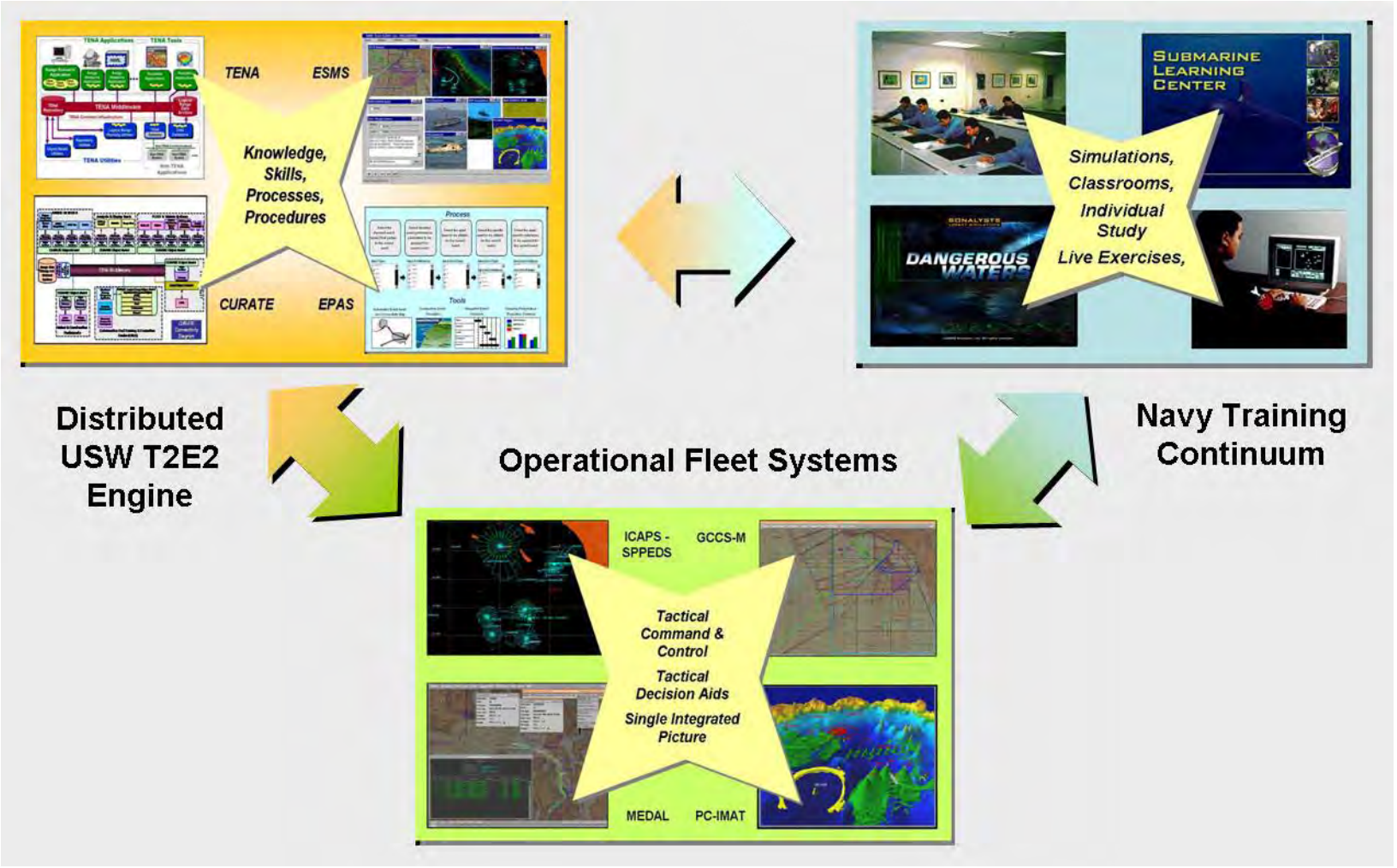
Embedded Trainers





Meeting the Challenge

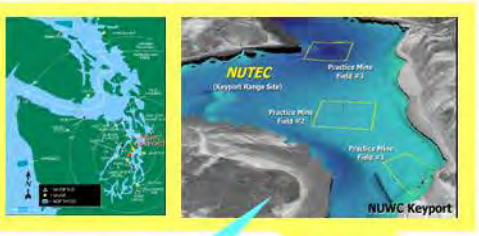
T&E Capability - to - Training Capability

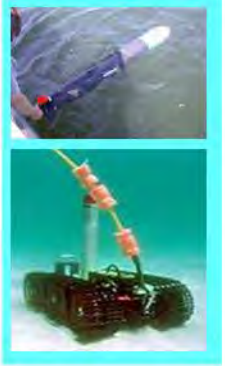


Success Strategy: *Integrate - Don't Re-Invent!*

Meeting the Challenge

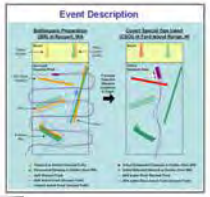
T&E Capability - to - Training Capability

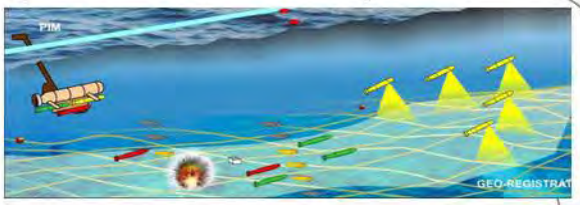


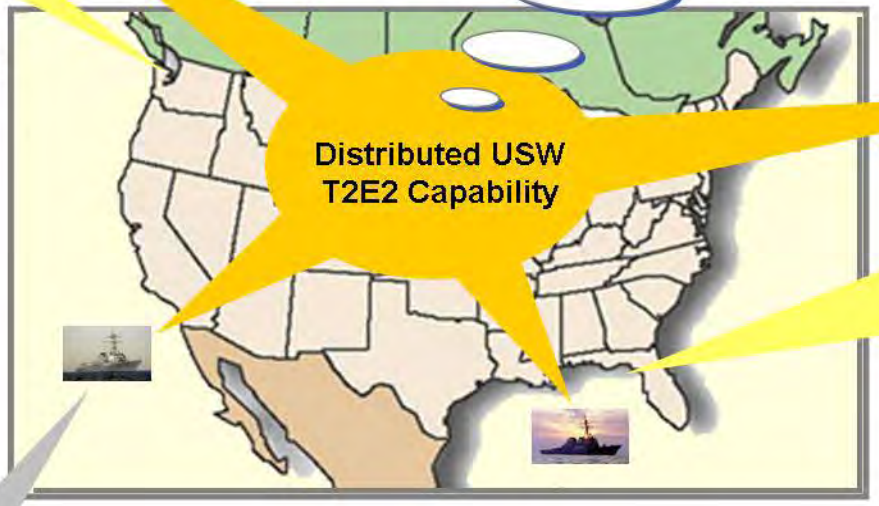


UUV Test & Experimentation Operation at NUTEC

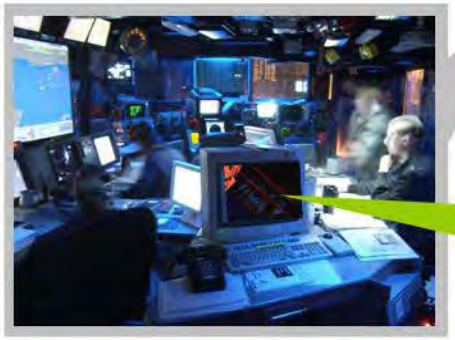
Notional Integrated MIW & ISR T2E2 Exercise Scenario







Fleet Training Exercise in SOCAL Area with Live, Virtual, Constructive Components



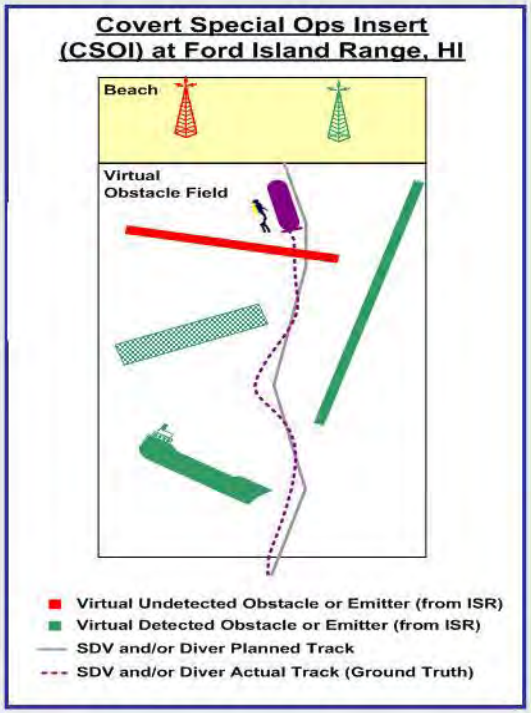
Fleet RMS Exercise on Gulf Range

Meeting the Challenge

AUV Fest Example

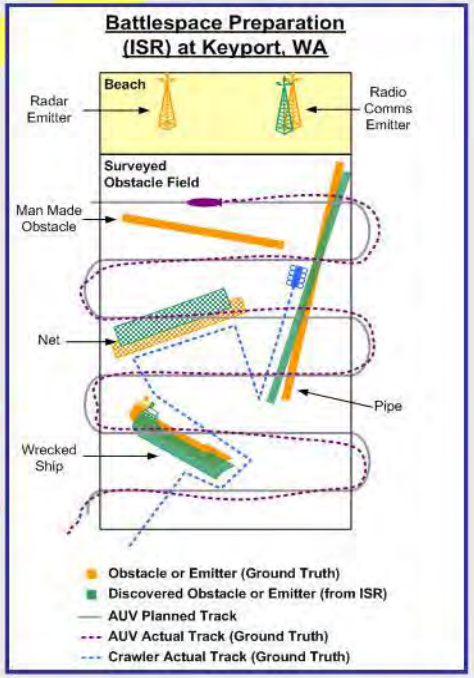
- **UUV and NUTEC assets at Keyport, WA capture ISR information**
- **"Virtual" ISR picture to SDVT-1 mission planners in Hawaii**
- **SDVT-1 participants use captured ISR information to support a covert insert operation**

A Covert Special Ops Insertion (CSOI) Operation involving a SDVT-1 vehicle (i.e. SDV) or diver using remotely collected ISR data transposed to transit a virtual range at Ford Island, Hawaii



A Battlespace Preparation Operation in a shallow water zone at Keyport, WA, in which ISR information will be captured using several UUVs (i.e. SAHRV, MARV)

Translate Detected Obstacle Locations & Types



Summary

Navy & Joint DoD thrusts powered by proven, advanced-technology capabilities promise the potential to equip the organic warfighter with the knowledge and skills necessary to effectively and efficiently employ new Unmanned Undersea Systems to meet the demands of the Fleet Response Plan.

Joint National Training Capability (JNTC)

- Joint Synthetic Environment
- Integrated Test, Training and Experimentation

Navy Transformation

- Sea Power 21 *(Sea Trial)*
- The "Revolution in Navy Training" (*Task Force Excel*)
- Navy Continuous Training Environment *(NCTE)*

New Tools

- Test & Training Enabling Architecture (TENA)
- USW T2E2 Infrastructure and Processes (NUTEC, CTEC, etc.)
- Simulation-Based, PC-Hosted Trainers

Test & Experimentation Events of Opportunity

The most valuable products of a T&E event are not necessarily fixed at the test location on the day of the test.

Recommended Path Forward

Integrated, Distributed, Testing and Training

- Begin now to develop a Fleet Unmanned Maritime System segment to the Navy Training Continuum
- Exploit existing distributed USW Test and Evaluation capabilities to enable a full distributed, integrated Test, Training, Evaluation and Experimentation capability
  - Hands-on operator training and ConOps development (Sea Trial)
  - Virtual training through remote participation in live events
  - Development of *UUV Test and Experimentation Event Archive* for use as schoolhouse and embedded training products
- Engage the Fleet as much as possible in early UUV experimentation and demonstration
  - Experiment design with a future ConOps/Tactics perspective
  - Live (Hands-on) and virtual involvement in operations
  - Participation by Fleet Trainers and curricula developers

Recommended Path Forward – cont'd

Integrated, Distributed, Testing and Training

- Capitalize on scarce resources: Every formal T&E event (contractor test, DT, OT) viewed as a potential Fleet Training event.
  - Employ real time remote event links to operators and trainers at distant locations (home ports, forward deployed)
  - Digitize, catalogue, and archive UUV event information for future Fleet classroom and shipboard use
- Encourage participation by the Distributed Learning and Simulation-based training product community
- Allocate residual T&E program assets (Developmental Vehicles Test Targets and Shapes) for use as training assets as recognized at initial National UUV Test & Evaluation Center (NUTEC) Workshop in 2001

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END

Revolution in Navy Training

The “Revolution in Navy Training” (*Task Force Excel*):

EXCELerate Sea Warriors through innovation and lifelong learning by being the world's best force development organization.

- Submarine Learning Center has been developing Interactive Multimedia Instruction (IMI) to improve learning and allow for standardized training between classroom and onboard
- PC simulation-based training will support operator training and reduce risk associated with deployment experience (while keeping cost down)
- Multimedia can be used to support Replay (Lessons Learned) as well as Distance Learning

Naval Personnel Development Command: *“We develop Sea Warriors.”*
Mission:

Integrate, standardize and support the Learning Centers in delivering the knowledge necessary to satisfy validated Fleet individual performance requirements that will improve Fleet readiness through the professional and personal growth of Sailors and Marines.

Revolution in Navy Training

- The Navy is fully engaged in this important transformation of training designed to merge the training and operational environments across the Services … enabled by a potential spectrum of training environments:
  - ***Live*** = real people in real locations using real equipment
  - ***Virtual Simulation*** = real people in simulators
  - ***Constructive Simulation*** = simulated entities in a simulated environment
- The LVC environment melds existing operational and strategic facets of exercises with live forces, creating a more robust and realistic experience by ...
  - Creating joint warfighting conditions through a networked collection of interoperable training sites and nodes that synthesize personnel, doctrine, and technology
  - Providing participants will have a global, network-centric capability that strengthens military transformation efforts to promote war fighter effectiveness.

RADM David B. Hart, Director, Fleet Readiness Division, CFFC - Testimony to HASC March

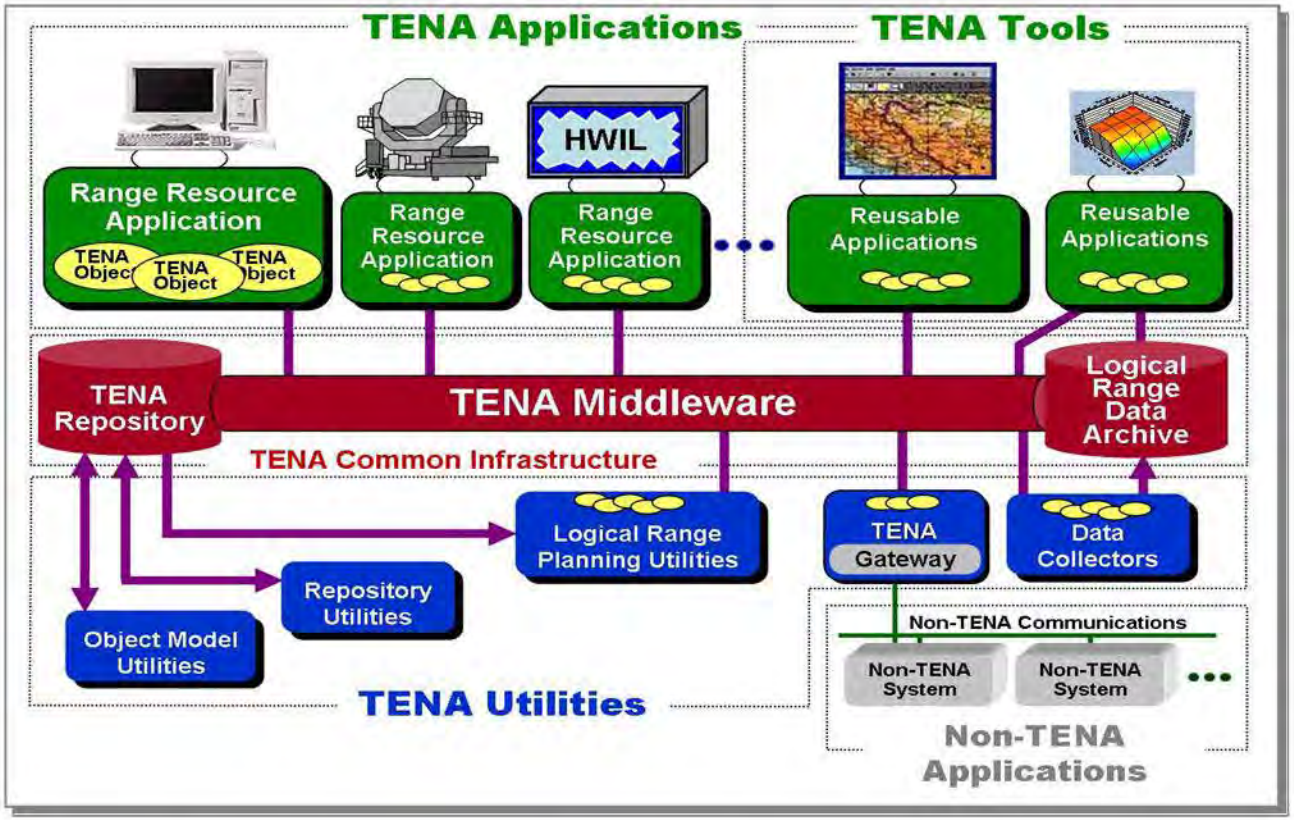
Sea Trial – Who's Who?

- ***CFFC's Sea Trial Executive Steering Group (STESG)*** … creates and maintains the environment supportive of discovery and learning … in the experimentation process.
- ***Navy Warfare Development Command (NWDC)*** …
  - Plans and coordinates execution, analysis, and assessment of Fleet Battle Experiments … and Navy participation in joint experiments.
  - Synchronizes experimentation to co-evolve technologies, tactics, techniques, procedures, doctrine, and organizational changes needed to field capabilities.
- ***Second and Third Fleet commanders, with Commander, Naval Network Warfare Command*** … are responsible for developing Sea Trial concepts, conducting operational assessments, and validating evolving fleet capabilities in their respective areas.
- ***Sea Trial Pillar Groups*** … provide the numbered fleets and Naval Network Warfare Command, with the expertise to develop and evolve "Sea Power 21" operational concepts ... and direct development and implementation of an iterative experimentation process design to bring transformational capability to the Fleet.
- ***Collaborative Teams*** … leverage the intellectual capital of warfare centers of excellence, along with NWDC, the Office of Naval Research, type commands, system commands, fleets, and other commands … to participate in Sea Trial experiments, and contribute to doctrine and tactics development for the new capabilities being delivered to the Fleet.

The Sea Trial Efforts

- Examples of productive Sea Trial experiments:
  - *Exercise Giant Shadow*, in which the USS *Florida* (SSBN-728) conducted complex operations designed to test SSGN technology and operational concepts in conjunction with a variety of air, land, and sea-based assets.
  - *Fleet Battle Experiment Kilo* conducted in April and May 2003, in which spiral events with Second Fleet tackled the thorny problem of collaboration between geographically separated elements of an integrated staff. The equally challenging tasks of commanding theater antisubmarine warfare, area air defense, joint fires, and the new expeditionary strike group were examined in an operational environment with Seventh Fleet during Tandem Thrust '03.
  - Experimentation with the High-Speed Vessel, *Swift,* to help develop mine warfare command ship operating concepts and will fuel the Littoral Combat Ship's attendant concept of operations.
- FY ’04 Experimentation in support of Sea Shield
  - Develop an undersea network and nonacoustic detection methods to enable a sensor-rich antisubmarine warfare environment and advanced weapon technology to counter littoral threats.
  - Evaluate the contribution of multiple autonomous UUVs to improving mine warfare rate of detection.

TENA: A Common Architecture & Protocol Standard



Test and Training Enabling Architecture (TENA)

- Distributed USW T2E2 tool used for T&E system interoperability
- Developed and managed by DOT&E via CTEIP
- Recently mandated by DoD Secretary of Defense

TENA - Executive Summary

- TENA supports the implementation of the Joint Vision 2020 by promoting integrated testing and simulation-based acquisition through the use of the concept of a ***"Logical Range."***
  - ***A logical range*** integrates testing, training, simulation, and high-performance computing technologies, distributed across many facilities, and ties them together with a common architecture.
  - In a ***logical range***, real military assets can interact with each other and with simulated weapons and forces, no matter where these forces actually exist throughout the world. TENA is designed to make the logical range vision a reality.
- A ***common infrastructure*** through the medium of the TENA object model encodes all of the information that is transferred between systems during a range event. It is the common language with which all TENA applications communicate.
- The core of TENA is the ***TENA Common Infrastructure***, including the TENA Middleware, the TENA Repository, and the TENA Logical Range Data Archive. TENA also specifies the existence of a number of tools and utilities, including those necessary for the efficient creation of a logical range.
- ***TENA Gateway applications*** allow the integration of TENA applications with non-TENA resources. Gateways communicate with both a TENA logical range (via the TENA Middleware) and another set of applications using some other protocol.

Improving "Ground Truth" Measurement & Stimulation for Unmanned Maritime Vehicle T&E

NDIA Unmanned Maritime Vehicle T&E Conference
Naval Undersea Museum, Keyport, WA

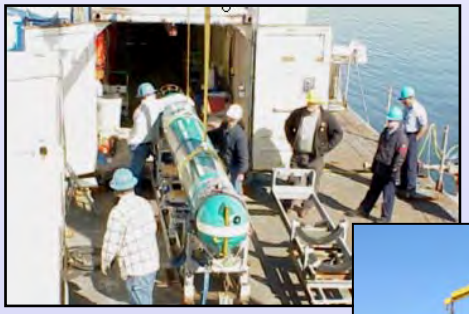
15 June 2005

NUTEC
National UUV Test & Evaluation Center

Presented By:
Mr. Troy D. Kelley
Naval Undersea Warfare Center
E-mail: Kelley@kpt.nuwc.navy.mil

NAVSEA
WARFARE CENTERS
KEYPORT

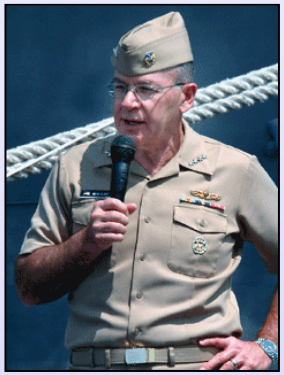
UMV TECHNOLOGIES ARE RAPIDLY ADVANCING & NAVY UMV PROGRAMS ARE MATURING

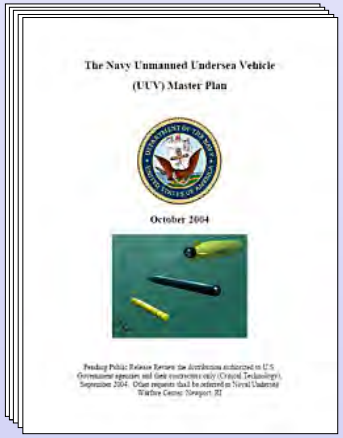


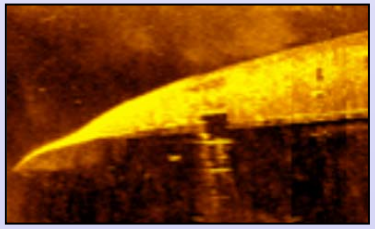
Maturing UMVs & Payloads are Driving Development of *New* UUV Testing & Training Support Capabilities

ADDITIONAL DRIVERS FOR DEVELOPMENT OF NEW UMV TEST & EVALUATION CAPABILITIES

- New UMV Technologies
- Sea Power 21 / Sea Trial Experimentation Focus
- U.S. Chief of Naval Operations Leadership Guidance: *"Reduce T&E Costs"*
- Updated UUV Master Plan Guidance -- Nine Mission Areas & Four Vehicle Classes
- Acquisition Reform & Spiral Development Emphasis
- War on Terror; Homeland & Maritime Security Needs
- New Types of Fleet Platforms & Modular Approaches
- Fleet Experience -- UUV Employment in Iraq







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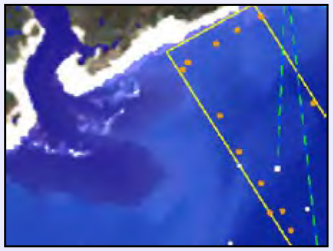
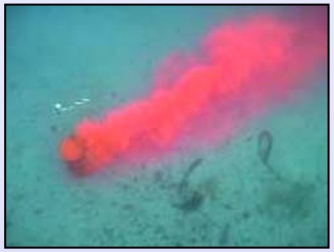
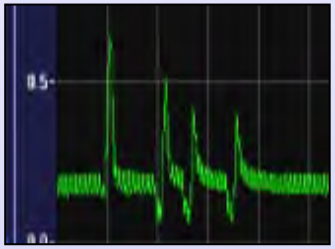
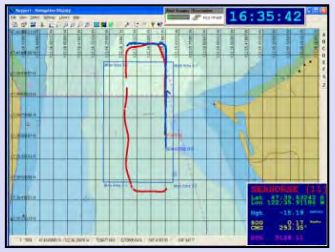
EXAMPLES OF SHORTFALLS IN "GROUND-TRUTH" UMV T&E AND EXERCISE SUPPORT CAPABILITIES

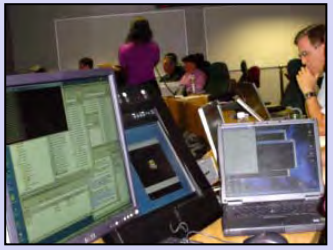
- Ground-Truth Information for the Undersea Environment at Test Sites
- Ground-Truth Information About Targets for Mine Countermeasrure Testing & Other Test Site Objects
- Ground-Truth Information for UMV Sensor Stimulation Sources
- Measurement of UMV Radiated Signatures
- Independent UUV Tracking
- Capturing UMV Exercise Communications (Voice & Data)
- Gathering All Important Exercise Data in One Place for Analysis











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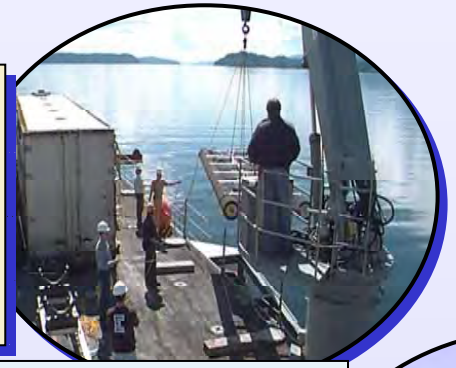
FULL-SPECTRUM T&E AND EXERCISE SUPPORT IS NEEDED FOR ALL PHASES OF UMV DEVELOPMENT & APPLICATION

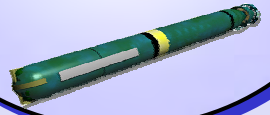
S&T and R&D:
- Few Formal Specifications
- Need Test System Flexibility
- Objective / "Ground Truth"



Shared, Standardized Resources Can Serve Multiple Program Requirements

Acquisition:
- Testing To Specifications
- "Requirements Compliance" T&E
- "User Operational Evaluation"
- DT / TECHEVAL / OPEVAL
- Production Acceptance Tests

Reliable **UUV Systems Available To The Fleet**



New Types Of Testing & Training Support Resources Are Required

In-Service:
- Verify Performance
- Check Repairs & Upgrades
- Mission Work-Ups
- Support UUV Cadre Training

A National Focus For Shared UUV T&E Solutions – *Across Programs; For All Levels Of Maturity; & For Training As Well As Testing* – Will Avoid Costs & Improve Results

NAVSEA WARFARE CENTERS KEYPORT

NUTEC "*ROADMAP*" FOR UUV TEST & TRAINING CAPABILITY UPGRADES

Key Initiatives Required

UUV Measurements & Sensor Stimulation Upgrades

- *UUV Signature Vulnerability Measurements*
- *Specialized UUV Targets & Sensor Stimulation Sources*
- *Environmental Monitoring & Stimulation*
- *Wide-Area UUV Tracking*

UUV Test Data Management Upgrades

- *Distributed Testing and Modeling & Simulation Tools / Support*
- *Information Technology & Connectivity Upgrades*
- *High-Bandwidth Underwater Range Backbone*
- *UUV Analysis & Evaluation Tools*

UUV Test Support Systems

- *UUV Launch, Recovery, & Handling Support*
- *Test-Bed Vehicle(s) For UUV Sensor T&E*

UUV Testing In Mission-Specific Environments

- *Test Area Expansion & Environmental Documentation*
- *Oceanographic Data Collection For UUV Test Sites*

Four Key Initiatives

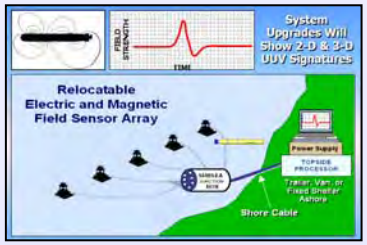
IMPROVED NAVY UUV T&E AND SUPPORT CAPABILITIES

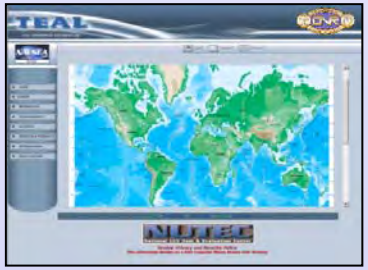
- SUPPORT NAVY UUV MASTER PLAN OBJECTIVES
- ANYPLACE, ANYTIME TESTING & TRAINING
- ACCELERATE UUV DELIVERY TO THE FLEET
- REDUCE OPERATIONAL RISK
- ENHANCE FLEET READINESS TRAINING

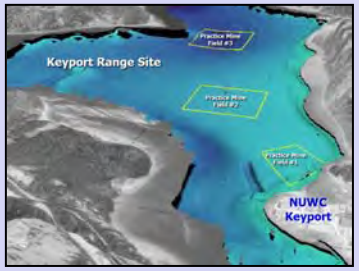
8 of the 12 Requirements-Driven Thrust Areas for NUTEC's T&E Capability Upgrades Are Related To *Ground-Truth Measurement, Stimulation, & Display Capabilities*

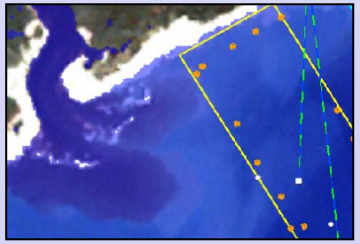
EXAMPLES OF NEW GROUND-TRUTH MEASUREMENT, STIMULATION, & DISPLAY CAPABILITIES

- *UMV Electric & Magnetic Field Vulnerability Measurement (EMFVM) System*
- *In-Situ Characterization of Practice Mine Shapes & No-Mine Bottom Targets*
- *UMV "Shadow Tracking"* – Providing a Virtual Range Anywhere
- *UUV Environmental Test Chamber (ETC)* – Endurance Testing Under Operational Temperature & Depth Conditions
- *Test Environments Assessment Lab (TEAL)* – Aids Understanding, Evaluating, & Selecting UMV Test Sites; Includes 3-D Environmental Visualization Tools
- *Common Operational USW Picture (COUP)* – A Viewing Portal for Real-Time UMV Exercise Observation, Decision Making, & Rapid Assessment
- *Portable Oceanographic & Environmental Measurement (POEM) System* – Real-Time Characterization of UMV Test Sies









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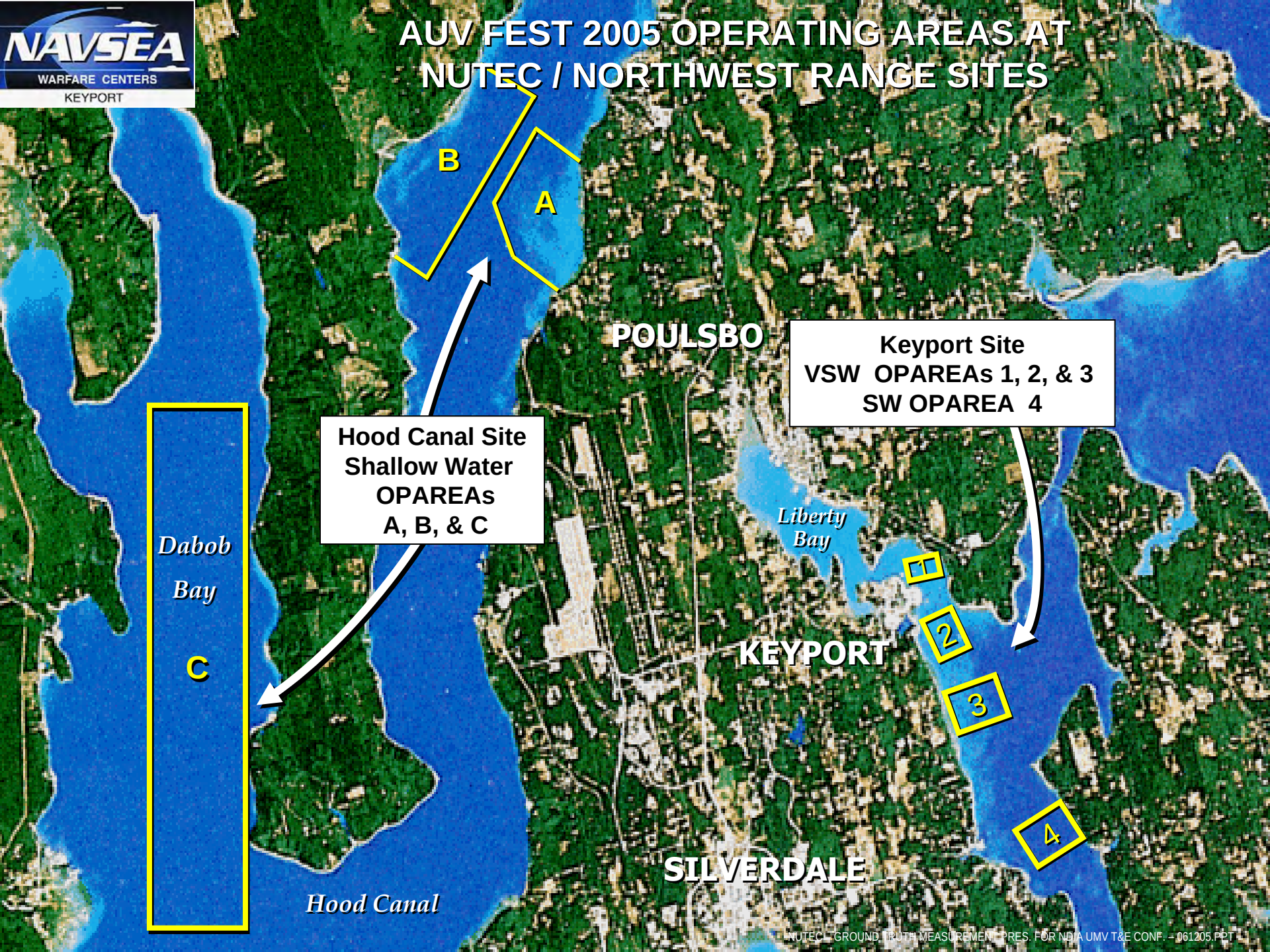
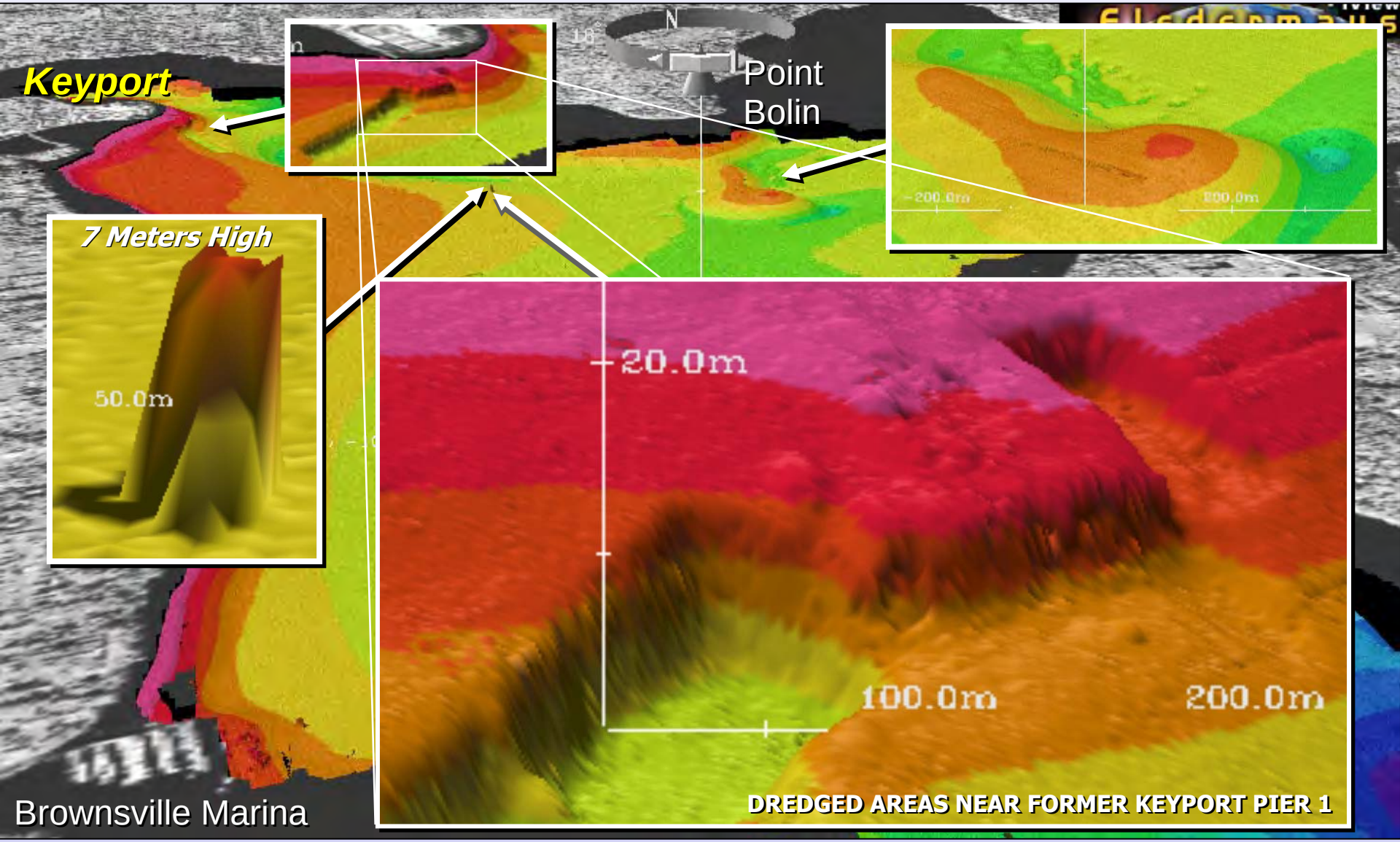
AUV FEST 2005 LOCATION
NUTEC / NORTHWEST RANGE SITES


NAVSEA
WARFARE CENTERS
KEYPORT
AUV FEST 2005 OPERATING AREAS AT
NUTEC / NORTHWEST RANGE SITES
B
A
POULSBO
Keyport Site
VSW OPAREAs 1, 2, & 3
SW OPAREA 4
Hood Canal Site
Shallow Water
OPAREAs
A, B, & C
Liberty
Bay
Dabob
Bay
C
1
2
3
4
KEYPORT
SILVERDALE
Hood Canal
NUTEC GROUND TRUTH MEASUREMENTS PRES. FOR NDIA UMV T&E CONF. – 061205.PPT

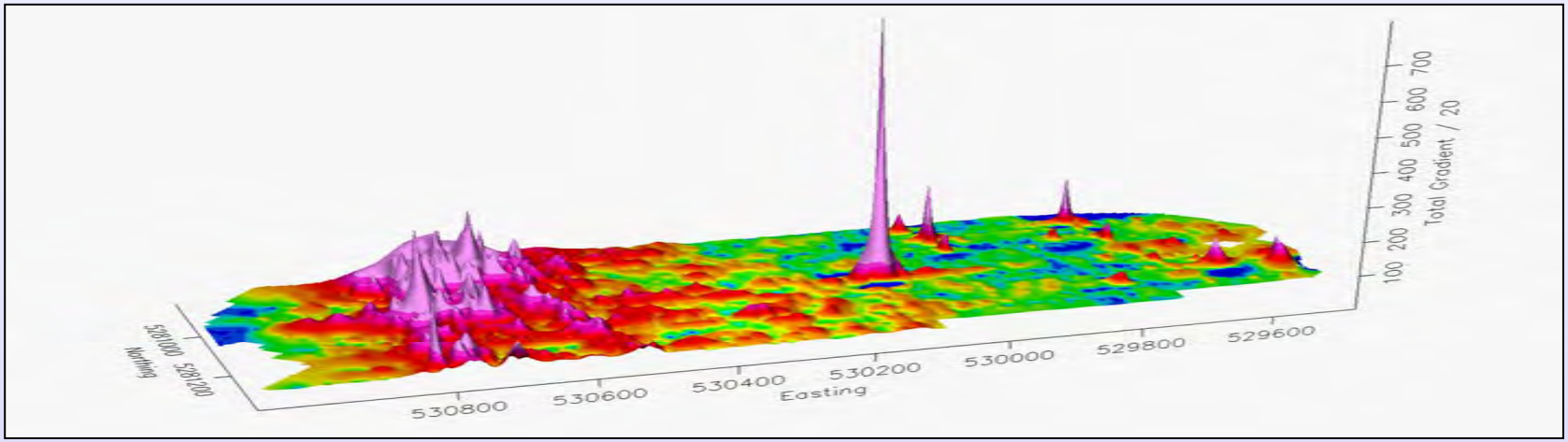
NAVSEA
WARFARE CENTERS
KEYPORT

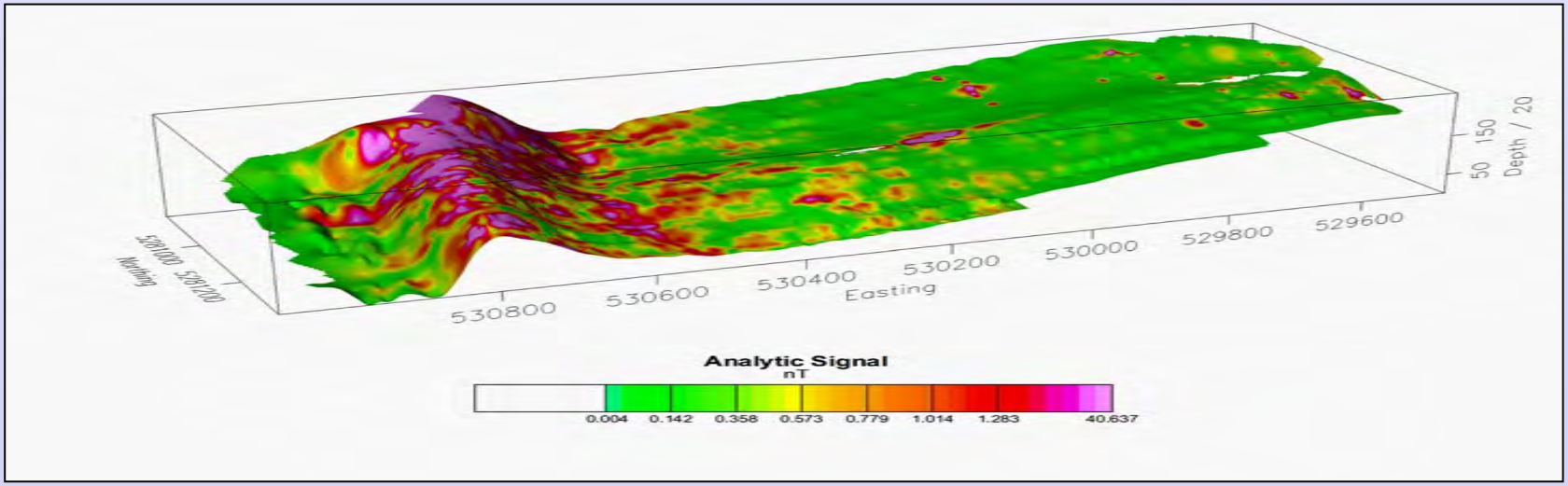
UMV TEST SITE CHARACTERIZATION
- EXAMPLE: GROUND-TRUTH BATHYMETRIC DATA SETS -



UMV TEST SITE CHARACTERIZATION
- EXAMPLE: AMBIENT MAGNETIC FIELD "GROUND TRUTH" -

Magnetic Area Survey Results at the Keyport VSW Range Site





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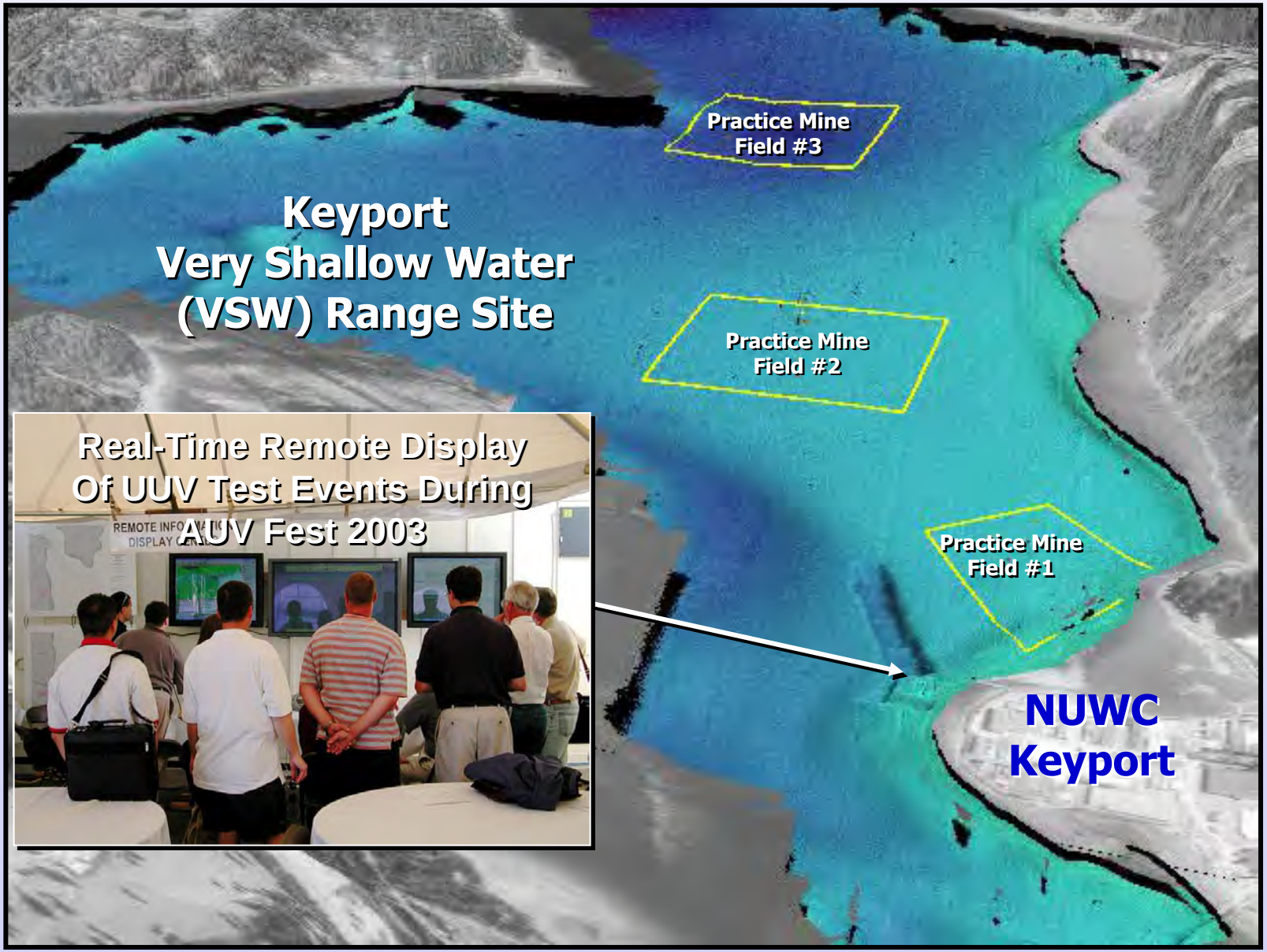
KEYPORT

VISUALIZATION TOOLS FOR UMV TEST SITES - EXAMPLE: KEYPORT VSW RANGE SITE -



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DEVELOPMENT OF SHARED UMV TEST CAPABILITIES CONTINUES IN SUPPORT OF NAVY PROGRAMS

NUTEC's Focus: Full-Spectrum UUV Testing & Training Support -- *Anyplace, Anytime*

Current Projects:

- ***Improved "Ground Truth" for UMV Tests & Fleet Exercises***
- ***Expanded UUV Signature Measurements***
- ***UMV Test Support / More Portable Capabilities***
- ***Remote & Distributed Testing & Rapid Exercise Analysis Tools***
- ***Capabilities to Enhance UMV Testing in Mission-Specific Environments***

NUTEC
National UUV Test & Evaluation Center

NAVSEA
WARFARE CENTERS
KEYPORT

SUMMARY

- **Technology Advances & Sea Trial Experiments are Bringing T&E Challenges & New UMV-Specific Requirements**
- **New UMV T&E Capabilities -- Designed to be Shared Across Programs & Used for All Phases of Vehicle Development -- are Being Provided to Help Meet These Challenges**
- **Navy UMV Programs are Encouraged to Participate in Addressing UMV-Community-Wide Issues Such as Ground-Truth Measurement Improvements & Standardized T&E Processes**
- **NUTEC is Meeting the Sea Trial and T&E Goals Set by the Chief of Naval Operations to:**
  - ***Accelerate Experimentation*** **of Distributed and Off-Board Systems**
  - **Streamline T&E Processes Through *Collaborative Efforts to Reduce the Navy's Cost for T&E***

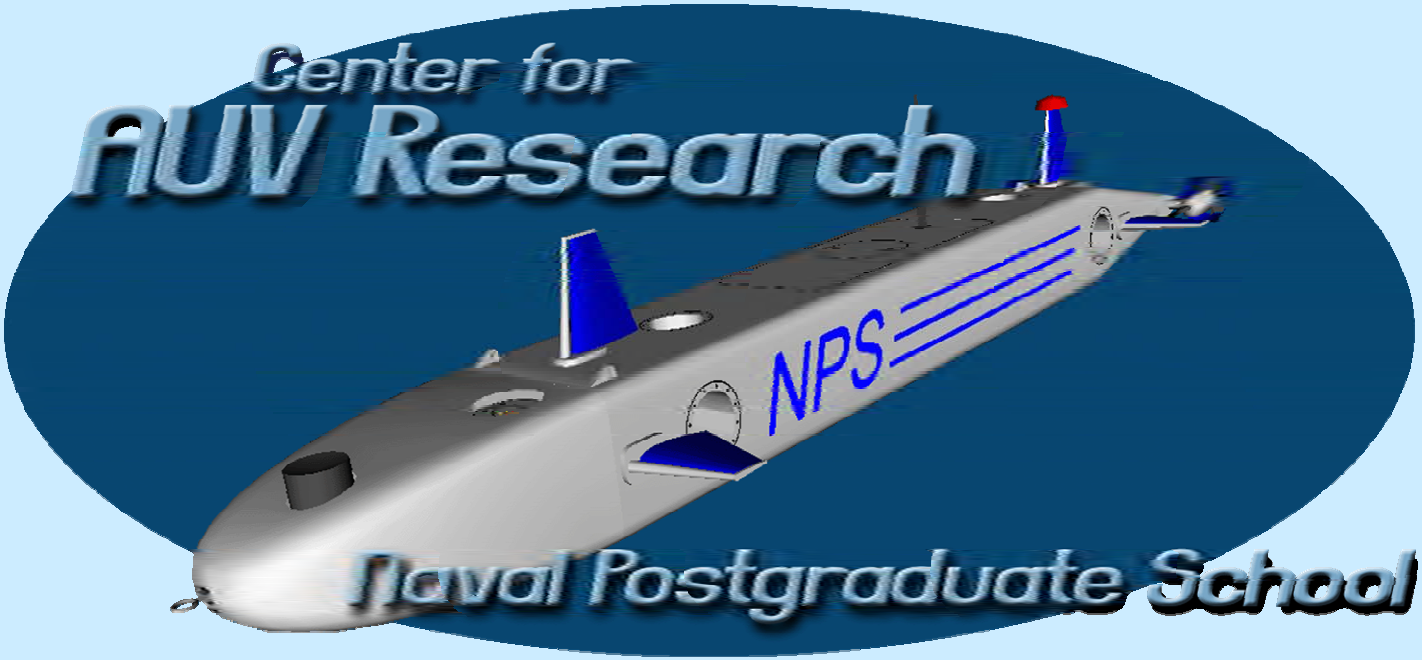
NAVSEA
WARFARE CENTERS
KEYPORT

Questions?

NUTEC
National UUV Test & Evaluation Center

NAVAL POSTGRADUATE SCHOOL

High Bandwidth Wireless Networks for Unmanned Maritime Vehicle Communications



by
Sean Kragelund

NAVAL POSTGRADUATE SCHOOL

Need Statement

- Unmanned Maritime Vehicles (UMVs) can collect environmental data quickly and economically
- Tactical applications (ISR, OMCM) can benefit from simultaneous deployment of multiple UMV systems
- Data must be collected, distributed, and assimilated into meaningful information quickly
- Volume of data can overwhelm existing comms systems
- **Higher bandwidth communications can significantly improve collaborative UMV missions**

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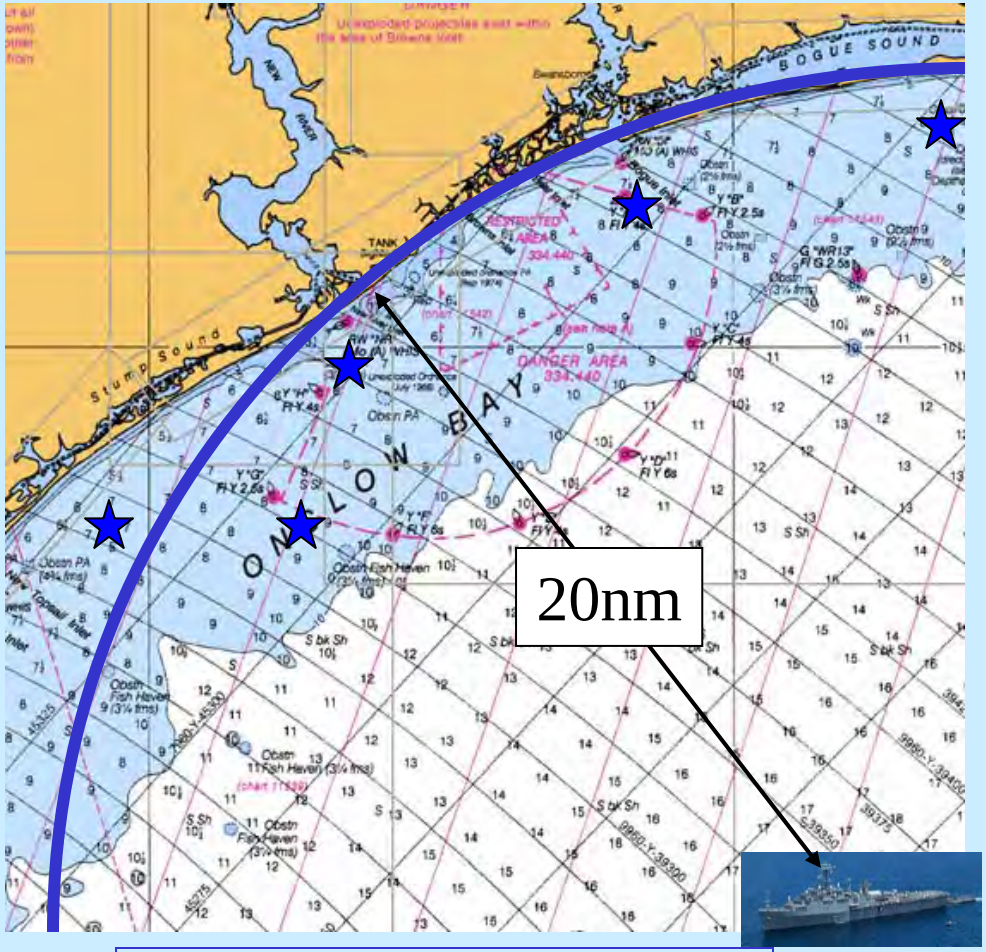
Operational Concept



- Blue Force tasked with finding the best beach landing site
- Teams of UMVs deployed for wide area reconnaissance & VSWMCM
- Challenges and considerations:
  - **Interoperability of different UMVs**
  - **Sonar, video, and bathymetry data is voluminous**
  - **Data must be passed back for rapid assimilation, assessment & planning**
  - **Not always feasible (or desirable) for vehicles to return from missions**

★ UMV (AUV, USV or Crawler)

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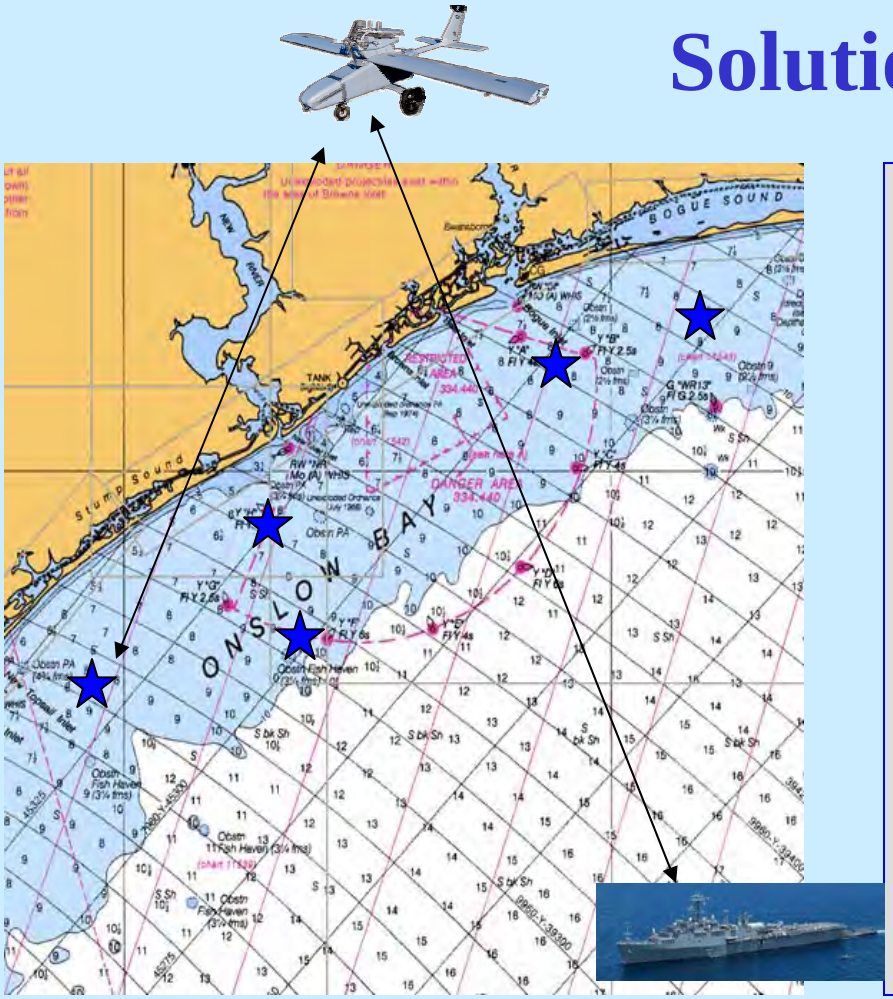
Solution



- Enable UMVs with high bandwidth data links (currently 802.11b)
- Employ UAVs to extend comms to C2 ship in international waters

BENEFITS

- Common WLAN architecture
- Overcome comms range limitations
- Increased UMV time on station
- Data transfer: no more “snippets”
- C2: facilitates coordinated behavior

★ UMV (AUV, USV or Crawler)

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NPS ARIES

(Acoustic Radio Interactive Exploratory Server)

FEATURES:

- 802.11B Wireless LAN antenna
- GPS, DGPS receivers, Kearfott INS
- 900MHz Freewave modem
- APL:UW Blazed Array Forward Look Sonar
- Benthos Telesonar Acoustic Modem
- RDI 600KHz ADCP
- Video Camera
- Digital Video Recorder

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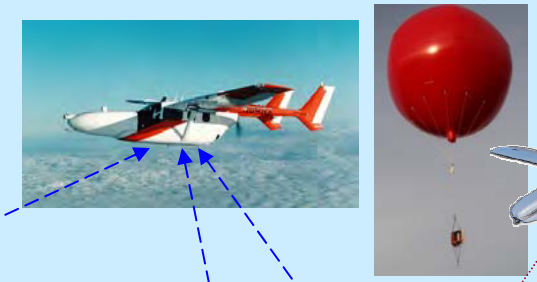
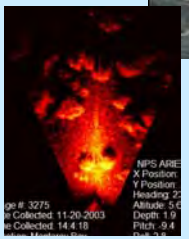
NPS Wireless Network Experiments

- Quarterly USSOCOM field experiments:
  - 2003-04: STAN
  - 2005: TNT
- Employ COTS networking equipment in operationally relevant scenarios
  - –Enhance warfighting capability of SOF with wireless links to vehicles and sensors
- Demonstrate tactical utility of WLAN
- Test & evaluate network performance and robustness on the battlefield





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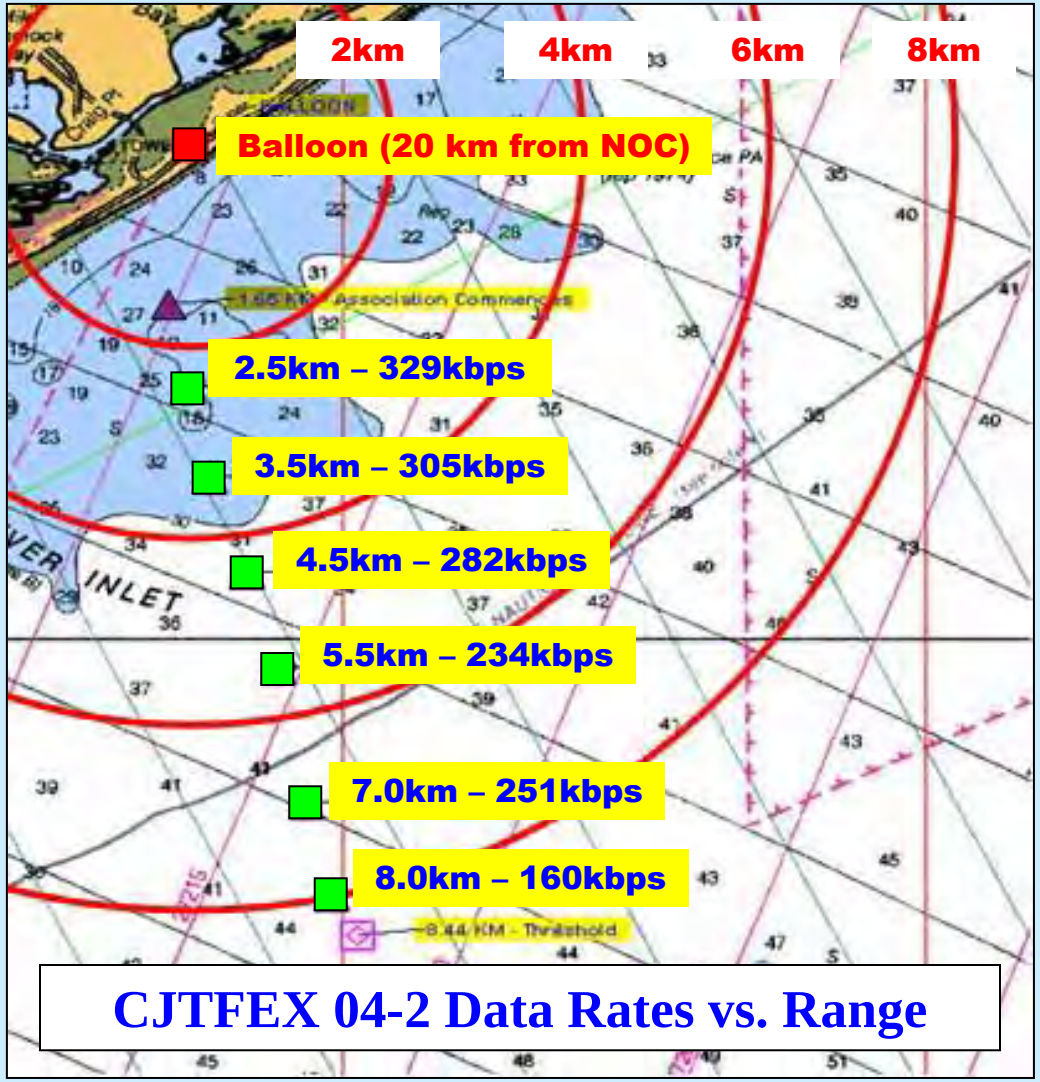
Experiment Results



CJTFEX 04-2 Data Rates vs. Range

IEEE 802.11b

- Provided a reliable TCP/IP compliant data link
- Total link length of 3 nodes with ranges out to 28 km
- File transfer rate vs. range:
  - 2 Mbps under 1 km
  - 500 kbps from 3 km to 22 km
  - 200 kbps at 28 km

IEEE 802.16 (OFDM)

- Max range (LOS) of 13 km
- Used for wireless backbone from NPS to CR (>150 km)
- Data rates up to 6 Mbps

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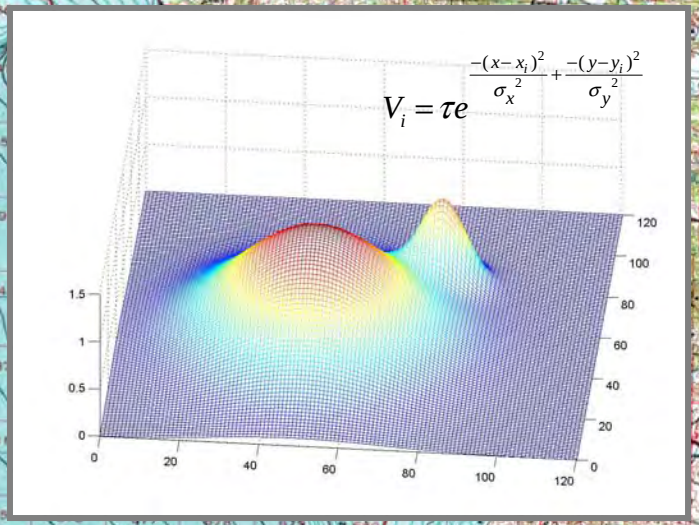
Optimal UAV Positioning



- UAV positioning is critical to maximize data throughput
- Signal strengths of surface nodes can be measured by spectrum analyzer
- Use sensory-based navigation to autonomously position the UAV for optimal throughput
- As surface vehicles enter/exit the network topology, UAV automatically repositions

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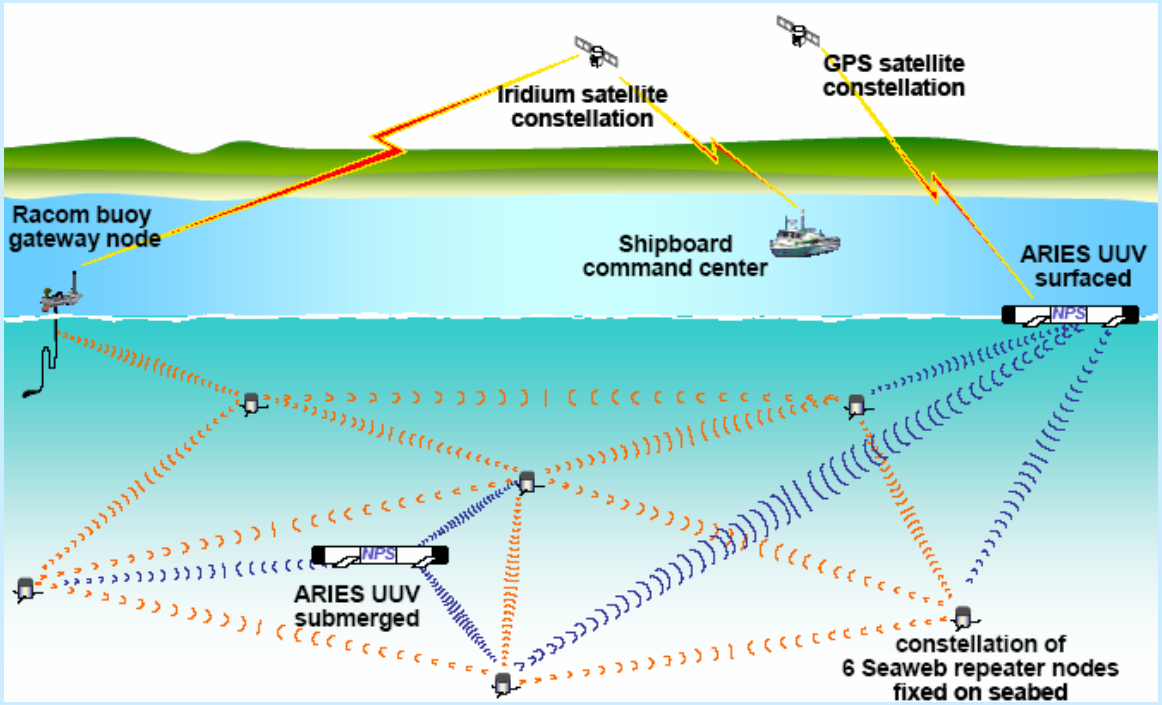
Seaweb Underwater Comms Network



- Extend command and control comms range (node-node distances of 2500 m)
- Ad Hoc underwater tracking and navigation aid
- Mobile nodes can function as data trucks or communications gateways

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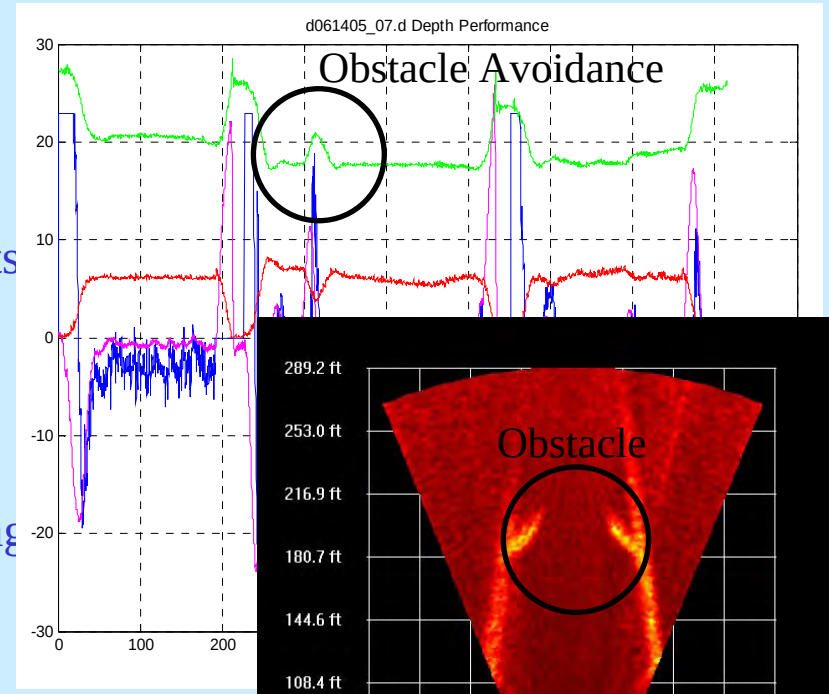
UMV Testing & Data Acquisition

High Bandwidth WLAN

- UMV-recorded data is available instantly
  - –Vehicle recovery not necessary
  - –Wireless download to operators and analysts
- More tests and data per range time
  - –Onsite mission review (i.e. navigation data or sonar imagery)
  - –Permits vehicle re-tasking or reprogramming



Seaweb Underwater Comms Network

- Ad Hoc underwater tracking range
- Extend command & control comms range

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Conclusion

- Benefits of COTS Wireless Networks for UMV T&E:
  - Low cost
  - Reliable
  - Readily available
  - Easy to administer
  - Industry standard protocols
  - Promote interoperability

- Issues requiring attention:
  - Easy to jam
  - Security considerations for sending classified data

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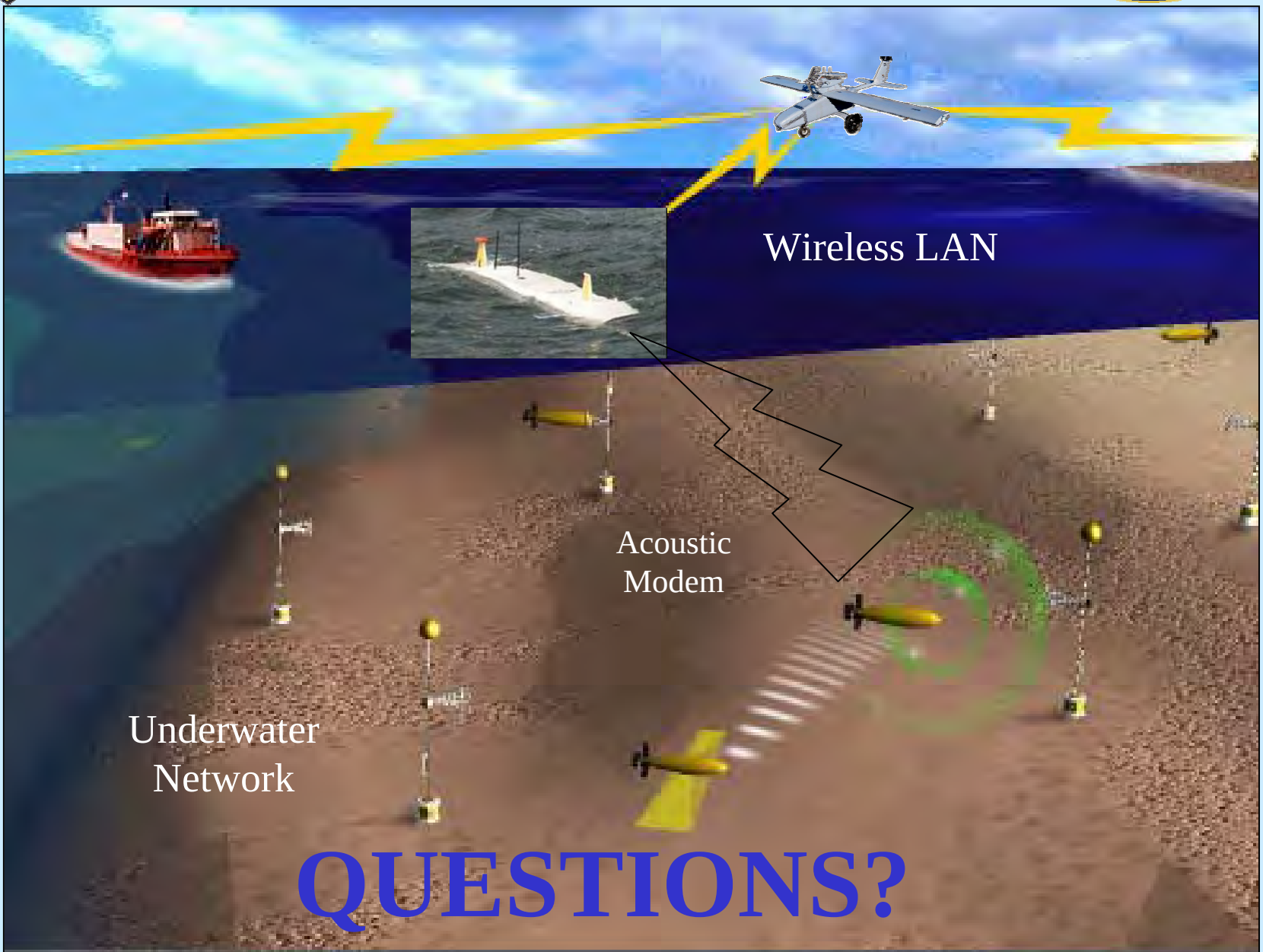

QUESTIONS?

Backup

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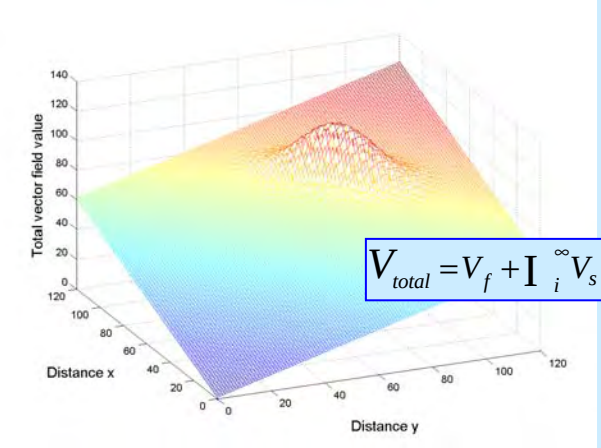
General Methodology

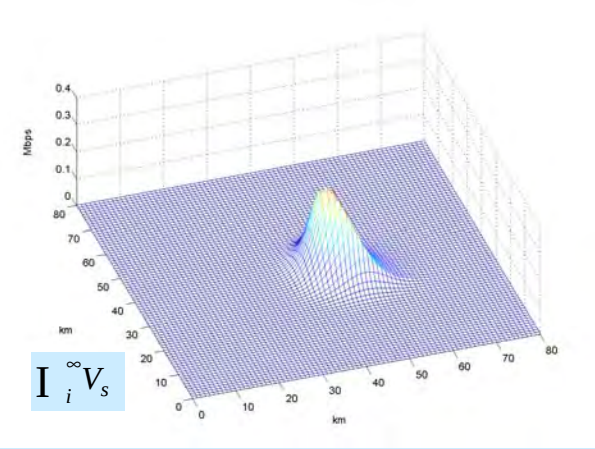
- Model signal strengths with representative Gaussian distributions
- Estimate the intersection of the distributions as another Gaussian fct.
- Use Artificial Potential Fields together with a Sliding Mode Controller to enable autonomous UAV navigation
- Using the intersection of signal strengths from the surface network nodes ensures that there exists at most one global maximum

Total Vector Field



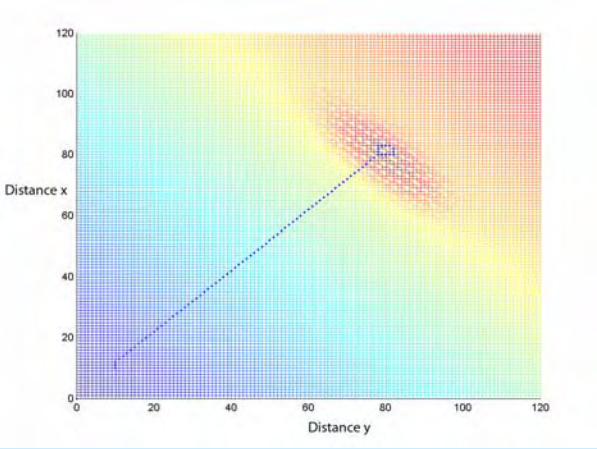
$$V_{total} = V_f + \mathrm{I}_i^{\infty} V_s \quad for\ i = 1..\infty$$

Intersection of Gauss Functions



$\mathrm{I}_i^{\infty} V_s$

Simulated UAV Nav



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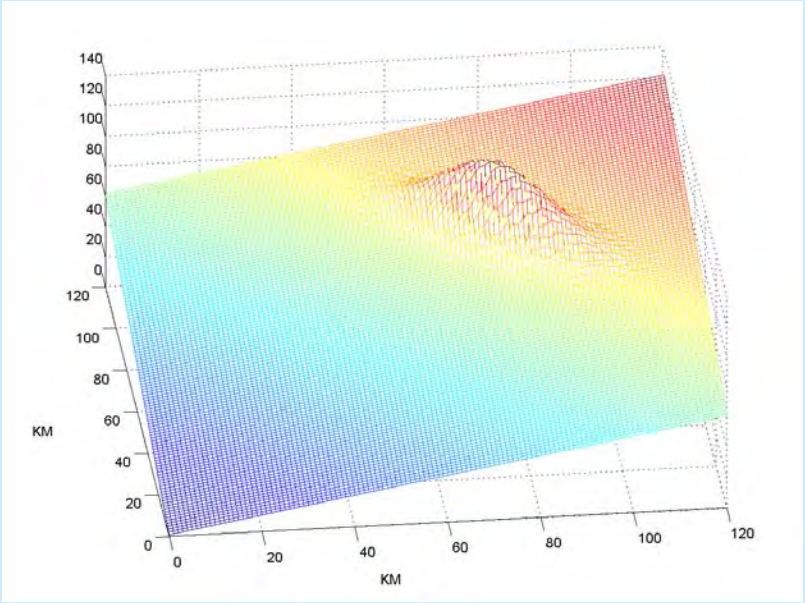
Sensory-Based Navigation

- The measured signal strength can be used for UAV navigation
- The intersection of multiple surface nodes signal strength is where the maximum data transfer rate should be.
- Artificial Potential Fields is a technique which can be applied for an autopilot algorithm for UAV navigation



Artificial Potential Fields

- Draws from Potential Field Theory in Physics
- APF traditionally thought of for Obstacle Avoidance
- Basic idea
  - A vector field is constructed consisting of a preferred path and obstacles
  - Desired path has an attractive force (gradient is steep)
  - Obstacles have a repellant force (gradient is shallow)
  - At each navigation step the field gradient is calculated and the vehicle navigations toward the steepest gradient

Artificial Potential Fields

- Limitations
  - –You need to be able to identify the obstacles in advance
  - –Trap situations can occur due to local minima
  - –Difficulties in passage between closely spaced obstacles
  - –Oscillations in the presence of obstacles
  - –Oscillations in narrow passages
- Good News
  - –For this particular application none of these present difficult issues for UAV navigation
  - –The Vector field is an intersection of signal strength vs an additive field so that calculation of the additional attractive object is straightforward.

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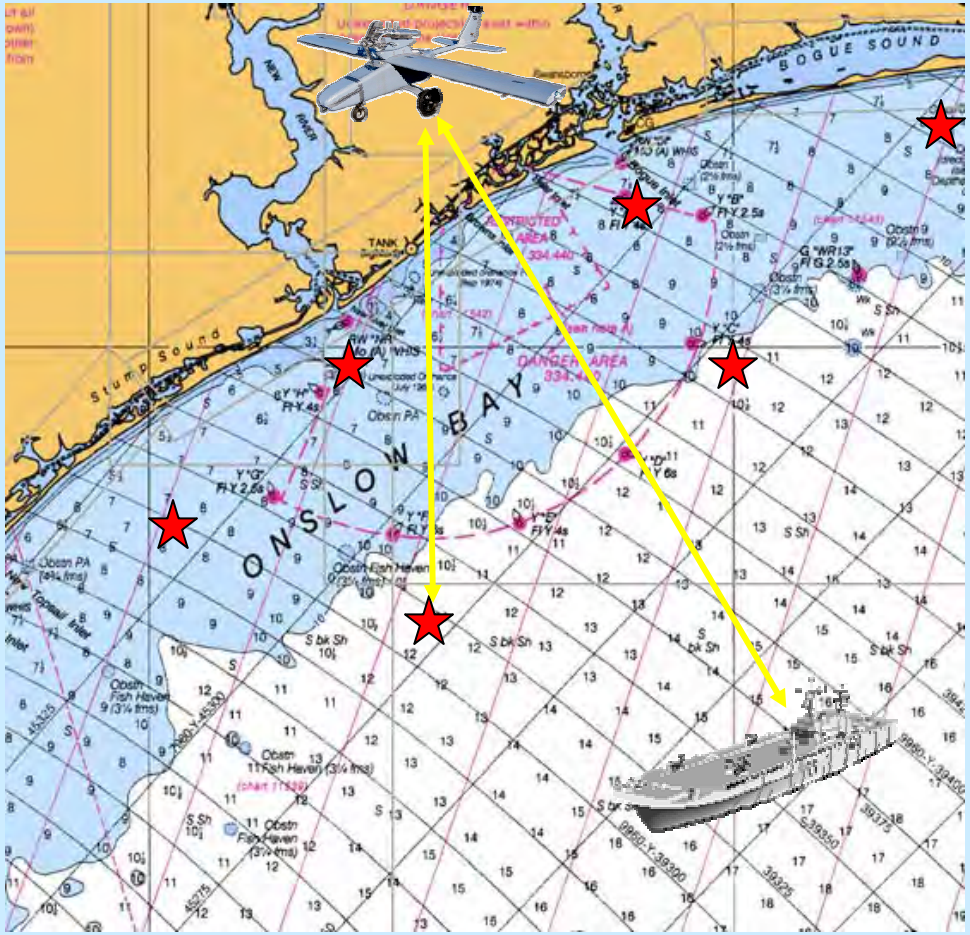
UAV APF Algorithm

(Conceptual Overview)

- Support vessel at sea
- AUV operations are underway
- UAV launches from the ship
- Through prior knowledge and over-flights UAV characterizes signal strength of sea nodes
- UAV start/defaults to waypoint nav
- When AUV surfaces Freewave msg (900MHz) sent to UAV giving position
- UAV calculates the Total vector field and reverts to APF Navigation
- When in vicinity UAV uses onboard sensors for fine tuning positioning



★ AUVs, Crawlers

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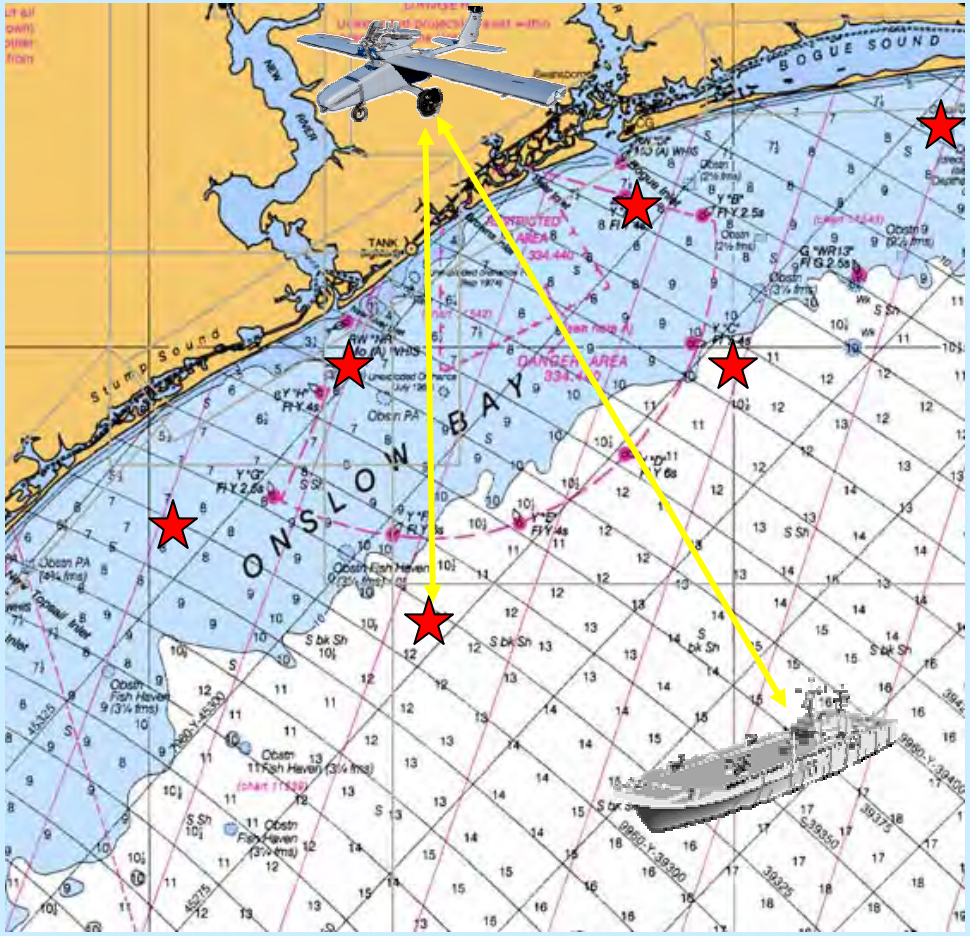
APF Algorithm

(Conceptual Overview - continued)

- As vehicles become available the intersecting calculations determine if there is an optimal position
- If no optimal position is available UAV continues with present loitering position until data transfer is complete
- AUV waiting to transfer data either waits for the UAV to reposition or continue on its mission
- Many other variants possible
  - –UAV collects from one node and acts as a data bus



★ AUVs, Crawlers

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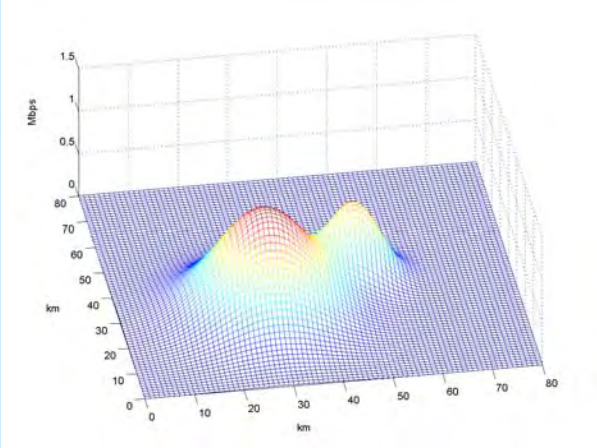
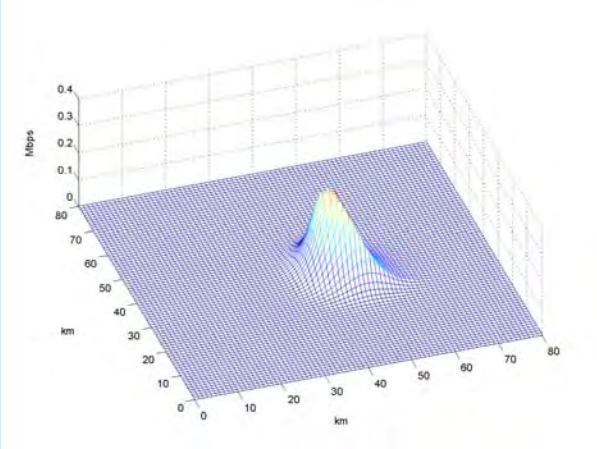
APF UAV Navigation

(Mathematical Steps)

- Initially using a Gaussian equation to model the SNR ratios of the surface vehicles.
- Construct the intersecting volume – again modeled as Gaussian volume using the max/mins to determine σ_x σ_y
- Orient the volume to the vector field through Euler azimuth tranformation
- Bearing calculated based on the highest gradient in the vector field

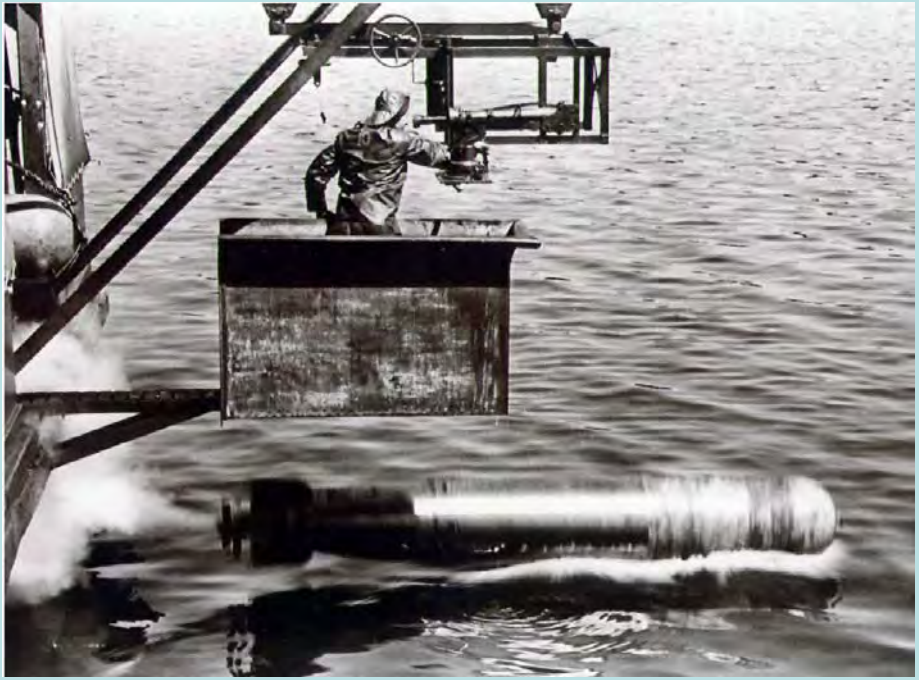




UUVs at War: Operation Iraqi Freedom

…[UUVs] were the main workhorses of the mine clearing effort …"

- LT Richard Haas, USN, OIC, NSCT-1



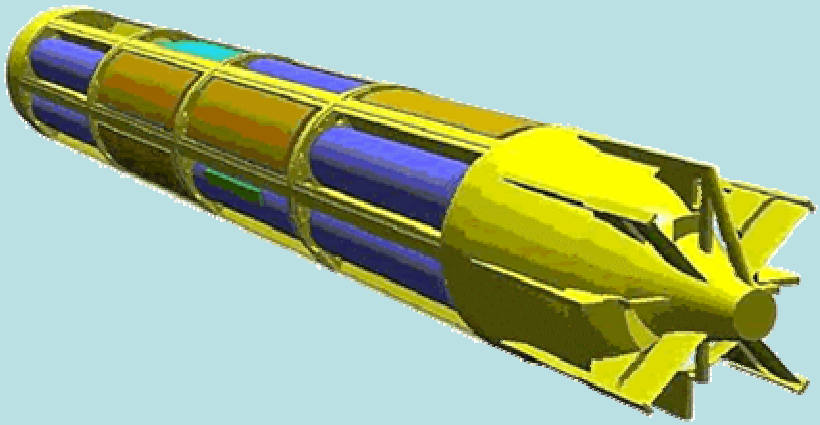
Early T&E at Keyport

AUV Fest 2005 Demonstrations Supporting Navy UUV Master Plan Objectives

	Number of Demonstrations
FORCEnet	
Intelligence, Surveillance and Reconnaissance (ISR)	9
Oceanography (OC)	8
Communications/Navigation Network Node	10
SEA SHIELD	
Mine Countermeasures (MCM)	22
Anti-Submarine Warfare (ASW)	4
Inspection/Identification (ID)	9
SEA BASE	
Payload Delivery (PD)	2
SEA STRIKE	
Information Operations	3
Time Critical Strike	2

Participants

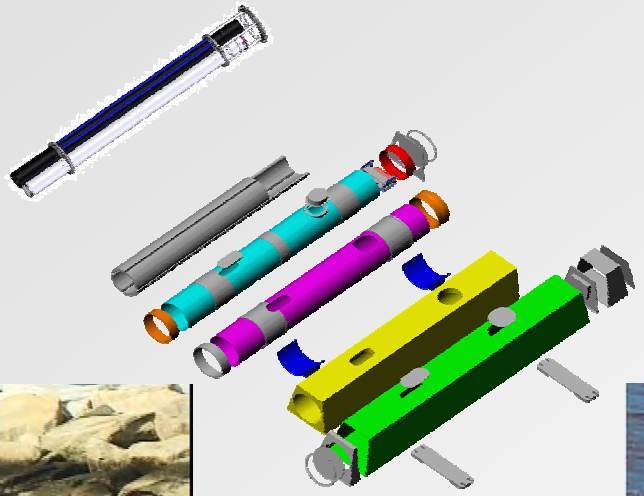
Alaska Native Technologies	Slocum Glider
APL / University of Washington	Seaglider
ARL:University of Texas	COIN
Autonomous Undersea Systems Institute	Solar AUV
Bluefin Robotics Corp	Bluefin 12 (12.75" Diameter UUV)
Florida Atlantic University	Gateway Buoy
Hydroid, Inc	REMUS (SW)
Lockheed Martin Perry Technologies	CETUS II RIN
MIT	CARP
NAVAIR	Autonomy Software
Naval Oceanographic Office	HUSCy (USV)
Naval Postgraduate School	ARIES
Nekton Research LLC	Ranger
Nekton Research LLC	TransPhibian
NSCT-1	UUV Operations
NSWC Panama City	Bluefin 9 - SEA LION
NSWC Panama City	CRAWLERS
NSWC Panama City	REMUS UUV and ASH USV
NSWC Panama City / WHOI	REMUS 600 (12.75" Diameter UUV)
NUWC Keyport	CTEC ISR Vehicle Simulation
NUWC Keyport	HAIL (Acoustic Communications)
NUWC Newport	BioRobotic AUV
NUWC Newport	ISR Simulation
NUWC Newport	MARV (12.75" Diameter UUV)
SPAWAR San Diego	GAVIA 8" UUV
Woods Hole Oceanographic Institution	REMUS (VSW)



SEAHORSE UUV

Seahorse UUV Launch from SSGN

Advanced Surface Launcher (ASL)



Prepared by:
Michael Connelly (NUWCDIVNPT 4124) and Dave Lussier (SEA CORP)

Prepared for: NDIA UMV Conference
June 15, 2005

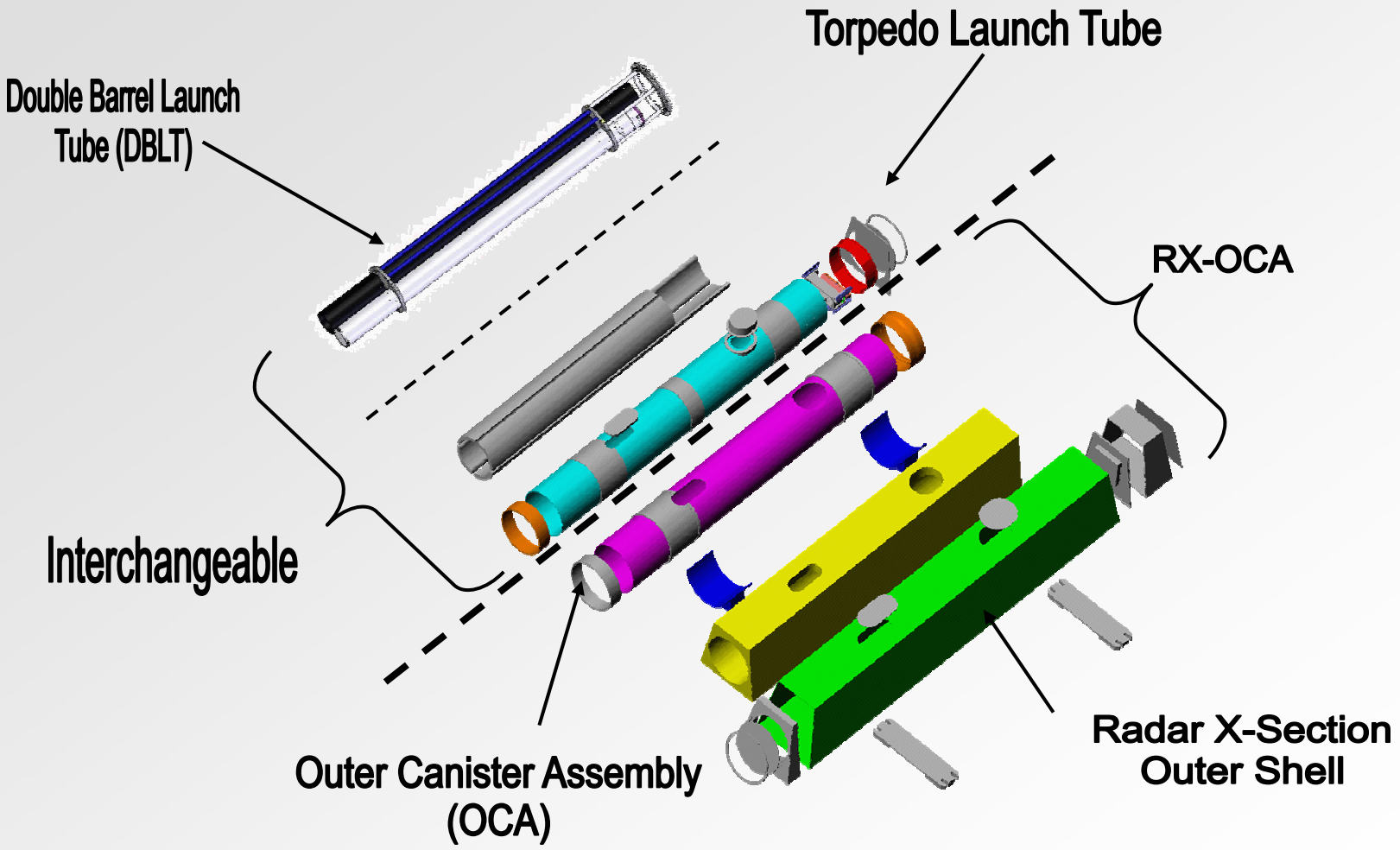
Agenda

- ASL Overview
- Summary of Testing Conducted
  - *Millennium* High Speed Ferry Testing
  - 11M USV Testing
- ASL Road Ahead Summary
- UMV Applications

Why ASL?

- **Proven**
  - **Mechanically at Technology Readiness Level 7**
- **Supports All-Up-Round (AUR) Concept**
- **Modular**
  - **Can be configured for a variety of platforms and payloads**
- **Commonality across different Navy Platforms**
- **Reliable**
- **Cost Effective**
- **Maintenance friendly (no high pressure air)**
- **Simple to configure/operate**
  - **Well suited for autonomous operations**

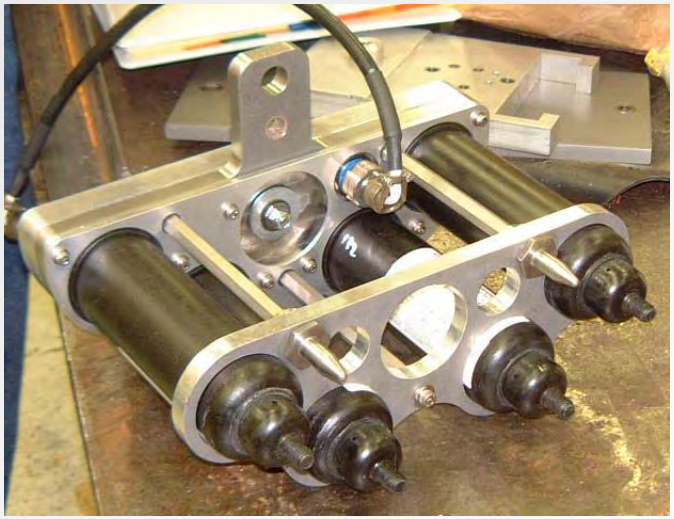
ASL Components Overview



Advanced Surface Launcher Concepts

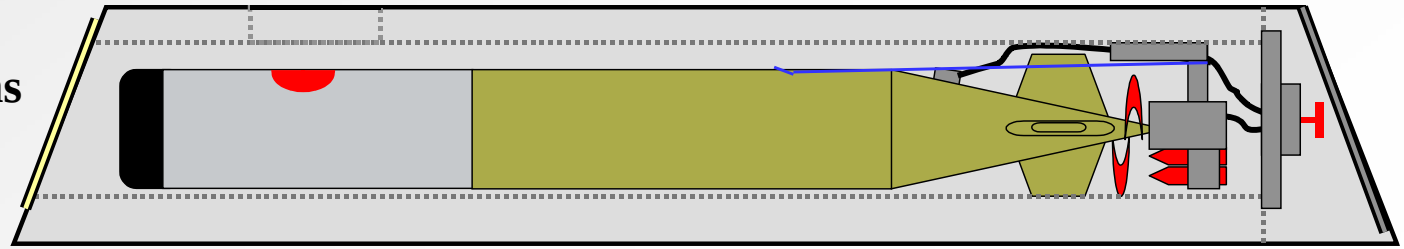
COTS AUTOMOTIVE AIRBAG INFLATORS

- Environmentally Benign
- Maintenance Free w/ Extended Service Life
- Inherently Safe & High Reliability
- Controllable & Predictable
- Simple Electrical Interface
- DoD Hazard Classification Completed (2.2)



"SMART" ALL-UP-ROUND LAUNCH CANISTERS

- Self-Contained Launch Functionality
- Seamless Interface to Fire Control
- Low Maintenance
- Unmanned Stations



Torpedo Launch Tube Assembly (Built and Tested)

Compatible With Torpedoes MK 46, 50 and 54
(Shown with Torpedo MK 50 Installed)

Summary of Testing Conducted

May 2004
Millennium
High Speed Ferry

January 2005
11M RHIB
Manned USV

May 2004 Test Platform
Millennium - High Speed Ferry

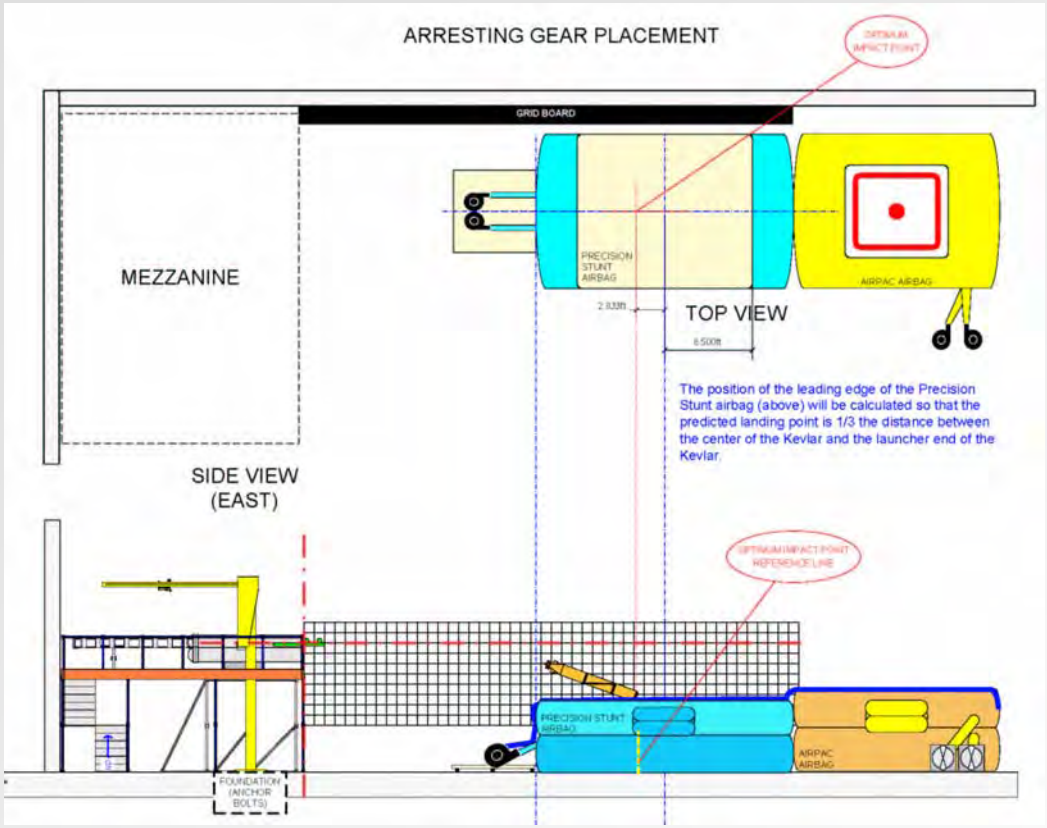
LOA: 122 ft Beam: 33 ft Power ~ 5200 HP Speed: > 35 kts
Launcher Height: 28 ft (waterline to barrel center)

Land Based Prerequisite Testing Summary

LAUNCH #	DATE OF LAUNCH	SHAPE	WEIGHT	TLS ELEV	# OF INFL	ACTUAL ACCEL (g)	ACTUAL PRESSURE (PSI)	ACTUAL EXIT VEL (FPS)	COMMENT
T-0	23-Apr	AIR-SLUG	N/A	HORIZ	4	N/A	N/A	N/A	AIR-SLUG TO TEST LICS TO ASL SUBSYSTEM INTERFACES.
T-1	26-Apr	54R	359	HORIZ	3	N/A	25.0	43.6	INITIAL MK 54 LAUNCH
T-2	26-Apr	54R-I	361	HORIZ	4	10.9	26.5	60.6	SECOND LAUNCH INTRODUCES INSTRUMENTATION TO REXTORP
T-3	26-Apr	50R	440	HORIZ	4	N/A	31.7	*54.8*	INITIAL MK 50 LAUNCH
T-4	27-Apr	50R	440	HORIZ	4	N/A	31.7	52.6	SECOND LAUNCH FOR REPEATABILITY
T-5	27-Apr	50R	361	HORIZ	3	N/A	31.2	*34.5*	START PROGRESSIVE INFLATOR FAILURE TESTS 4-3-2-1.
T-6	27-Apr	50R	361	HORIZ	2	N/A	32.0	18.5	CONT PROGRESSIVE INFLATOR FAILURE TESTS 4-3-2-1.
T-8	28-Apr	54R-I	361	HORIZ	3	No Data	26.9	*37.0*	R&D AND/OR DEMO LAUNCHES.
T-9A	30-Apr	54R-I	361	HORIZ	4	10.0	26.2	*57.1*	

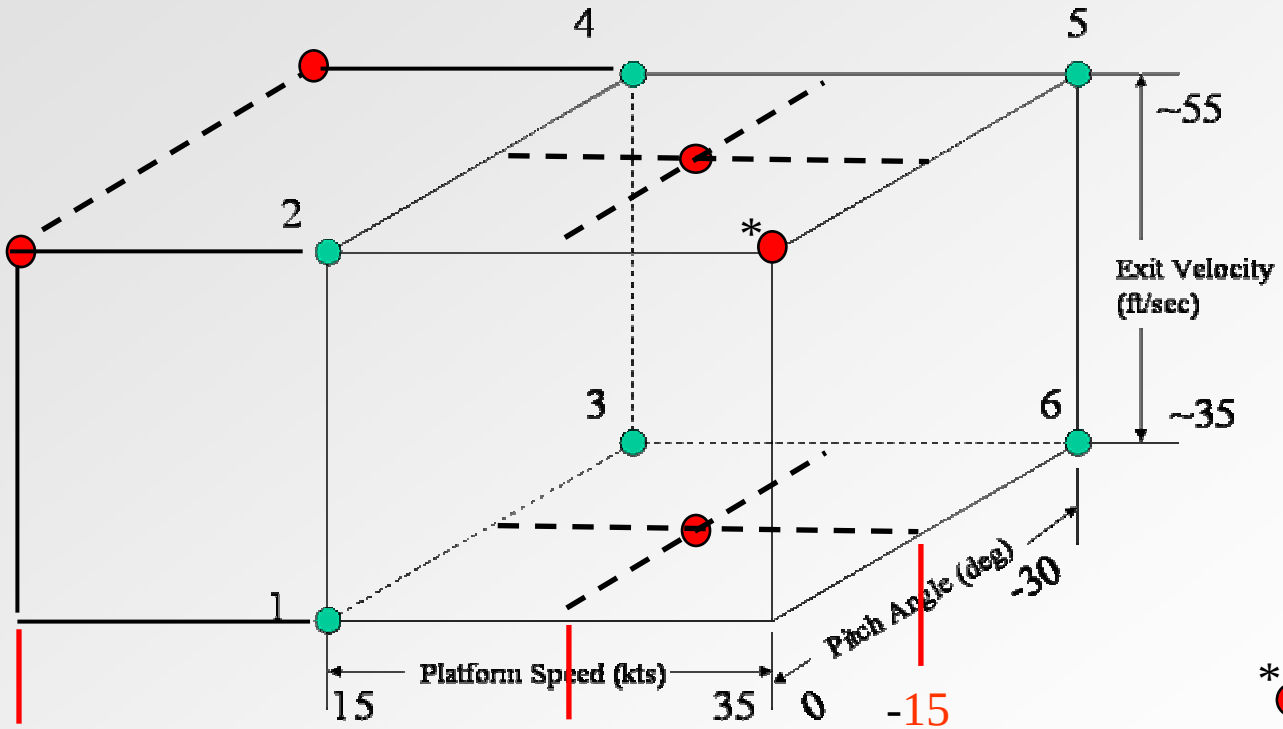
Land Based Prerequisite Testing Facility

SEA CORP Dynamic Test Facility (DTF)



Actual Launch window
MK 54R-I Torpedo

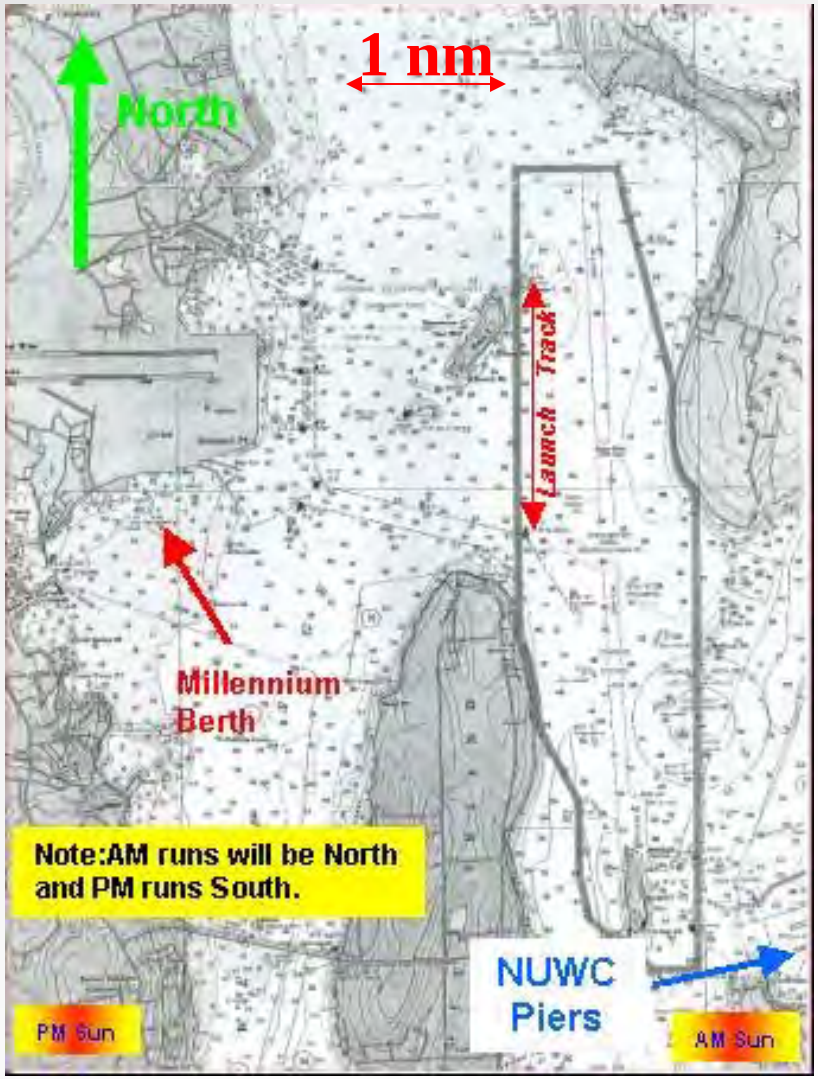
12 Launches Conducted
All Instrumented



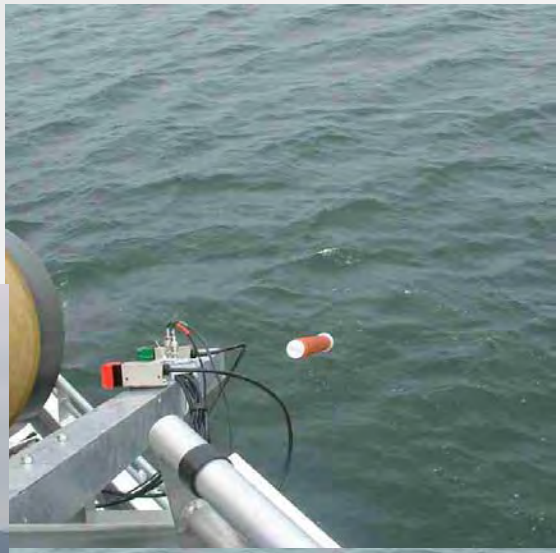
- Planned Test
- Additional Test Conducted
- * Two Launches conducted

Test Location

- **NUWCDIVNPT shallow water test range in Narragansett Bay**

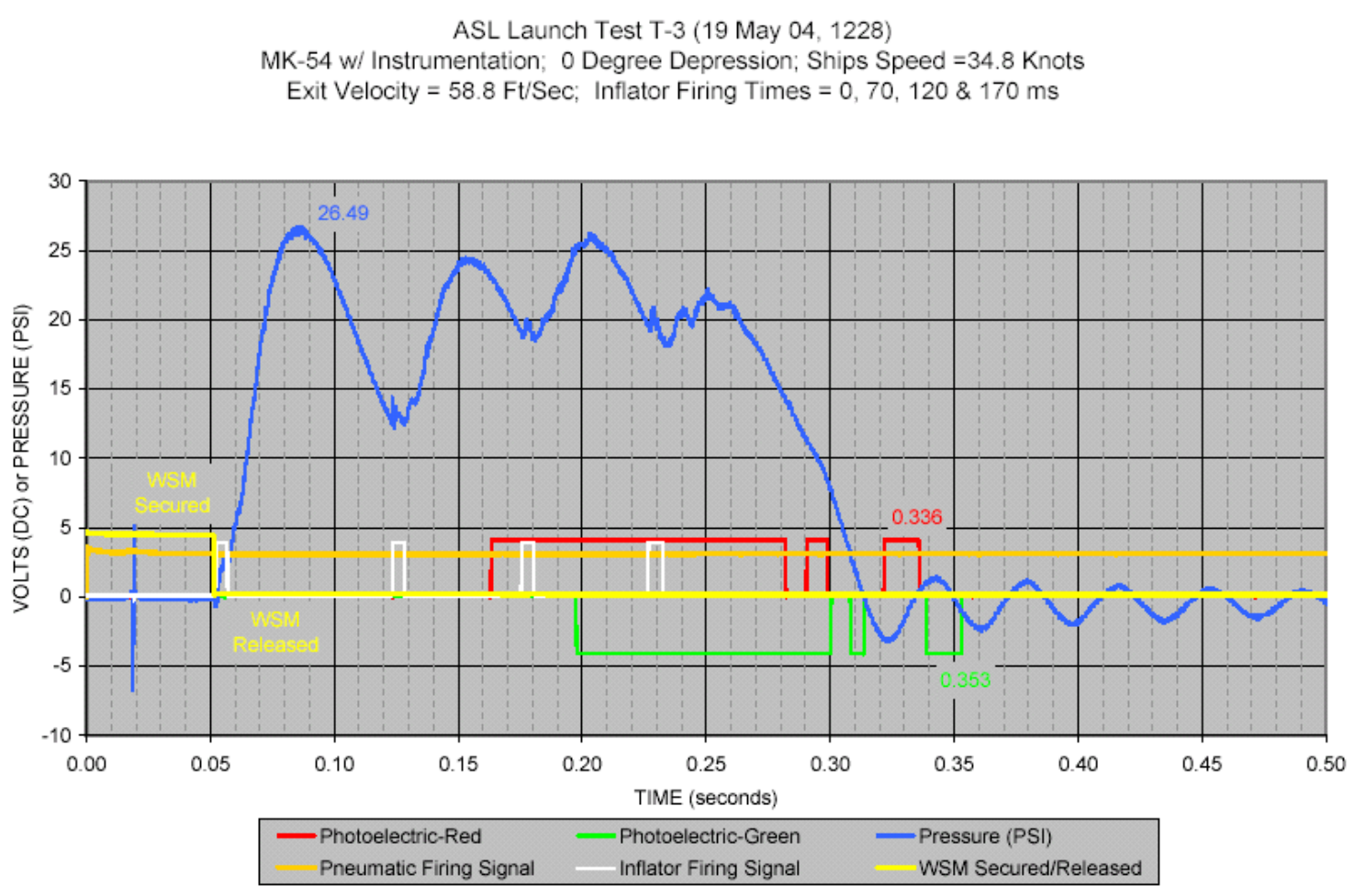


Test Images
(Countermeasure Launch)

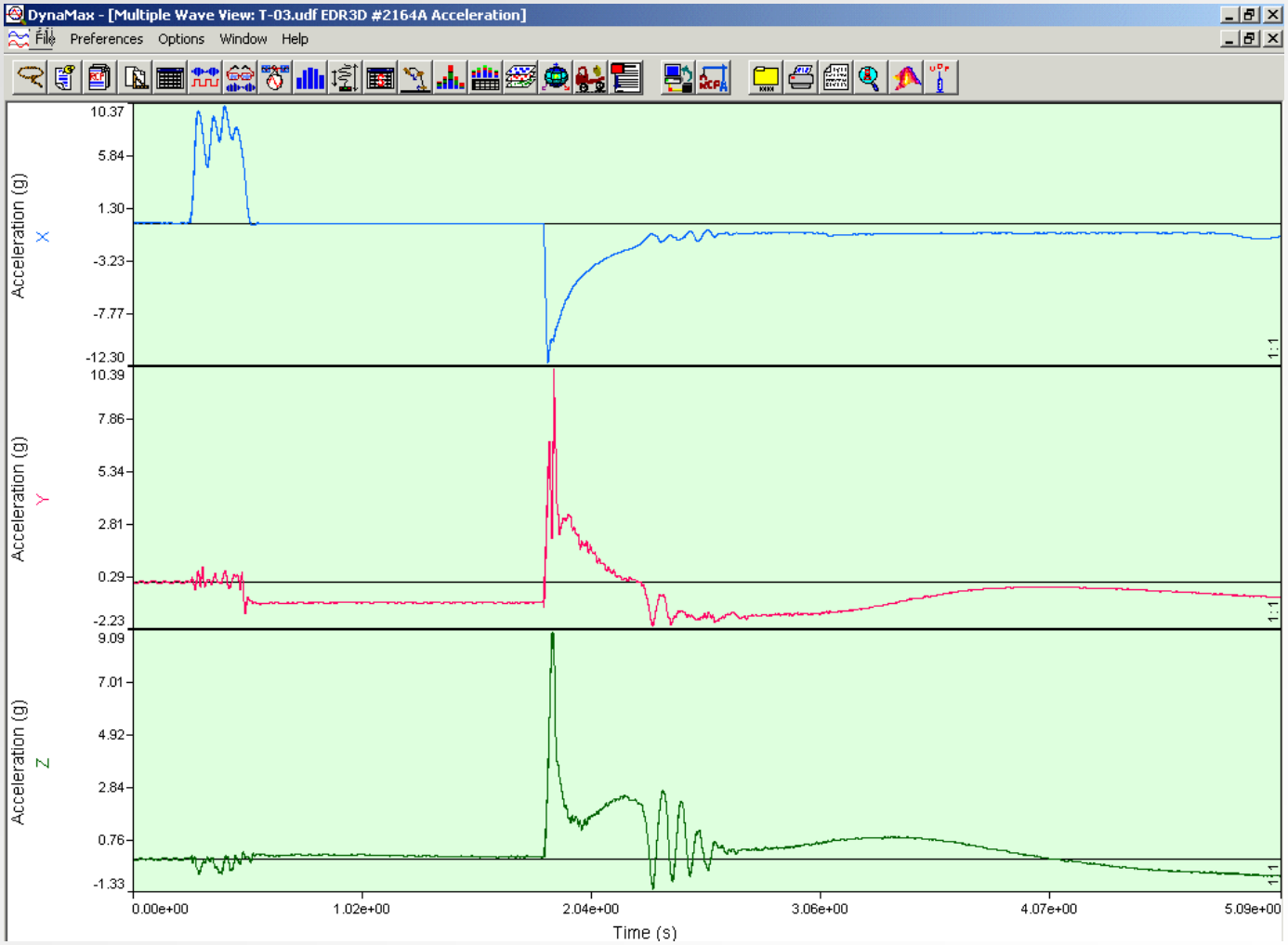


Test Images
(MK 54 REXTORP Launch)

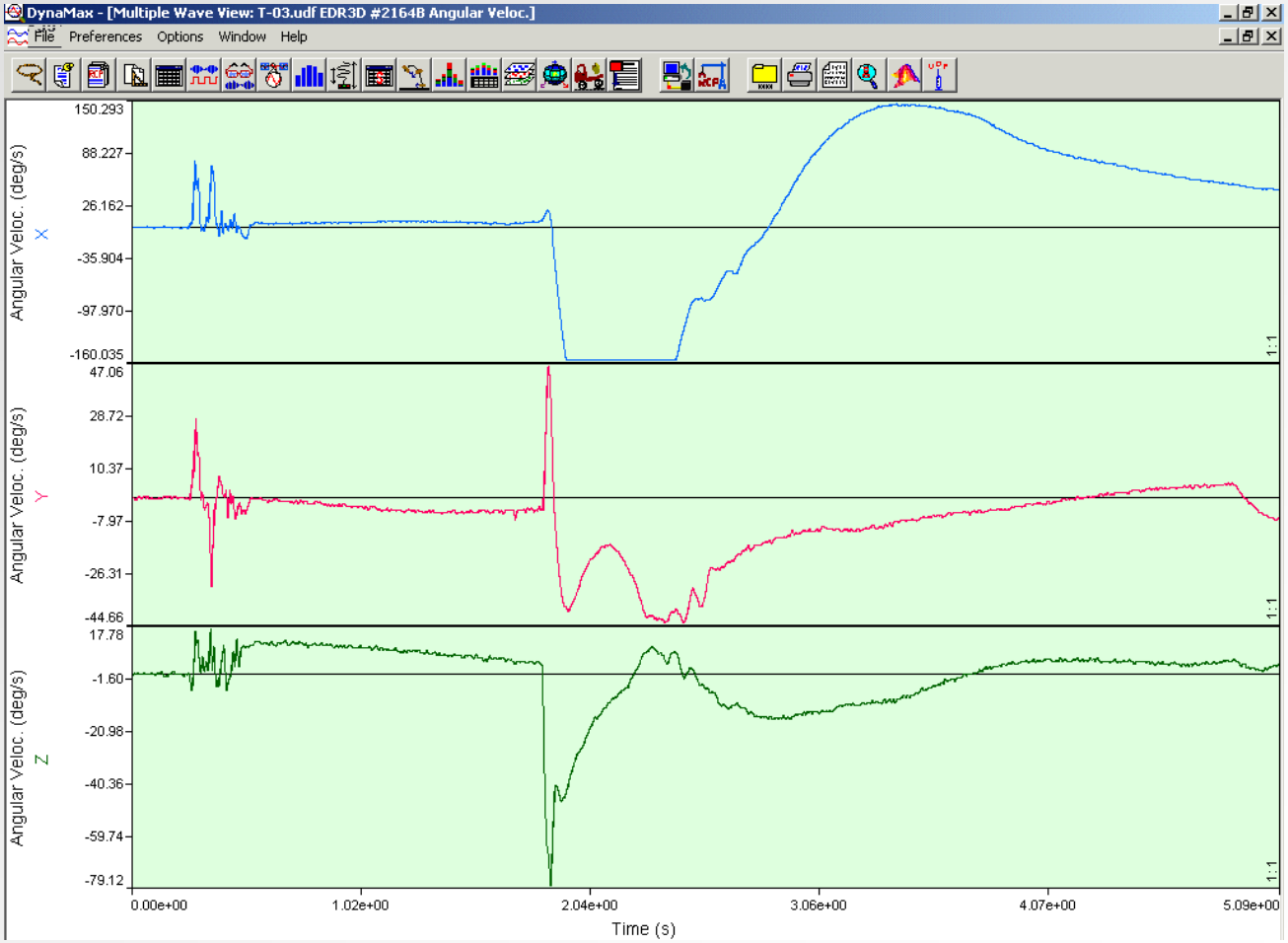
Sample of Launcher Instrumentation Data



Sample of Motion Master Acceleration Data

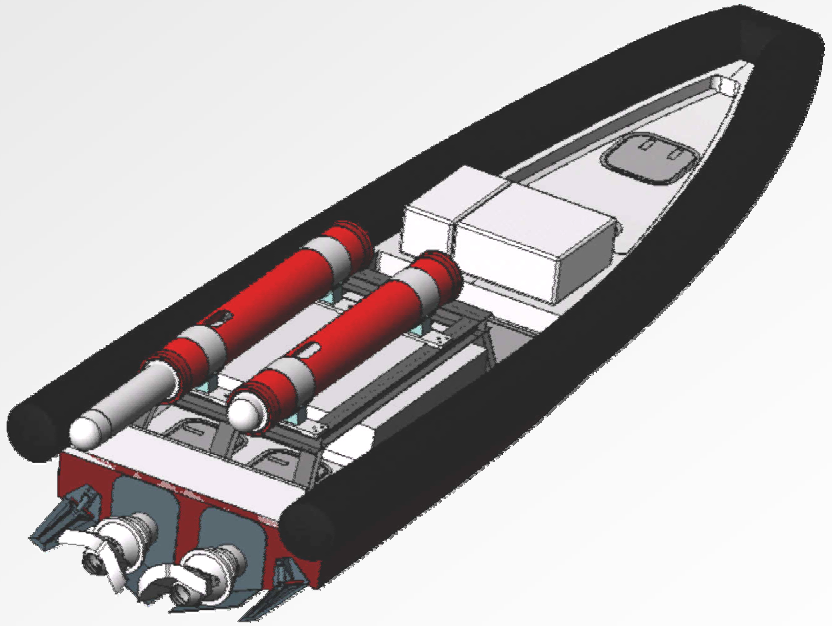


Sample of Motion Master Rate Sensor Data



JAN 05
11M RHIB/ASL Test Objectives

- Demonstrate 11M RHIB capability to support ASL launch dynamics
- Evaluate ASL performance with:
  - various launch platform speeds
  - various test shapes
  - various launch exit velocities



11M RHIB/ASL

Land Based Prerequisite Testing Summary

DAY	LNCH #	SHAPE	WEIGHT	INFL TYPE APH-1A	INFL TYPE ASH 2.2	MAX PRESSURE (PSI)	MAX REACTION FORCE (LBS)	EXIT VELOCITY (FT/SEC)	COMMENT
ONE 10/27	T-0	AIR-SLUG	N/A	5	1	N/A	N/A	N/A	
	T-1	50L	440	3	1	28.8	3675	34.8	
TWO 10/28	T-2	50L	440	3	1	28.3	3611	34.8	
	T-3	50L	440	3	1	32.1	4096	35.7	
	T-4	46H	518	3	1	27.9	3560	31.3	
	T-5	50L	440	3	1	29.4	3752	34.5	Confirm booster drops Max pressure by 2-3 psi when compared to T-1 and T-3.
THREE 10/29	T-6	50L	440	3	0	30.2	3854	34.5	Without Booster. Repeat of Millennium shot with heavier LWT.
	T-7	54H	606	3	1	26.6	3394	30.3	Motion Master trigger point not reached.
	T-8	54H	606	3	1	26.9	3433	29.4	
	T-9	50H	753	3	1	32.7	4173	25	
	T-10	54H	606	5	1	27.3	3484	45.5	
FOUR 11/1	T-11	54H	606	5	1	27.8	3548	43.5	Noticed 3rd peak about 2 psi lower then T-10. Believe due to inflator KPA variation.
	T-12	50H	753	3	1	30.1	3841	24.4	Measured Strain on Breech Plate.
	T-13	50L	440	4	1	30	3828	55.6	Measured Strain on Breech Plate.
	T-14	50H	753	5	1	31.3	3994	41.7	Measured Strain on Breech Plate.
FIVE 11/2	T-15	50H	753	5	1	30.3	3867	40	
	T-16	46H	518	5	1	29.7	3790	47.6	With pinger attached to propeller using muffler bracket. No damage to pinger.
SIX 11/8	T-17	46H	518	5	1	27	3445	47.6	With pinger attached to propeller using muffler bracket. No damage to pinger.
			TOTAL:	69	17				

Grey shade indicates low speed Time Delays for SPARTAN Testing

Purple shade indicates high speed Time Delays for SPARTAN Testing

Test Parameters

- Payload Configurations
  - Torpedo shapes 440-750lbs
  - CM shape @ 140lbs
- Low and High exit launch velocities
  - 25 ft/sec → 59 ft/sec
- Various Boat Speeds
  - Dead in the Water (DIW) to 10kts
    - Constraint of 10kts due to current test support fixture design
    - Expect flank speed capability in future testing

11M RHIB/ASL JAN 05 Demo Run Table/Results Summary

LNCH#	SHAPE	WEIGHT	BOAT SPEED (kts)	# INFLATORS		MAX PRESSURE (PSI)	ACTUAL EXIT VELOCITY (FPS)	SHAPE MAX G's						11-M RHIB MAX G's		
								Launch			Water Entry					
				APH-1A	ASH 2.2			X	Y	Z	X	Y	Z	X	Y	Z
T-0	N/A	N/A	5	5	1	N/A	N/A									
T-1	50L	440	5	3	1	29	34.8*									
T-2	54I	608	5	3	1	25.9	29.4	5.3	0	0	0	3.1	0	0.5	0.7	0.6
T-3	50H	753	5	3	1	27.8	24.4							0.8	1.8	3.2
T-4	50L	440	10	4	1	27.3	55.6*							0.8	2.1	1.2
T-5	54I	608	5	5	1	27.8*	43.5*	5.7	0	0	0	1.7	0	0.5	1.2	1
T-6	54I	608	10	5	1	27.8*	43.5*	5.8	0	0	0	2	0	0.7	1.9	1.6
T-7	50H	753	10	5	1	30.3*	40*							0.8	3.2	3.9
T-8	54I	608	DIW	5	1	25.9*	29.4*	5.2	0	0	0	3.2	0	0.4	1.3	1.5
T-9	50H	753	DIW	5	1	30.3*	40*							0.8	1.5	2.2
				ASH 2.2	ASH 2.1											
CM-0	ITD	140	DIW	2	1	N/A	N/A									
CM-1	ITD	140	5	0	1	73	27									
CM-2	ITD	140	5	1	1	110.3	43.5									
CM-3	ITD	140	10	2	1	110.4	58.8									

* No pressure & velocity data available (used DTF data)

Axes Definitions:

X: Fore/Aft

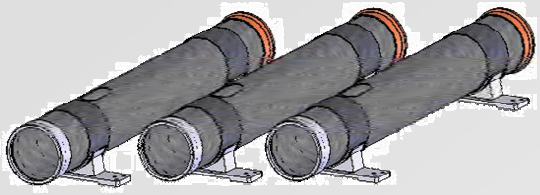
Y: Athwartships

Z: Vertical

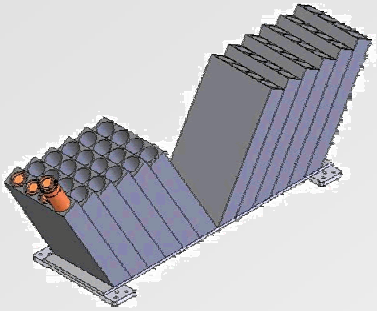
11M RHIB/ASL JAN 05 Demo Video

LCS ASW Mission Module Component Options

Launched Payloads *Common Mechanical Footprint + Common Electrical Interface to USV*

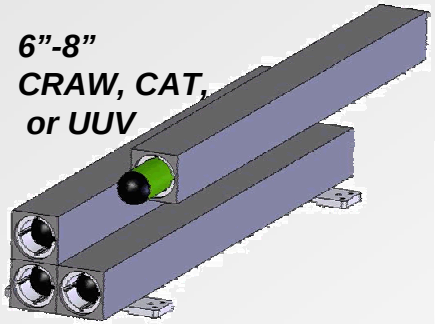


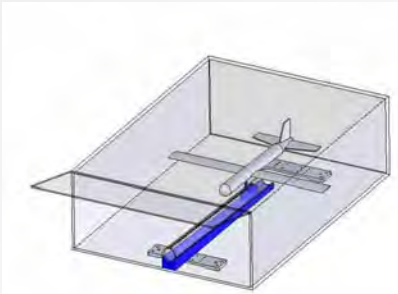
Mk 54 Torpedoes or 12.75" UUVs



Sonobuoys
EMATTs
or UAVs

6"-8"
CRAW, CAT,
or UUV

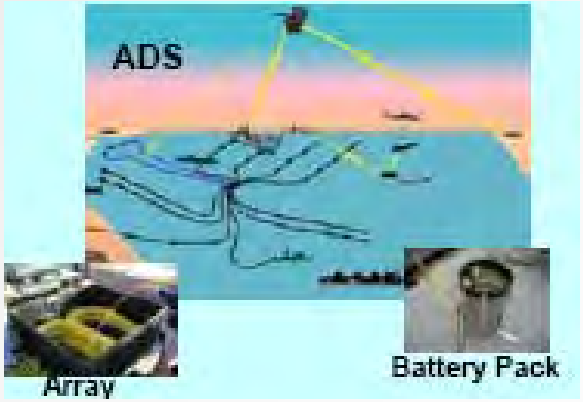


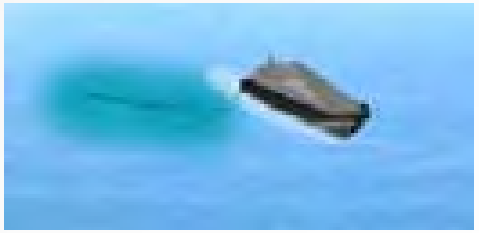


UAV

Sensors *Deployable from MH-60R, same USV, other USV, or LCS host*

ALFS





Towed Array

ASW Mission Module Component Options (cont)

- **Many combinations exist for equipping USVs with ASW components**
  - **USV payload weight constraint**
    - **Tradeoff with fuel capacity/USV range/duration/Sea Frame constraints**
  - **ASW mission must be modeled/optimized to choose best mix of components for deployment on USV**

For any combination of launchable payloads:
The ASL Team can design/build/prototype/test any combination that will be reliable for autonomous launch from a USV.

ASL Team recommendation: Out of the 90+ combinations of USV ASW components, focus on ~10-15 and design the structural interface to the USV for "plug & play" for those combinations. Give the warfighter flexibility in theatre.

ASL Road Ahead Summary

ASL Configurations
Block Definitions

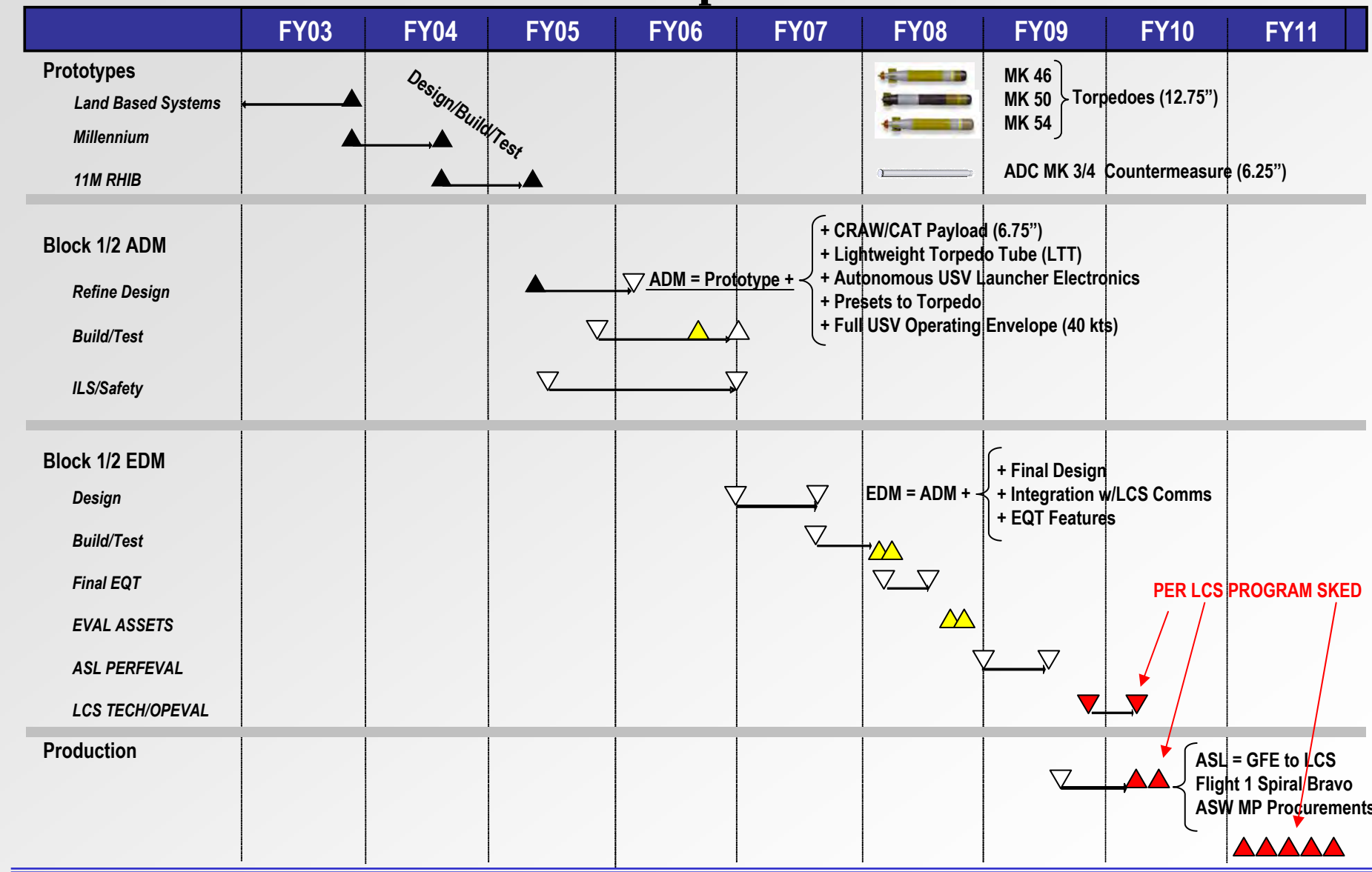
Prototype → ADM → EDM → Production

ASL Block 1 = Mk54 torpedo capability from an 11M USV

PLATFORMS

PAYLOADS				**USV**	**DDG 51**	**LCS**	**DD(X)**	**TBD**
	TORPEDOES		MK 54	*1*	*3?*			
			MK 50		*3?*			
			MK 46					
	6X	6.75	CRAW	*2*				
			CAT	*2A?*				
		6.25	ADC CMs	*2*				
	SLC		Sonobuoys					
			EMATT					
	UAVs		SLC (Coyote)					
			SWARM					
	3X		ADC CMs					
			SSXBT / SSXSV / Others					
			Pyros / Smokes					
	UUVs		MARV					
			UUV TBD					

Advanced Surface Launcher (ASL) Block 1 Development Schedule



Current ASL Developments

- **Currently working on the following ASL ADM Block 1 development tasks:**
  - **New 11M RHIB (USV) ASL mounting structure**
    - **Supports full USV operational envelope (35kts+ and sea state 3)**
  - **New ASL Electronics**
    - **Supports autonomous USV torpedo preset and launcher control**
  - **New Lightweight Torpedo Tube (LTT)**
    - **Same principle as internal torpedo tube used in JAN 05 demo**
      - **Without Outer Canister Assembly (OCA)**
      - **Lighter weight**
  - **New lightweight 6.25” payload (ADC Mk3/4) launcher development**
  - **New lightweight 6.75” payload (CRAW/CAT) launcher development**

Summary

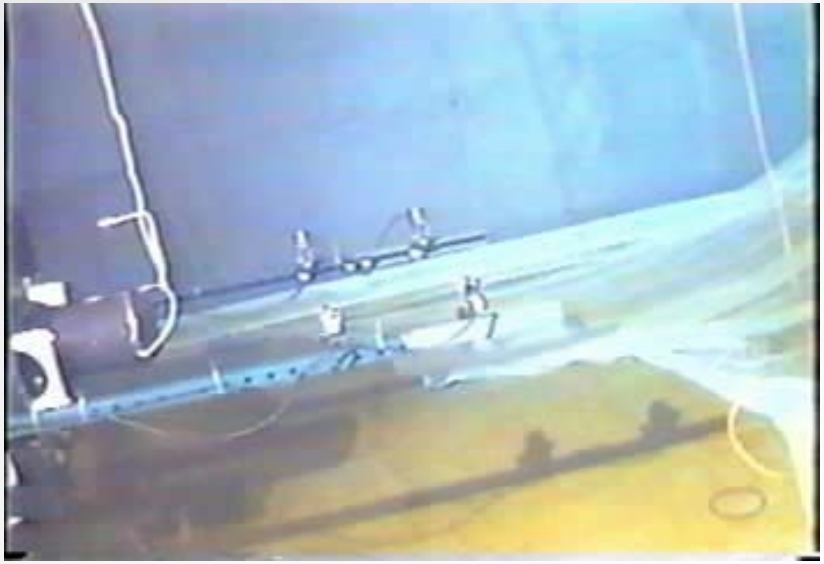
- **ASL Concept of Launch:**
  - **Optimal for autonomous and reliable launch operations**
  - **Proven through at-sea testing**
  - **Capable of being configured for multiple payload types**
- **ASL development for other payloads can be done simultaneously as current Block 1 initiatives**

UMV Applications

- 12.75” UUV (MARV)
  - Easy adaptation of existing torpedo configuration to MARV
  - Must accommodate antenna or redesign retractable antenna
- Other UUVs or UAVs
  - Given payload launch exit velocity and max acceleration, ASL can accommodate virtually any payload size/shape from any platform

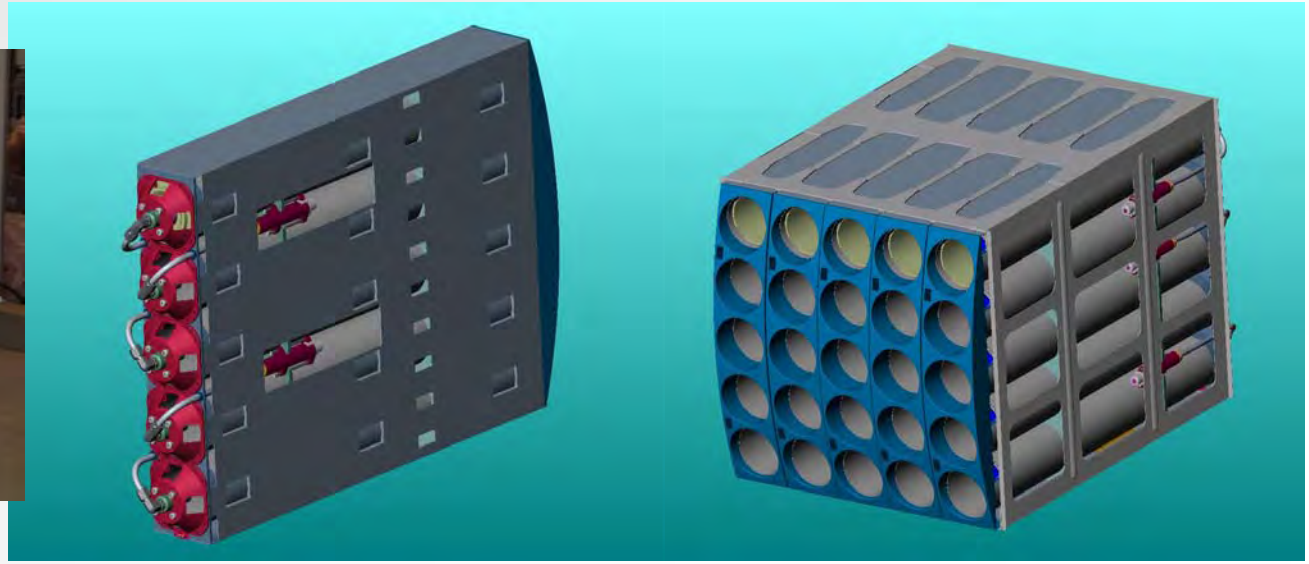
UMV Applications (cont)

- **Underwater Launch**
  - **During SBIR Phase II, SEA CORP designed/built a pressure balanced launcher for a 6.25” ADC countermeasure shape (164 lbs)**
    - **Exit velocity at ~35 fps at 15’ depth**
    - **Capable of going higher if required**



UMV Applications (cont)

- **Sonobuoys and other SLC payloads**
  - **Through a SBIR Phase II with NAVAIR**
    - **SEA CORP is currently designing/building a modular launcher for the MH-60R helicopter**
    - **First launch tube built/tested**
    - **Working on networked 25 tube modular system**



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NORTHROP GRUMMAN

DEFINING THE FUTURE

Design and Testing of the Spartan USV Mine Warfare Module

14 June, 2005

Dr. Robert Mons
Sr. Advisory Engineer
Northrop Grumman Corporation

Acknowledgement

This work was sponsored by The Naval Undersea Warfare Center under Contract N66604-01-9-126B

NORTHROP GRUMMAN

Agenda

- Spartan USV and MIW Module
- Requirements
- AQS-14/24 Payload
- L&R Design
- Testing and Operation
- Conclusions

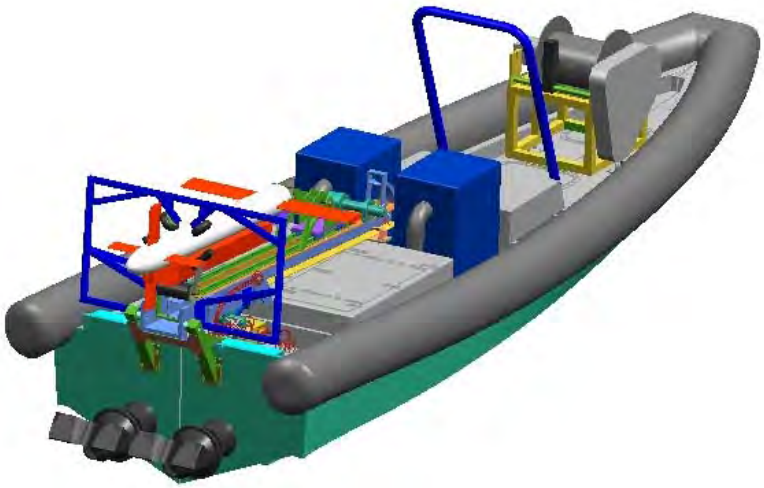
Agenda

- **Spartan USV and MIW Module**
- Requirements
- AQS-14/24 Payload
- L&R Design
- Testing and Operation
- Conclusions

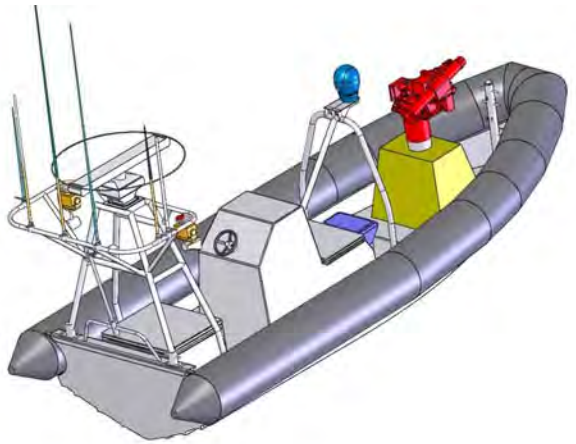
NORTHROP GRUMMAN

Spartan is Developing Three Modular Payloads

- 11 M RHIB



- 7 M RHIB



- MIW Module

Subject of This Paper

- ISR & Force Protection
- ASW Module (French)

SPARTAN Scout ACTD

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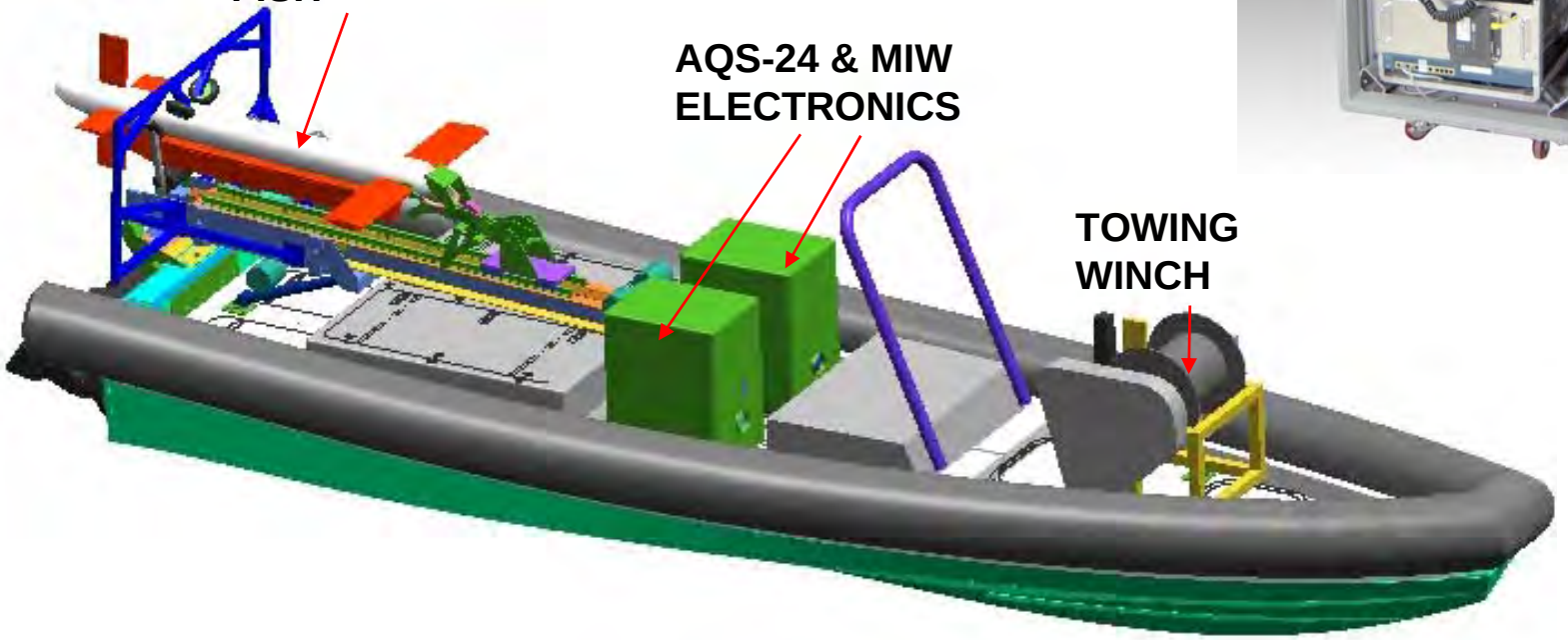
MIW Module Provides Capability for Remote Operation from USV

HOST OPERATOR'S CONSOLE

AQS-24 TOW FISH

AQS-24 & MIW ELECTRONICS

TOWING WINCH



SPARTAN Scout ACTD

NORTHROP GRUMMAN

Agenda

- Spartan USV and MIW Module
- **Requirements**
- AQS-14/24 Payload
- L&R Design
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Key Requirements for MIW Module

- Modular design to facilitate interchangeability
- Positive restraint of towfish when stowed (for high speed transit)
- Semi-automated L&R control with future transition to “one button” and autonomous operation
- Weight limit of 3690 lbs
- Water Depths up to 200 Ft (170 Ft tow depth)
- Operate up to Sea State 3
- Maximize Area Coverage Rate (tow speed)
- Withstand wave slap load of 500 psf

SPARTAN Scout ACTD

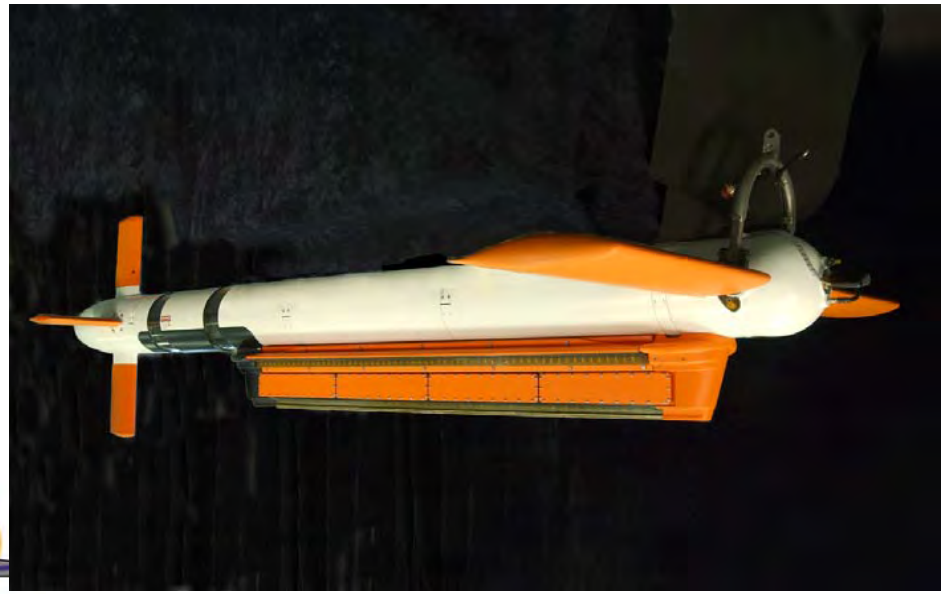
NORTHROP GRUMMAN

Agenda

- Spartan USV and MIW Module
- Requirements
- **AQS-14/24 Payload**
- L&R Design
- Testing and Operation
- Conclusions

AQS-14/24 Tow Fish Is Suited To USV Operation

- **High resolution SLS to detect & classify bottom mines**
- **112 Inches L X 64 Inches W. Weight 550 Pounds**
- **Key features**
  - Bottom tracking or constant depth modes.
  - Can operate at different SLS resolutions to accommodate radio link bandwidth.



SPARTAN Scout ACTD

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On Board Electronics Are Mostly NDI

Space for Switch if needed to interface w Core Radio link

L&R Computer Controls winch and L&R mechanism

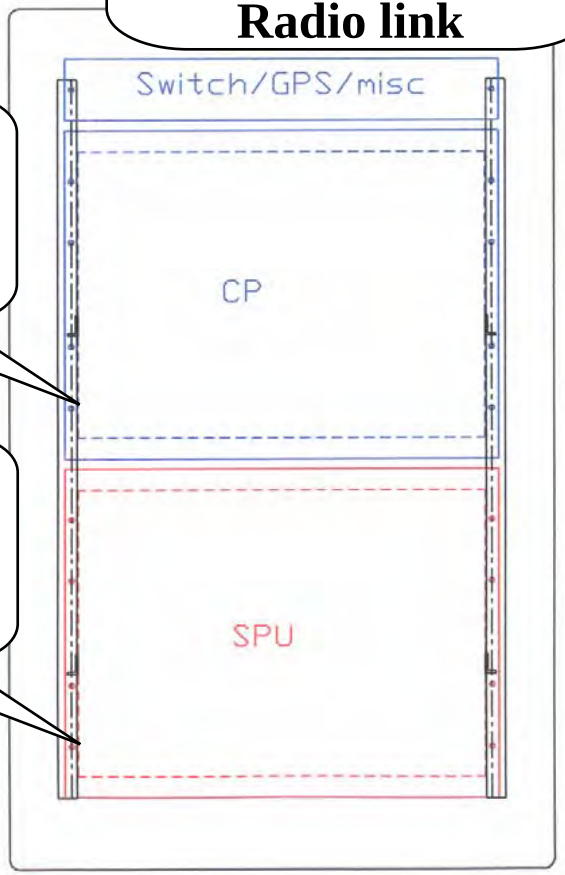
AQS 24 Control Processor

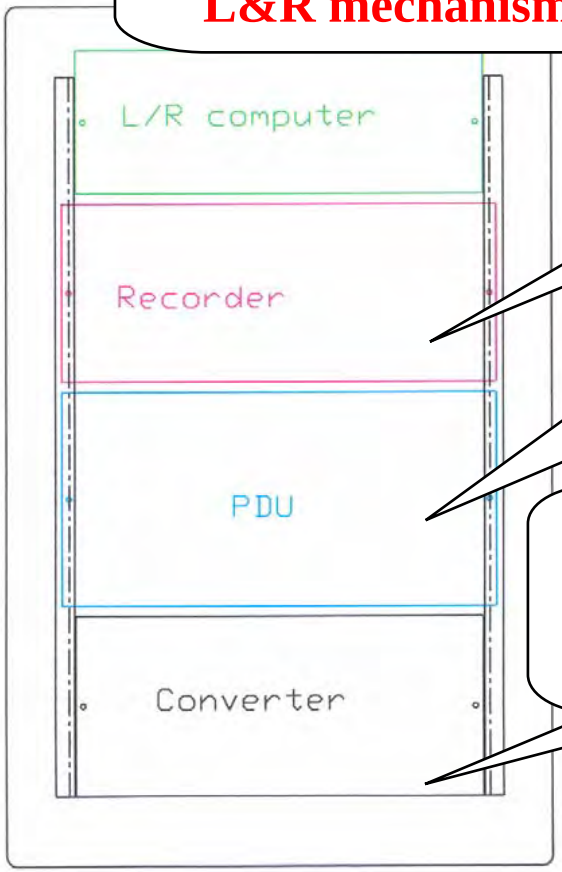
AQS 24 Sensor Processor

AQS 24 Recorder

AQS 24 Power Distribution

60 to 400 Hz. Converter

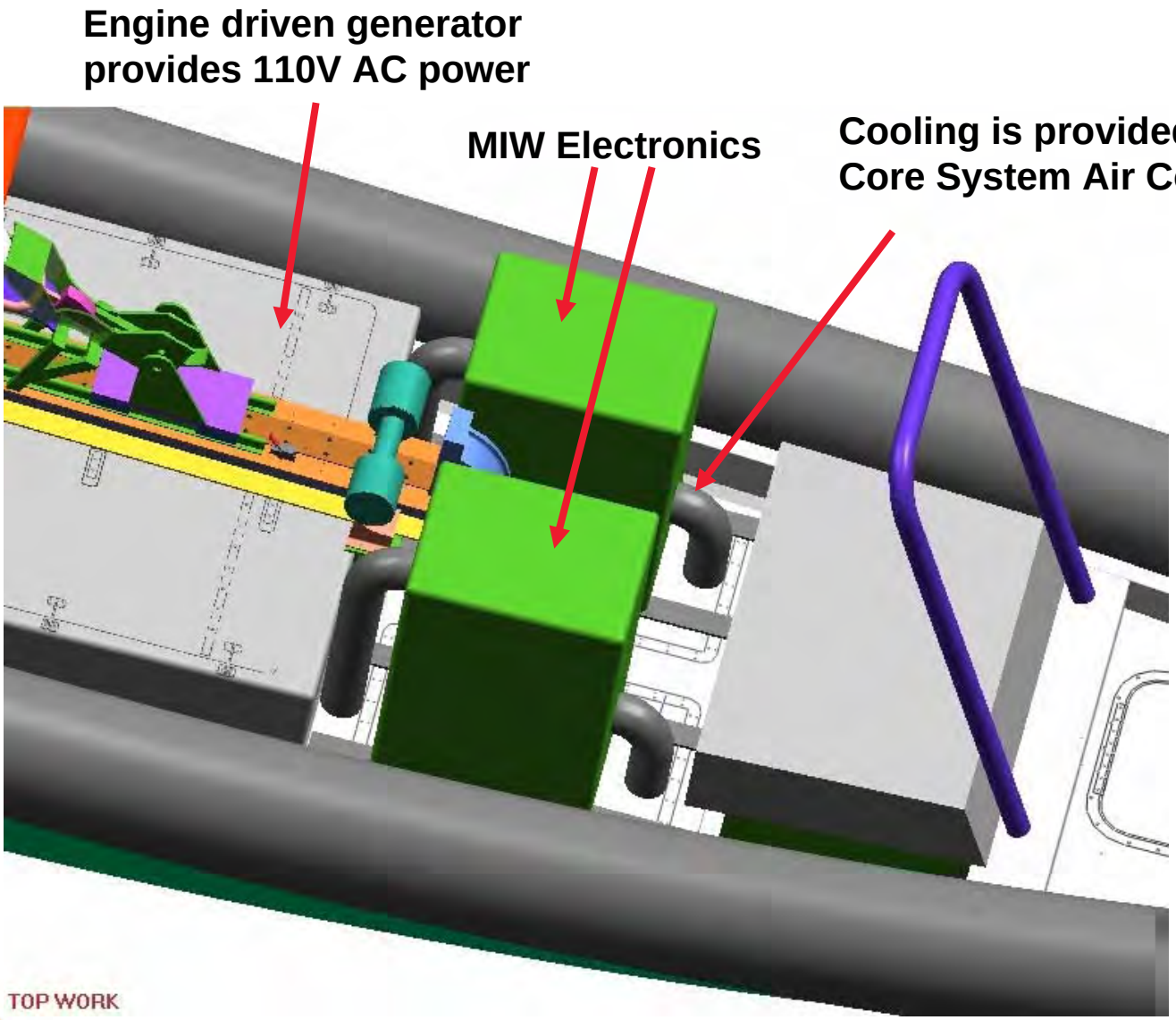




Black Type = NDI

Red Type = Custom

Electronics are Housed in Deck Mounted Ruggedized Cases



TOP WORK

SPARTAN Scout ACTD

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Operators Console is Configured To Allow Location Flexibility

OPERATORS SONAR DISPLAY

L&R CONTROL

CONTROL PROCESSOR CONTROL JOYSTICK

SPARTAN Scout ACTD

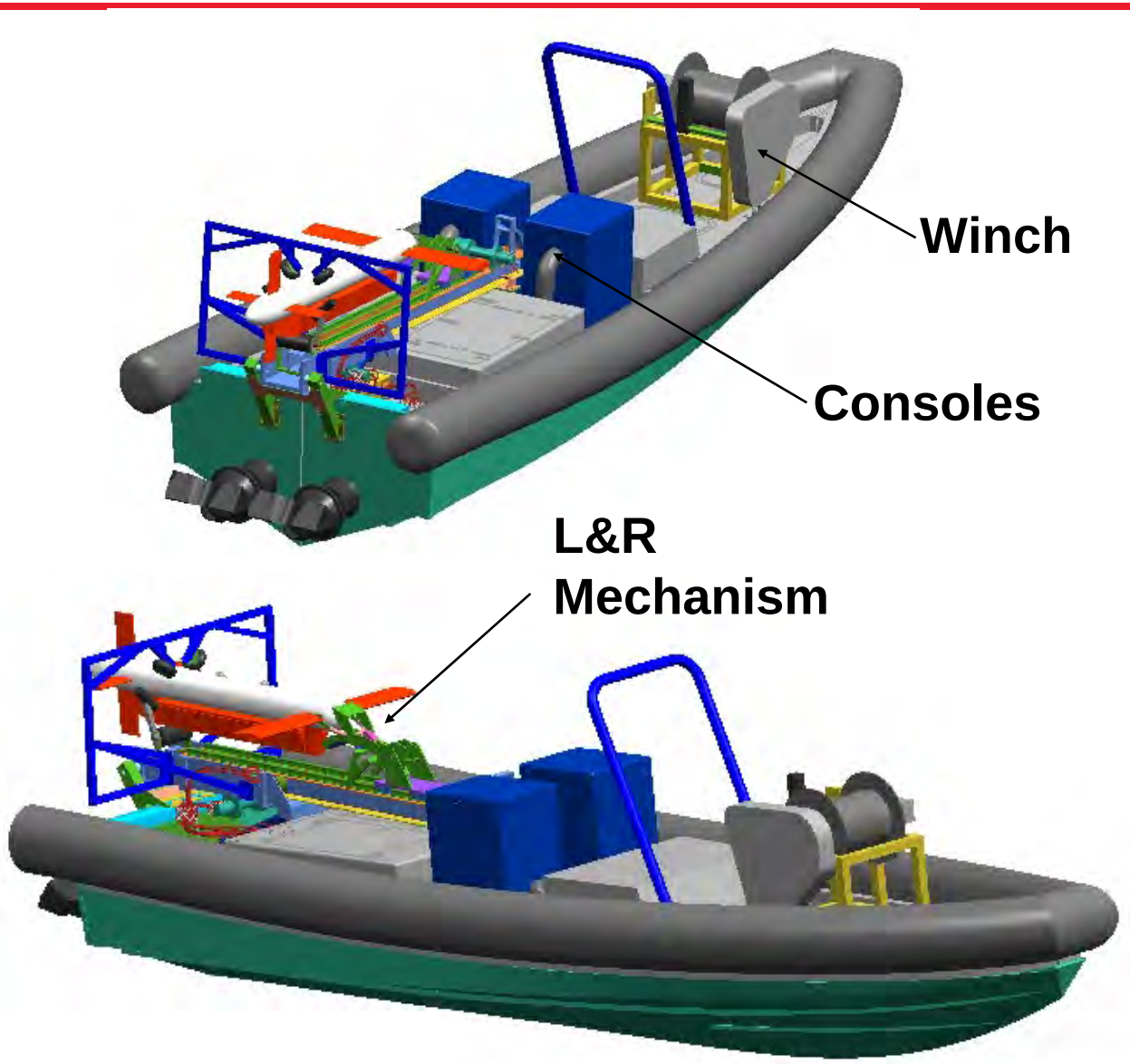
NORTHROP GRUMMAN

Agenda

- Spartan USV and MIW Module
- Requirements
- AQS-14/24 Payload
- **L&R Design**
- Testing and Operation
- Conclusions

NORTHROP GRUMMAN

General Arrangement



SPARTAN Scout ACTD

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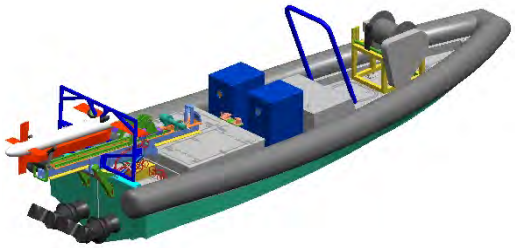
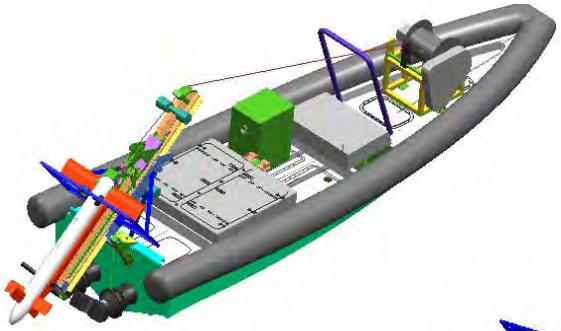
Key MIW – Craft Interfaces

- Primary Electrical Power from Core (117 VAC, 60 Hz At 6 KW
- Hydraulic Power for L&R and Winch from Core. 0 to 10 GPM at 3000 PSI $\pm$ 10%
- Cooling Air for MIW Onboard Electronics from Core, 9000 BTU/hr and 400 CFM at $\Delta P = 1.3$ in. H_2O
- 3 Mbit/sec Uplink Bandwidth for Data Transmission
- Ethernet switch port at USV and host for command and status
- Video cameras NTSC input to video processor
- Foundations for Winch, L&R, and Electronics

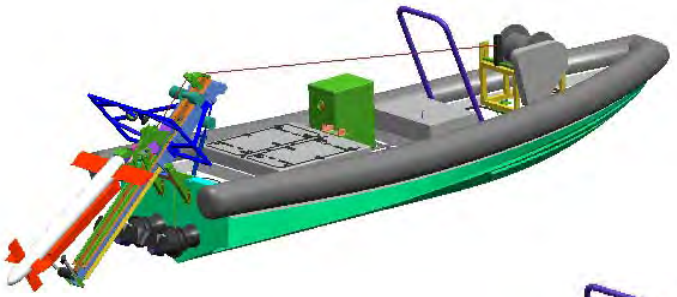
Major Steps in L&R Deployment



Extend Rail ½ Way

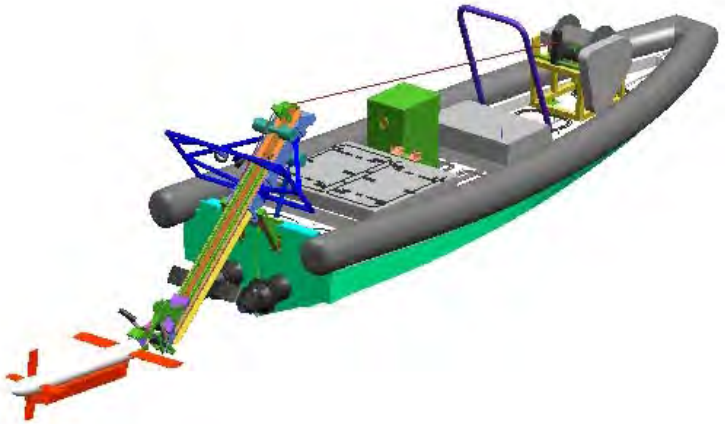


Tilt Rail



Recovery reverses launch sequence

Finish Rail Extension



Extend Docking Carriage

SPARTAN Scout ACTD

NORTHROP GRUMMAN

Agenda

- Spartan USV and MIW Module
- Requirements
- AQS-14/24 Payload
- L&R Design
- **Testing and Operation**
- Conclusions

Spartan MIW Has Undergone Progressive Level Test Program

- **Builder's Trials March, 2005 in Chesapeake Bay**
  - Operation of L&R system
  - Software & GUI refinement
  - Craft manned
- **Government Trials April, 2005 in Narragansett Bay**
  - Conducted remote L&R operations
  - Data exfil via radio link
- **Operational Demonstration**
  - TBD – In planning

Video of System Operation

SPARTAN Scout ACTD

NORTHROP GRUMMAN

Conclusions

- **MIW Module provides shallow water mine hunting capability from small unmanned surface craft**
  - Modular interfaces
  - Positive tow fish restraint
  - Within craft weight limit
  - Semi-autonomous operation
- **System is adaptable to variety of support craft**
- **Utility demonstrated in series of realistic operational tests**

SPARTAN Scout ACTD

NORTHROP GRUMMAN

Surveillance Buoy

Test and Evaluation Conference
June, 2004

Northrop Grumman Corp.
Daniel D. Morris, *Franklin D. Snyder*

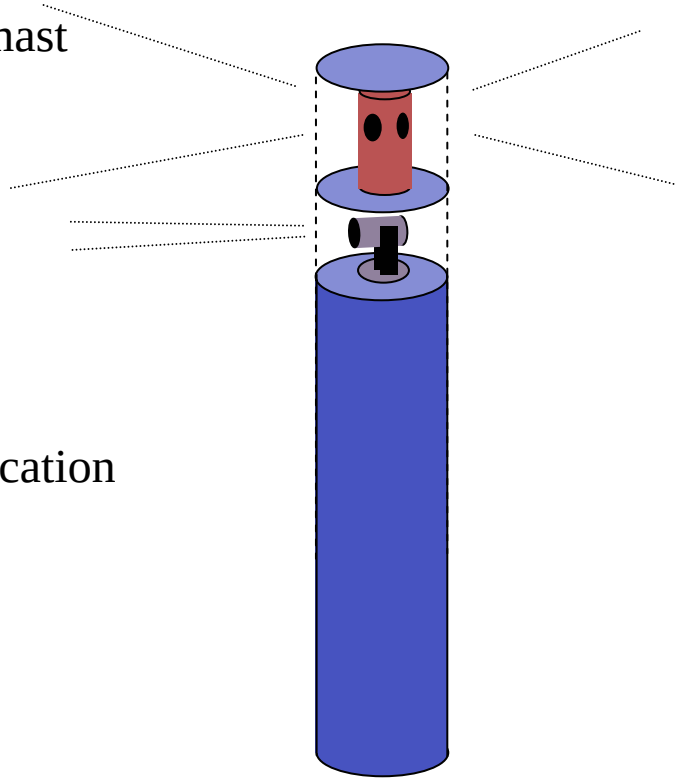
Naval Surface Warfare Center
Eric C. Hansen

Sponsored by: ONR, PM Marc Steinberg, N00421-03-C-0027
Content or information does not necessarily reflect the position or policy of the Government and does not infer any official endorsement.

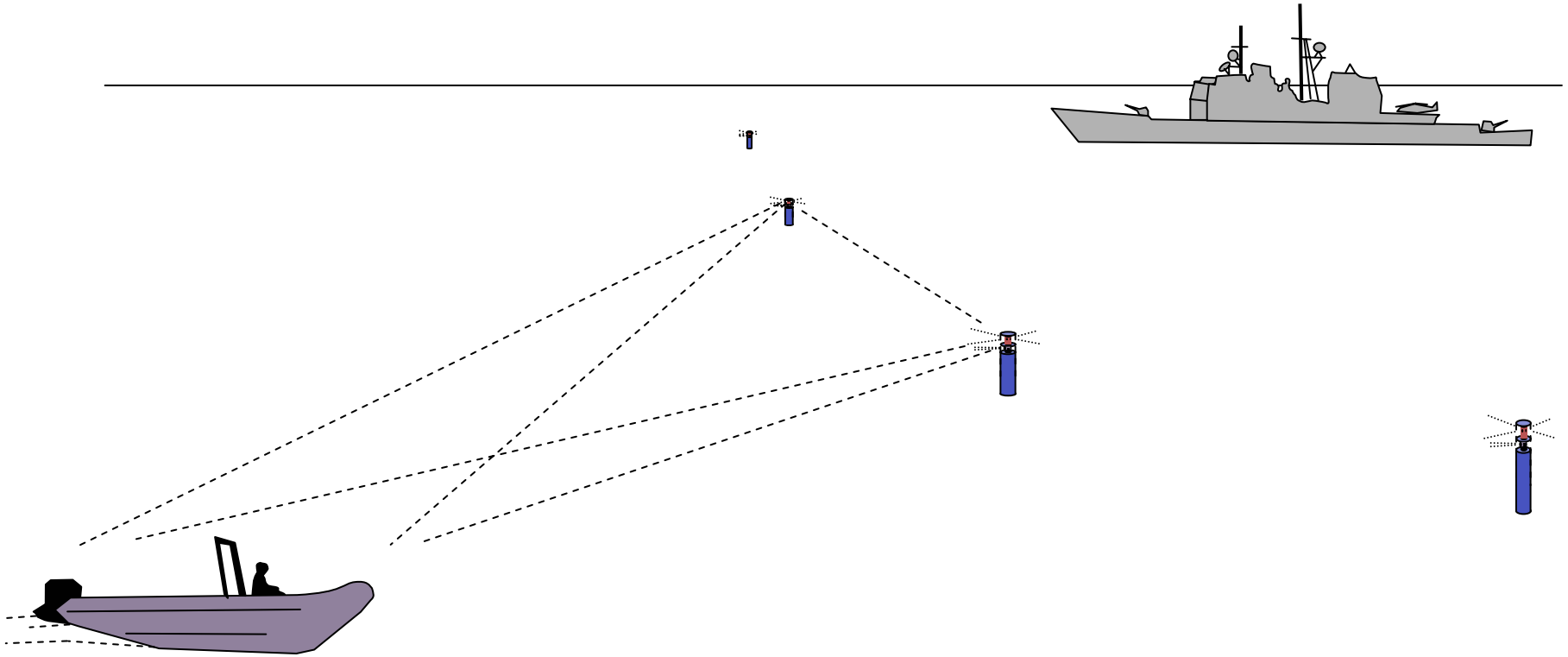
Surveillance Buoy Project

Algorithms for buoy-based maritime surveillance

- ONR technology development on an inexpensive platform
  - Apply developments to a surfaced UUV with an EO mast
  - Secondary interest in a standalone surveillance buoy
- Full 360 degree ship and watercraft detection
  - Horizon / shoreline in all directions for stabilization
  - Multi-hypothesis ship segmentation
- Cued pan-tilt-zoom analysis
  - Close-in view to confirm detection and enable classification
- Watercraft trajectory estimation
  - Track watercraft and build trajectory model over time
- Watercraft classification
  - Collect large database of images to train classifier
  - Enable multi-class discrimination
- Install and test on buoy



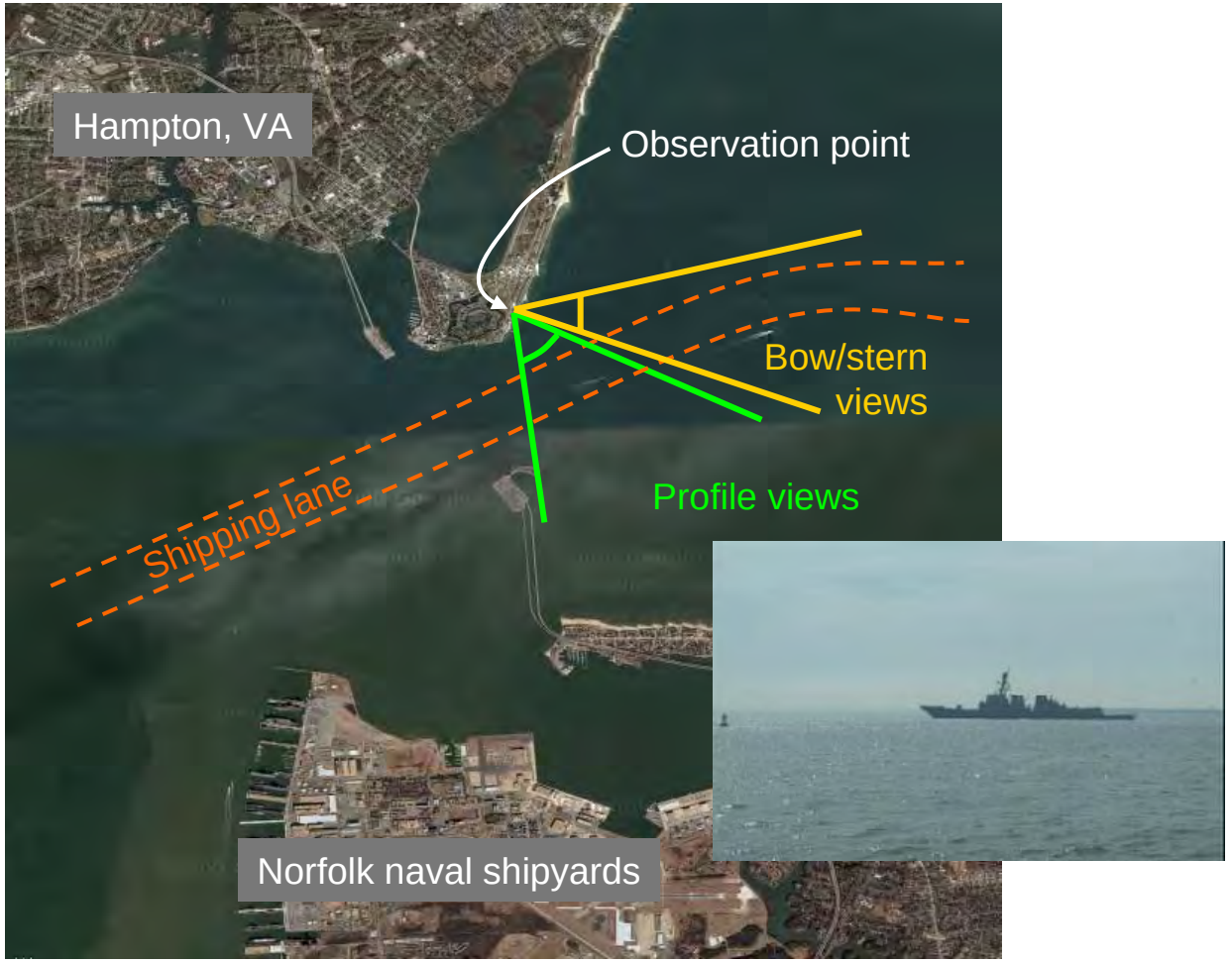
Concept: Buoy Array



Current Achievements

- Data collection (ongoing)
  - Over 2 months of imagery of commercial and military shipping passing Norfolk VA shipping lane
  - Automatic detection of ships in images
- Classification
  - Developed feature sets
  - Manually classified ships in imagery (ground truth)
  - Preliminary training of classifier
- Test and Evaluation
  - Response Operator Curve (ROC) for a variety of classes

Data Collection Site

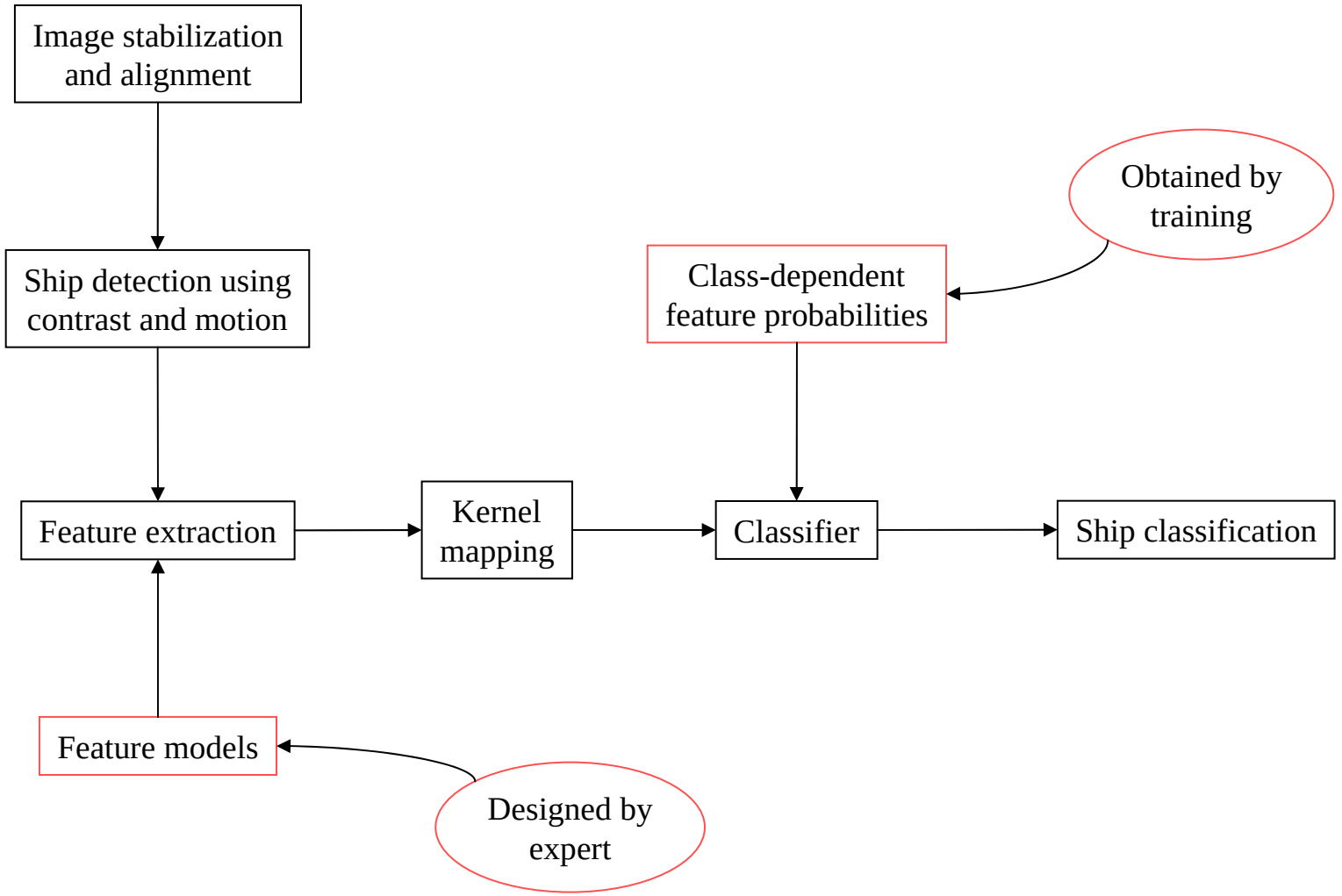


Copyright Google Maps

Data Collection Hardware

- Sony camcorder 3CCD
- Time-delay recording:
  - 0.5 sec video every 30 sec
  - 1 DV tape lasts 3.5 days
- Over 2 months of images so far

Classification Flow Chart



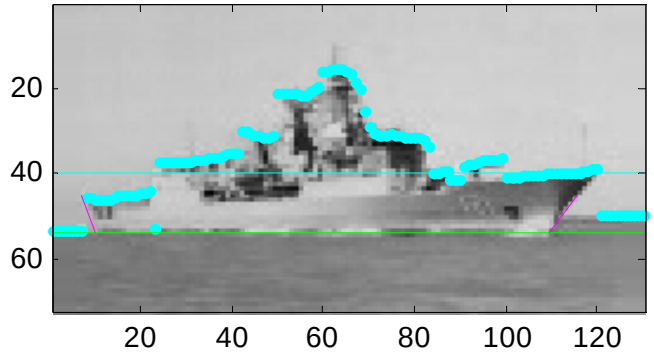
Automatic Ship Detection

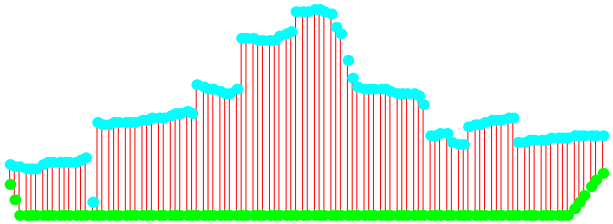
1. Collect images
2. Stabilize
3. Use contrast and change detection to locate ships in video

Classes

- Military
  - Aircraft, helicopter carriers
  - Frigate, destroyer, cruiser, transport
  - Gunboat, cutter
  - Submarine
  - RHIB
- Commercial
  - Barge
  - Cargo freighter
  - Dredger, Sailboat
  - Motorboat
  - Tugboat
- Other
  - Other
  - Partial
  - Not a ship

Features

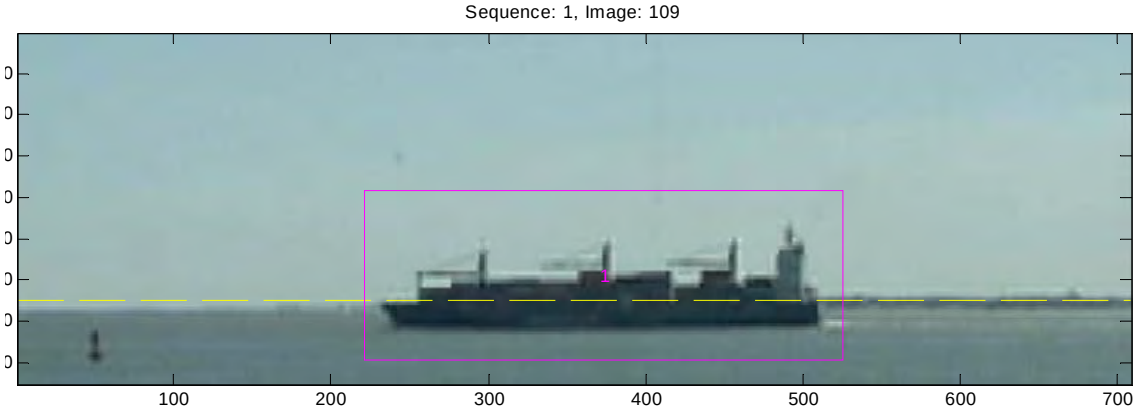




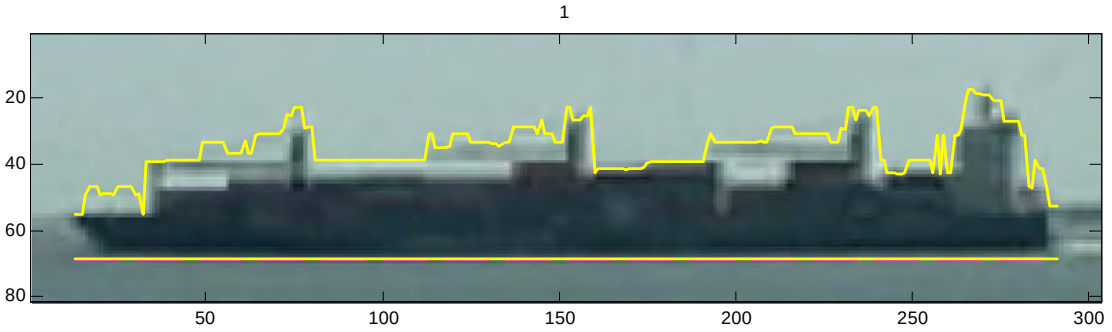
- Candidate Features:
  - Moments
  - Profile heights
  - Gradient ratios for each column: $g_x/(g_x+g_y)$

Feature Extraction

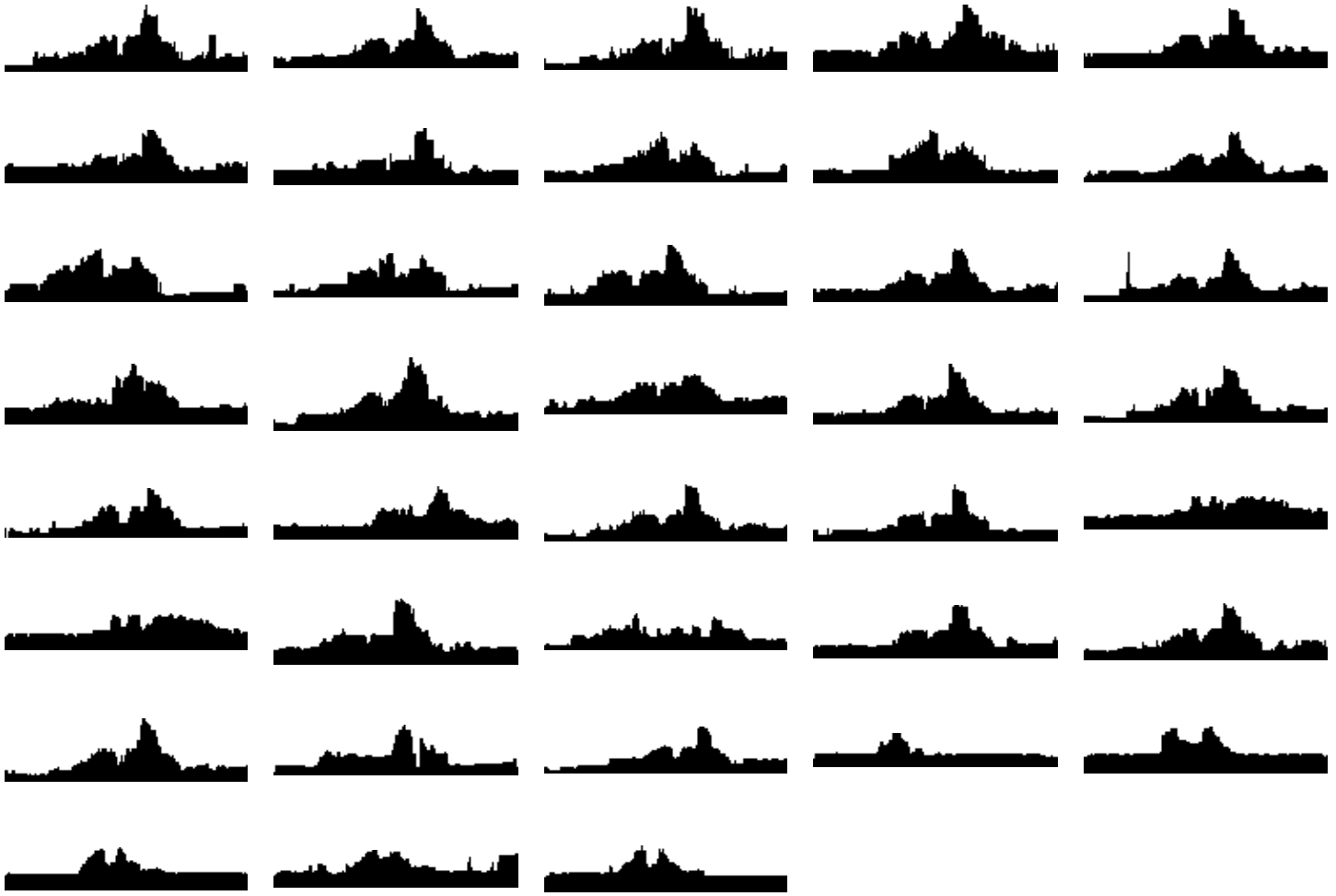
Auto detection:



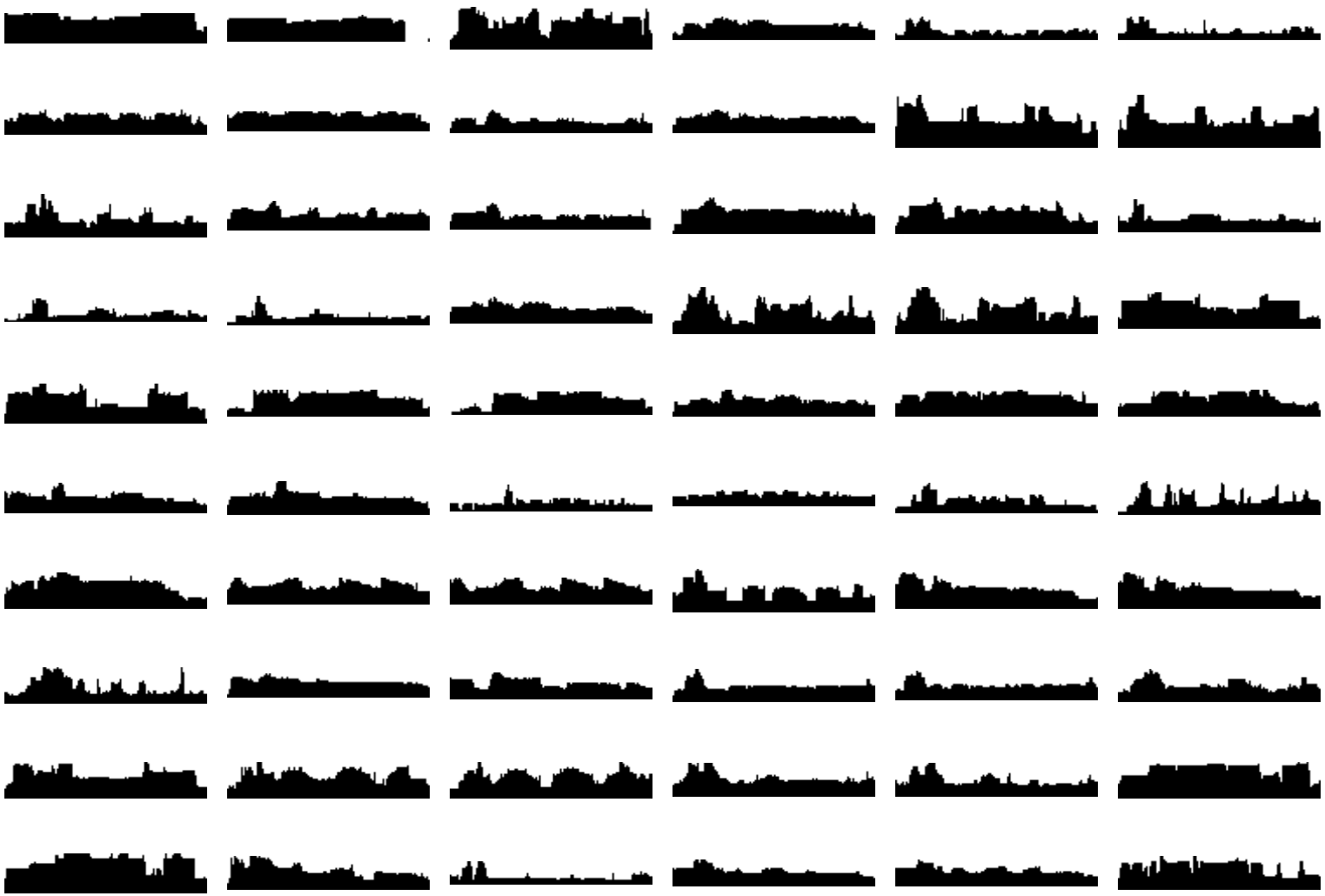
Auto profile estimation:



38 Fighters & Carriers

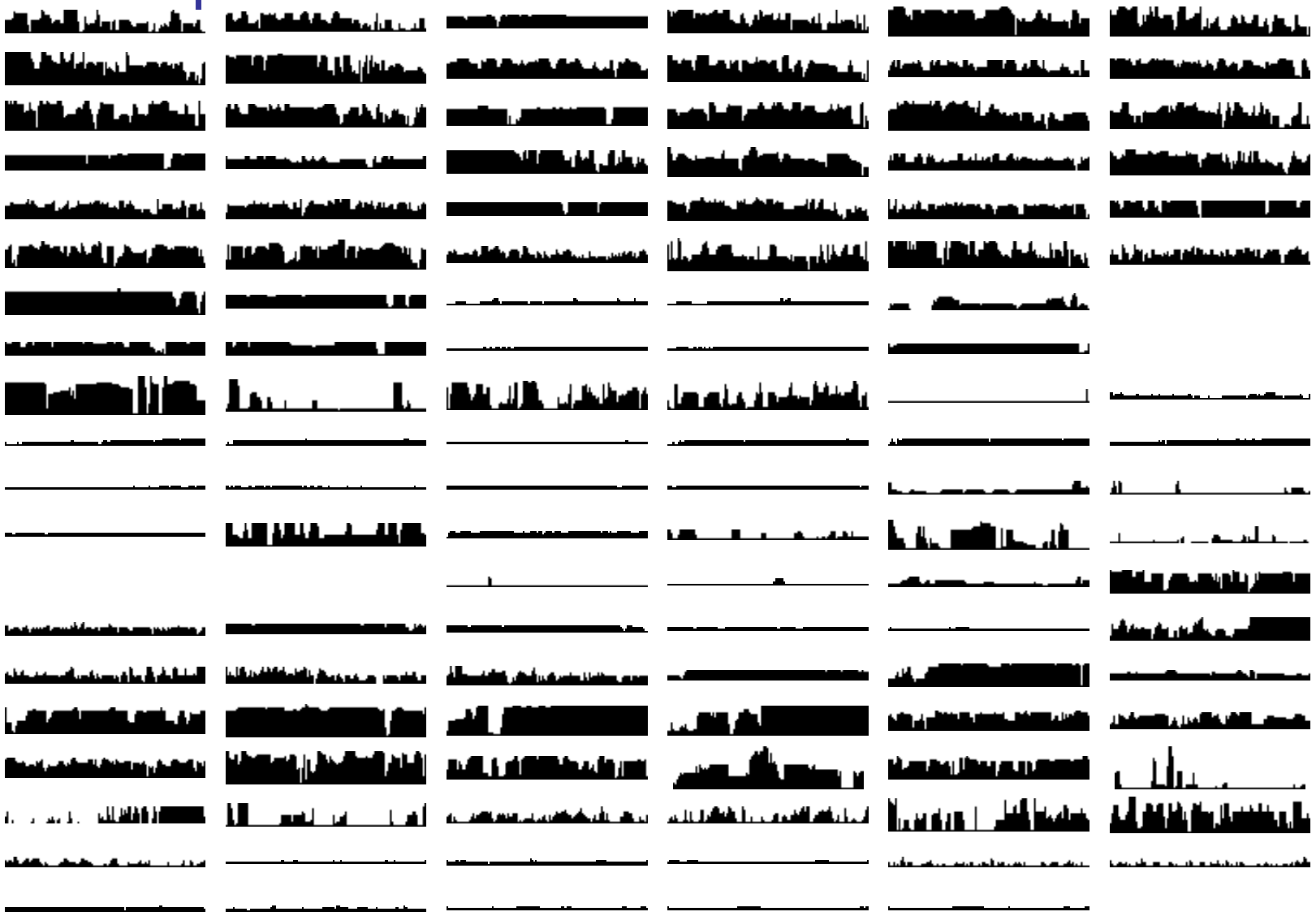


116 Freighters



128 Barges

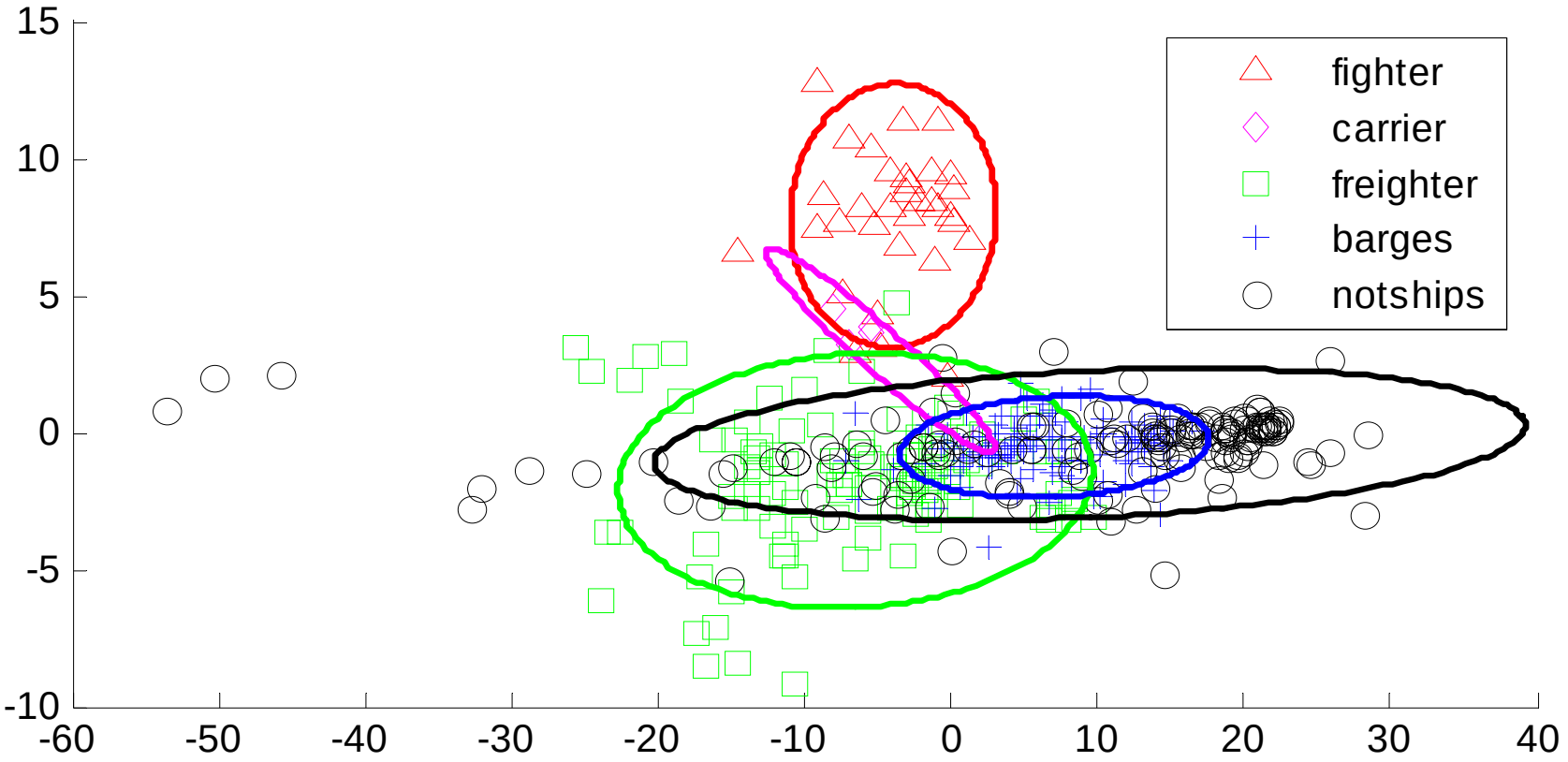
Not Ships



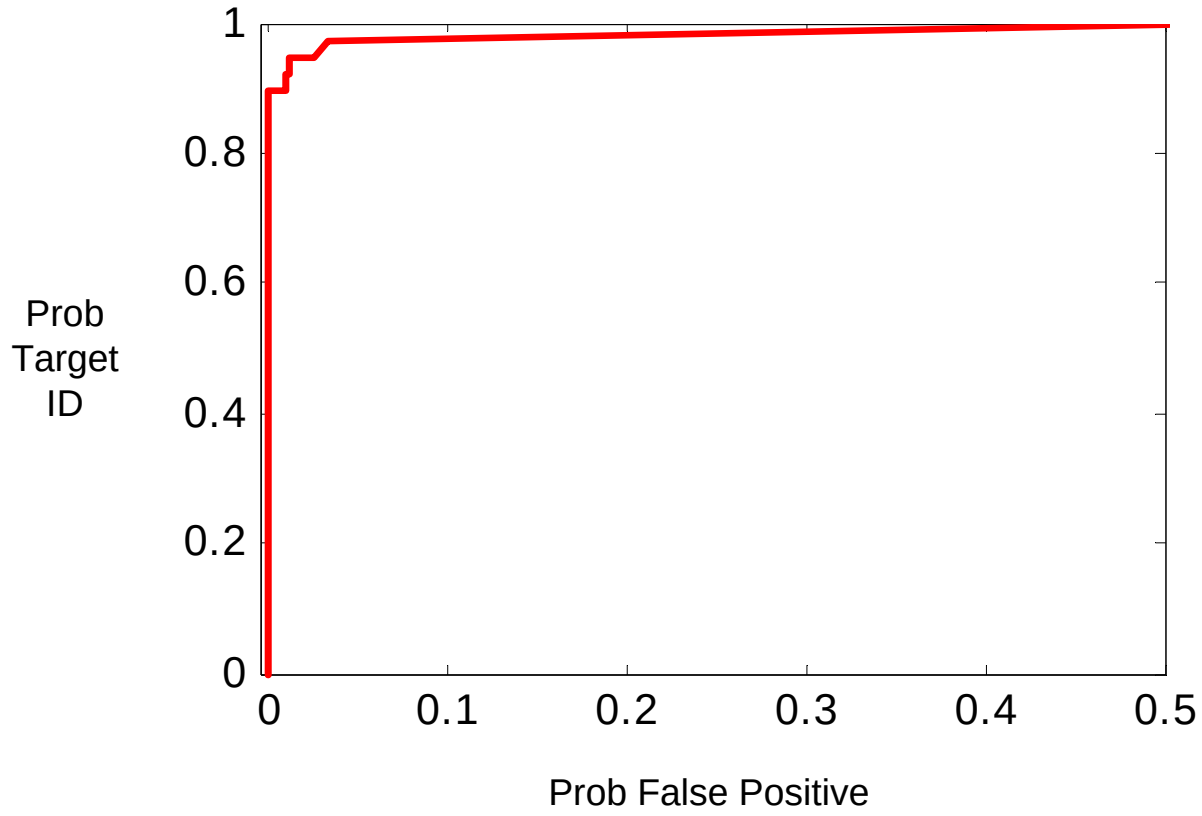
Classifier

- Bayesian classifier with Gaussian density models
- Reduced parameter space using Principal Component Analysis (PCA)
  - 128 dimensions to 4 dimensions
- Manually classified image clips for training
  - Ground truth
- Evaluated using leave-one-out technique

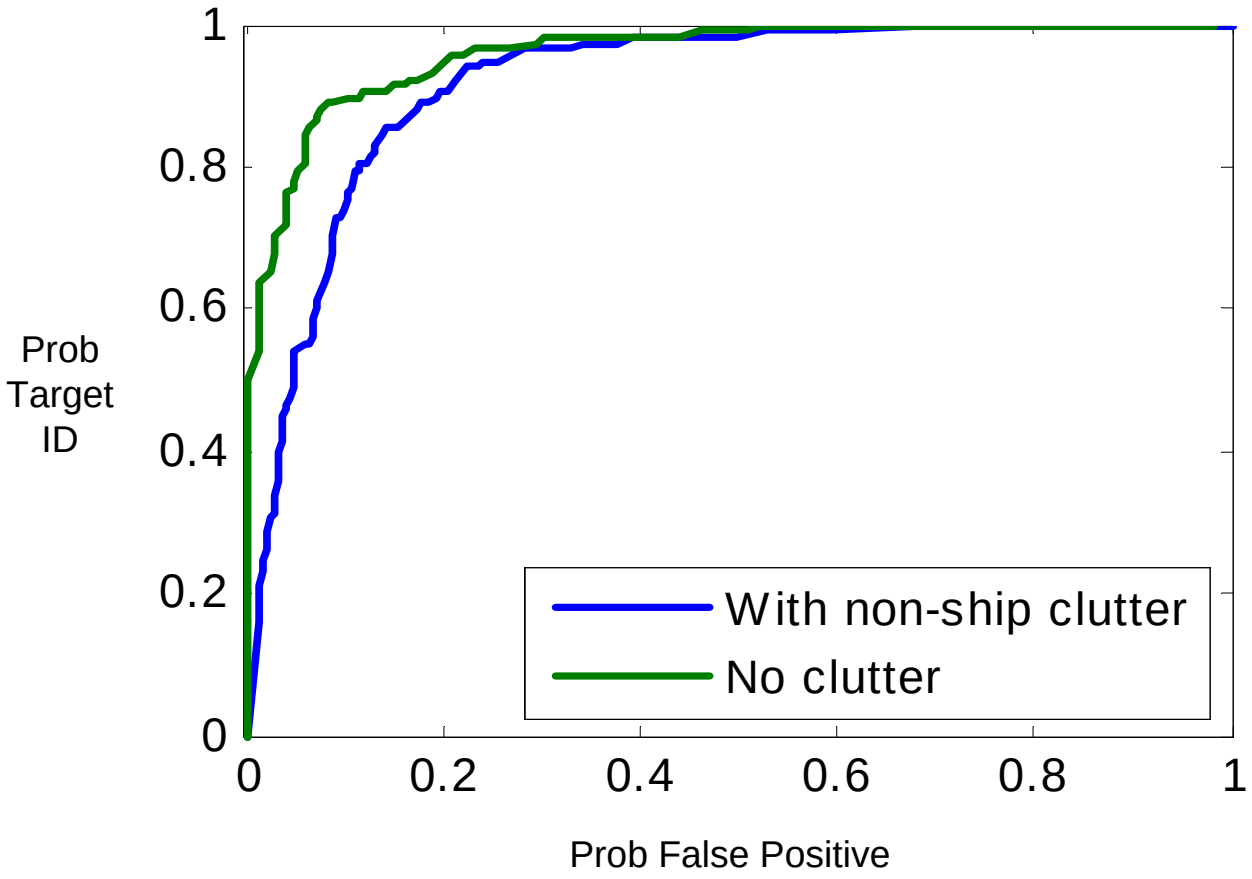
Top 2 Profile Dimensions with PCA



Fighter + Carrier ROC



Freighter ROC



Ongoing work

- Developing new features
  - Enable classification of smaller craft
- Gathering more data
- Gathering multiple viewing angles
- Use motion (tracking) to mitigate false alarms

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An Experimentation Framework to Support UMV Design and Development

Dr Roger Neill, Dr Francis Valentinis*
and Dr John Wharington

Maritime Platforms Division, DSTO

*Swinburne University of Technology

June 2005

The Cedessa Framework

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- An experimentation framework supporting the design of Uninhabited Maritime Vehicles (UMVs) and Uninhabited Air Vehicles (UAVs) has been developed.
- This framework, which is called “Cedessa” is being applied by DSTO and Swinburne University of Technology on a number of projects in both the UMV and UAV domains.
- The framework consists of tools for performing experiments in which both simulation models and/or vehicle control/flight systems software is exercised, evaluated and/or optimised.

The Cedessa Framework

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- Experimentation can be undertaken on systems implemented either strictly in simulation or arbitrary combinations of simulated and hardware-in loop systems.
- The framework is based on a simulation infrastructure that is capable of both distributed and low-overhead non-distributed off-line operation.

Simulation in the Cedessa Framework

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- Unlike the majority of UMV simulation toolsets, the Cedessa framework components allow an experimenter to model and simulate not just a single vehicle, but multiple UMV's and their entire operating environment.
- This means that experiments can be conducted in which simulated vehicles autonomously and collaboratively work on complex tasks.
- There are three standard components to the Cedessa simulation subsystem: The multi-body dynamics engine “ODESSA”, the six degree of freedom flight vehicle model “VSIM”, the lightweight connectivity system “Centrale”.

Virtual World Management: ODESSA

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- The multi-body dynamics engine ODESSA allows complex worlds to be modeled.
- The initial implementation was based on the Open-Source ODE framework. ODE is a high-performance software library designed for implementing realistic physics in computer games.
- DSTO revised the original source code considerably, with an emphasis on making the engine reliable for engineering work whilst performing a number of important performance optimisations.

Virtual World Management: The ODESSA Toolkit

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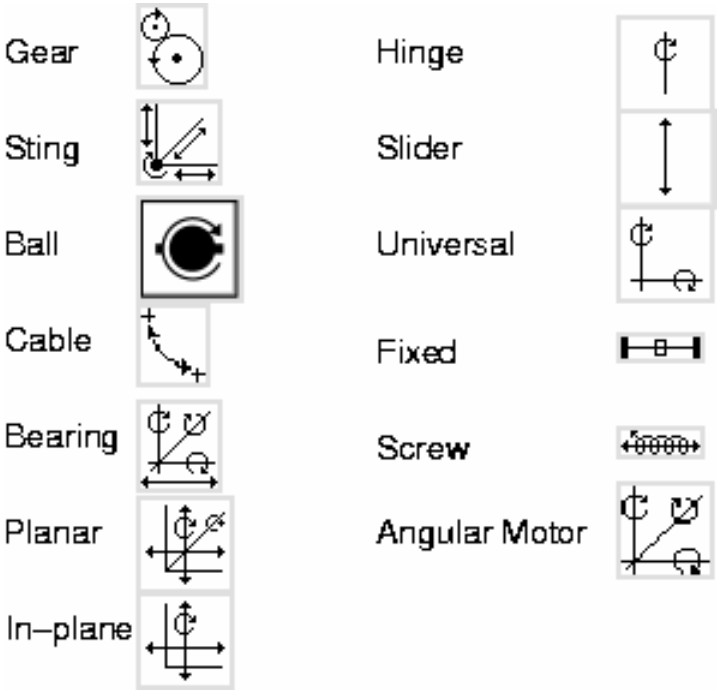
- ODESSA enables simulation of multiple bodies interlinked by various joints.
- It handles kinematics and collisions.



Virtual World Management: ODESSA

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- The ODESSA multibody universe is currently defined by means of an XML file, plus GUI based editors are in development.
- The engine can run in either an off-line mode or an interactive real-time mode. In the interactive mode, an OpenGL based scene visualiser is available.
- The engine can be interfaced to a variety of systems implementing specific models. By linking it to VSIM for example, multiple vehicles can be simulated.
- Live interfaces to Matlab, GNU Octave, HLA, and Centrale are available to permit auxiliary simulation models to influence bodies in the world.

Connectivity: The HLA

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- Multiple ODESSA simulation “islands” can be distributed across the network by enabling a connectivity mode that allows it to interface seamlessly with either a Centrale or a HLA federation.
- Likewise, distributed simulation federates implementing specific functions can be interfaced with ODESSA, allowing for simulation of active participants in the simulation.

Connectivity: Centrale

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- In addition to using the HLA either to interface simulation entities to ODESSA, or for ODESSA itself to interface with distributed simulations, a second connectivity system called “Centrale” can be used.
- Centrale is a lightweight connectivity system supporting basic distributed simulation functionality. It can be used to integrate software modules that implement either simulations or flight software systems on board the vehicle.

Connectivity: Centrale

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- Importantly, it allows easy conversion of systems from distributed to non-distributed systems that incur no communications overhead.
- The first mode is ideal for large scale real-time distributed simulation. The second mode is also very useful for off-line, automated experimentation.
- Centrale achieves this flexibility by using a flexible software hub architecture. Software modules are developed as plug-ins that attach to a hub that both synchronises them and also provides a common data store.
- Optional network relays link different software hubs across a network, allowing for creation of virtual distributed hubs.

Connectivity: Centrale

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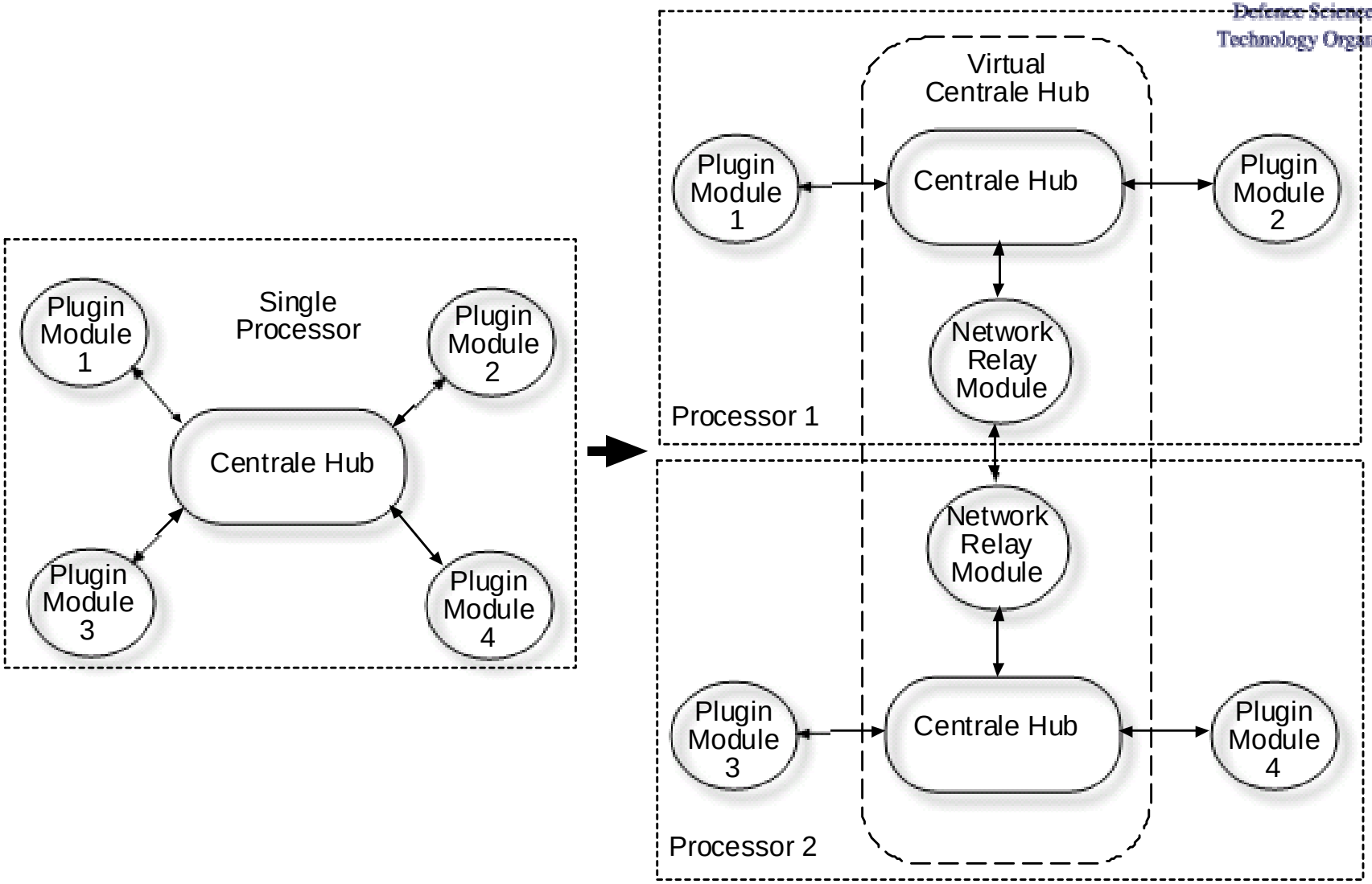

Flight Vehicle Simulation: VSIM

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- ODESSA itself performs only simulation and visualisation of the multibody universe. To bring that universe to life, ODESSA must be interfaced to other simulations or software systems.
- One important standard simulation model that is shipped with ODESSA is VSIM.
- VSIM is an extremely modular six degree of freedom flight model developed in the Matlab Simulink environment.

Flight Vehicle Simulation: VSIM

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- VSIM can be used as a stand-alone model in the Simulink enviroment, or can be converted to native code and compiled into a Centrale plugin for use with Cedessa.
- The system is structured as a series of shell modules, allowing for new vehicles of different kinds to be implemented with very little effort.
- To date a number of vehicle system models have been developed implementing simulations of both underwater vehicles and air vehicles.

Automated Experimentation: Scripting

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- Cedessa supports large-scale real-time simulations allowing for operator training, real-time systems testing and other conventional applications of distributed-simulation based experimentation.
- In addition, the flexible nature of the Centrale connectivity system allows the same distributed simulations to easily be converted to lightweight integrated software systems.
- These software systems can be executed in a faster than real-time mode permitting repetitive off-line execution under scripted control.
- Currently, software tools are provided with Cedessa to aid users in creating these types of experiments.

Automated Experimentation: Optimisation

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- Experimentation via scripts can result in powerful tests, however this approach alone will not always result in a desired result.
- Increasingly, optimisation is being used as an effective experimentation mechanism. Conventionally, it has been used to improve performance of flight systems.
- It can and has, however also been used as an approach for testing robustness by searching for fault states.

Automated Experimentation: Optimisation

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- Given the usefulness of optimisation in this context, Centrale itself supports an operating mode in which a software hub and its attached modules implements the cost function in an optimisation process.
- Currently, the optimiser uses the Particle Swarm Optimisation (PSO) technique. Shortly, support for a Genetic Algorithm and Simulated Annealing will be Added.
- All of these methods have been shown to provide good performance on highly non-linear multivariate problems.

Sample simulations:

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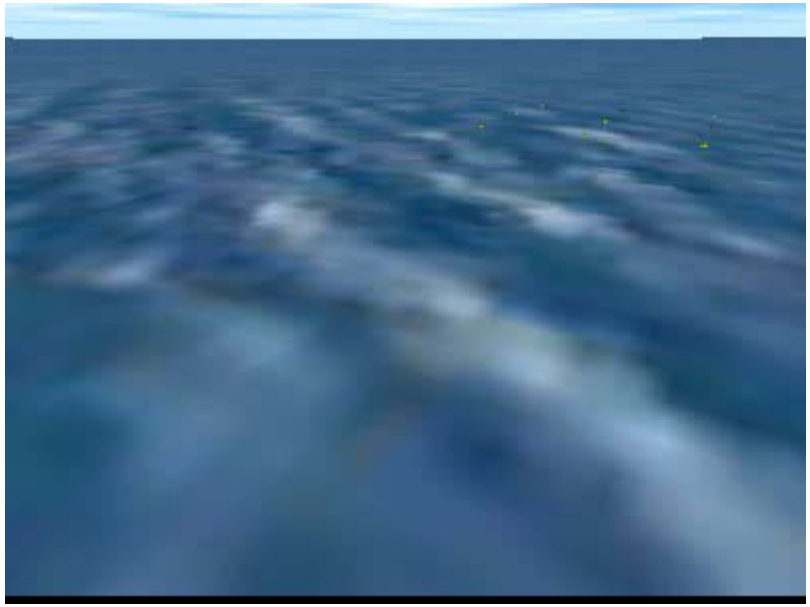
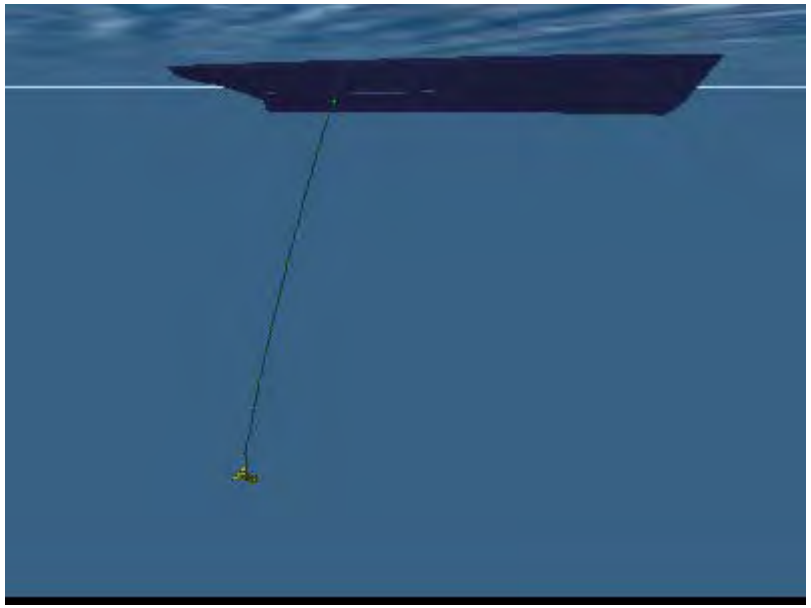
- A simulation of the *Wayamba* research vehicle (control is via keyboard input)



Sample simulations:

Australian Government
Department of Defence
Defence Science and
Technology Organisation

- A simulation of a mine disposal ROV operating off a Mine Hunter



Sample simulations:

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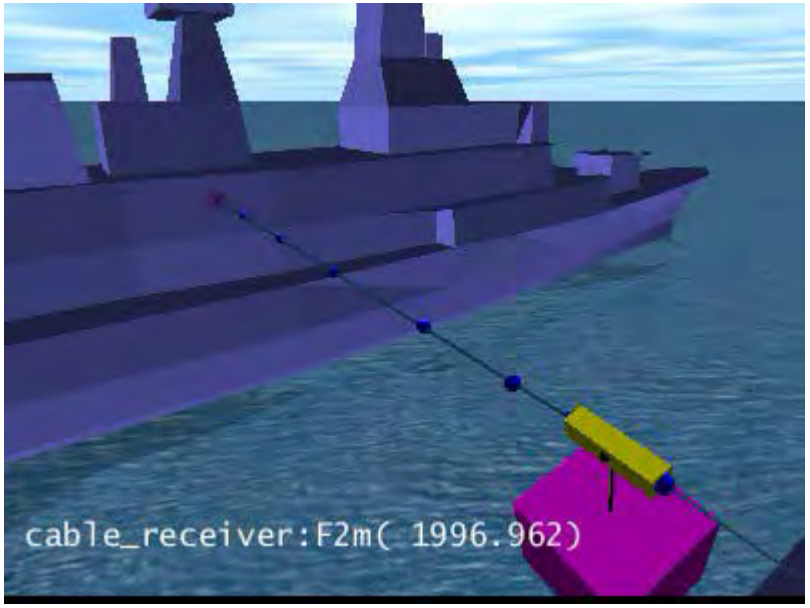
- A simulation of a replenishment at sea operation



Conclusions

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- The *Cedessa* framework has been observed to streamline and simplify the process of creating both manual and automated simulation-based experiments.
- These time savings are being realised at DSTO on a number of projects in both the UMV and the UAV domains.
- The key software components of Cedessa, namely Centrale, ODESSA and VSIM are in the process of being prepared for public release under open–source licences. Interested readers are encouraged to contact the author for availability information.

Further Information

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- A website is in the process of being constructed with further information about this project, and in the near future will include binary and source code downloads of the software.
- Please contact the following email address for updates on this development:
  - francis.valentinis@dsto.defence.gov.au

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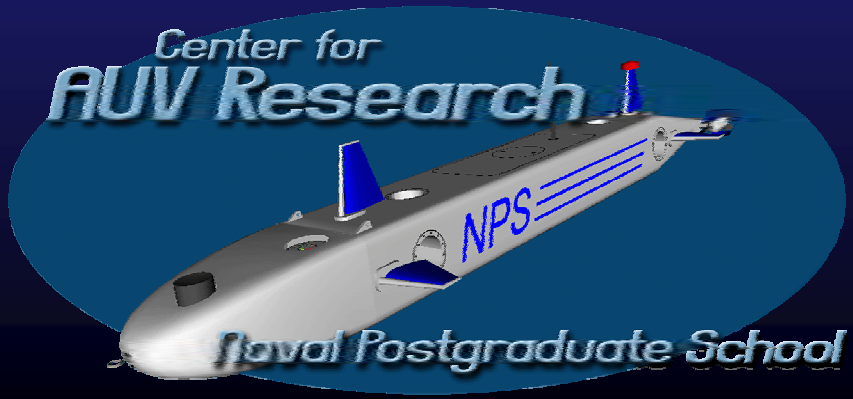
Naval Academy

Out-of-Water Test Methods to Accelerate Implementation of Autonomous Rendezvous in the NPS ARIES AUV

CAPT J.W. Nicholson, Ph.D.
United States Naval Academy



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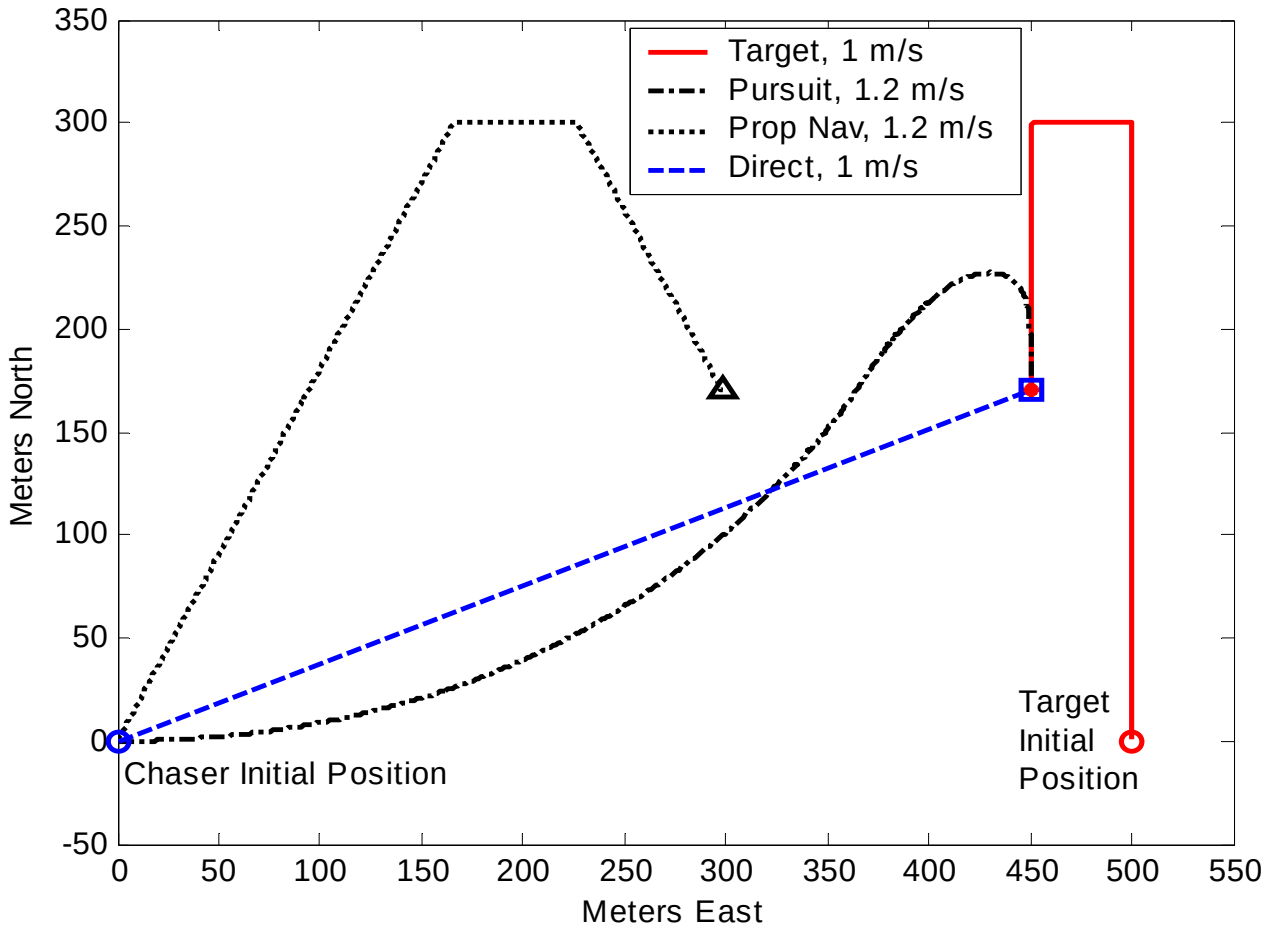
Development: Server Vehicle Rendezvous



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Challenges (As Always)

- Significant software changes requiring…
- Significant debugging
- Limited time, money, in-water opportunities

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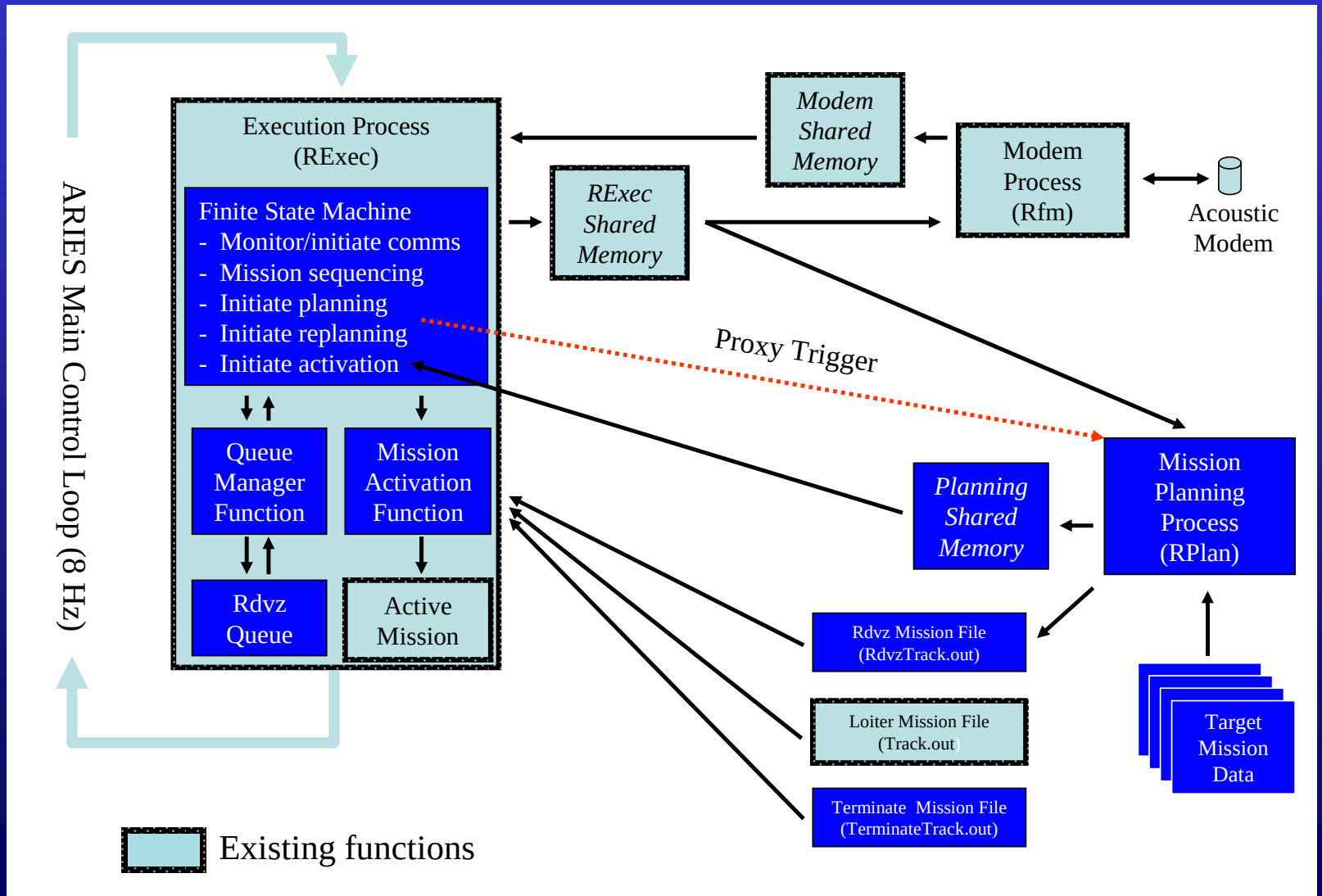
ARIES Software Modifications



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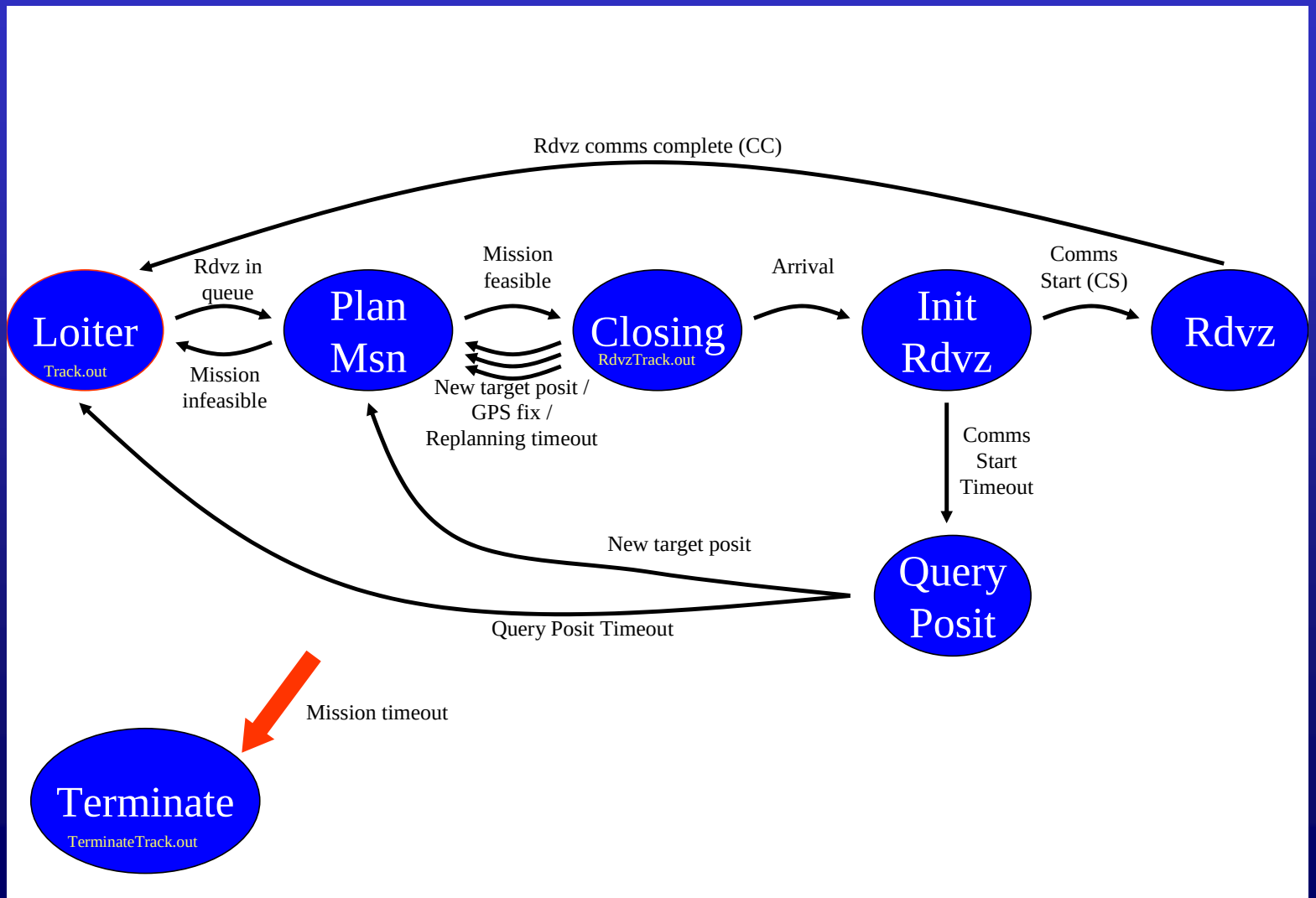
ARIES State Machine



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ARIES Control Architecture

STATE MACHINE
(Strategic Level)

MISSION CONTROL
(Tactical Level)

AUTOPILOTS
(Execution Level)

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Solution: Laboratory Test Program

- Hardware-in-loop software development / debugging
- Install the capability to run missions in laboratory (dry)
- Benefits
  - Time efficient
  - Cheap
  - Enhanced ability to monitor vehicle operation
  - Shortened run-debug cycle
- Barriers
  - Vehicle protective functions (abort signals: prop speed, minimum altitude)
  - Risk of equipment damage, inadvertent loss of protective functions
  - Providing simulated sensor inputs

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Overcoming the Barriers to Lab Testing

- Control all modifications with a common, reliably set and cleared signal
- Block unnecessary protective signals
- Reduce prop speed by factor of 10
- Inject simulated X-Y position and GPS reception data

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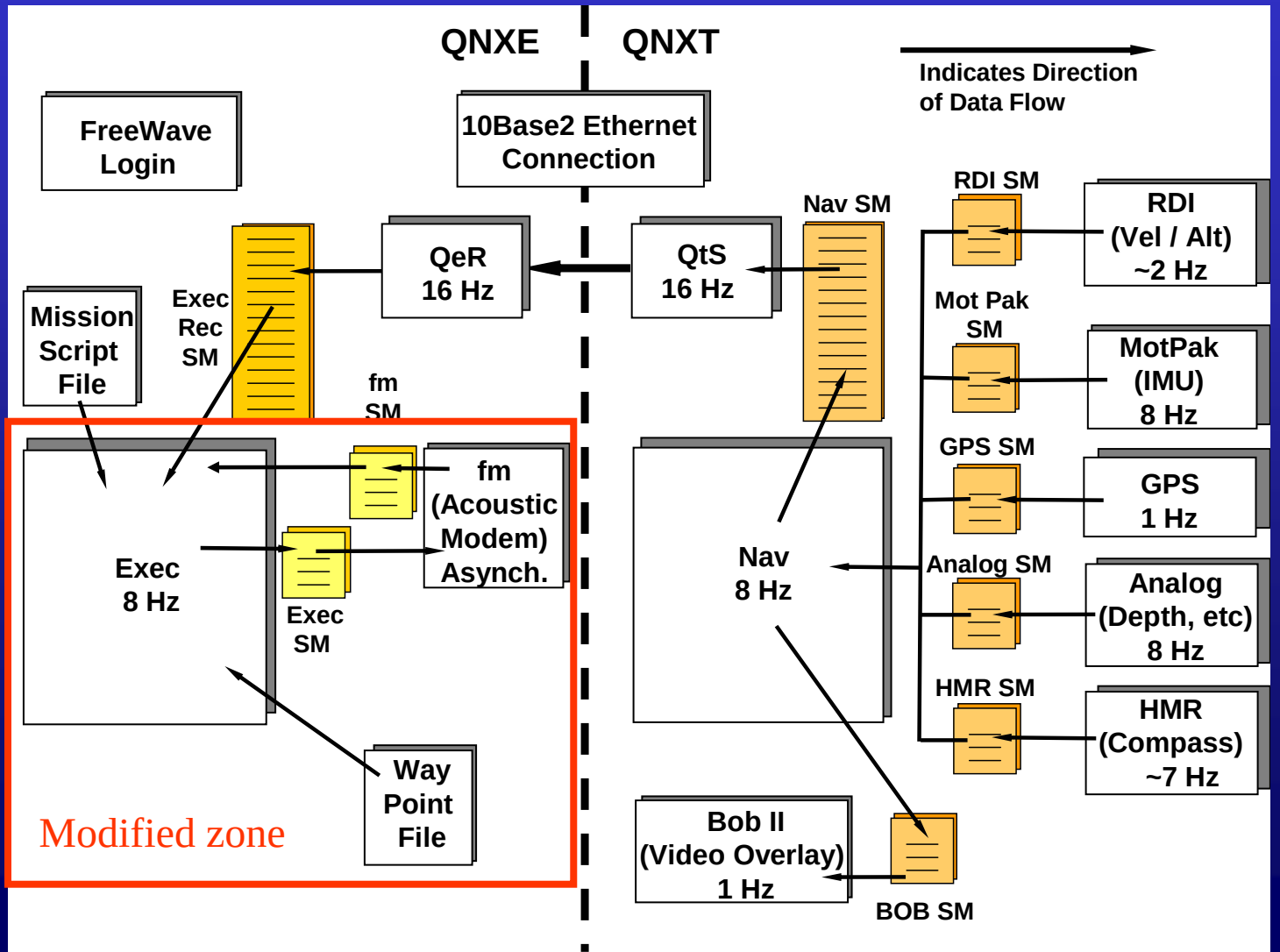
Original ARIES Software Architecture



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Initial (Stand-alone) Software Testing

- Acoustic modem
  - Minor modification of existing software and shared memory
  - Test on ARIES using actual modem software / hardware / inputs
- State machine and queue manager function
  - Logic intensive operations, but little math
  - Exhaustive testing of inputs versus states
  - Embed into existing function (Exec.c)
  - PC (MATLAB), translate into C on ARIES
- Mission planning module
  - Math / optimization / shared memory intensive
  - Could develop on PC, but translation to C and integration in ARIES would involve a second round of significant debugging
  - ARIES (C)

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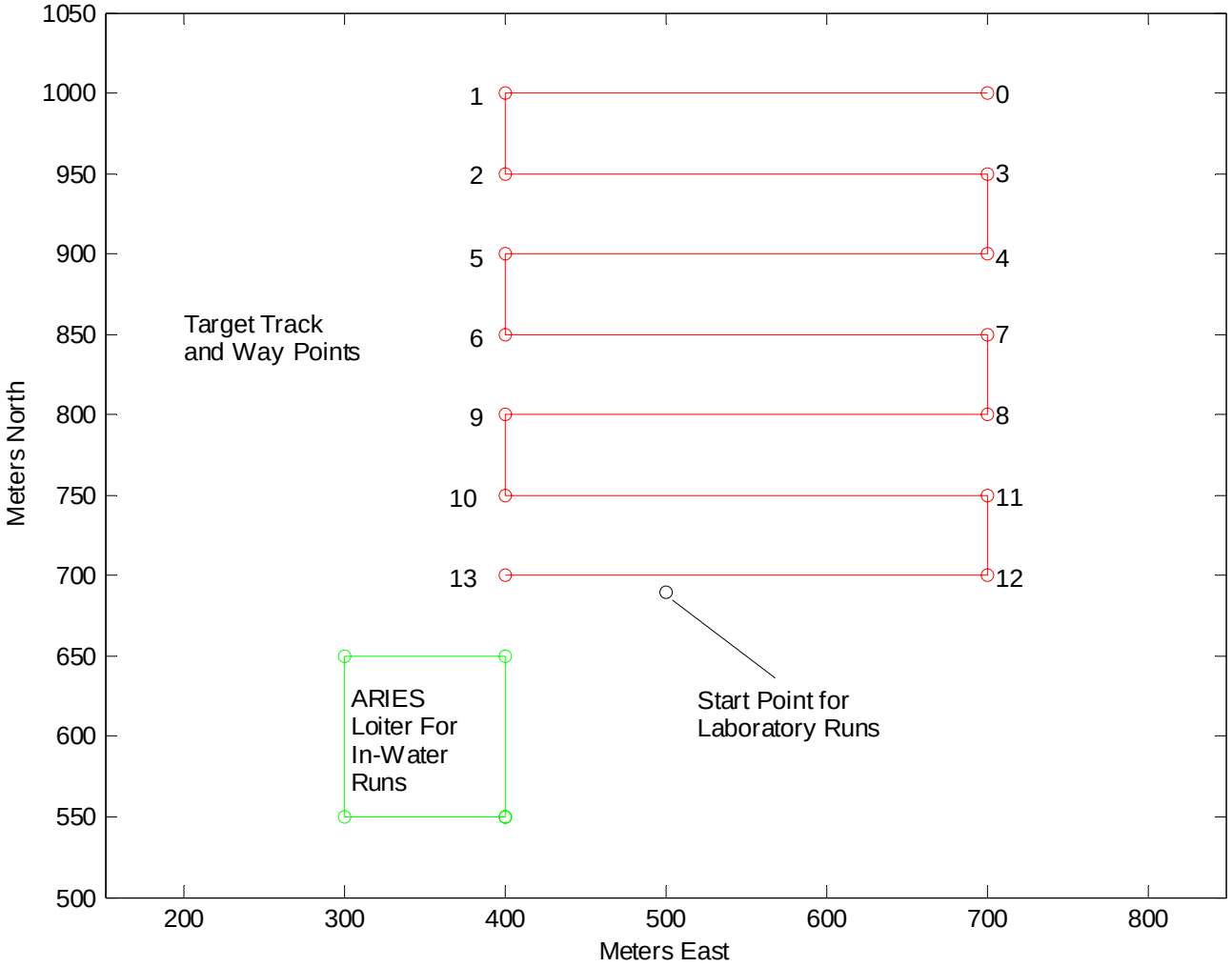
Integrated Software Testing Set-up



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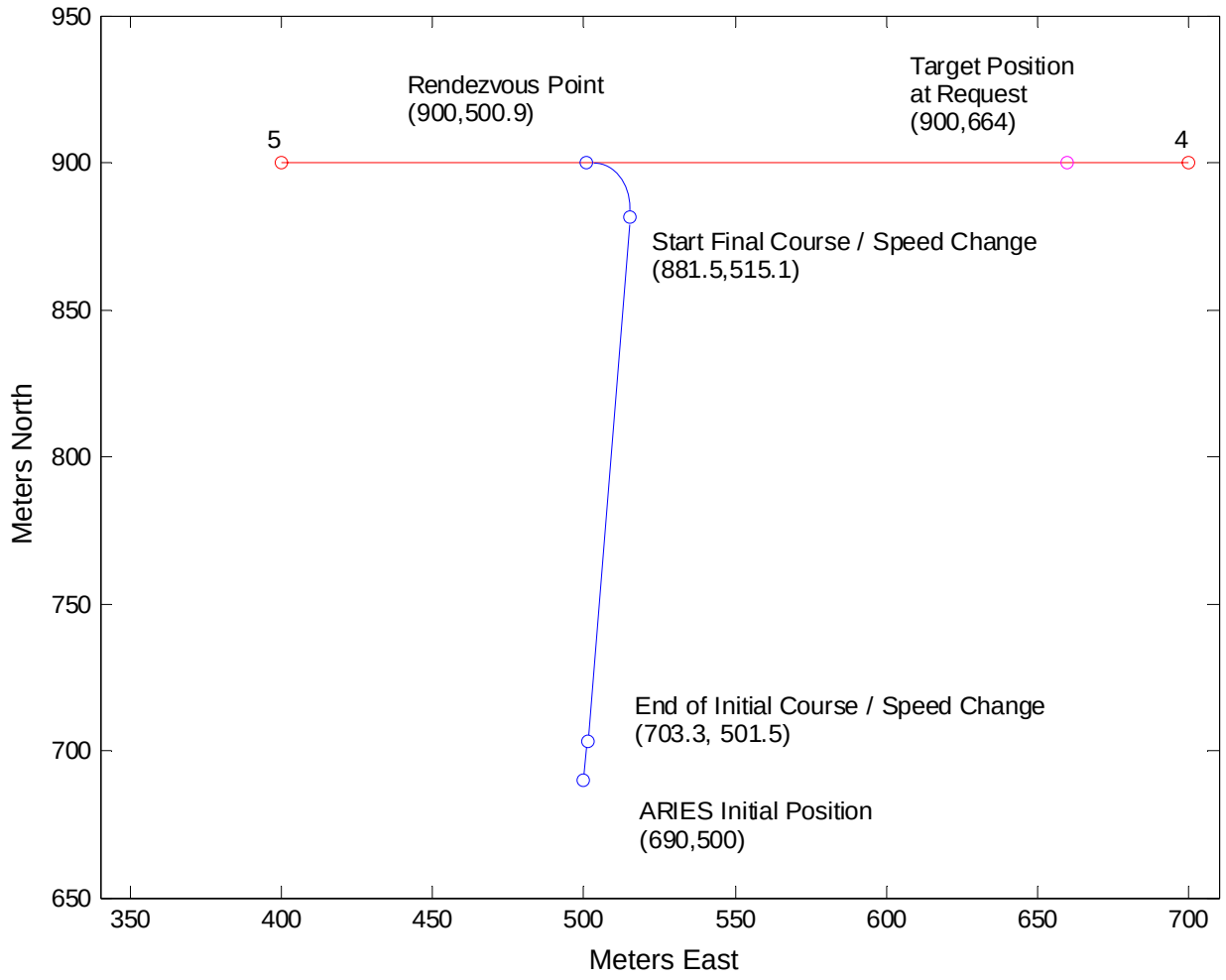
Time-Optimal In-Lab Track



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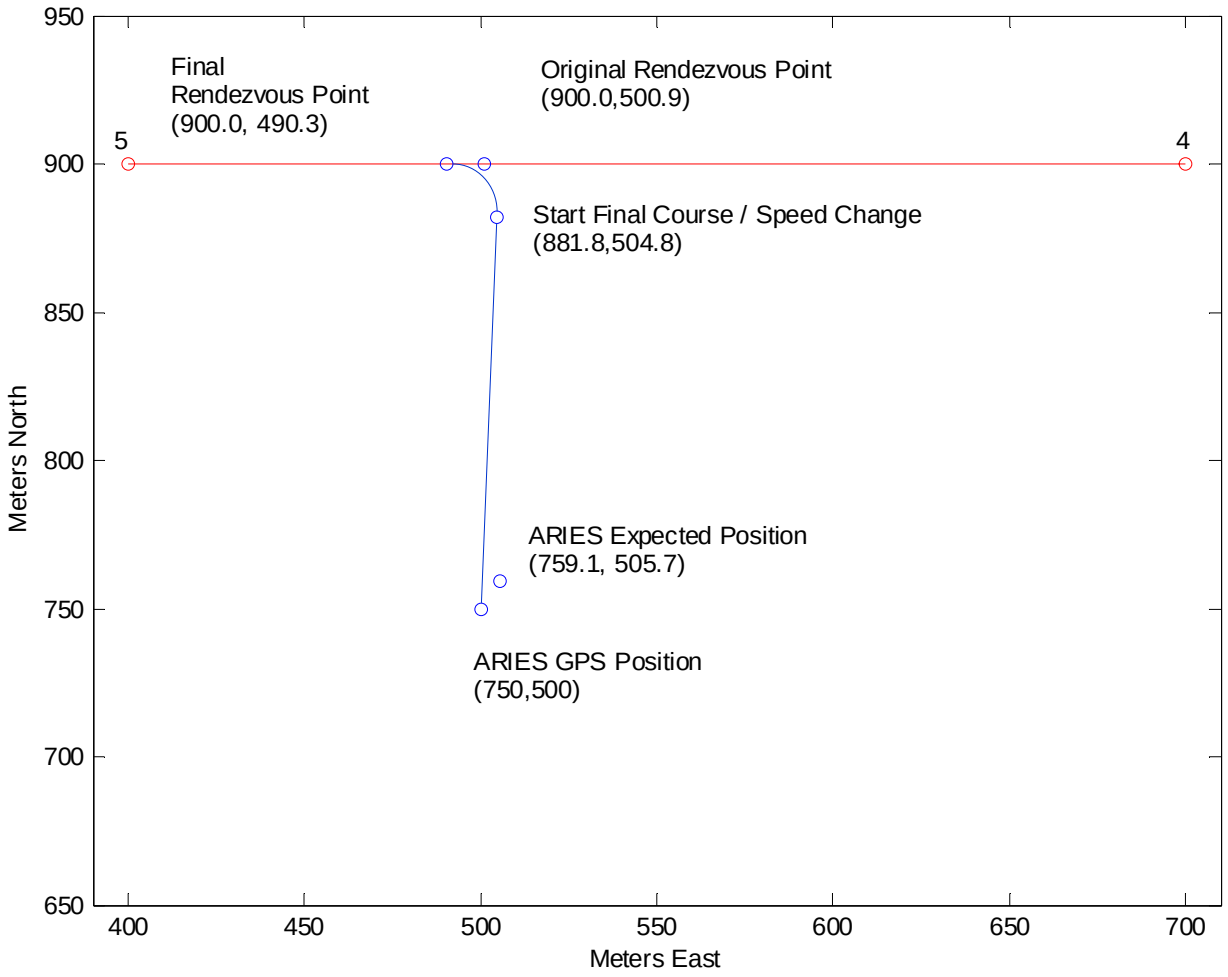
Replanned Time-Optimal Track



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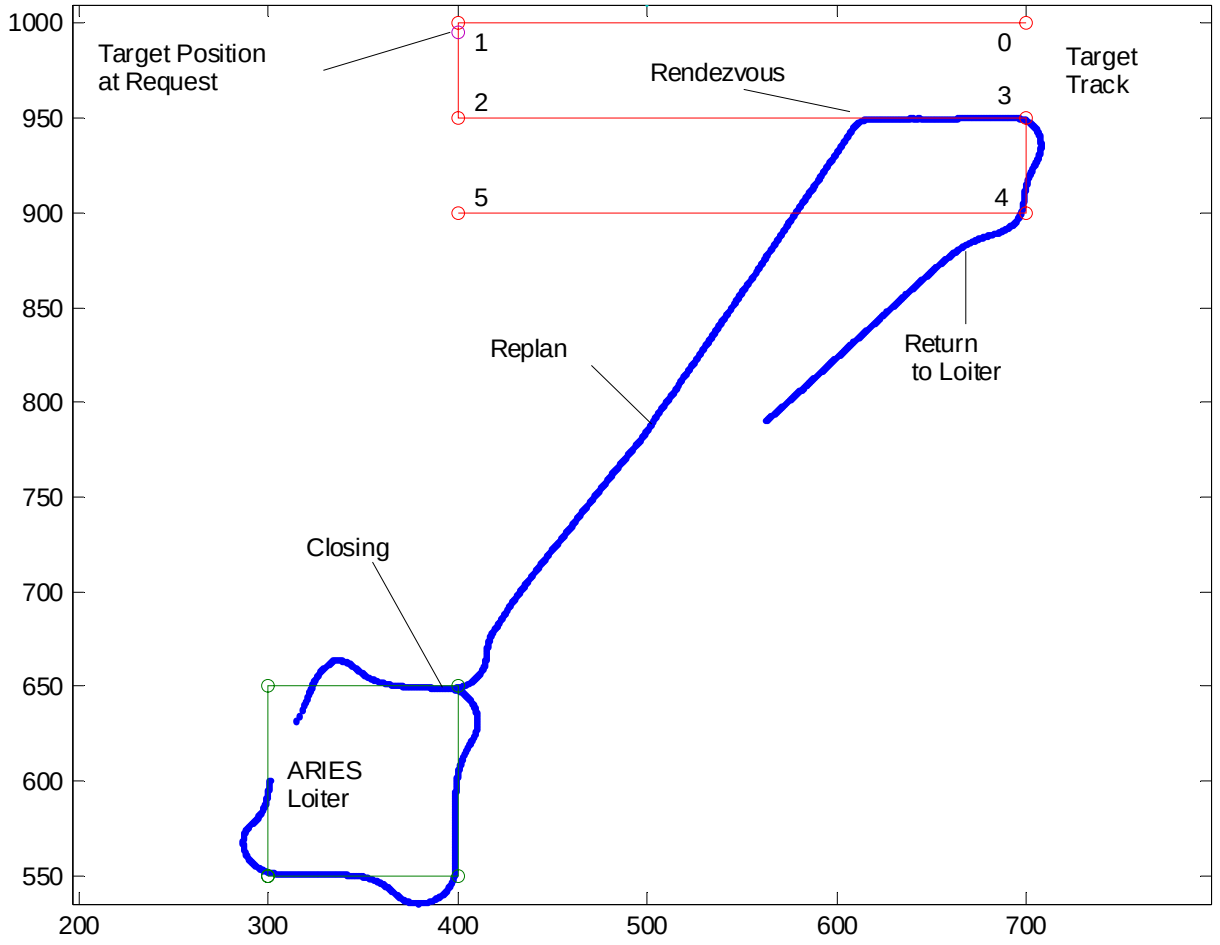
First In-water Run: Time-optimal Rendezvous



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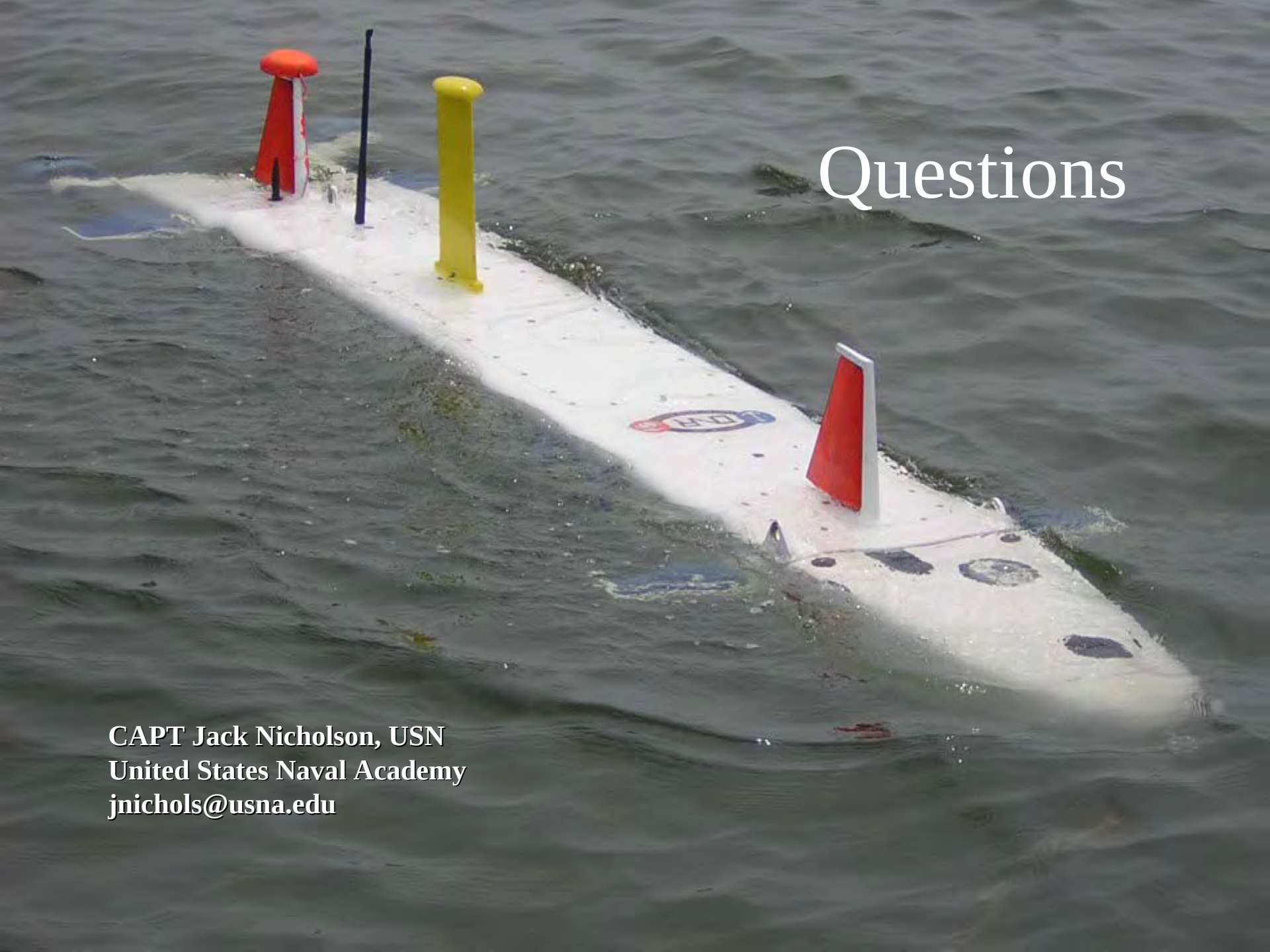
Naval Academy

Summary

- Significant savings in time / effort / money
  - Several hundred runs, in days (vice months)
- Enhanced fault diagnosis, rapid correction
- Simulated sensor inputs need not be complete set, or high fidelity (judgment / trade-offs)
- Care in blocking / restoring / retesting abort and other protective functions
- Power down unnecessary vehicle components to avoid wear and tear (nav / comms equipment)
- Nominal performance first time in the water



Questions

CAPT Jack Nicholson, USN
United States Naval Academy
jnichols@usna.edu

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Naval Academy

Back-up Slides

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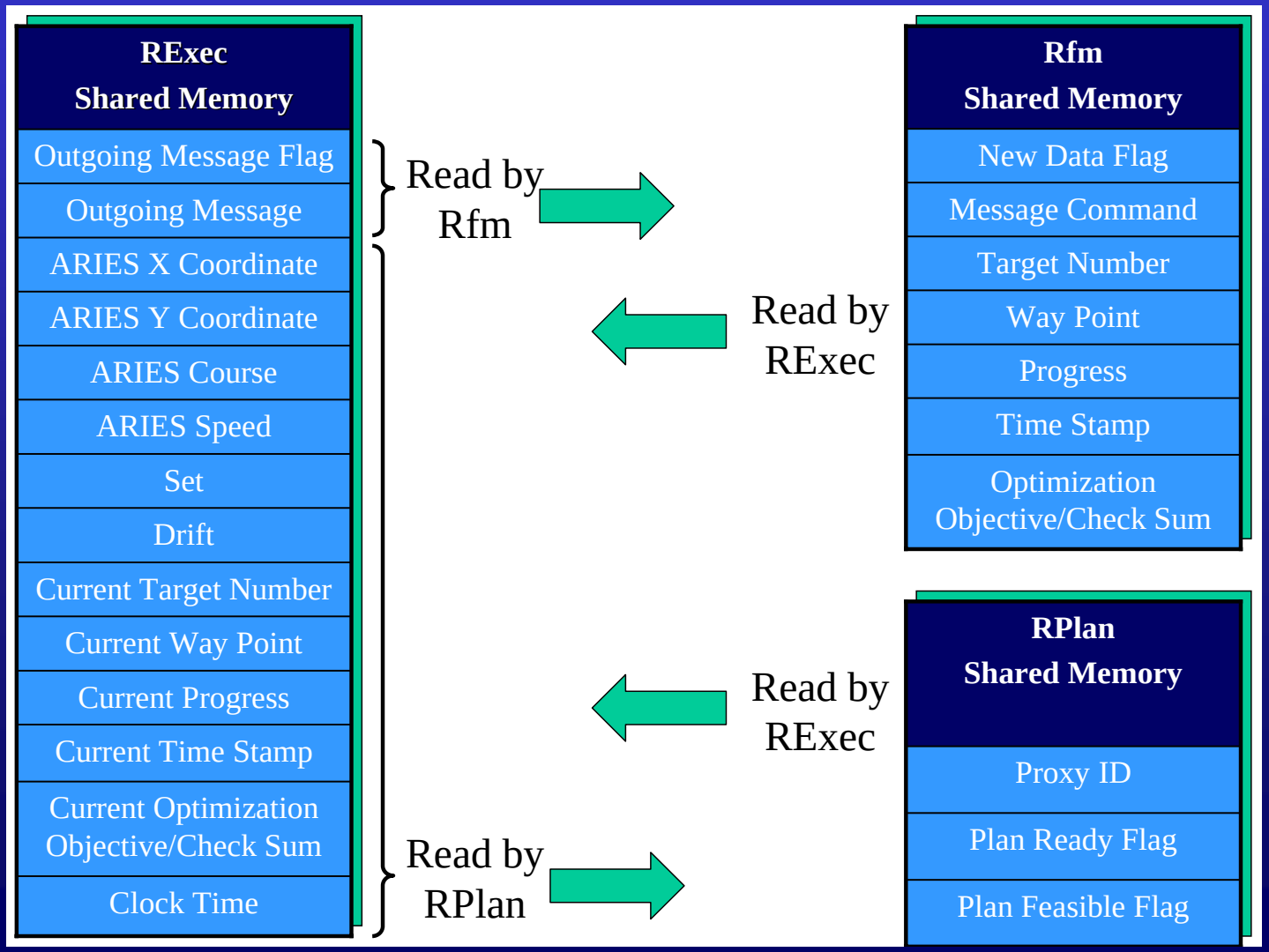
RENDEZVOUS SHARED MEMORY



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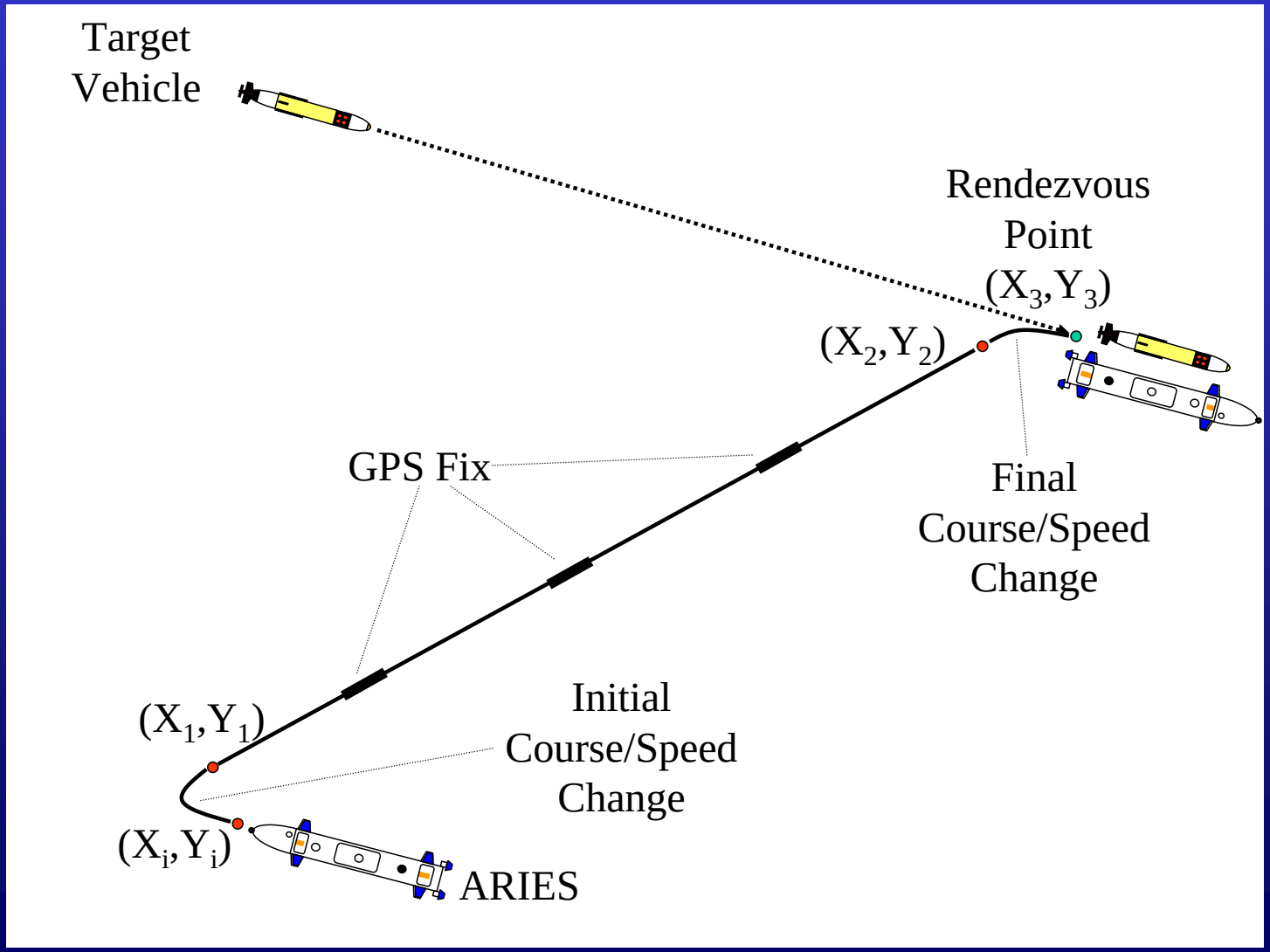
RENDEZVOUS TRAJECTORY



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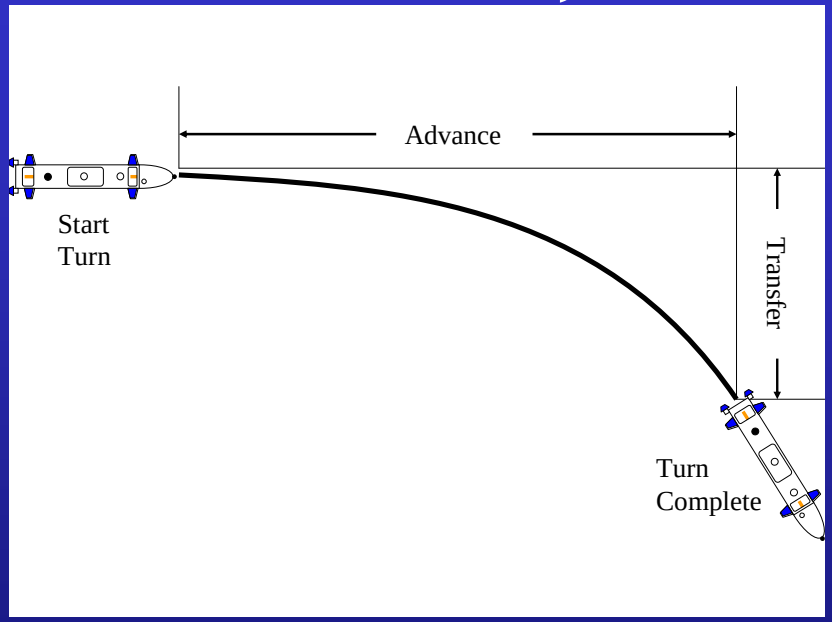
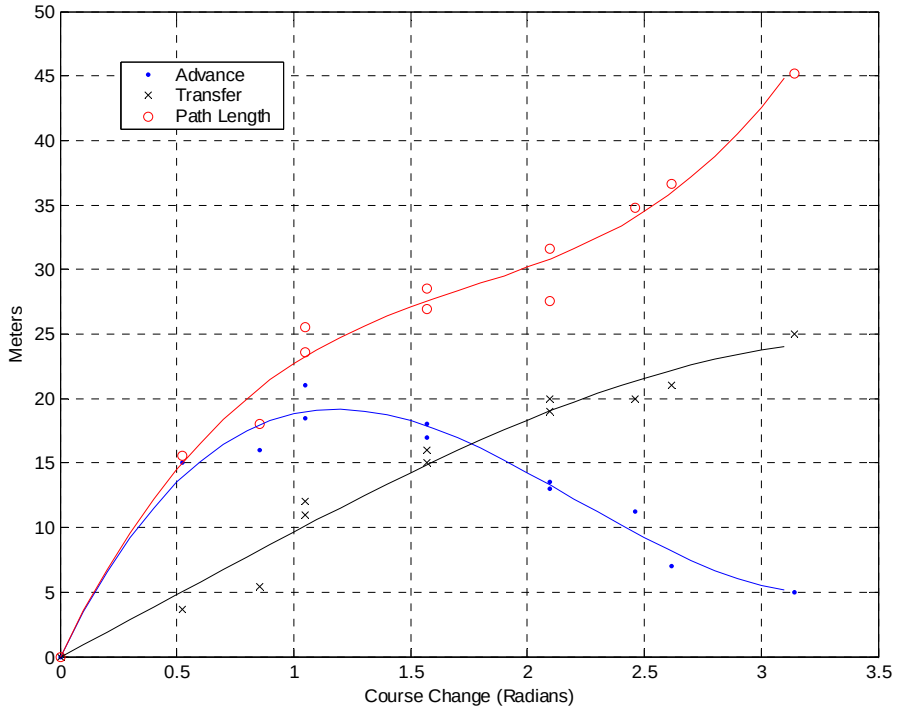
ADVANCE, TRANSFER AND PATH LENGTH



- Parameterization of turn characteristics



- Used to compute spatial and temporal turn effects

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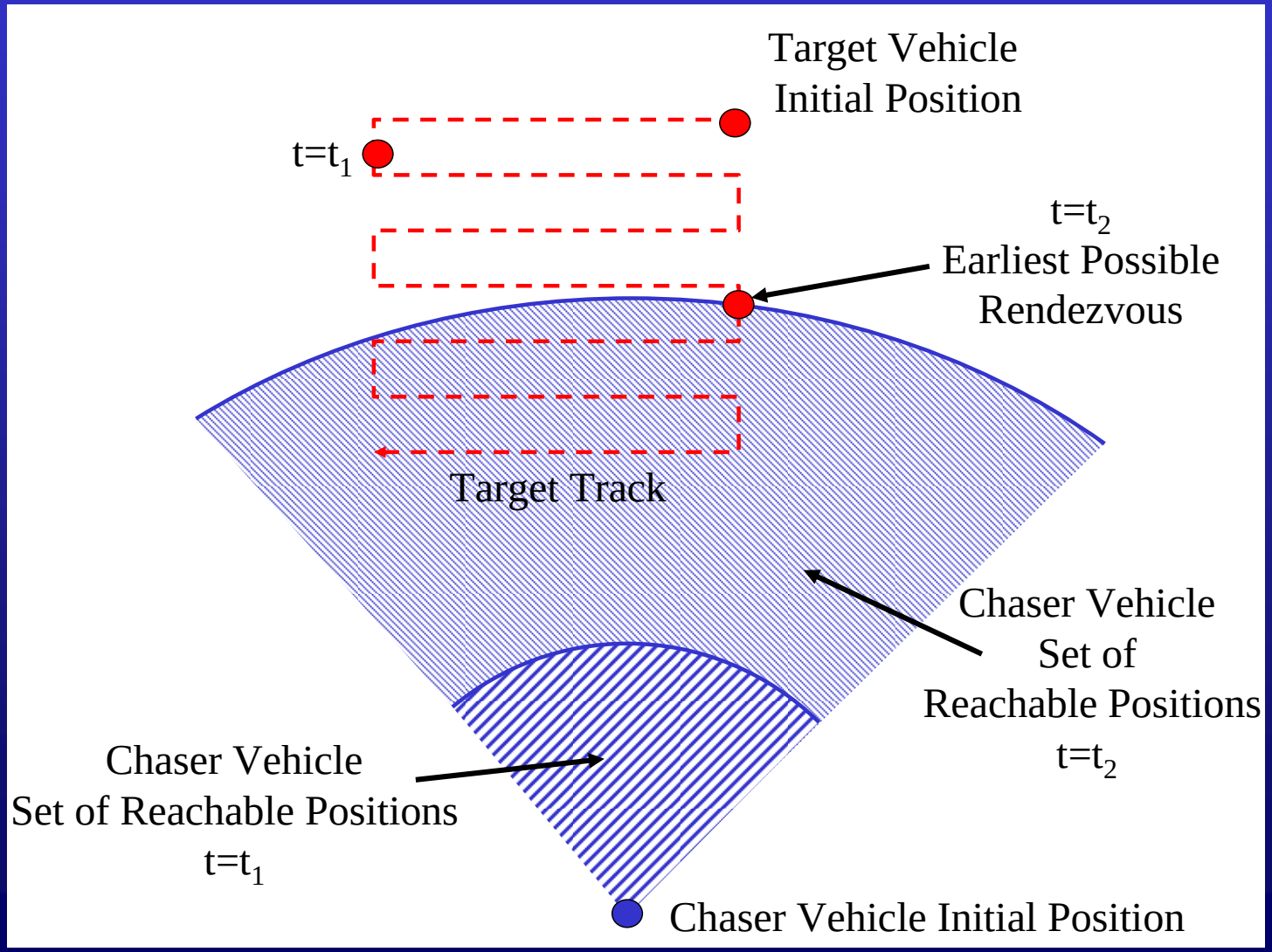
SET OF REACHABLE STATES



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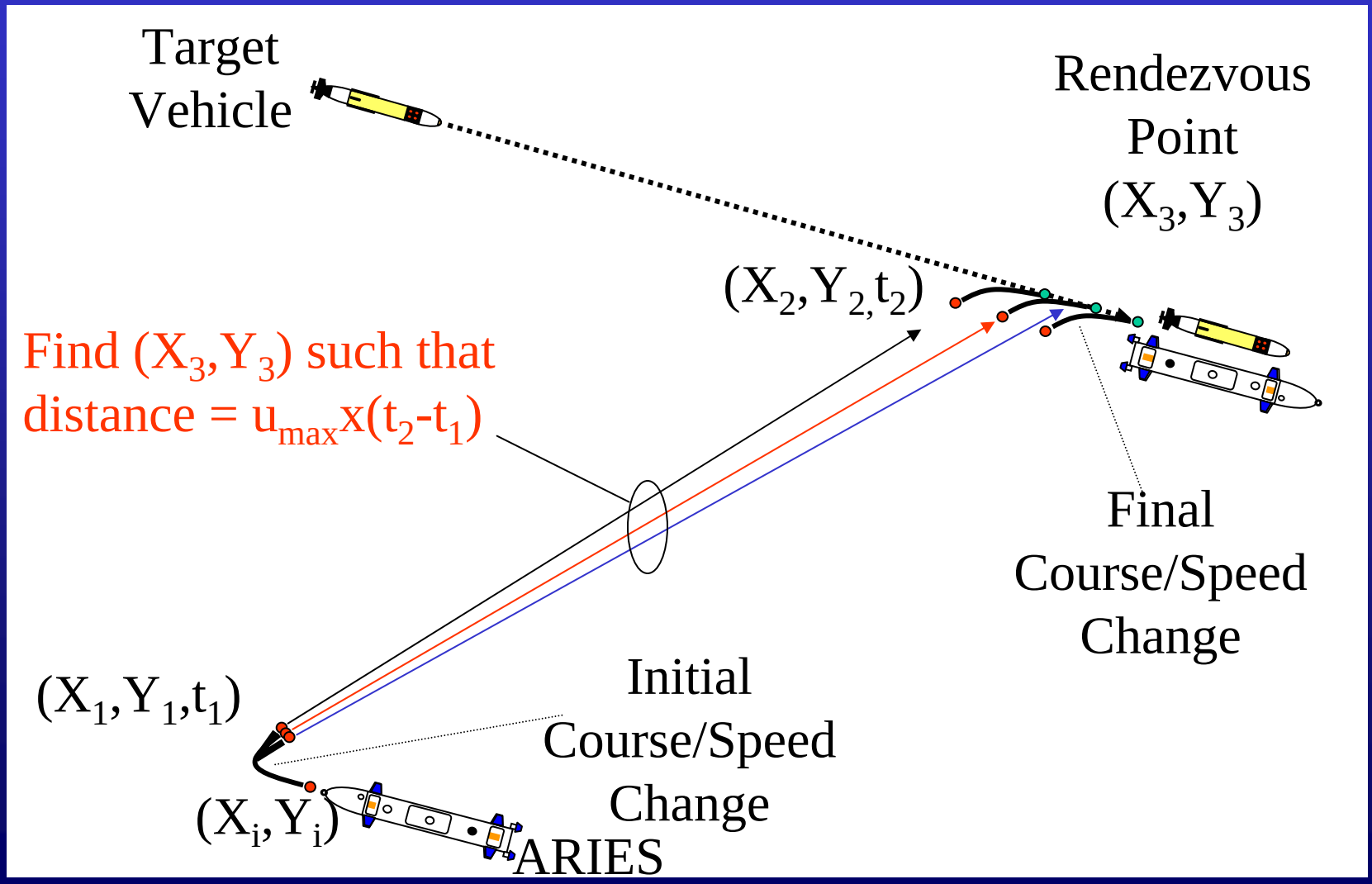
TIME-OPTIMAL RENDEZVOUS POINT



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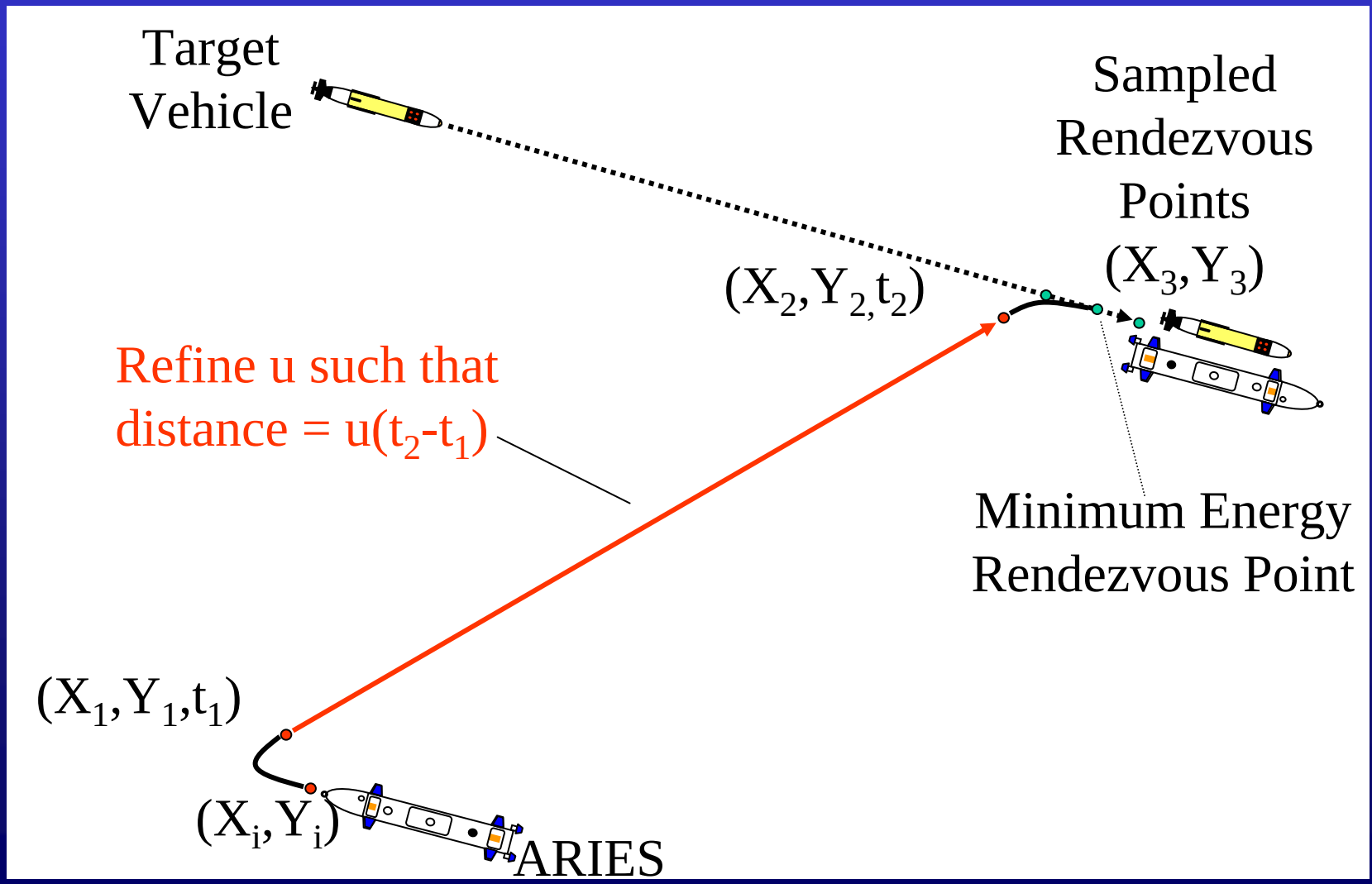
ENERGY-OPTIMAL RENDEZVOUS POINT



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IN-LAB RUNS

- Rendezvous request:

RVS,REQ,0,5,120,30,+/-155

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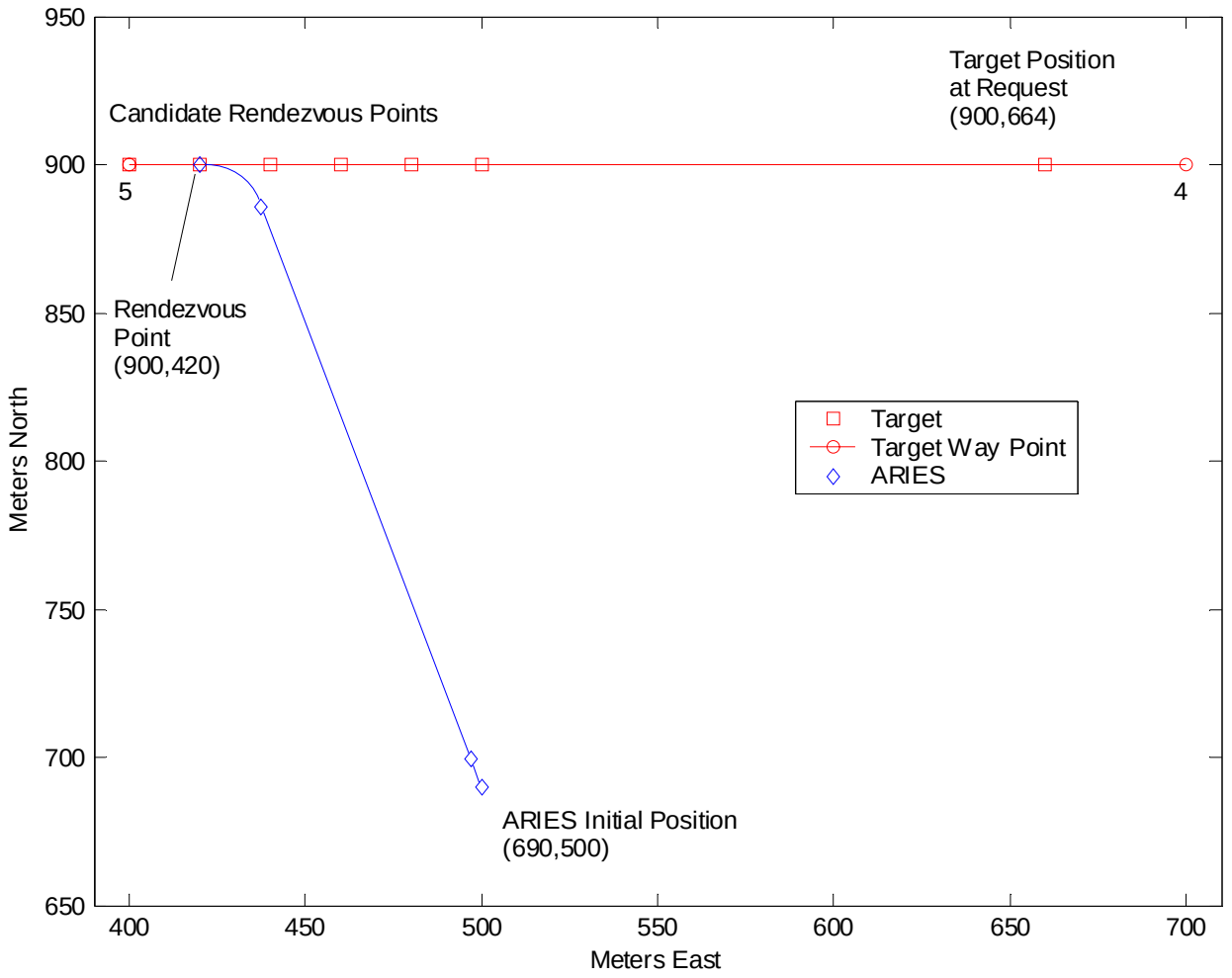
ENERGY-OPTIMAL IN-LAB TRACK



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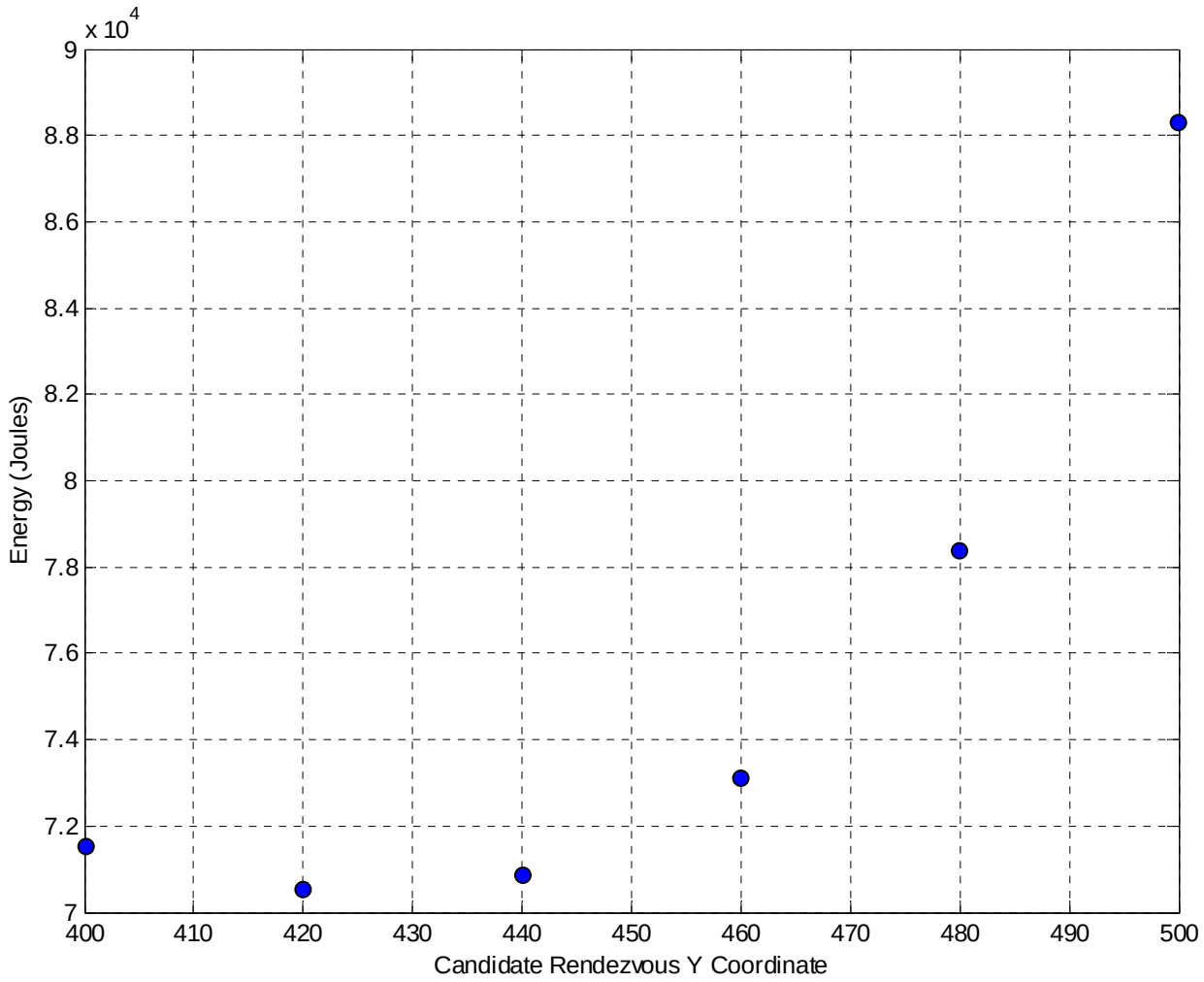
ENERGY-OPTIMAL CALCULATIONS



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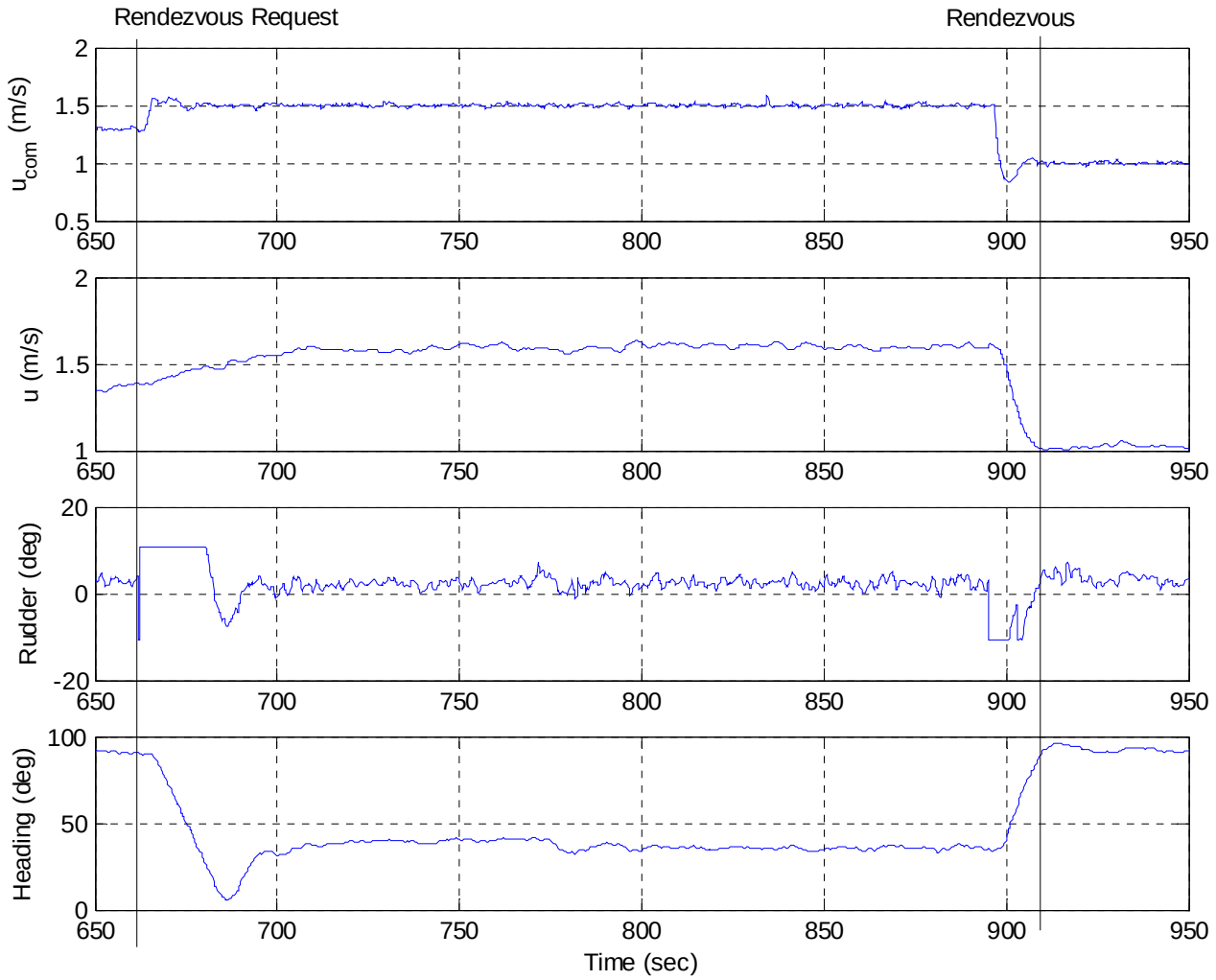
CONTROLS AND STATES



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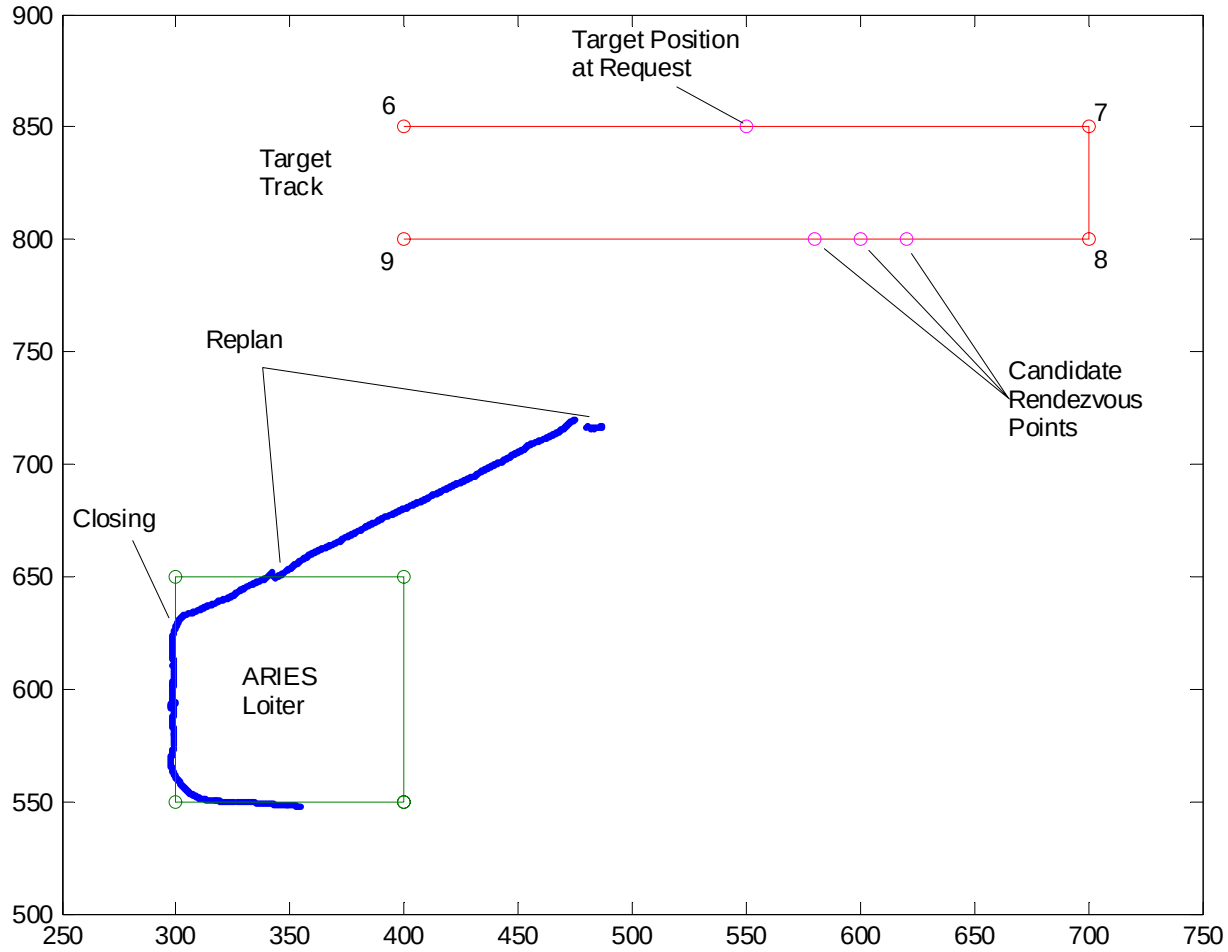
ENERGY-OPTIMAL IN-WATER TRACK



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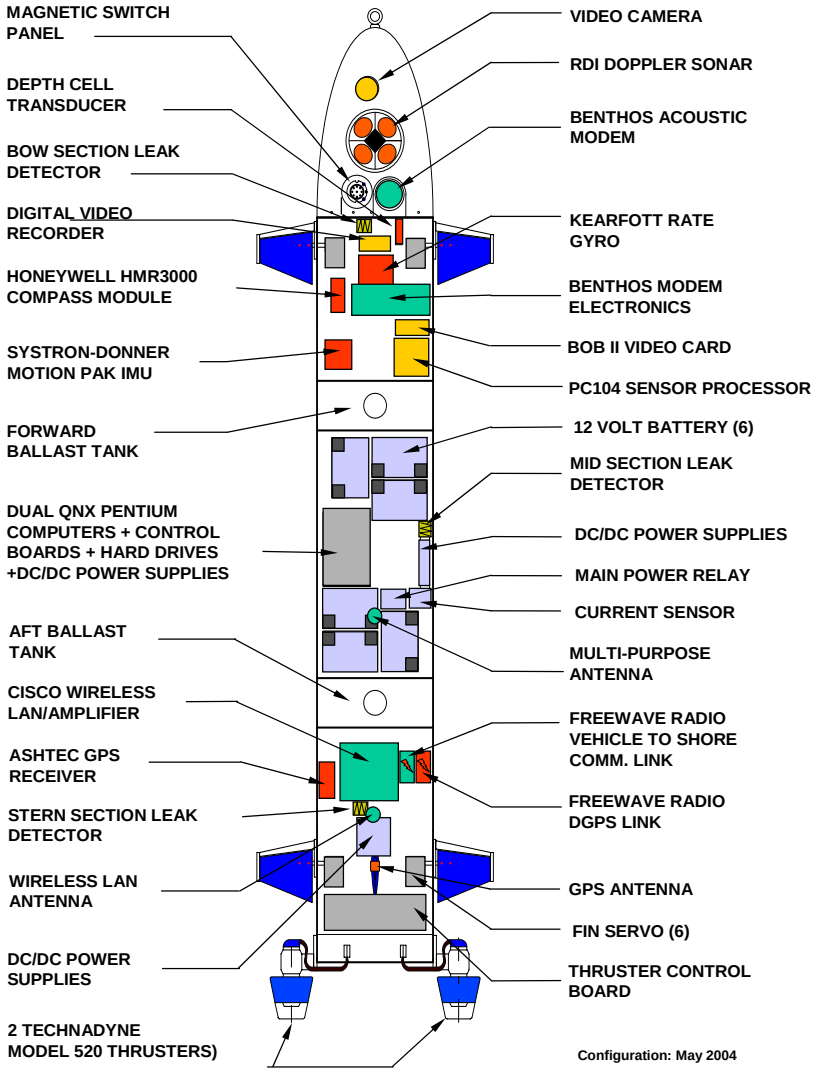


PANEL MEMBERS

PANEL MEMBER	ORGANIZATION	UMV COMMUNITY SEGMENT
Mr. Rob Simmons	PMS EOD	Navy Acquisition Program
Mr. Rick Vosburgh	Nekton Research LLC	Commercial UUV Development
CDR Roy Barnes	Operational T&E Force	Test & Evaluation
Dr. Thomas Swean	Office of Naval Research	Science & Technology
Mr. Jim Griffin	Naval Undersea Warfare Center	Navy Laboratory
Dr. Don Brutzman	Naval Postgraduate School	Academia
CDR Jon Wood	Naval Special Clearance Team One	Fleet Operational End User
Mr. Edward Gough	Naval METOC Command	Fleet Oceanography

AUV Fest 2005: Highlights

W[M] Schopfel
ONR Test Director

AUV Fest: History

- 6 events beginning in 1997
- Gulfport Mississippi & Keyport Washington
- Purpose remains the same
  - S&T community
  - Collaborative & challenging environment
  - Test emerging technologies

Push the envelope

AUV Fest 2005: Statistics

6 -17	June 2005
6	Sponsors
18	Organizations
210+	Participants
30+	Technologies
7	Range Areas

AUV Fest 2005: Advancements

Vehicle Technology

Sensor Development

Navigation

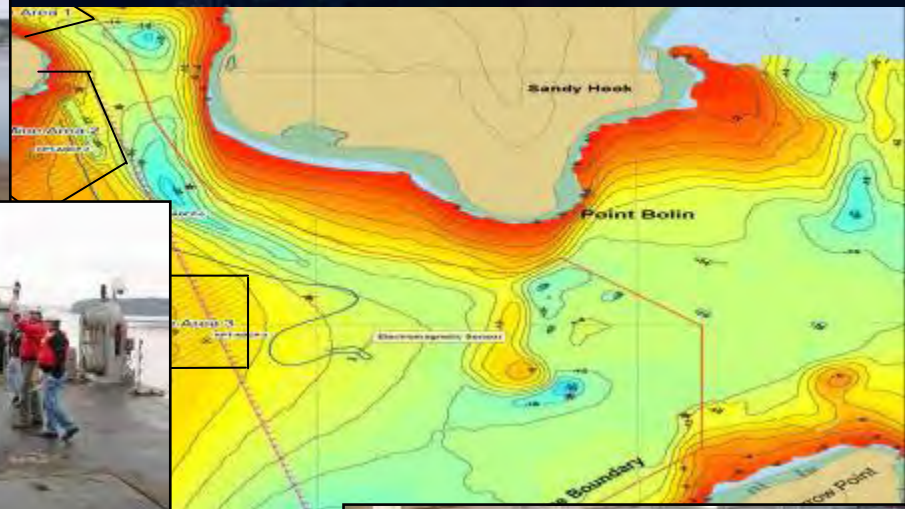
Communications

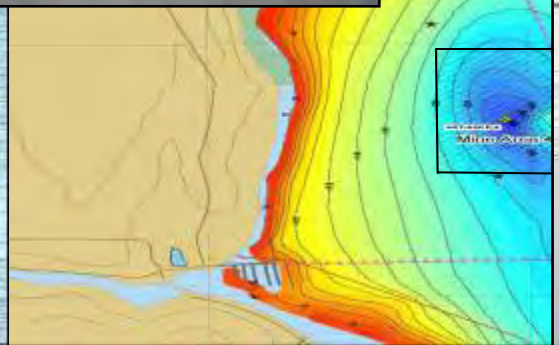
Collaborative Operations

Environmental Characterization

T2E2

AUV Fest 2005: Support





AUV Fest: Support

PEOPLE

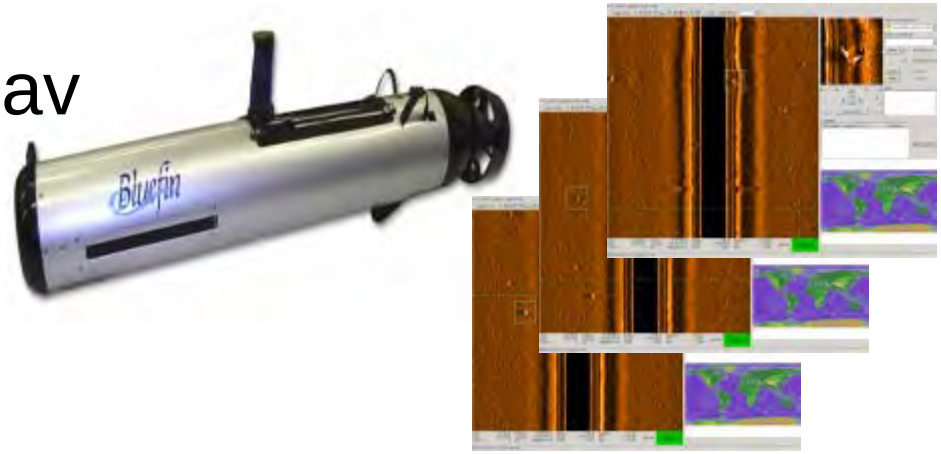
NSCT-ONE

- Fleet operations – Reason for AUV Fest
- Integrator of new equipment, procedures, doctrine with current TTPs and legacy equipment
- Beyond “Demonstration” – T2E2
  - Unit Training
  - Testing (Equip / Procedures / Tactics)
  - Experimentation -- UOES
  - Evaluation – Foreign Comparative Test (FTC) Program

NSCT-ONE

- GAVIA (Iceland)
  - Foreign Comparative Test Program
  - Dual Frequency SSS
  - Modular payloads

- Sea Lion (Bluefin 9”)
  - “Transponder less” Nav
  - UOES
  - SSS
  - Video

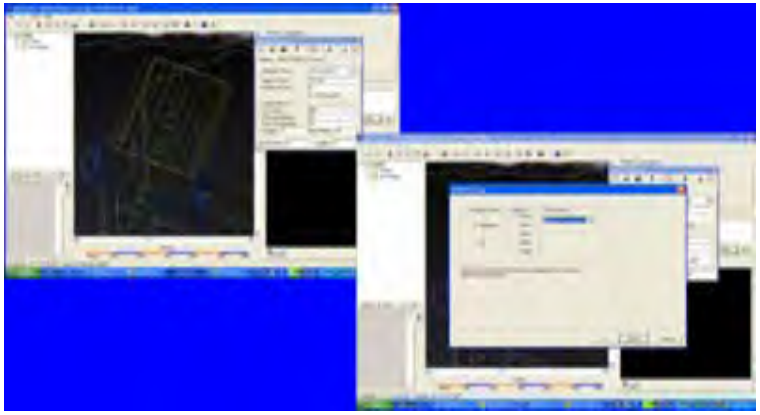


AUV Fest 2005

NSCT-ONE

- R & I Vehicle
  - SCM & RAI Missions
  - Dual Frequency SSS
  - UOES

- Common Operator Interface (COIN)
  - Msn Planning, Execution, and Reporting Tool
  - Common system interface

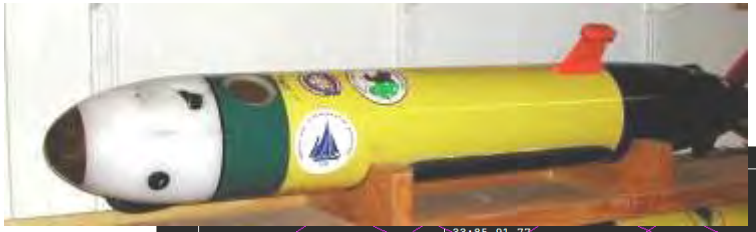


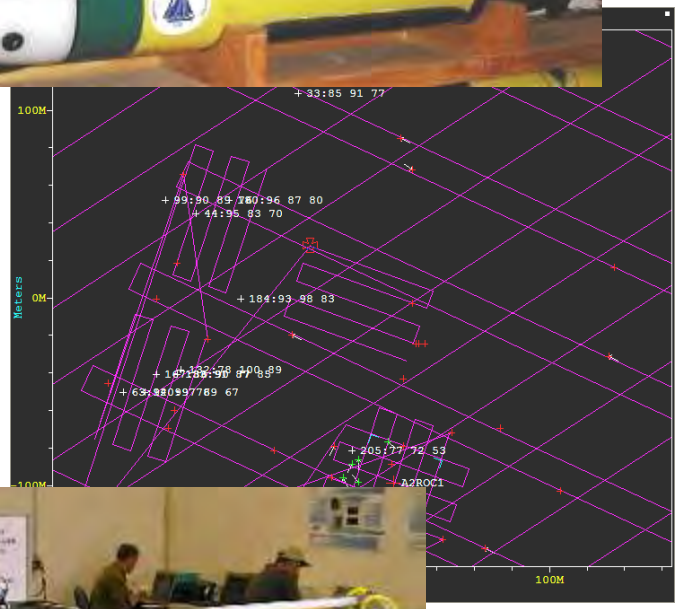
* Ask about UAVs

AUV Fest 2005

REMUS VSW

- Collaborative Operations
  - CRAWLERS
  - CETUS II
  - NEKTON
- Submarine Dry Dock Launch
  - Underwater Release
  - Surface & GPS Lock
  - Transit-Mission-Return
- UW Docking



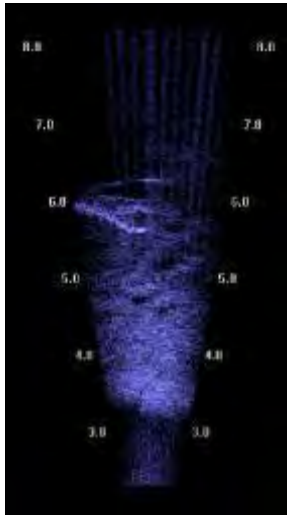


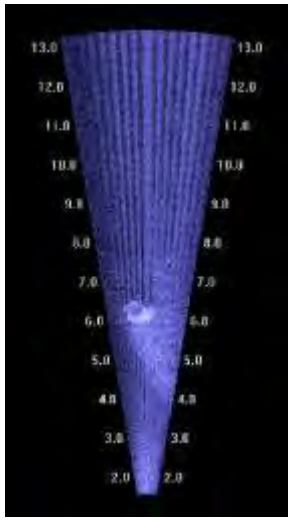
WHOI

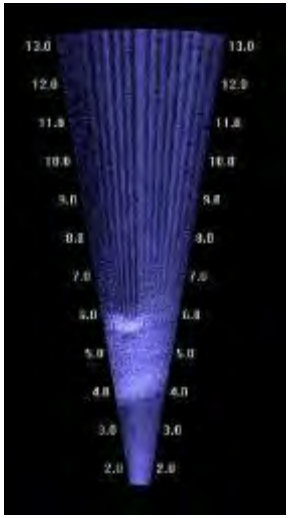
CETUS II--RAI

- Hover Capable UUV
- R & I Vehicle
  - MIRIS Forward Looking Sonar
  - Collaborative Ops with REMUS and/or CRAWLERS

∗ Ask about other CETUS variants





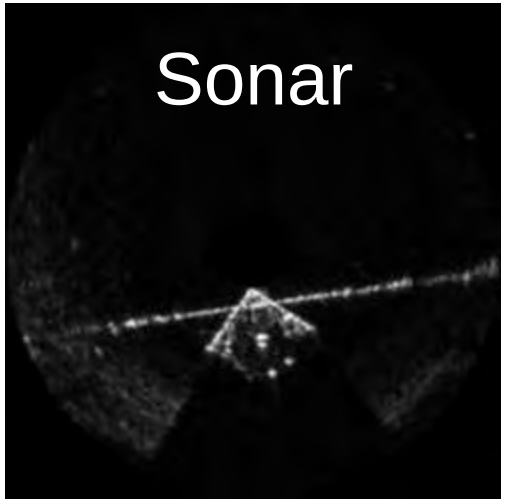


LOCKHEED MARTIN PERRY

AUV Fest 2005

CRAWLERS

- Conducted Collaborative Ops w/REMUS & CETUS
- Multi-Mission Capable
  - R & I
  - Neutralization
  - SCM in the Surf Zone



NSWC-PC

NEKTON RANGER & TRANSPHIBIAN

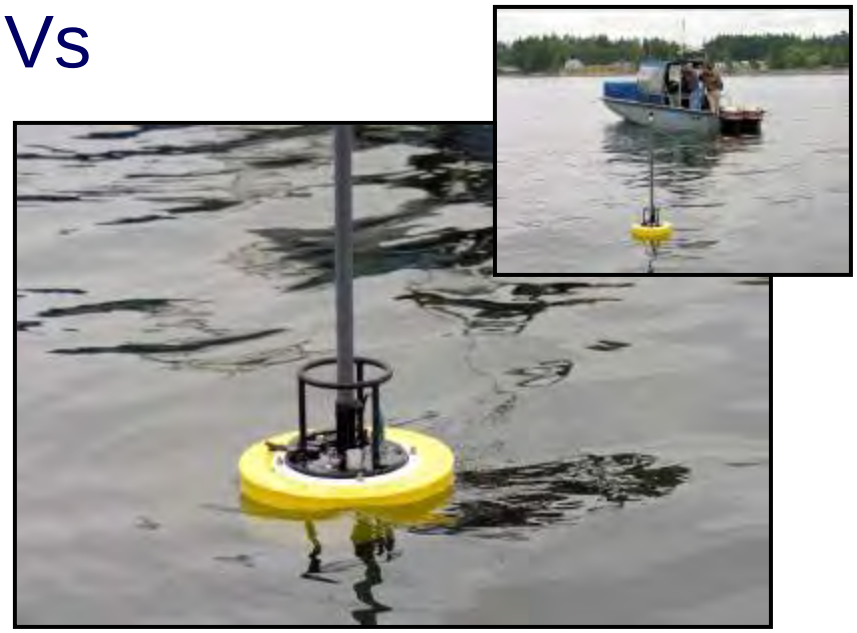
- Small Hand Held UUV
  - Reacquire and Neutralize Volume Mines
  - Blazed Array Sonar

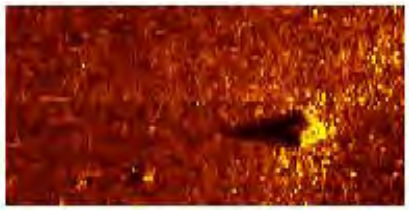
- Mine Hunter/Neutralizer
  - Restricted Areas
  - Swims & Crawls
  - Rotating Head Sonar

NEKTON Research

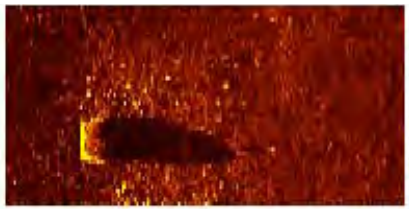
Acoustic Communications

- Acoustic Networking of UUVs
  - REMUS
  - Sea Lion
  - CETUS
  - CRAWLERS
- Real-Time Tracking
  - Standard Message Formats
  - Operators Ashore
- High Speed Modem
  - CAD/CAC SSS Images
- WHOI/Benthos Modem Interoperability





0. Target ID 1061
File:REMUS336.MST, Ping:91% X:-46%
Received:Mon Jun 13 14:41:16 2005
Position: 47N41.654 122W36.826
Score: 94.5 (94.5, 97.1, 91.9)



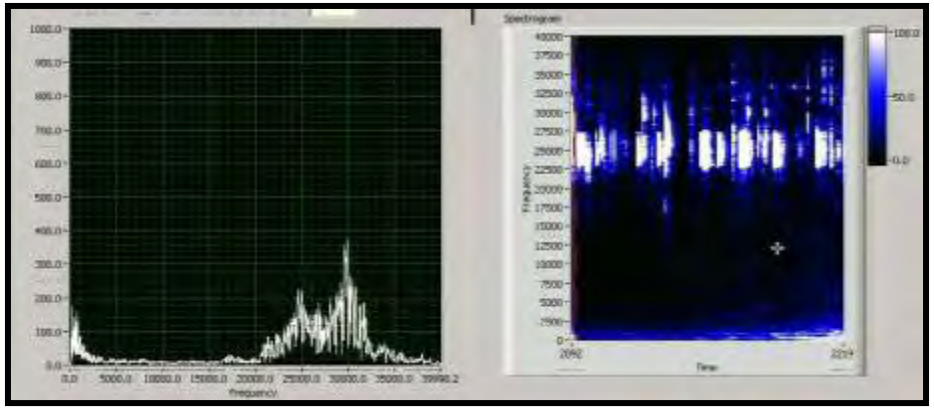
4. Target ID 1440
File:REMUS193.MST, Ping:35% X:43%
Received:Tue Jun 14 14:46:42 2005
Position: 47N41.589 122W36.881
Score: 87.8 (95.3, 99.9, 68.1)

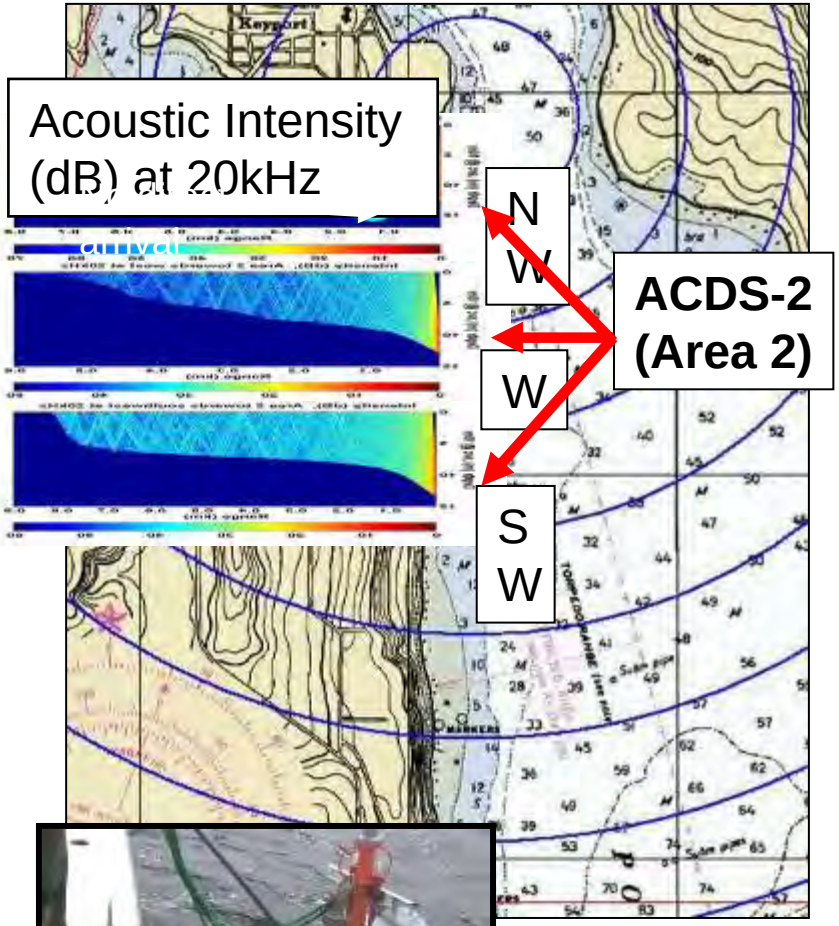
GATEWAY BUOY

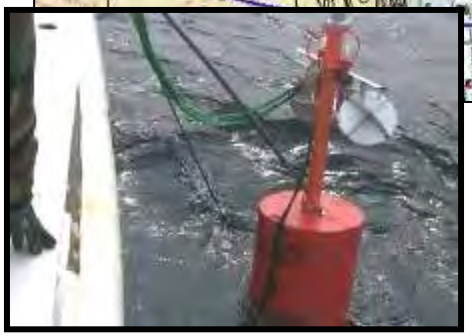
- Deployable Gateway Buoys
  - Helicopter
  - Fast Boat
  - Self Locating
  - Self Mooring
- Integrated into C2 Architecture
  - Collaborative Ops with REMUS and CRAWLERS

Acoustic Communication & Data Storage (ACDS)

- Characterization of the Acoustic Environment
- Deployed 3 Acoustic Communication and Data Storage Buoys
- Monitor and Record Acoustic Communications



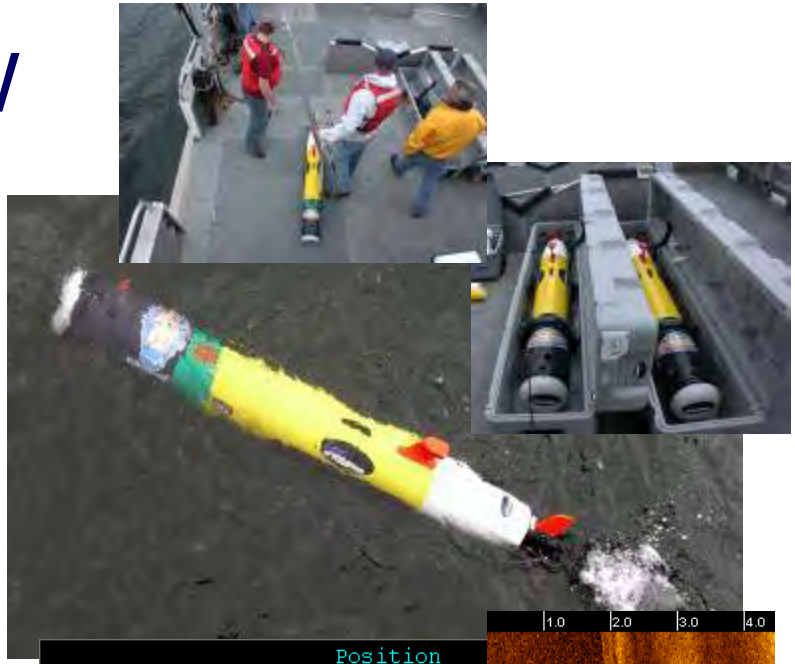


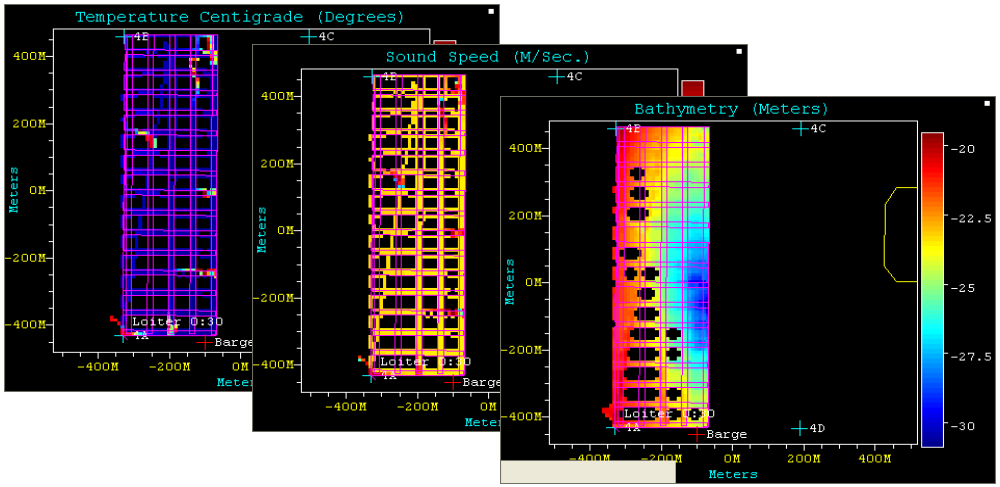


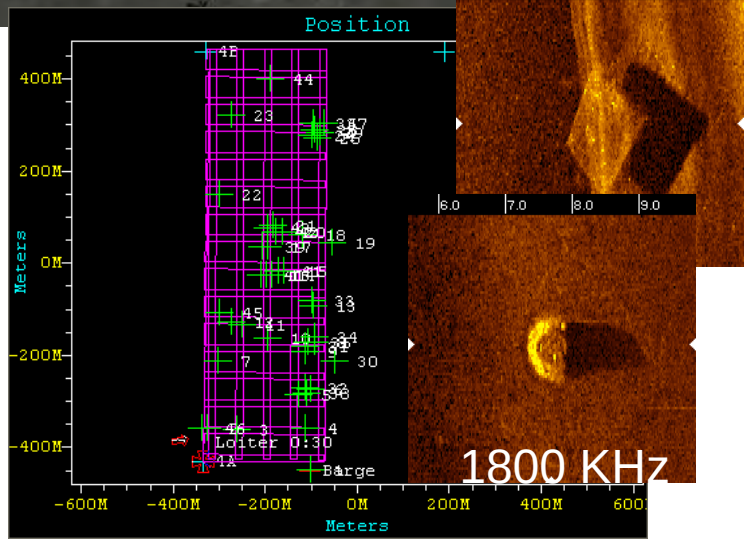
NRL

REMUS SW

- Improves on REMUS VSW Moves MCM into SW
  - Dual Frequency SSS for SCM and R&I
  - DIDSON
  - GPS/INU Navigation
  - OTH Iridium C2



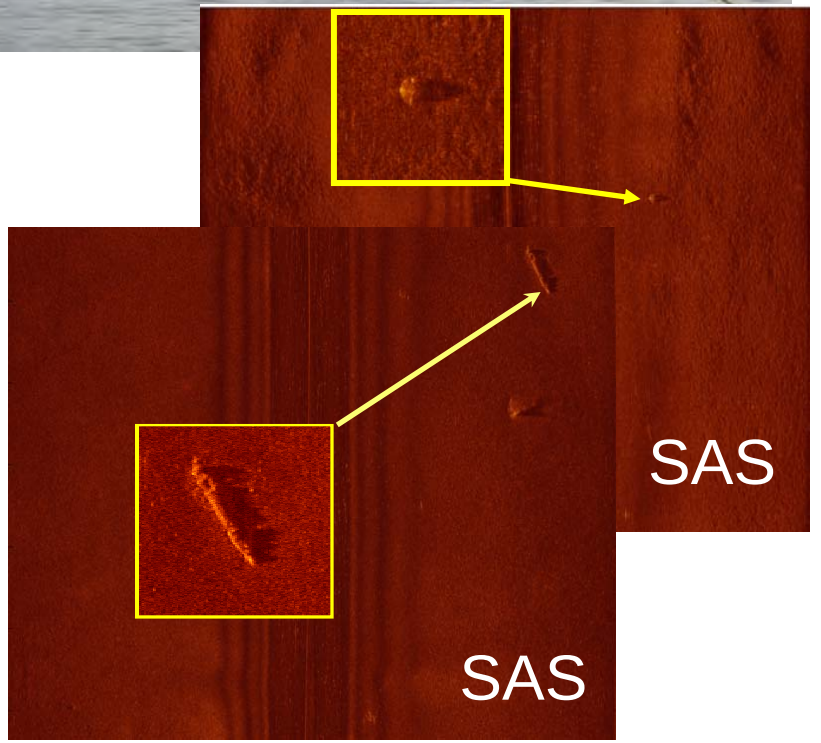




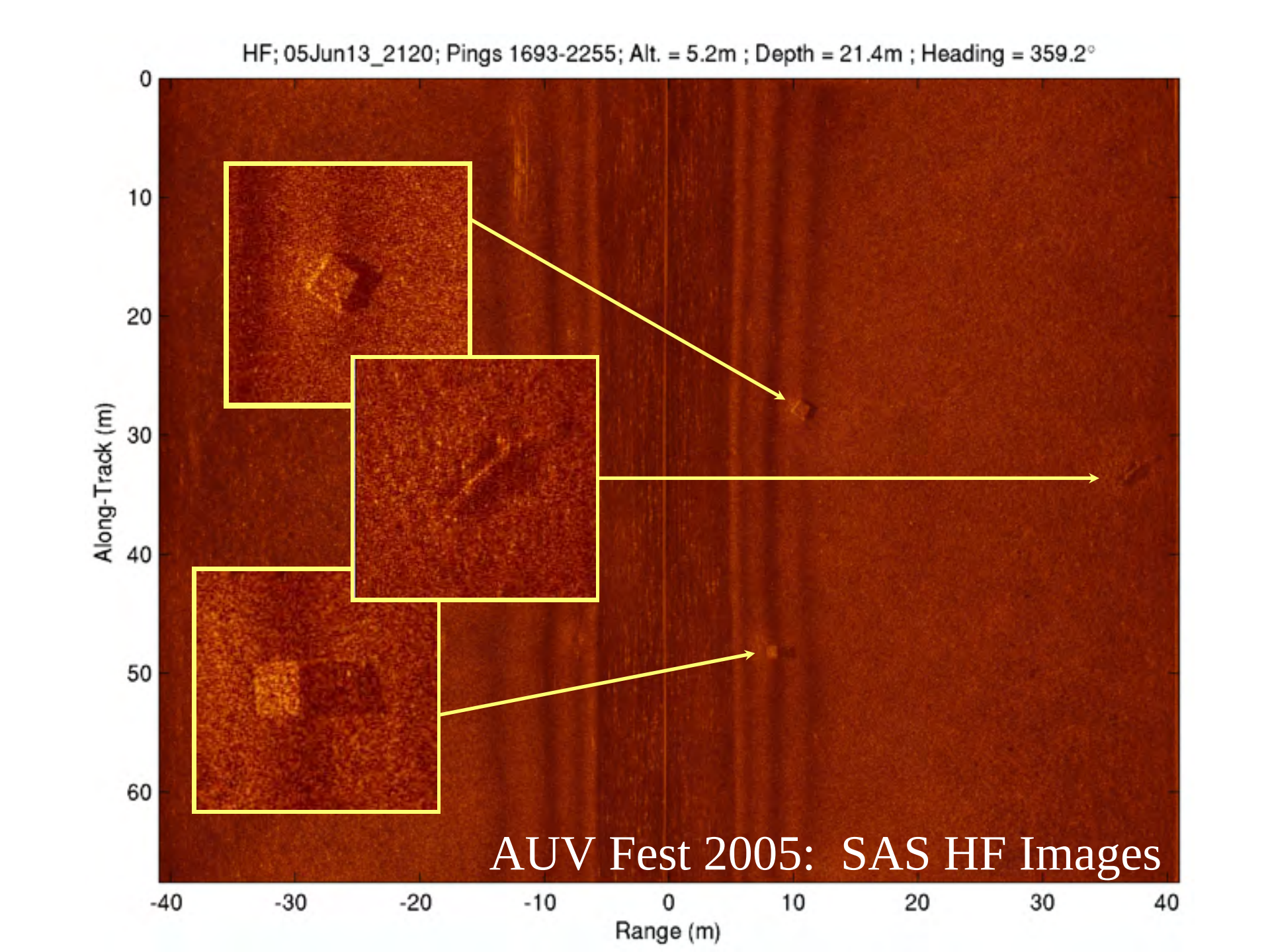
REMUS SW
“Two Man Transportable”

Small Synthetic Aperture Minehunter (SSAM)

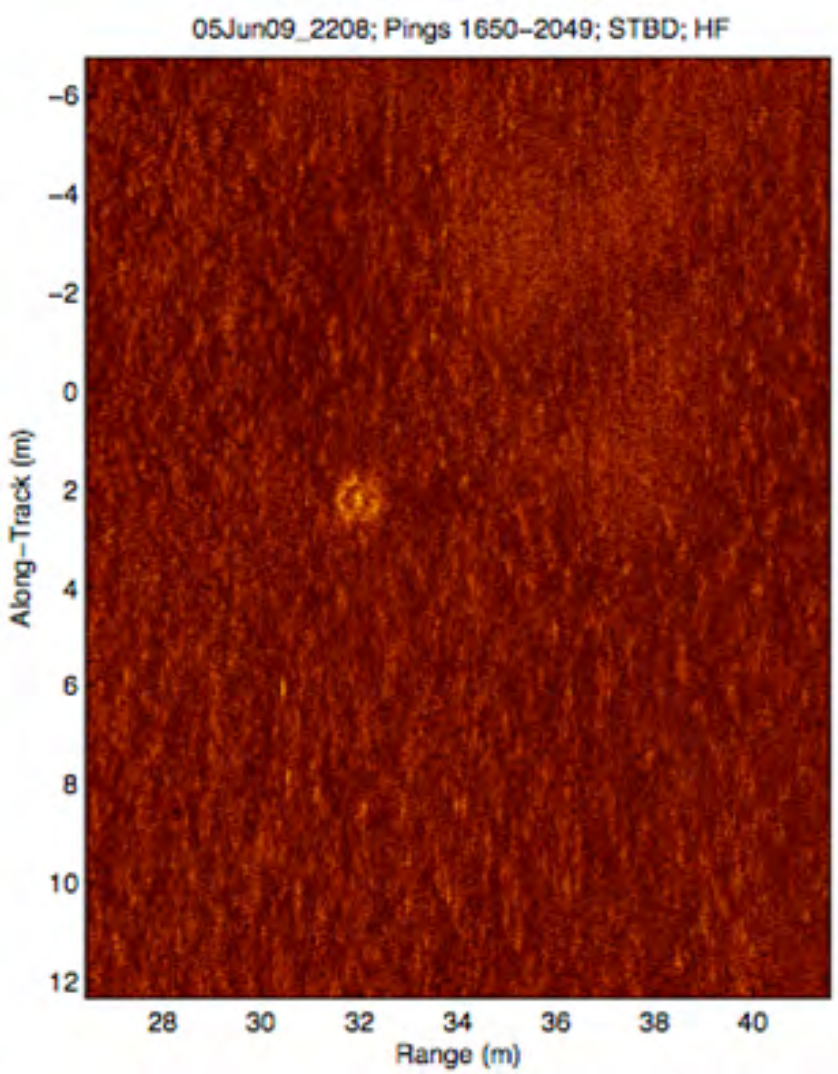
- REMUS – 600 UUV
- 12 ¾” Diameter
- Synthetic Aperture Sonar (SAS)
  - HF Imaging for High Resolution (ID Quality?)
  - LF Imaging for Buried / Partially Buried Mines
- Challenging Environment
  - Motion Sensitivity

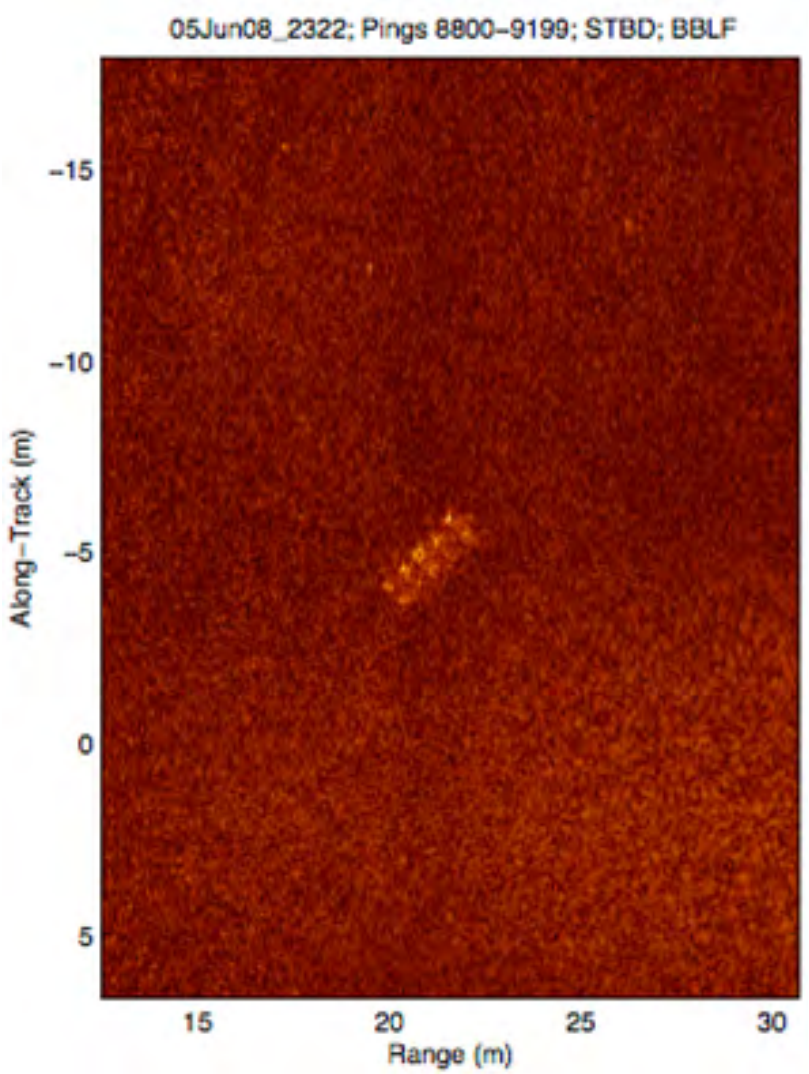


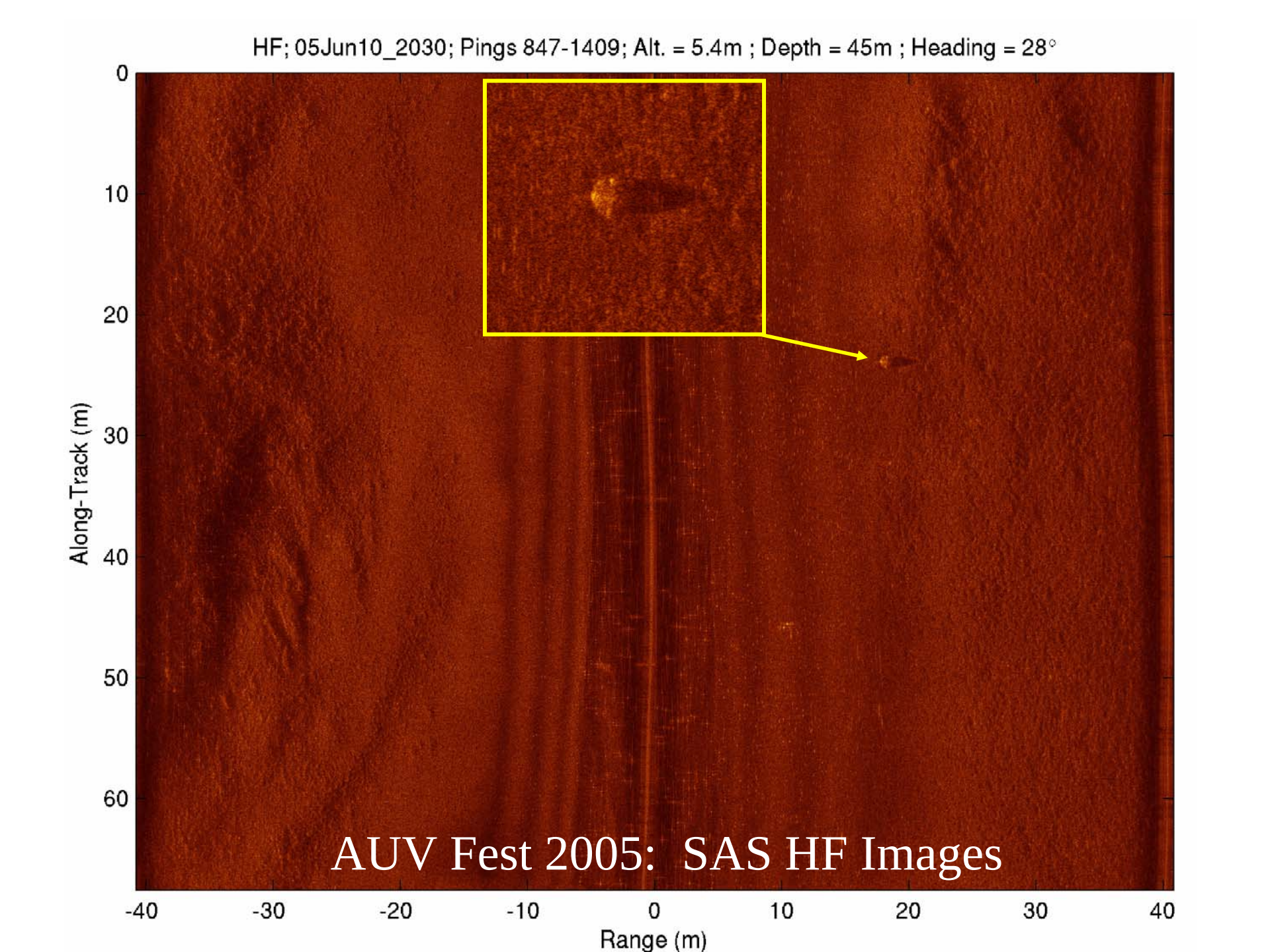
NSWC-PC & WHOI


HF; 05Jun13_2120; Pings 1693-2255; Alt. = 5.2m ; Depth = 21.4m ; Heading = 359.2°
Along-Track (m)
0
10
20
30
40
50
60
-40
-30
-20
-10
0
10
20
30
40
Range (m)
AUV Fest 2005: SAS HF Images

AUV Fest 2005: SAS HF Images



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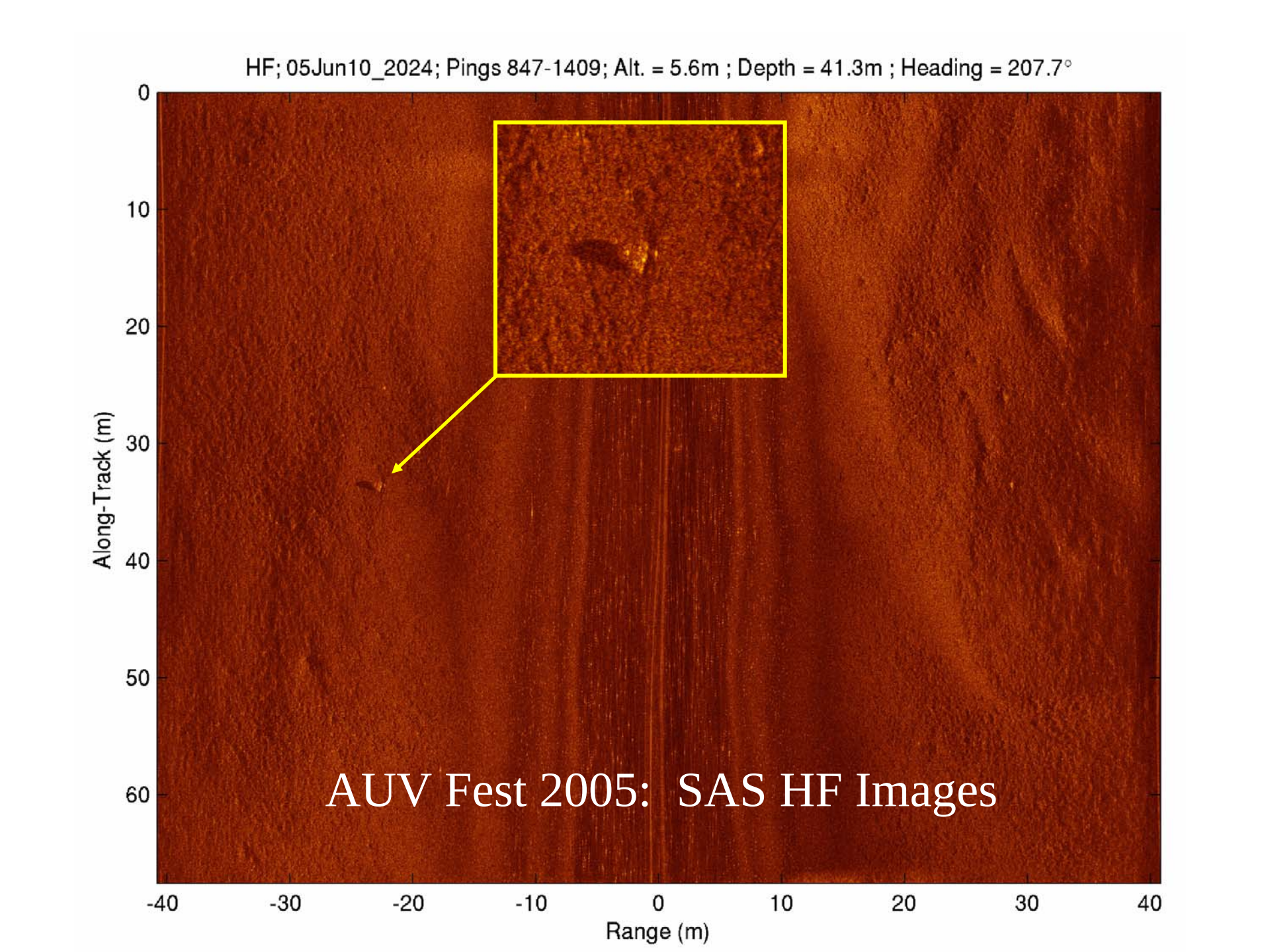
Along-Track (m)
0
10
20
30
40
50
60
-40
-30
-20
-10
0
10
20
30
40
Range (m)
AUV Fest 2005: SAS HF Images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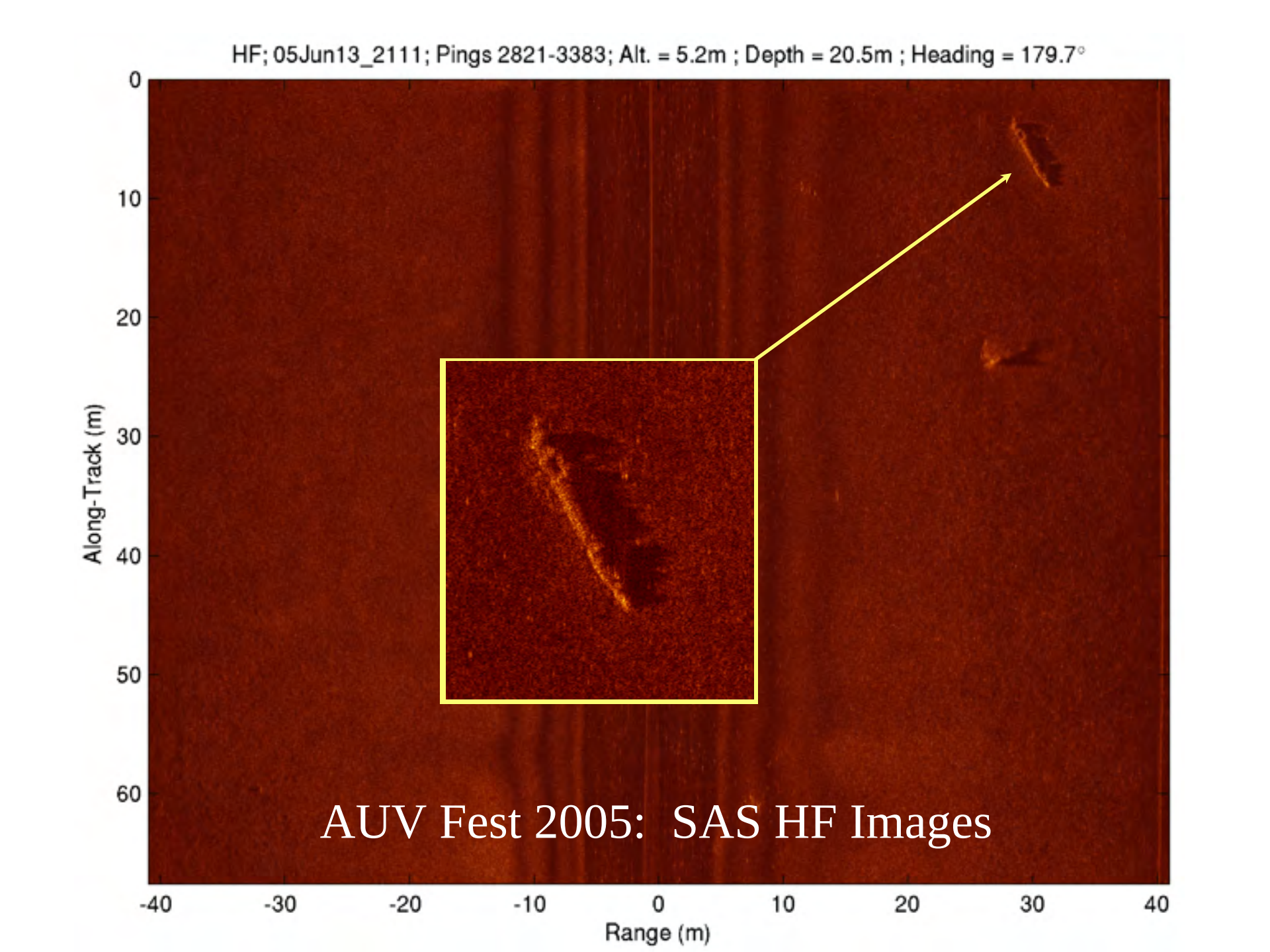
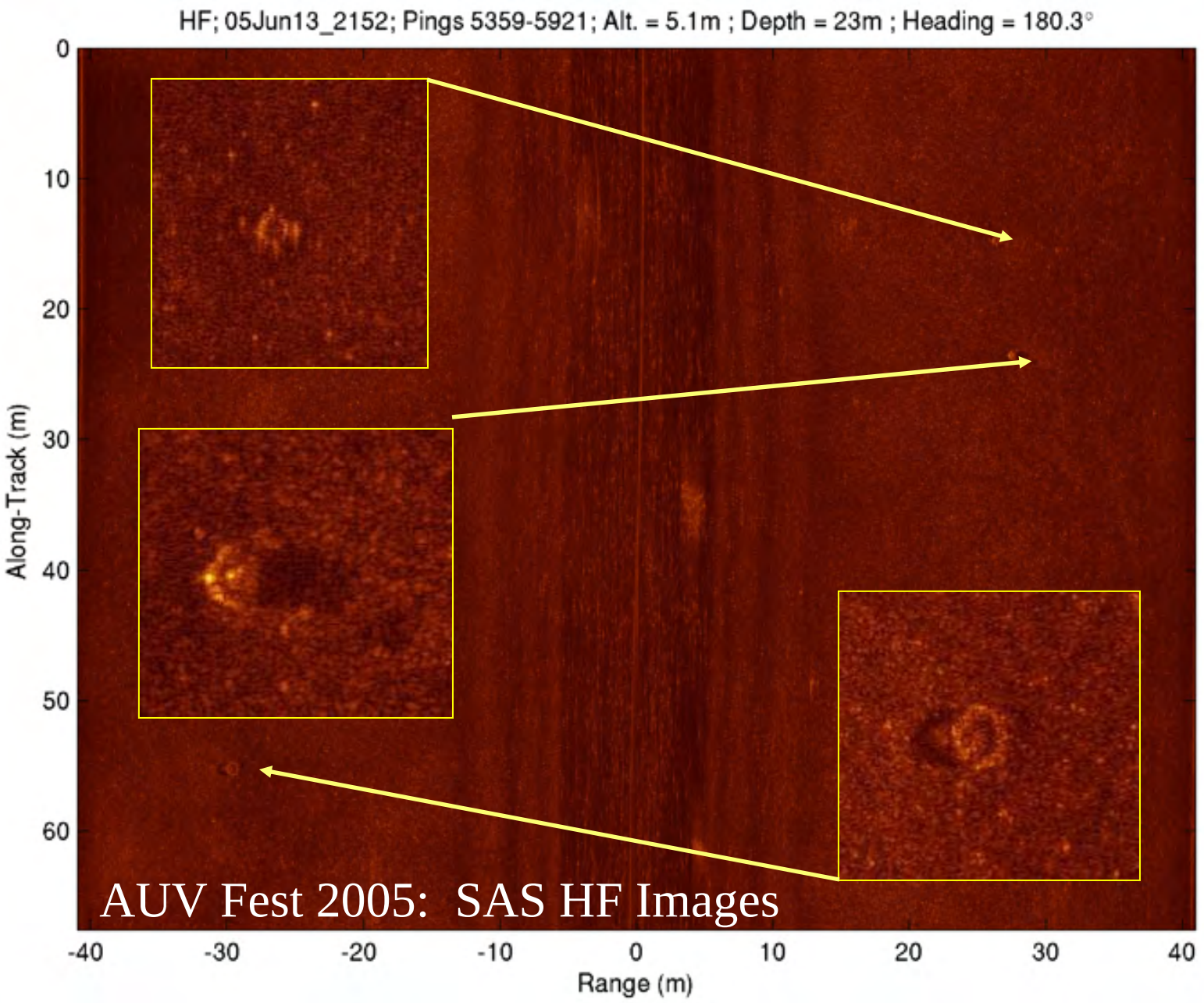
0
10
20
30
40
50
60
Along-Track (m)
-40
-30
-20
-10
0
10
20
30
40
Range (m)
AUV Fest 2005: SAS HF Images


HF; 05Jun13_2111; Pings 2821-3383; Alt. = 5.2m ; Depth = 20.5m ; Heading = 179.7°
Along-Track (m)
0
10
20
30
40
50
60
-40
-30
-20
-10
0
10
20
30
40
Range (m)
AUV Fest 2005: SAS HF Images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Along-Track (m)
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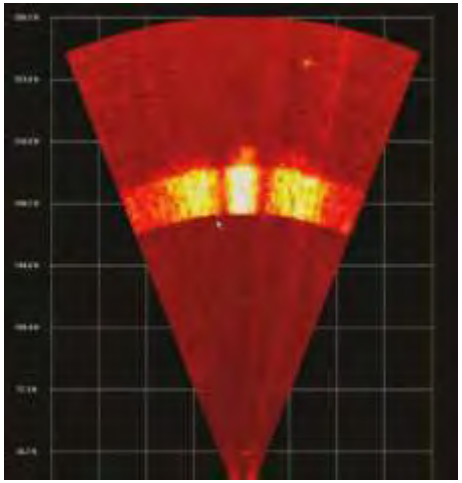
10
20
30
40
50
60
-40
-30
-20
-10
0
10
20
30
40
Range (m)
AUV Fest 2005: SAS HF Images

Acoustic Radio Interactive Exploratory Server (ARIES)

- ARIES UUV -- Navigation
  - Obstacle Avoidance – “Up and Over”
  - Forward Looking Blazed Array Sonar
  - Onboard Dynamic Image Processing
  - Small to Mid-sized UUVS



* Ask about Broadband Communications thru UAV

Naval Postgraduate School (NPS)

Mid-sized Autonomous RV (MARV)

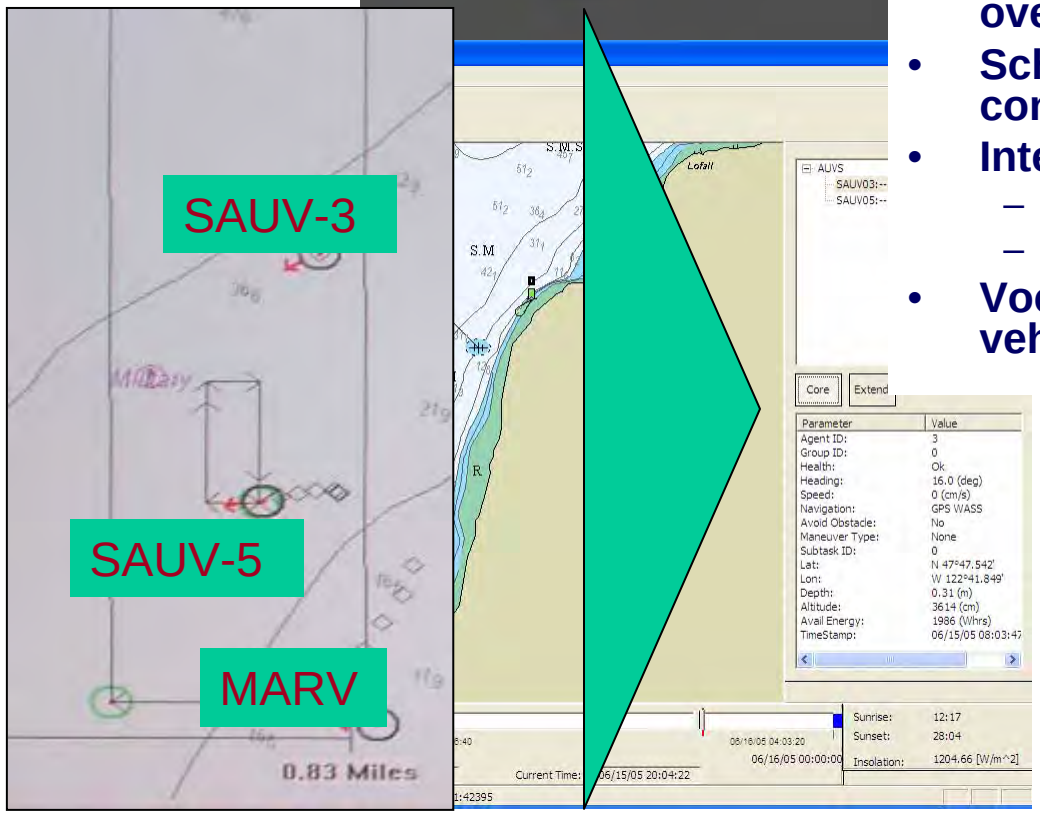
- Research Platform
- Multiple Payloads
  - Chemical Sensing
  - Color Video
- Operated in Hood Canal

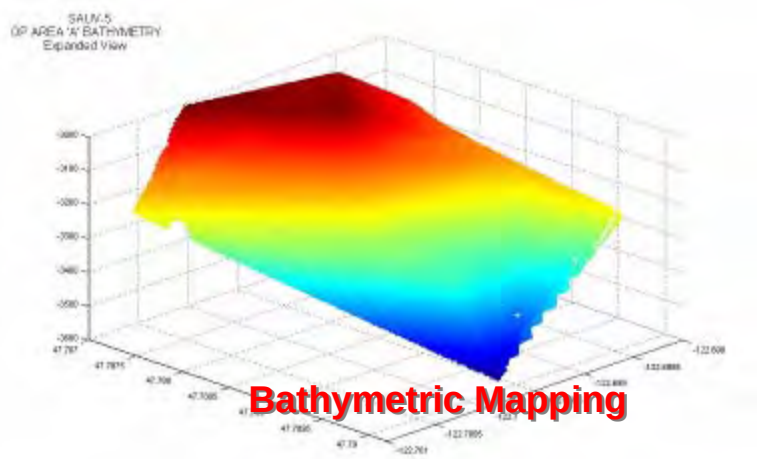
* Ask about “Hover” capability

NUWC Newport

Solar AUV

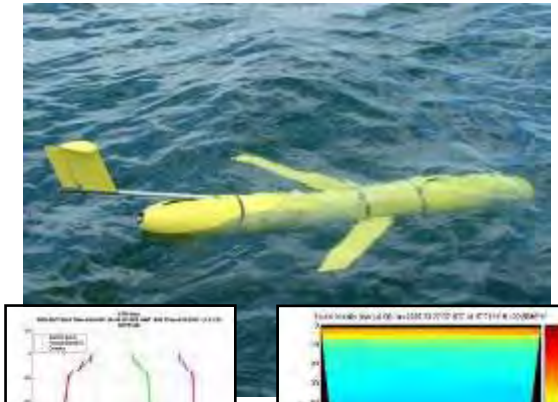
- Long Endurance-Multiple Vehicle Cooperation
- Acoustic Communication Networks
  - COFSNet few nodes
  - AUSNET many nodes
- Shore-based Multi-Vehicle Mission Planner
- SAUVs were 24 hour operationally-ready over 3 day scheduled mission
- Scheduled and unscheduled mission re-configuration
- Interoperability between mixed modem
  - SAUV with Benthos modem
  - SAUV with the micro modem
- Vocabulary and Grammar for multiple vehicle cooperation





AUV Fest 2005

GLIDERS



- Noise Mapping Glider
  - Alaskan Native Technologies
  - Slocum Shallow Water Glider
- Collects Ambient Noise & Environmental (SVP) Data
  - IRIDIUM & Free Wave C2

- Sea Glider
  - APL, University of Washington
  - Deep Water (0 –1000m) Long Duration Ops (190+ days)
- Environmental Data Collection
  - IRIDIUM Communications
  - Data to User - 45 minutes from call

AUV Fest 2005

SCOUT

- Cooperative Behavior between Vehicles
  - Precision Maneuvers
  - Collision Avoidance
  - Autonomous Ops
- Low Cost/COTS
- Bottom Mapping w/SSS

MIT

Hydrographic Unmanned Survey Craft (HUSCy)

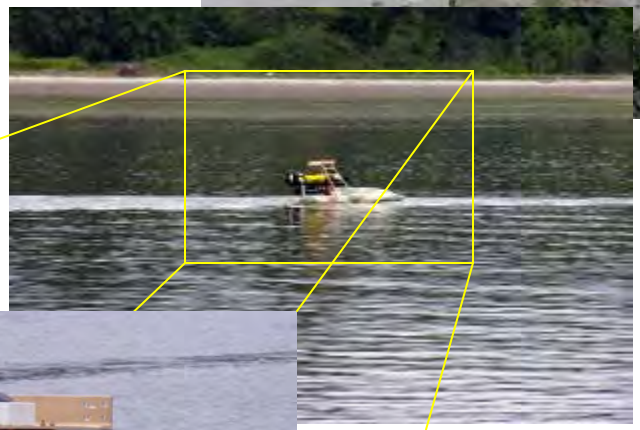
- Tactical Data Collection in SW and VSW (<100')
  - Hydrographic
  - Oceanographic
- Low Visibility
- Free Wave Data Link
- GPS Navigation
- SSS

Naval Oceanographic Office

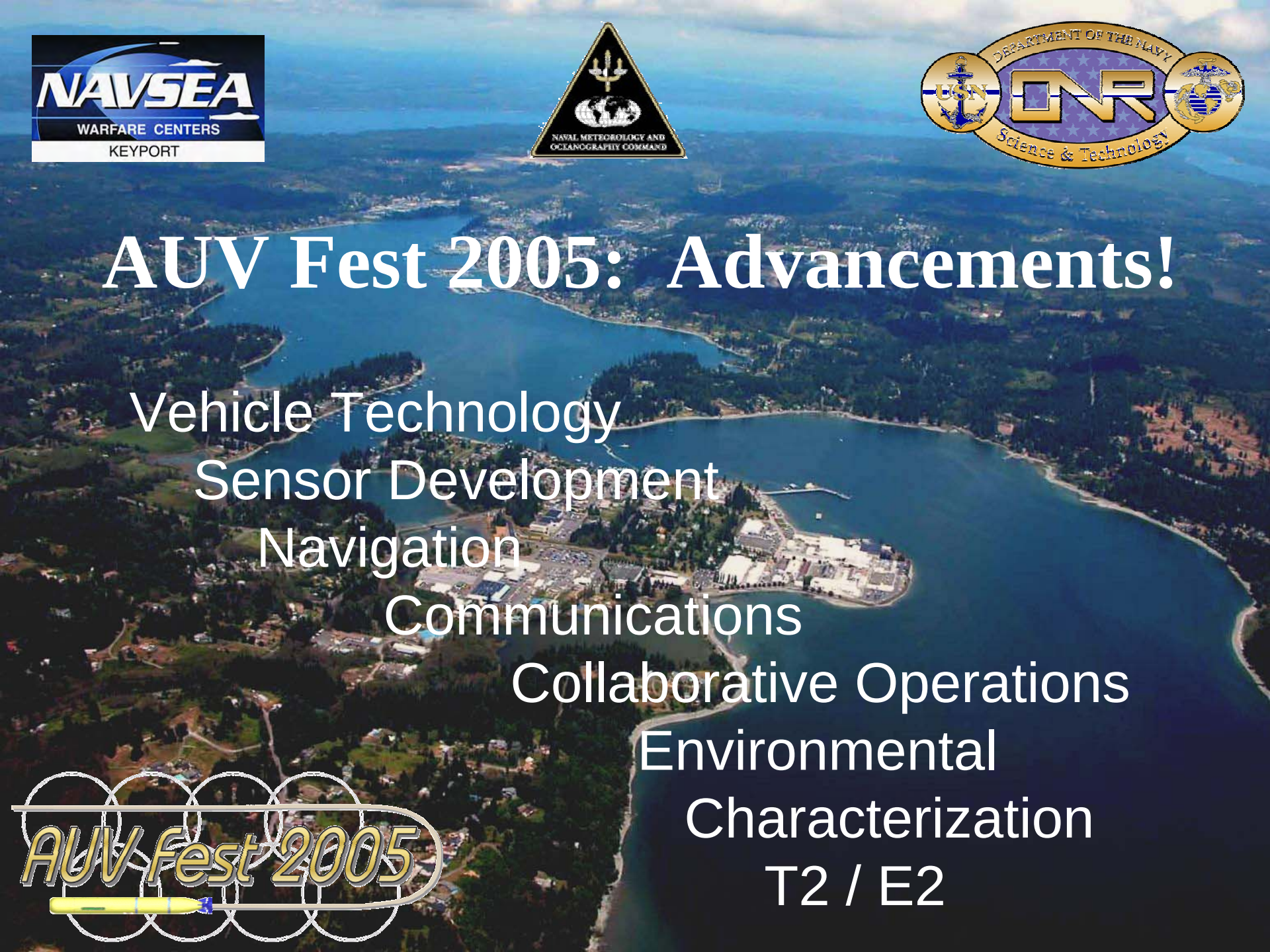
AUV Fest 2005

Remote Delivery of Unmanned Technologies (RDUST)

- Rapid Delivery of UUV
  - Autonomous Positioning
  - Beyond10 Miles
- Functions as Gateway Buoy
- Surface Awareness
  - IR
  - Video



NSWC-PC



AUV Fest 2005: Advancements!

Vehicle Technology

Sensor Development

Navigation

Communications

Collaborative Operations

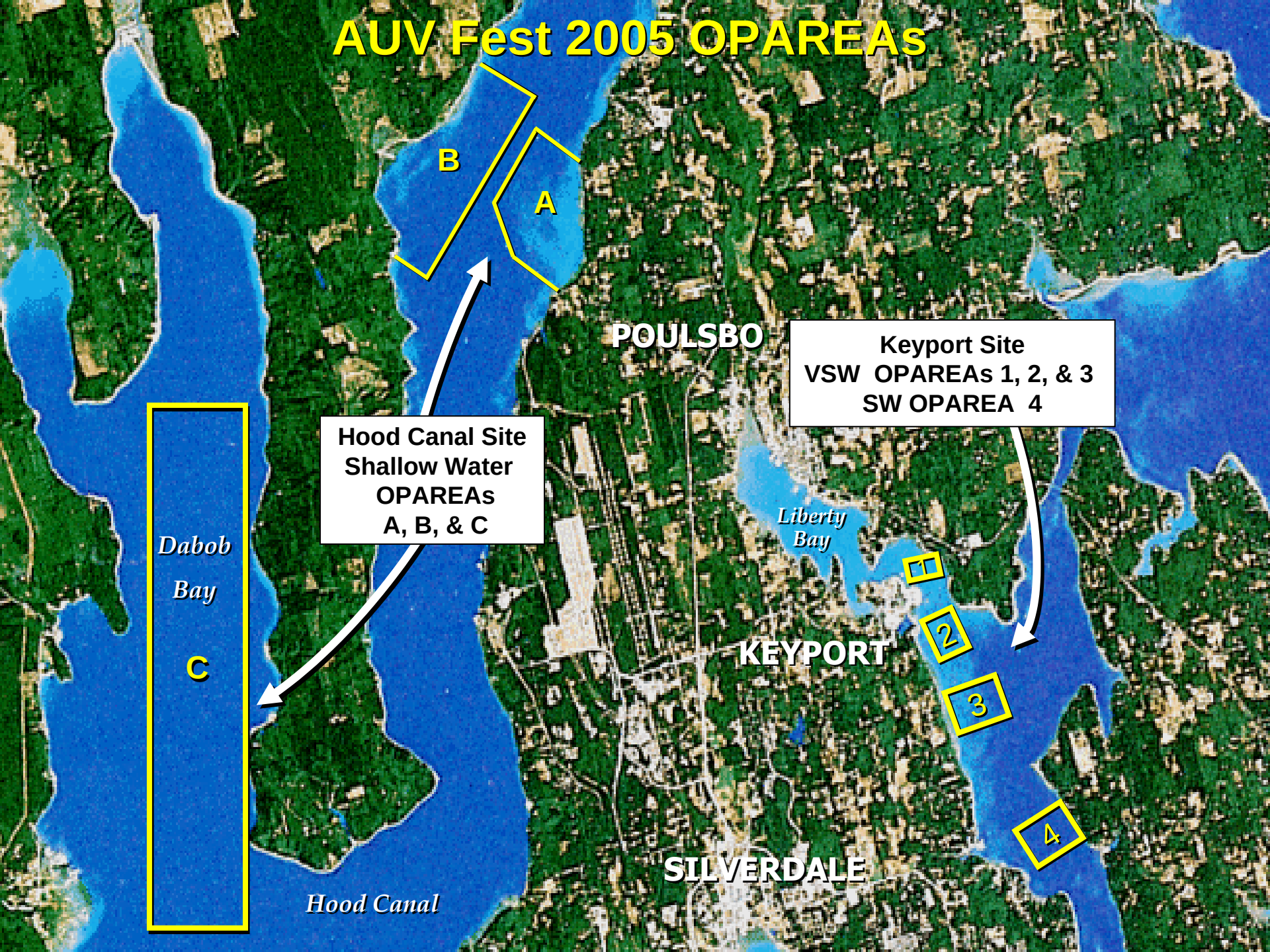
Environmental Characterization

T2 / E2

DV Day Touring & Demos

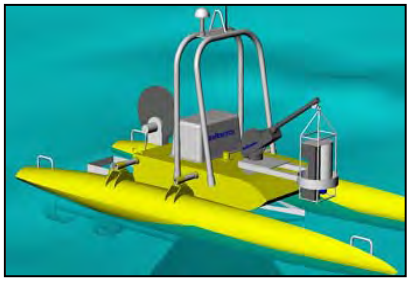
June 16, 2005

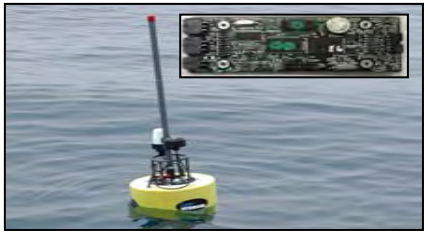
Steve Stuart,
AUV Fest 2005 Event Manager


AUV Fest 2005 OPAREAs
B
A
POULSBO
Keyport Site
VSW OPAREAs 1, 2, & 3
SW OPAREA 4
Hood Canal Site
Shallow Water
OPAREAs
A, B, & C
Liberty
Bay
Dabob
Bay
C
1
2
3
4
KEYPORT
SILVERDALE
Hood Canal

AUV Fest 2005 – 16 JUN
Simultaneous Operations

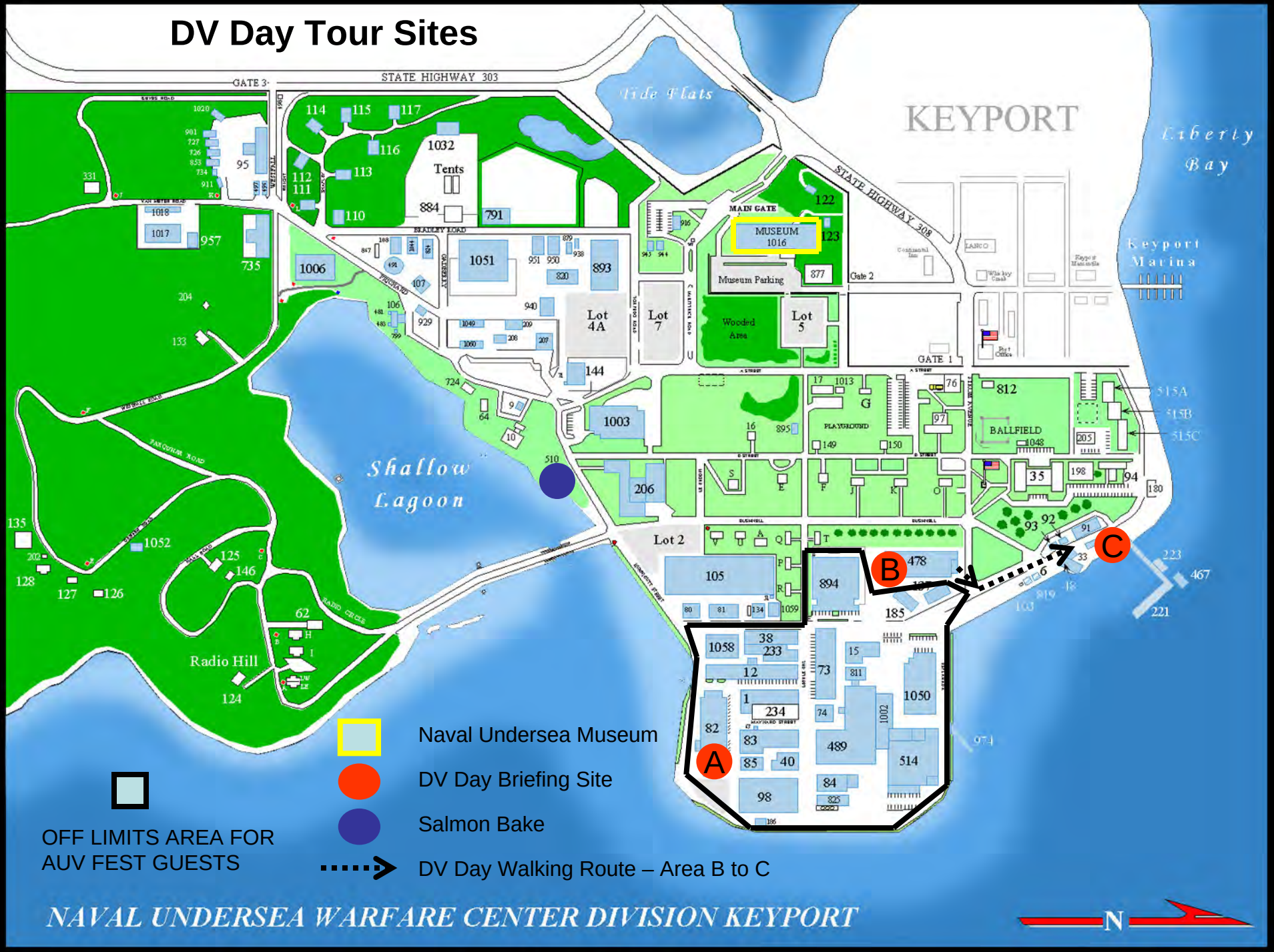
- NAVO's HUSCy
- MIT Scout
- NSWC Crawlers



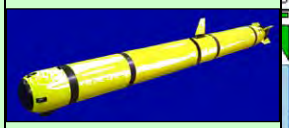


- Woods Hole REMUS & Gateways
- Naval Special Clearance Team One

DV Day Tour Sites



DV Day Tour Sites



OF
AU
R

Naval Undersea Museum

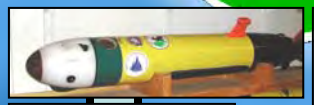
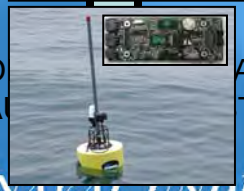
DV Day Briefing Site

Salmon Bake

DV Day Walking Route – Area B to C

NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT

DV Day Tour Sites

Naval Undersea Museum

Day Briefing Site

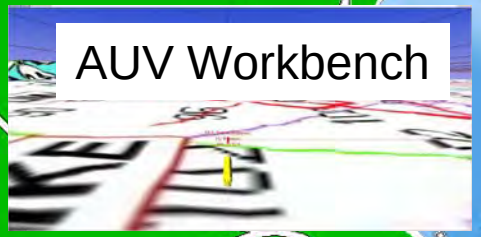
Salmon Bake

DV Day Walking Route – Area B to C

NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT

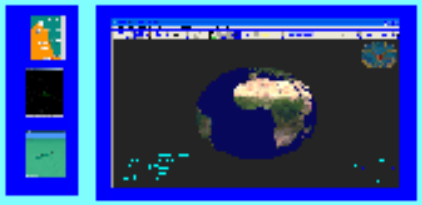
DV Day Tour Sites

CTEC



AUV Workbench

CARUSO Lab



ESMS - SIMDIS Views

KEYPORT

Liberty Bay

Keyport Marina

Shallow Lagoon

Tide Flats

STATE HIGHWAY 303

STATE HIGHWAY 308

GATE 3

GATE 2

GATE 1

MAIN GATE

MUSEUM 1016

Museum Parking

Wooded Area

Lot 4A

Lot 7

Lot 5

Lot 2

Tents

BALLFIELD

PLAYGROUND

A

B

C

Naval Undersea Museum

DV Day Briefing Site

Salmon Bake

DV Day Walking Route – Area B to C

OFF LIMITS AREA FOR AUV FEST GUESTS

NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT

N

DV Day Tour Sites

5:30 p.m.

Naval Undersea Museum

DV Day Briefing Site

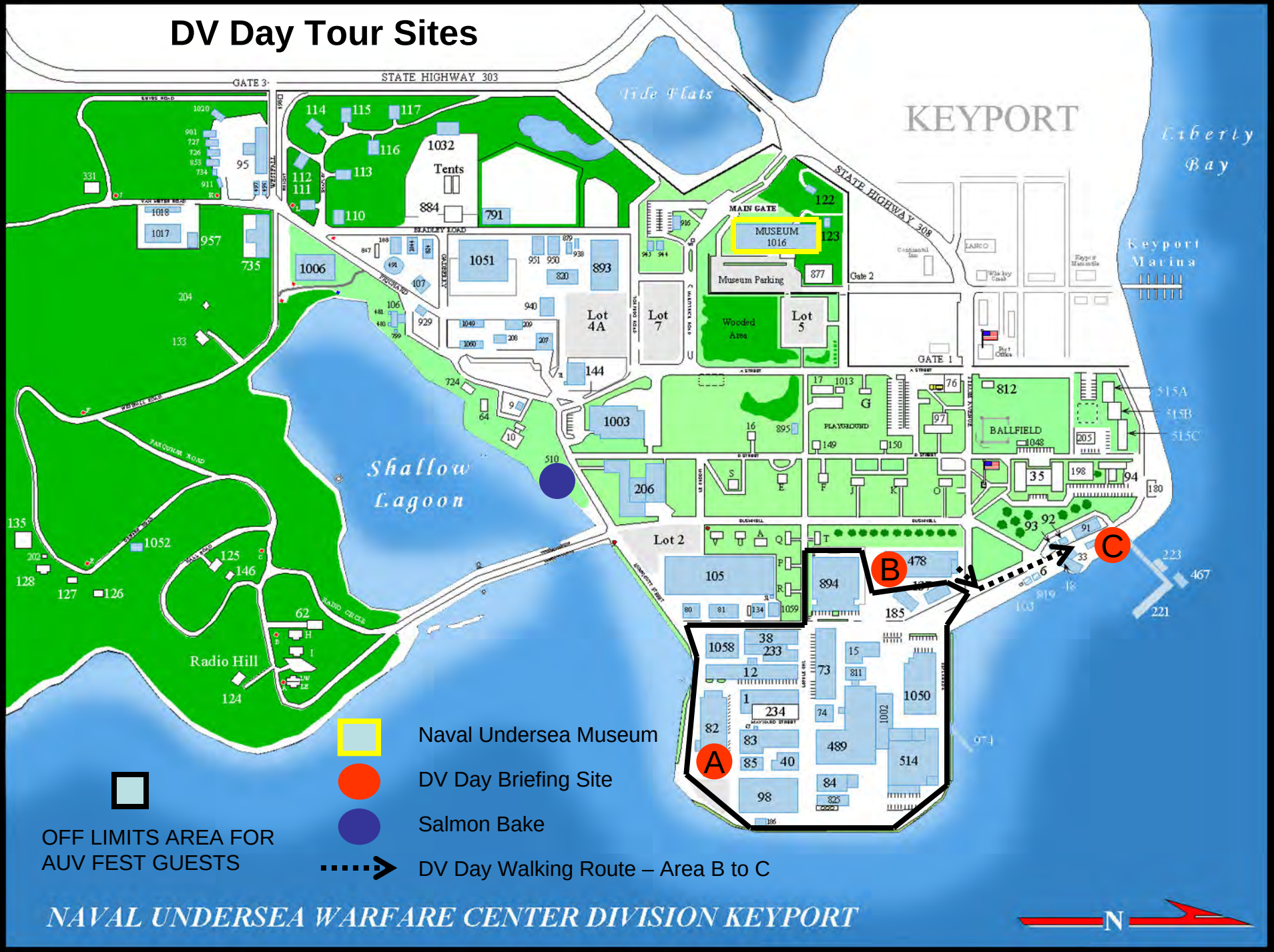
Salmon Bake

DV Day Walking Route – Area B to C

OFF LIMITS AREA FOR AUV FEST GUESTS

NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT

DV Day Tour Sites



ONR

Here we are

Secretary of the Navy

Assistant Secretary of the Navy

Research, Development and Acquisition

Research and Development

Acquisition

VCNO & ACMC

Office of Naval Research

Naval Research Lab

PEOs, Systems Commands, Warfare Centers

Basic Research

Applied Research

Advanced Tech. Development

Test & Evaluation

DEM/Val

EMD

Op. Systems Development

Warfare Centers

12 Program Executive Officers

3 Direct Reporting Program managers

6 Systems Commands

54 Major Program managers

467 Program managers

Aircraft carriers

Combat ships

Submarines

Aircraft

Weapons systems

Ammunition

Combat boots

Source: FY05 Blue Book, FY05 R-1

ONR S&T Departments

Code 31
Information, Electronics, & Surveillance S&T Department
- Mathematics
- Computers
- Electronics
- Surveillance
- C3
- Electronic Combat
- Modeling & Simulation

Code 32
Ocean, Atmosphere & Space S&T Department
- Battlespace Environments - BSE
- Undersea Warfare - ASW
- Undersea Warfare - MIW
  - NSW / EOD & Small Unit Ops
- Maritime ISR & Space Exploitation – ISR / SE
- Space S&T Office
- Countermine Program Office

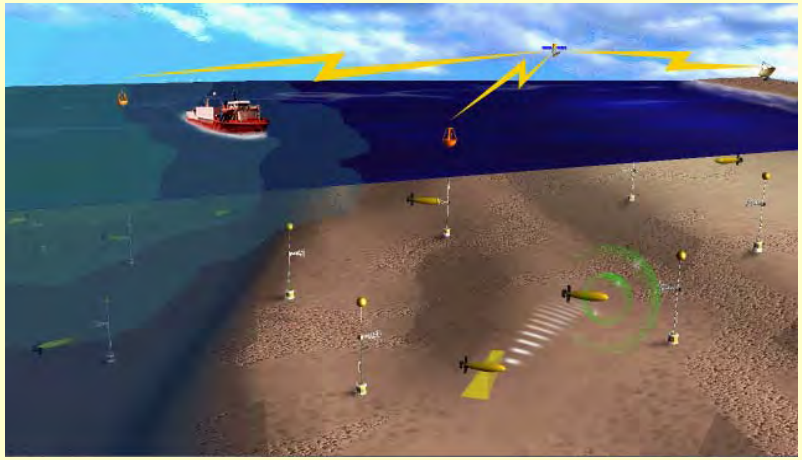
Code 33
Engineering Materials & Physical S&T Department
- Physics
- Chemistry
- Environmental Quality
- Materials
- Mechanics
- Energy Conversion & Explosives
- Ships & Submarines
- Undersea Weapons

Code 34
Human Systems S&T Department
- Biological, Health & BW / CW
- Cognitive & Neural Sciences and Human Factors
- Biorobotics
- Training & Training Devices
- Bioremediation, Biofouling
- Personnel & Clothing
- Logistics, Shore Facilities, Waterfront

Code 35
Weapons, Marine Corps & Special Programs S&T Department
- Surface / Air
- Weapons
- Aircraft
- LO / CLO
- Marine Corps S&T
- Special Programs

Code 36
Industrial Programs Department
- SBIR
- MANTECH / MANSCIENCE
- Navy Dual-Use Technology Program
- Tech Transfer/IR&D

ONR AUV S&T



Objectives

- Expand the state-of-the-art in component technologies for AUV systems
- Develop/demonstrate undersea mission adaptive behavior using networked multiple platforms

Component Technologies

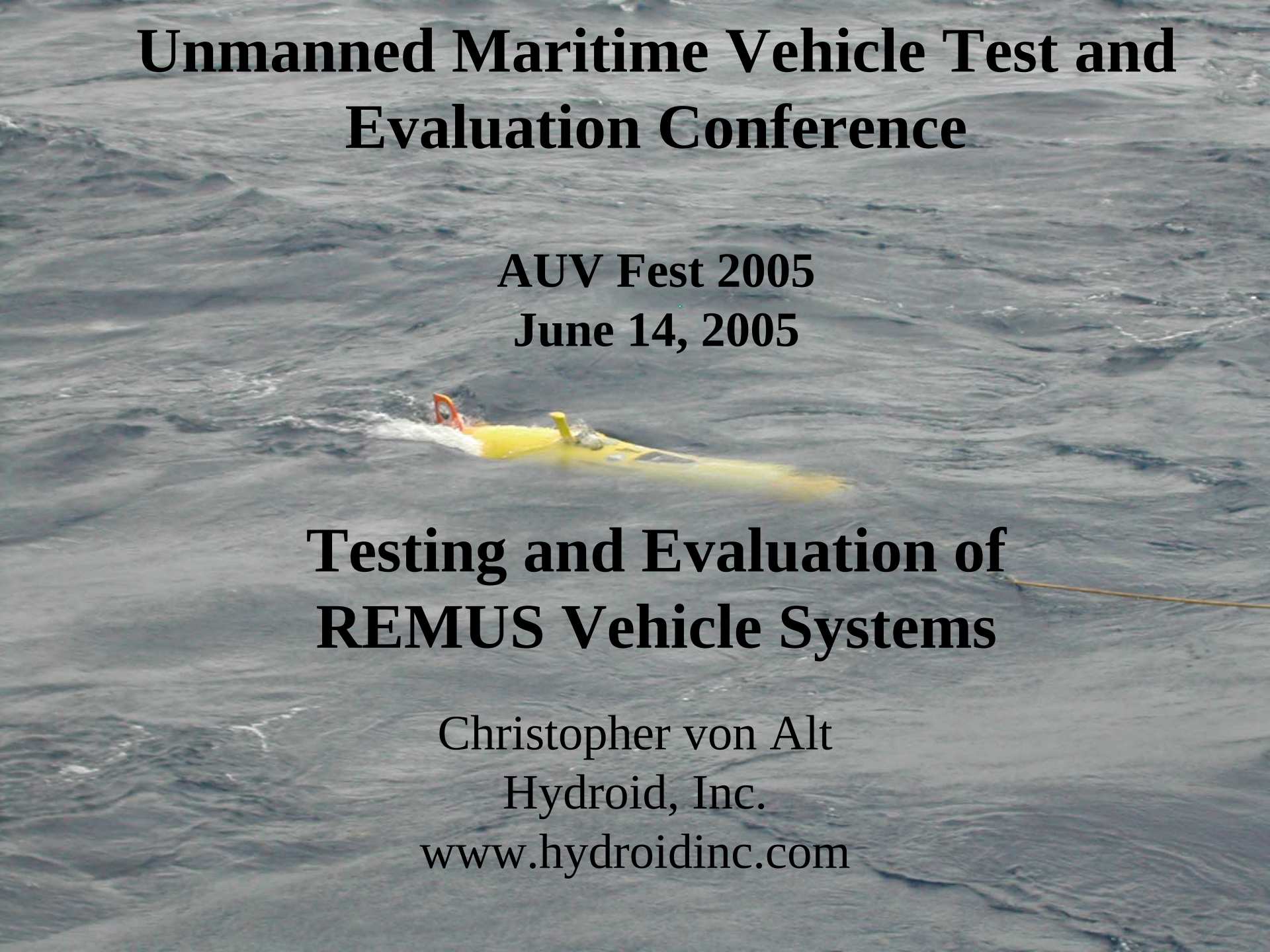
- Platforms (Control and Propulsion)
- Communication
- Navigation
- Energy
- Sensors
- Autonomy / Network Control

Approach

- System-oriented multi-disciplinary basic science and engineering research *(MURI Programs)*
  - Integrated artificial muscle, high-lift bio-hydrodynamics and neuro-control for biorobotic AUVs
  - Adaptive Sampling and Prediction
- Capability-oriented innovative technology development – Basic and Applied Research *(Small Business Innovative Research, Small Business Technology Transfer)*
- Mission-oriented Applied Research and Advanced Development *(Mine Counter-measures, Anti-Submarine Warfare, Tactical Oceanography, Hydrography, Salvage)*
  - Deep Convection Experiment (Labrador Sea)
  - Frontal Dynamics Experiment (Haro Strait)
  - Organic Mine Countermeasures Future Naval Capability
  - Autonomous Operations Future Naval Capability
  - Undersea Persistent Surveillance
- Develop new generation of scientists and engineers in Autonomous Systems *(AUVSI Student Competition)*

Unmanned Maritime Vehicle Test and Evaluation Conference

AUV Fest 2005
June 14, 2005



Testing and Evaluation of REMUS Vehicle Systems

Christopher von Alt
Hydroid, Inc.
www.hydroidinc.com

Hydroid Inc. holds the exclusive license from the Woods Hole Oceanographic Institution for the manufacture and further development of REMUS Autonomous Underwater Vehicle (AUV) technology.

REMUS

Concept, Development, Transition, Commercialization, War

FY 93 / 94 | FY 95 | FY 96 | FY 97 | FY 98 | FY 99 | FY 00 | FY 01 | FY 02 | FY 03 | FY 04 | FY 05

Development

Prototype Tested

Environmental Sensors

1.2 MHz ADCP Operational

Predictive Coastal Modeling

20 NM Surveyed in 5.5 Hours

Autonomous Docking Node

Docking Node

Operation LEO 15

Vehicle Docked Autonomously

REMUS Development for NSW

600 KHZ SSS Integrated

UUV Fest 1 | FE I | FE II | FE III | ADM | SDV Demo

ORD Threshold Achieved

Hydro Model

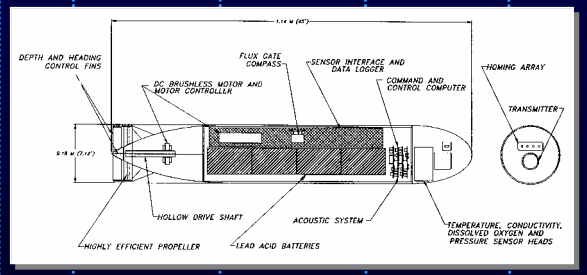
6DOF Model

HYDROID, INC
WHOI Spin-off

LCS Mission Module

REMUS Original Concept

45"



EDM | DT | OPEVAL | IOC 8 Units | FOC 18 Units | Product Improvement Plan ACOMMS, CAD/CAC, OAS, PNAV

REMUS Development for MCM

(DEMO FOCUS) → FBE-H (SCM) | KB-01 (R-I) | UUV Fest (ACOMMS) | FBE-J (CAD/CAC) | UUV Fest (Multi –UUVs) | CJTFEX (MSN Modules)

PMS EOD SCM / RIN

UOES SCM | ATFP | SCULPIN | UOES R-I | IOC SCM SYS

Call to Duty

- Umm Qasr – FEB 03 (IRAQI FREEDOM)

REMUS Production Version

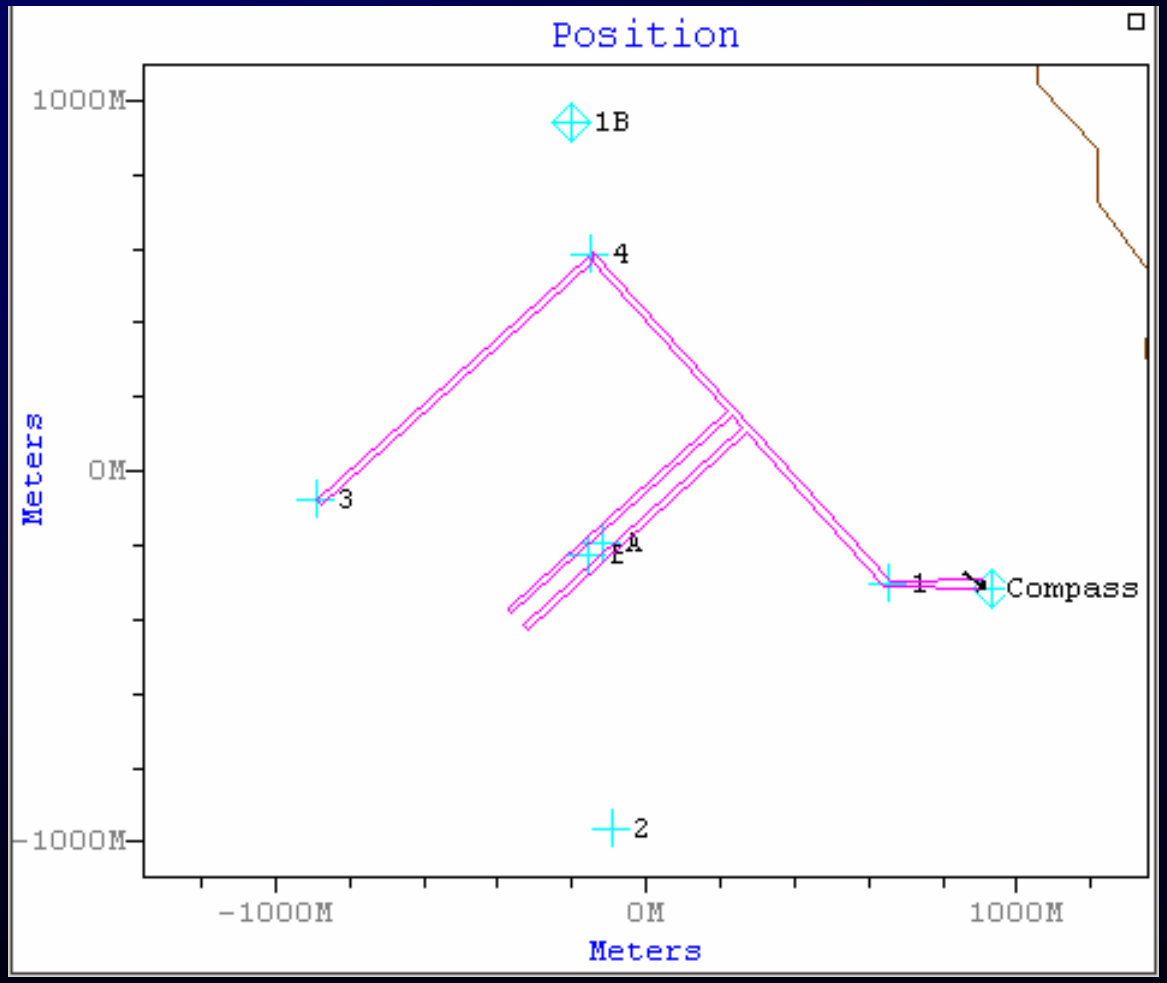
Transitions

ACAT IV-T MK 14 Mod 0 SAHRV

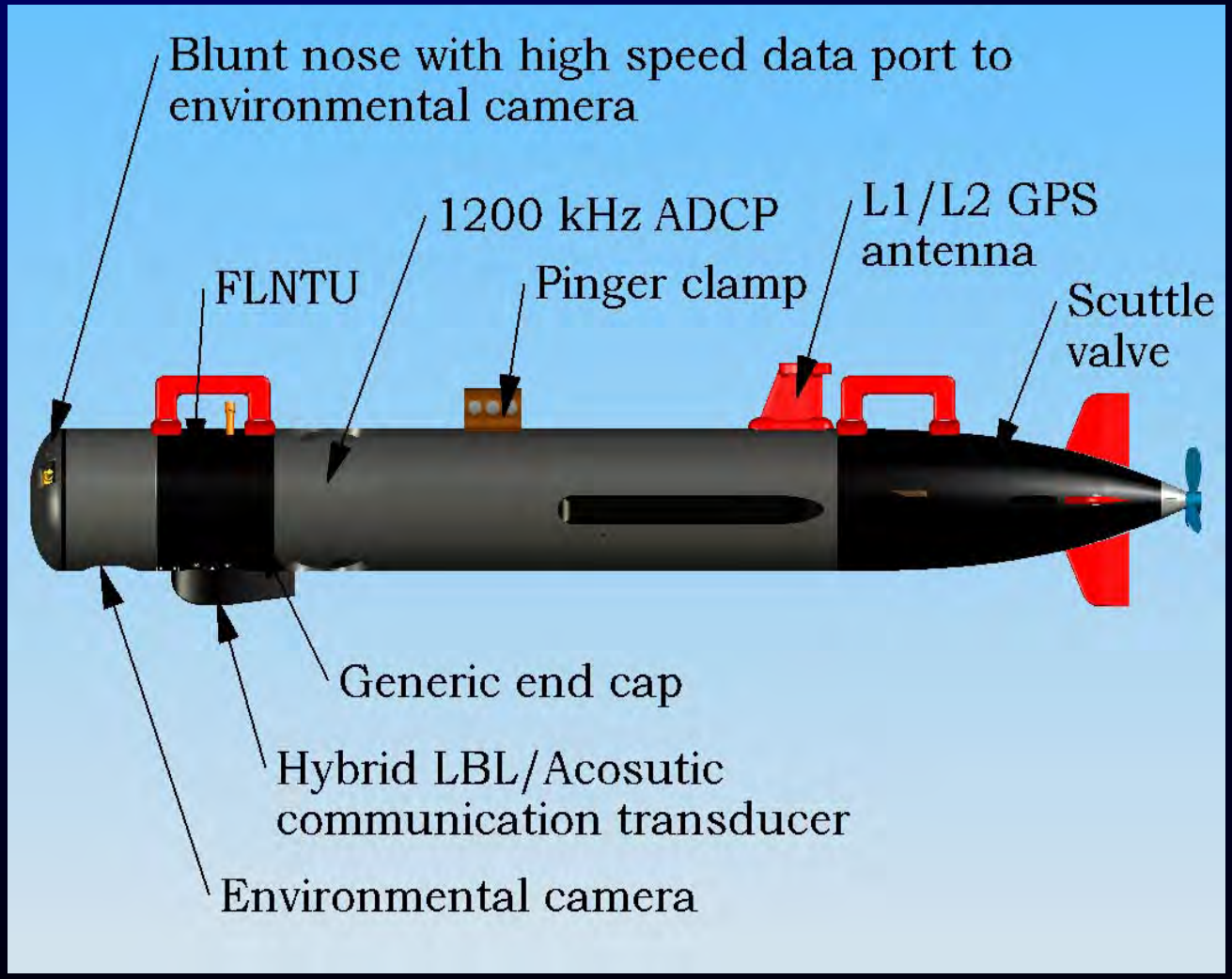
SAHRV Factory Acceptance Test (FAT)

- Reviewed and approved by U.S. Navy to test SAHRV systems
- Verifies system's capabilities to meet specification for:
  - Compass Calibration
  - LBL Navigation Range
  - Navigation Accuracy
  - Sonar Resolution
  - Battery Capacity
  - Vehicle Speed
  - Altitude Accuracy
  - Depth Accuracy
  - HTML Report Generation

All Requirements are evaluated during two hour mission



EOD UUV SCM Prototype



UK MOD System

Hydroid received major contract from the United Kingdom Ministry of Defense to supply (10) REMUS Autonomous Underwater Vehicle systems to the Royal Navy

“REMUS will enable the Royal Navy to undertake rapid mine reconnaissance in the Very Shallow Water (VSW) zone an area which, currently, is accessible to divers only. Employing REMUS will reduce the risk to clearance divers during operations in the detection and clearance of maritime mines."

RECENT REMUS DEMONSTRATIONS/TRAINING

REMUS Trials in Germany
Trials in Rotterdam Harbor
Trails_Finland
German Navy training
NATO Undersea Research Centre (NURC)
Scandinavian demonstrations

Shallow Water Reacquisition Technology

3 REMUS 100 vehicles
86 lbs, 7.5 hours @ 4.5 knots modular end cap

2 Gateway Buoys

SENSORS
900/1800 kHz sonar
1200 kHz ADCP
Optical backscatter
Conductivity Temp
CAD/CAC

NAVIGATION
LBL acoustic
P-code GPS
Kearfott T-16 IMU
(ADCP, GPS, LBL aided)

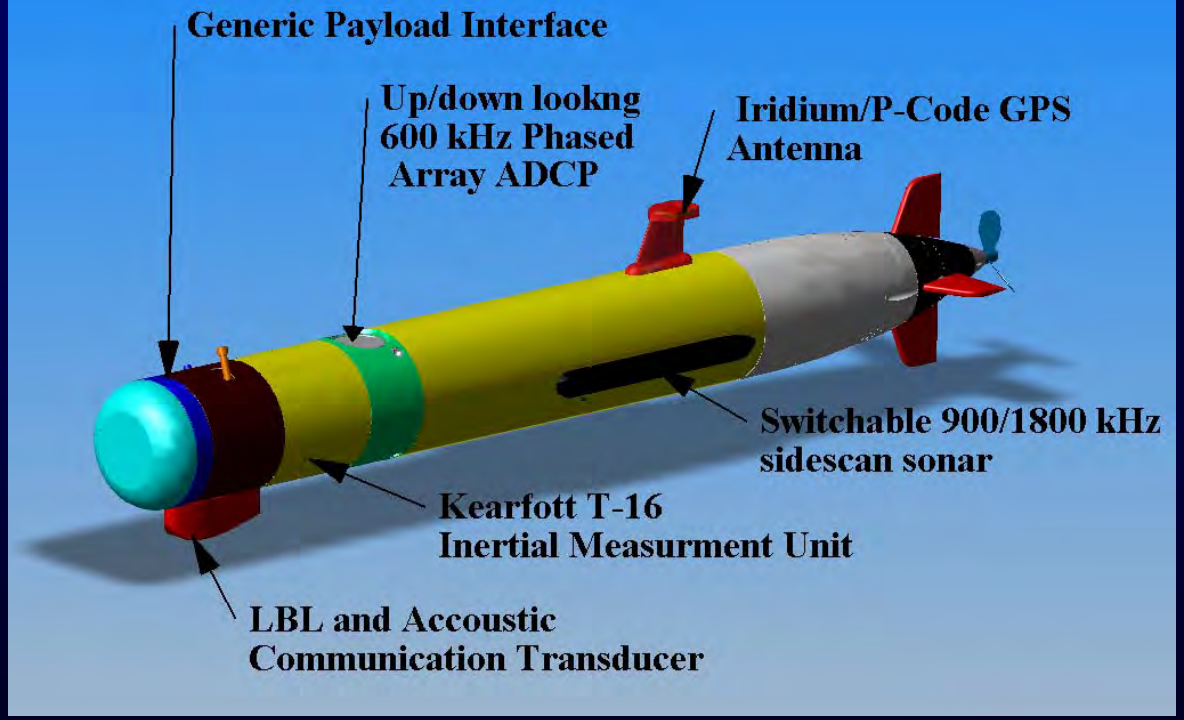
COMMUNCATION
Acoustic Modem
Iridium Modem

COMMUNCATION
Acoustic Modem
Iridium Modem
FreeWave Modem
GPS

REMUS 100 –MCM Vehicle
Mission Flexibility

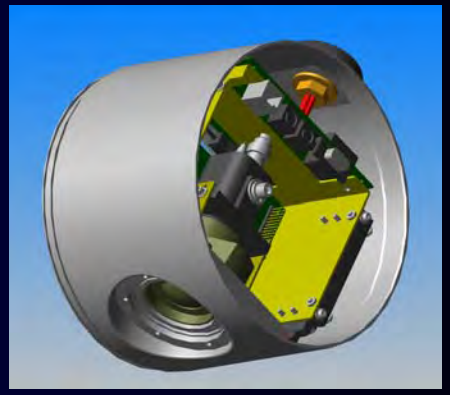
HYDROID

Supports Search & Classify & Map and Reacquire & Identify Missions



- 1.6 m long vehicle
- 39 kg – 14 hour mission duration at 1.5 m/s
- Ship by commercial overnight carrier
- Submarine compatible

Forward-looking Sonar DIDSON



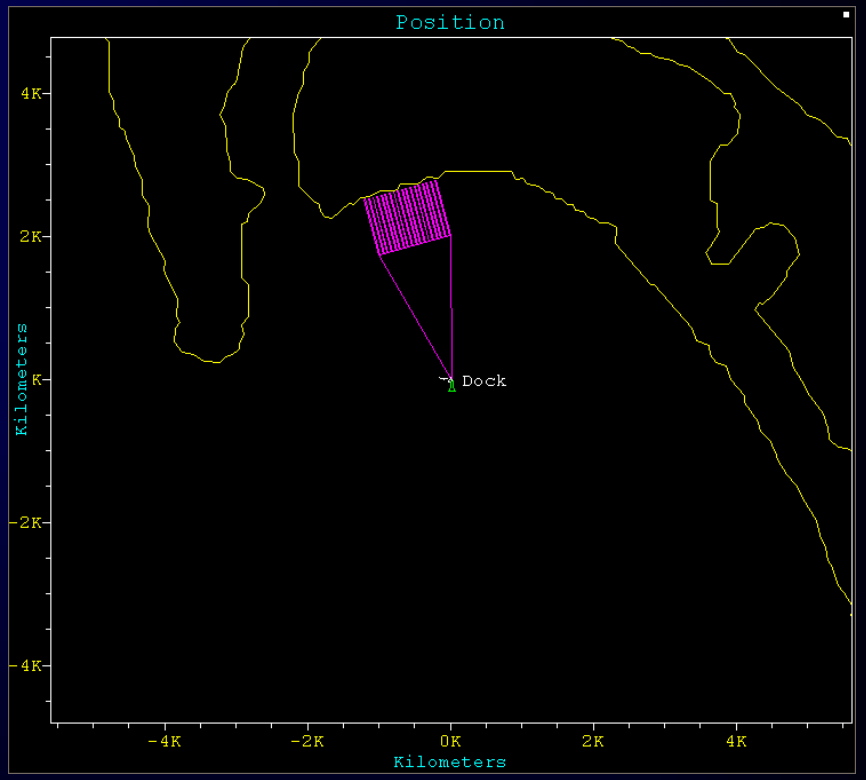
Low-light video camera

REMUS Customers

- WHOI has delivered 17 REMUS systems
  - 4 Academic institutions
  - 13 U.S. Navy
- Hydroid has delivered 60 REMUS systems
  - 36 U.S. Navy
  - 6 U.S. Government
  - 8 Academic institutions
  - 1 German Navy
  - 2 Royal Dutch Navy
  - 2 NATO Undersea Research Centre
  - 2 Singapore Navy
  - 3 Commercial

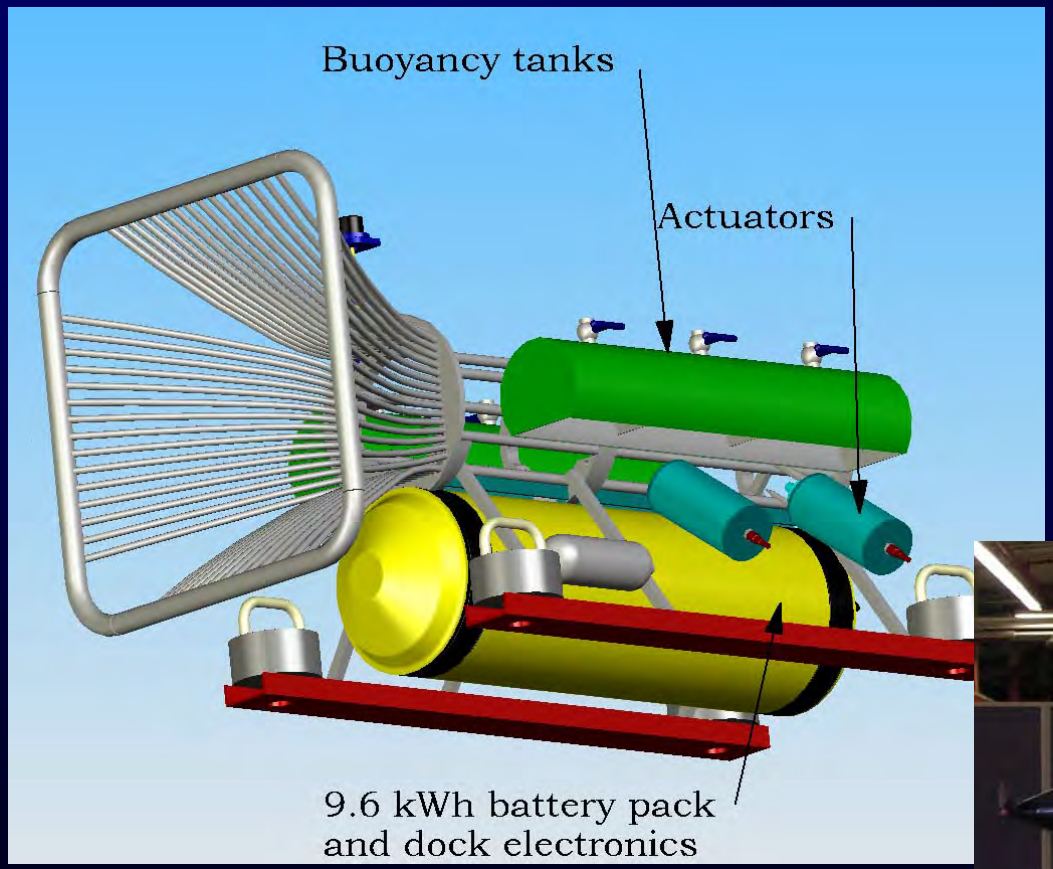
Autonomous Docking Problem

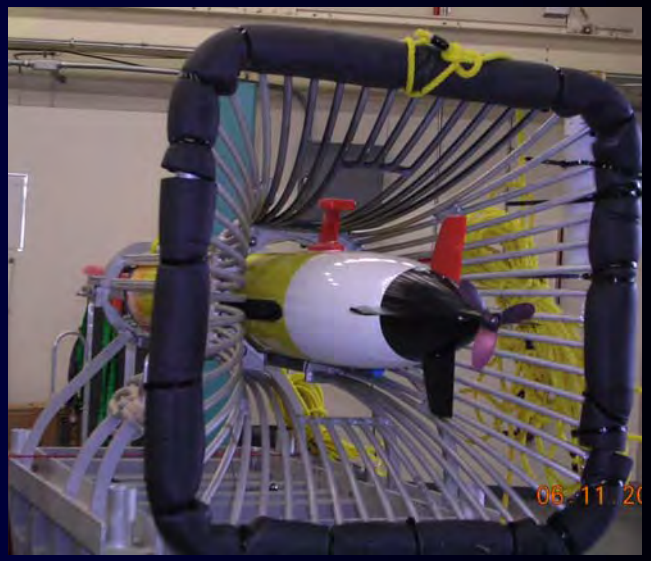
- Provide sustainable and affordable access to littorals using robotic technologies that are compatible with fleet technology
- Provide technology that facilitates its creative use by war fighters



Sustained autonomous operations in the littoral environment

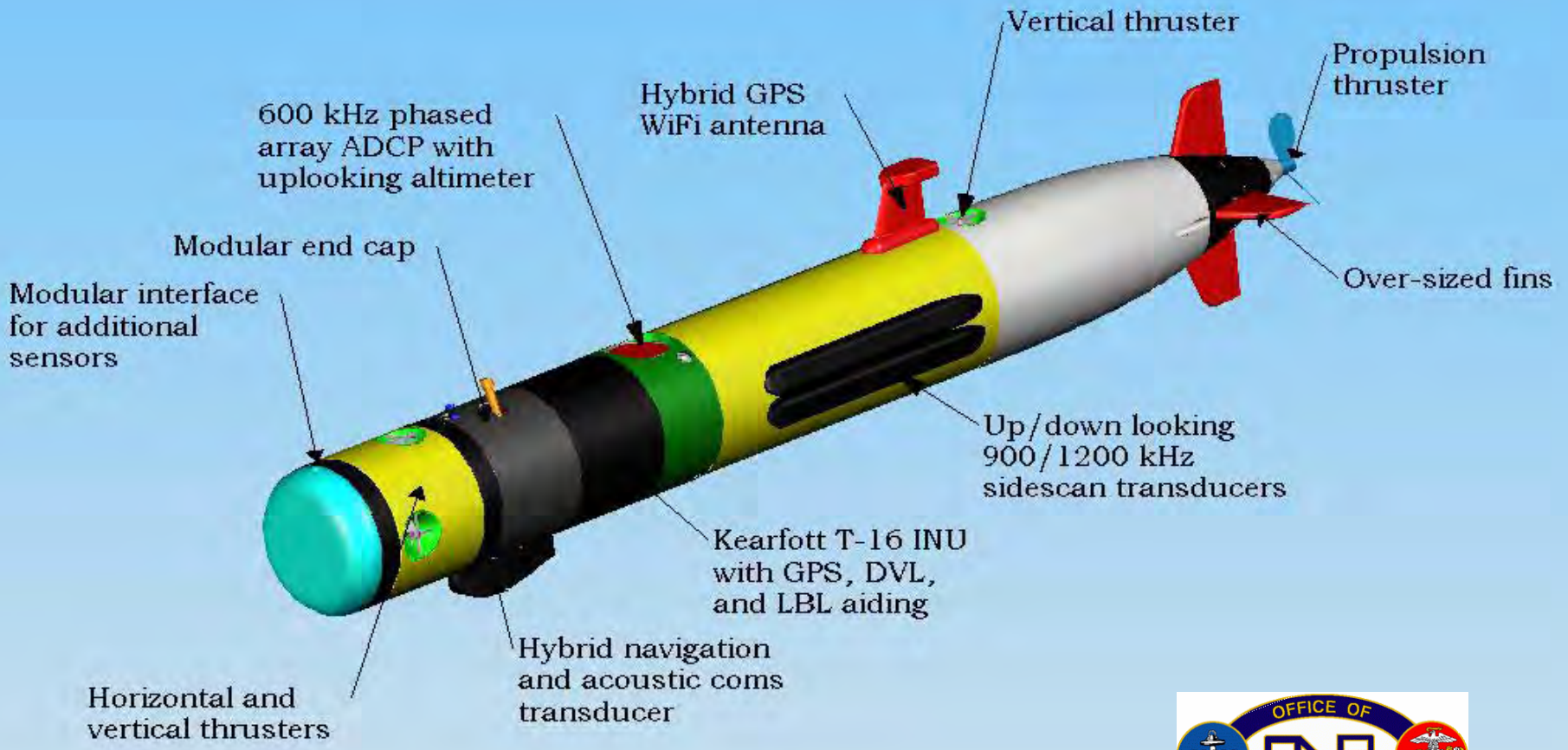
REMUS Docking system





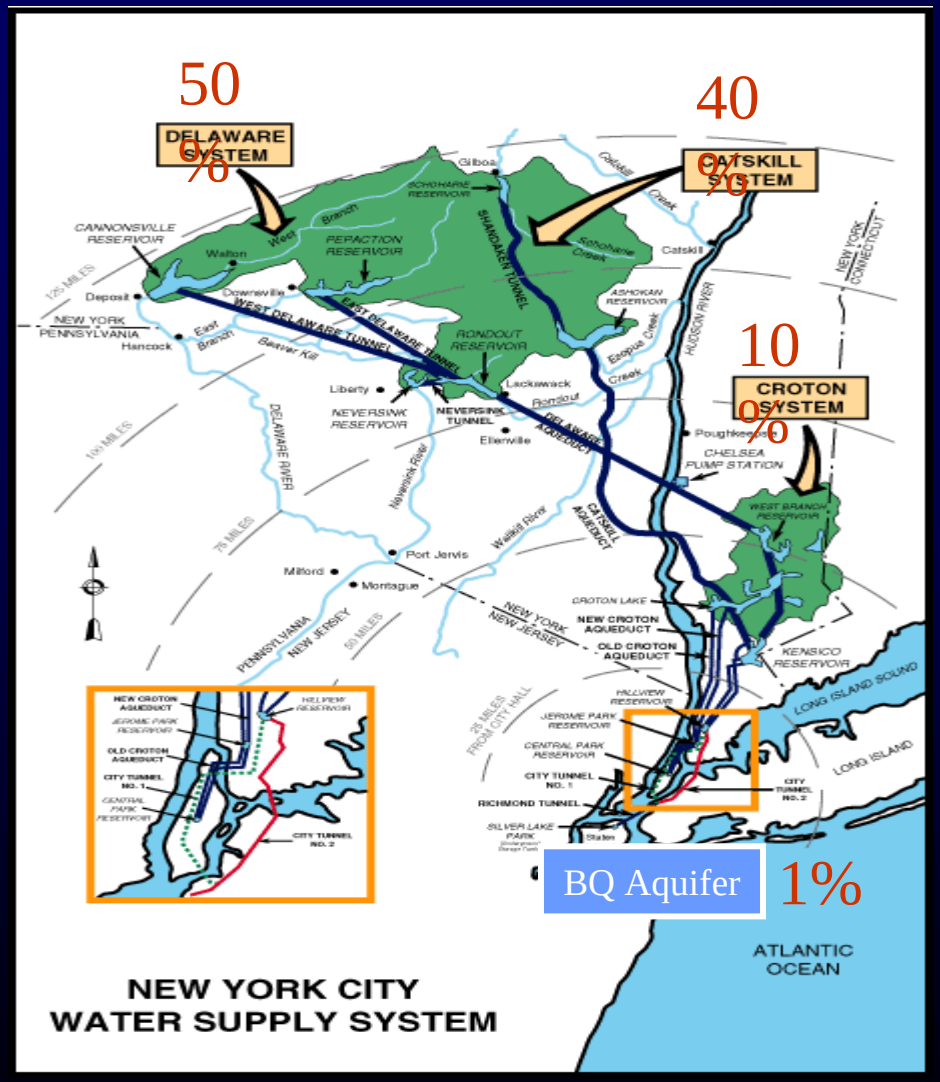
Docking Test Results

REMUS 100
Harbor security and under hull surveys

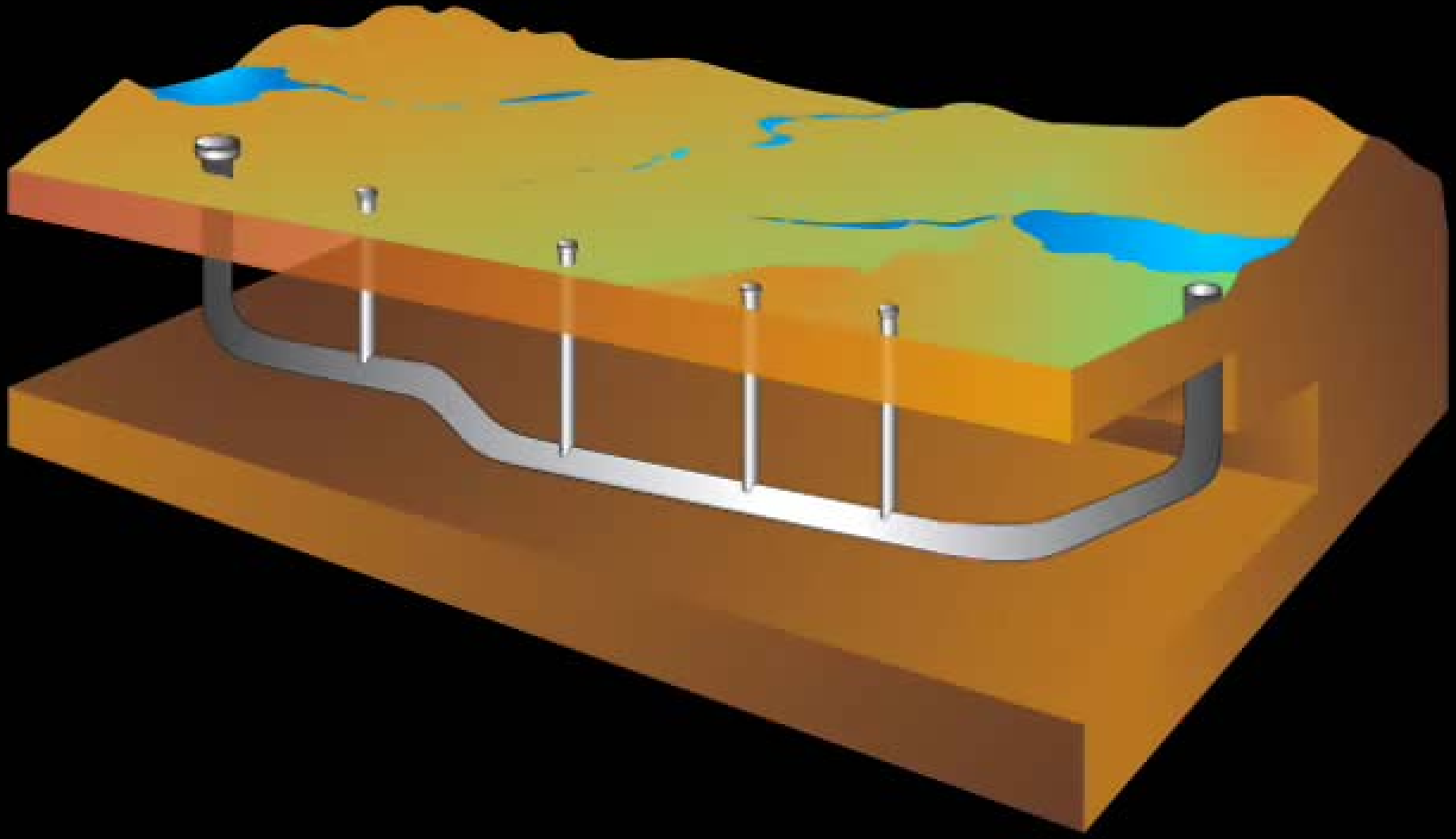


286565
DEP
WOODS HOLE OCEANOGRAPHIC INSTITUTION

Map of New York City Watershed



Delaware Aqueduct Under Construction



286565
DEP
WOODS HOLE OCEANOGRAPHIC INSTITUTION

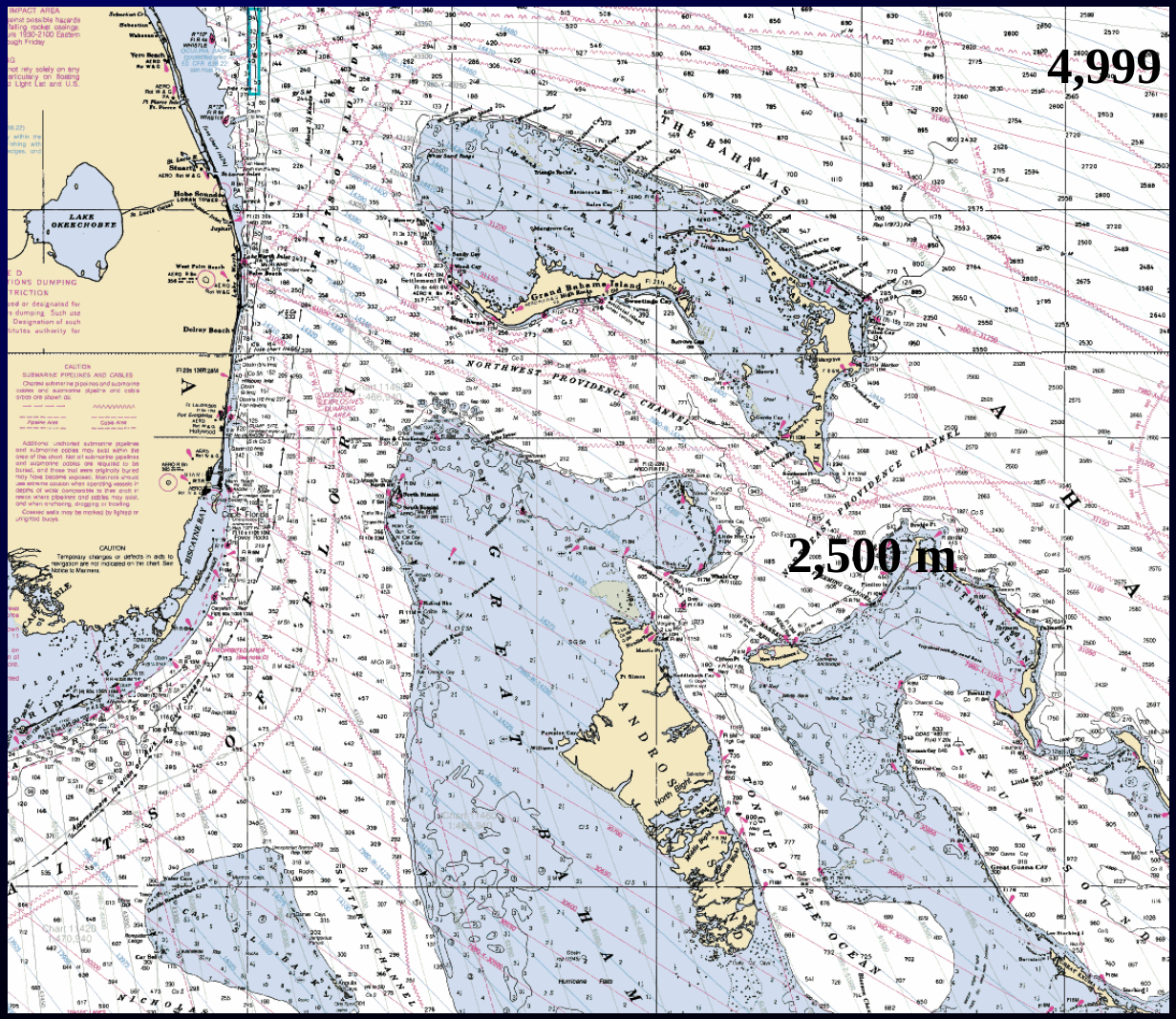
REMUS 6000
Base line Configuration

- Survey
  - Switchable 300/900 kHz sidescan
  - 12 hour duration at 4 knots
  - Field exchangeable battery packs
  - Multi-vehicle operations
  - Mission redirection over acoustic or Iridium links
- Navigation
  - Acoustic long base line
  - INU aided with GPS and ADCP
- Communication
  - Iridium modem
  - Acoustic communications –WiFi
- Payload exchange
  - Electronic still camera & strobe
  - Sub-bottom profiler

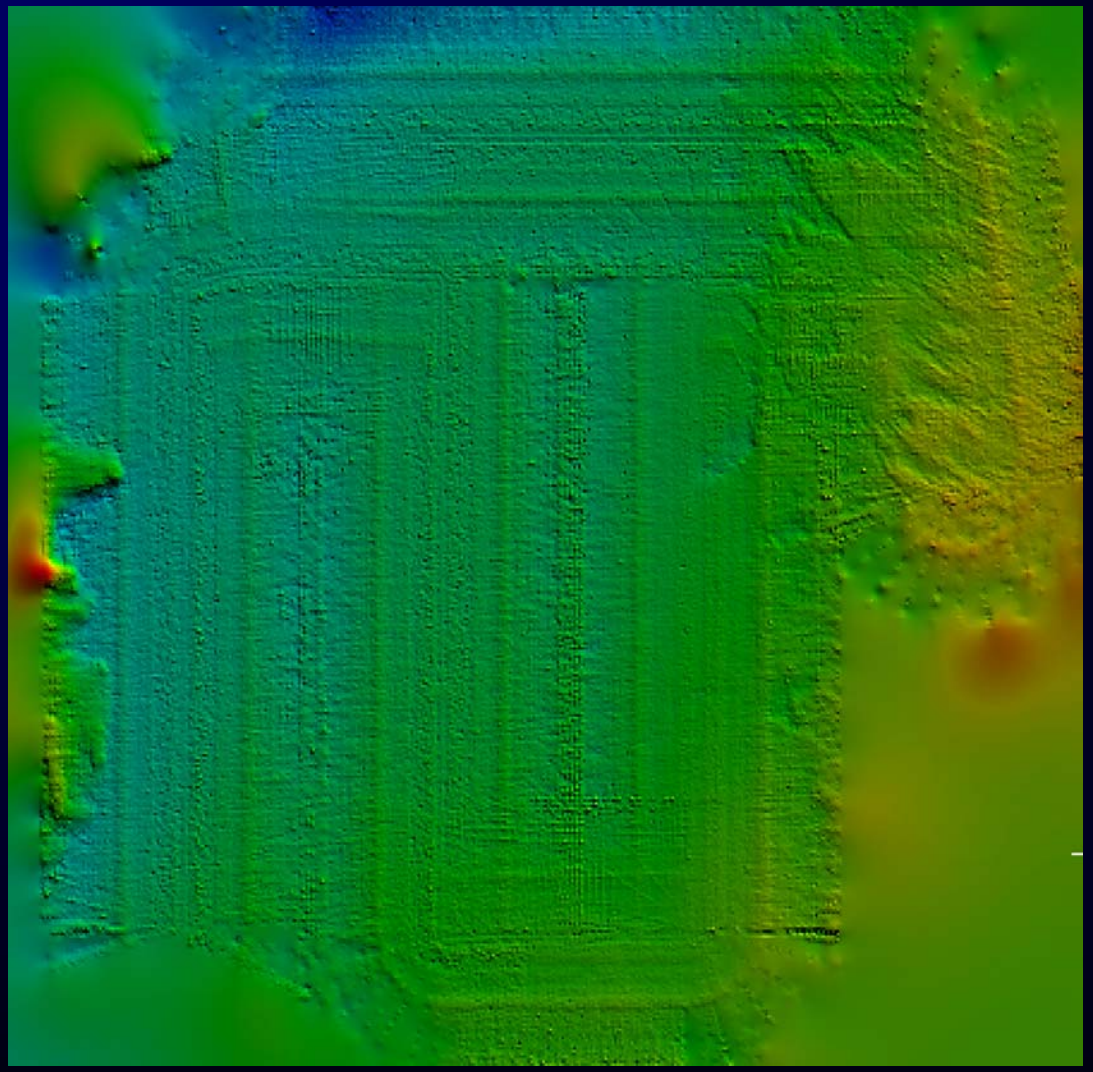
REMUS 6000 Launch and Recovery

Successful Operations have been conducted in 15 foot Seas

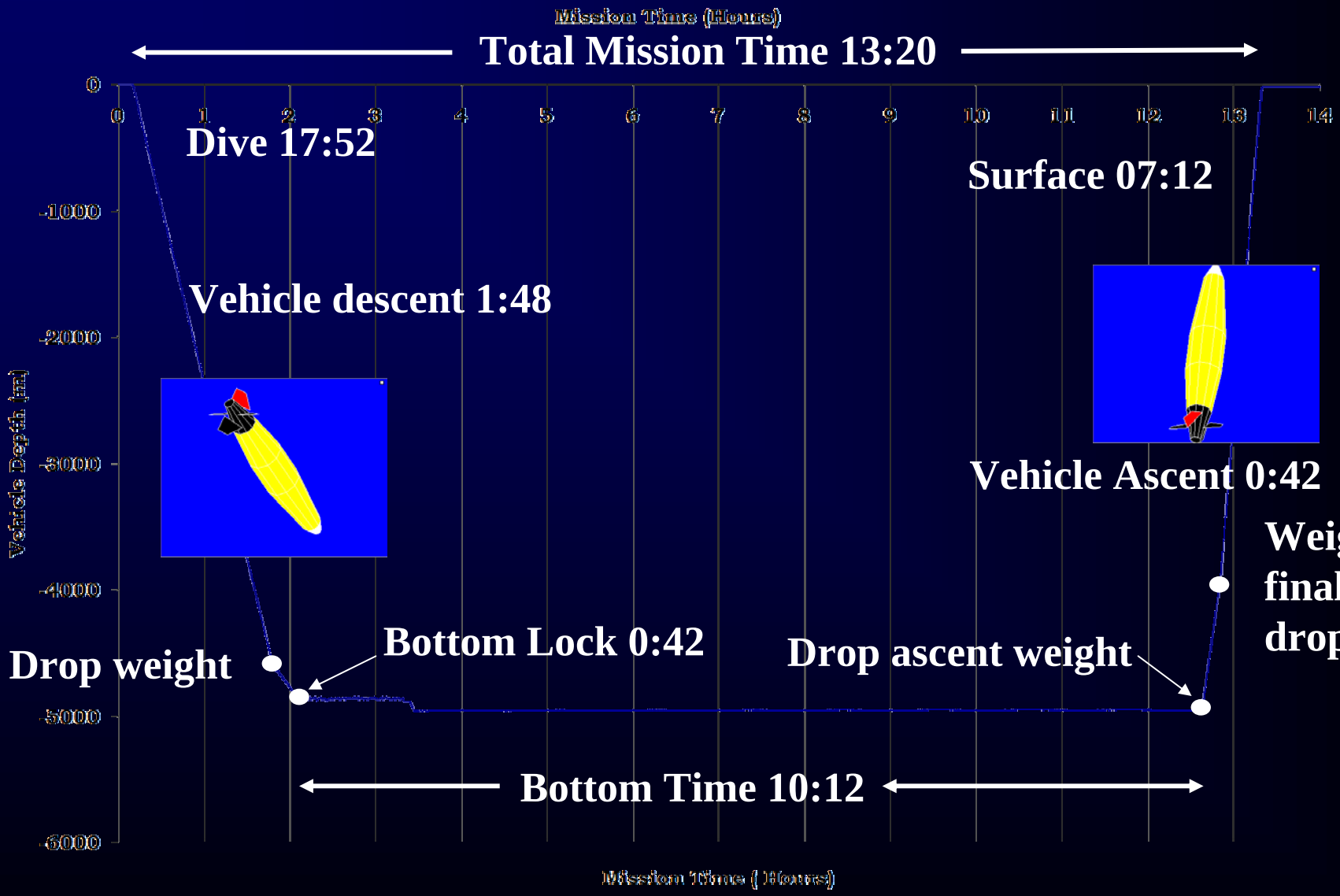
March 03 Test Areas



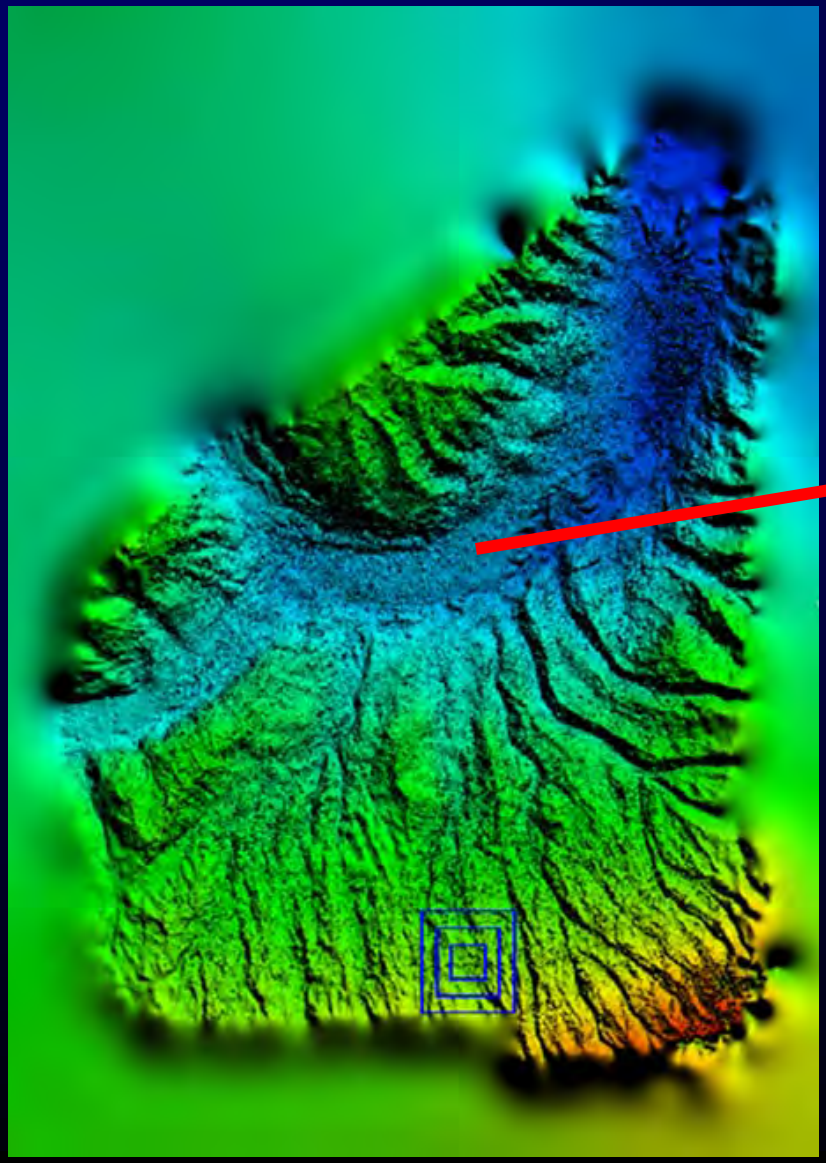
4,999 M Test Area

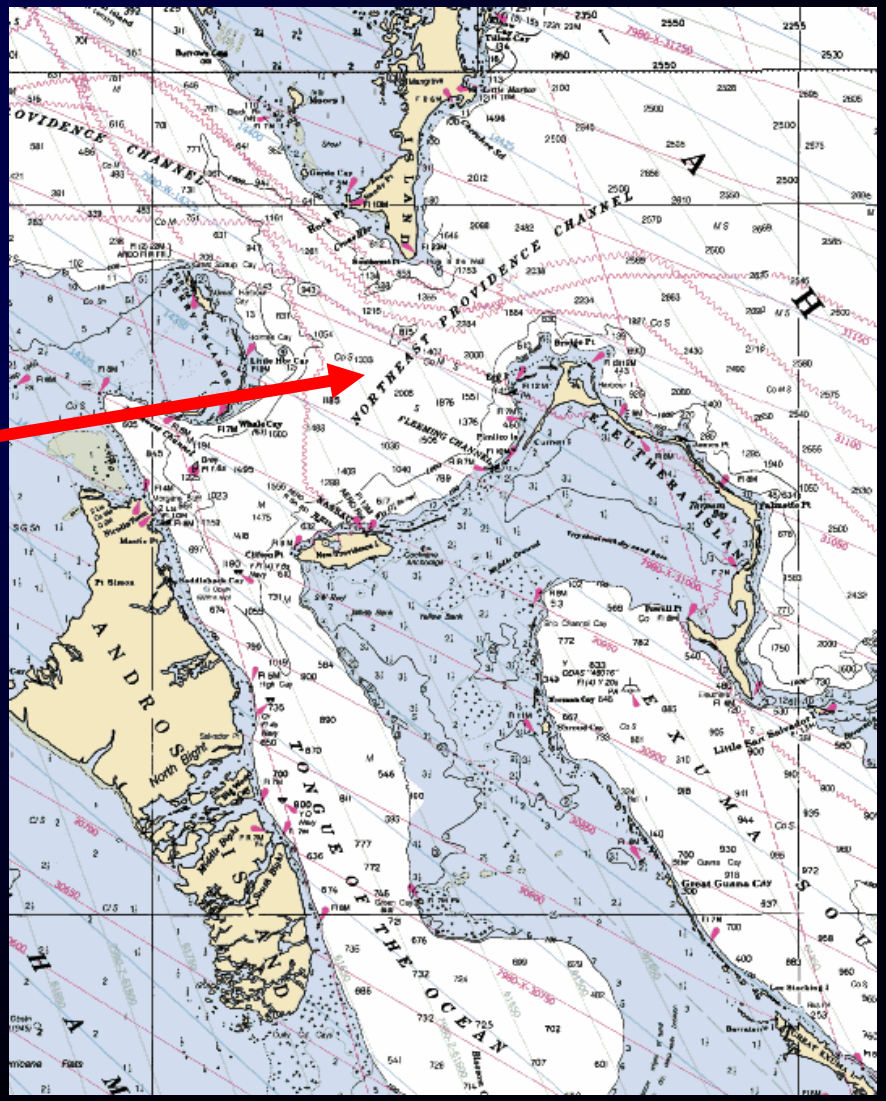


SAMS Mission 9 Profile

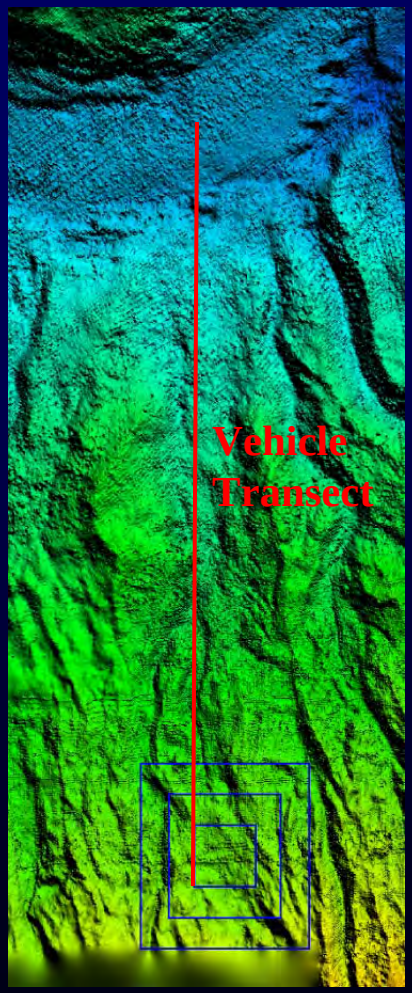


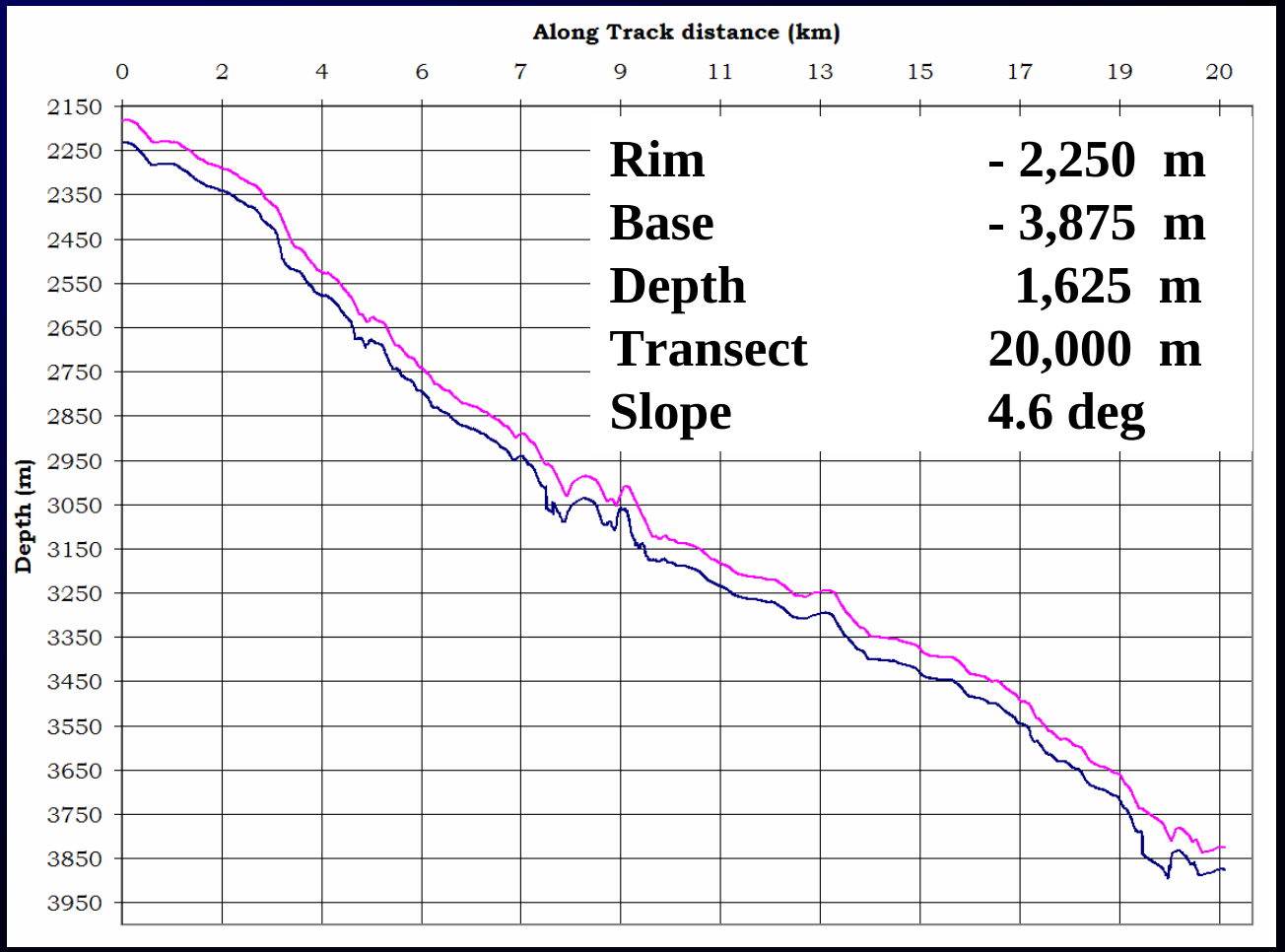
2,500 m Test Area



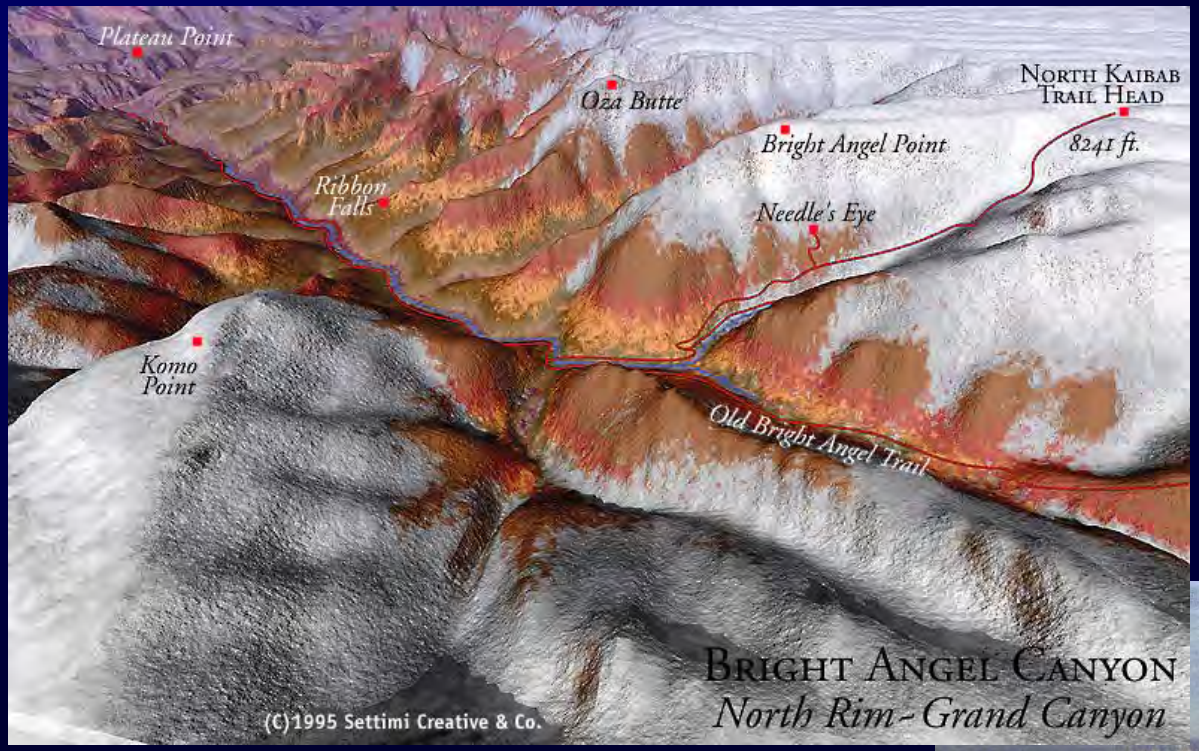


Mission 13 12nm Redirect





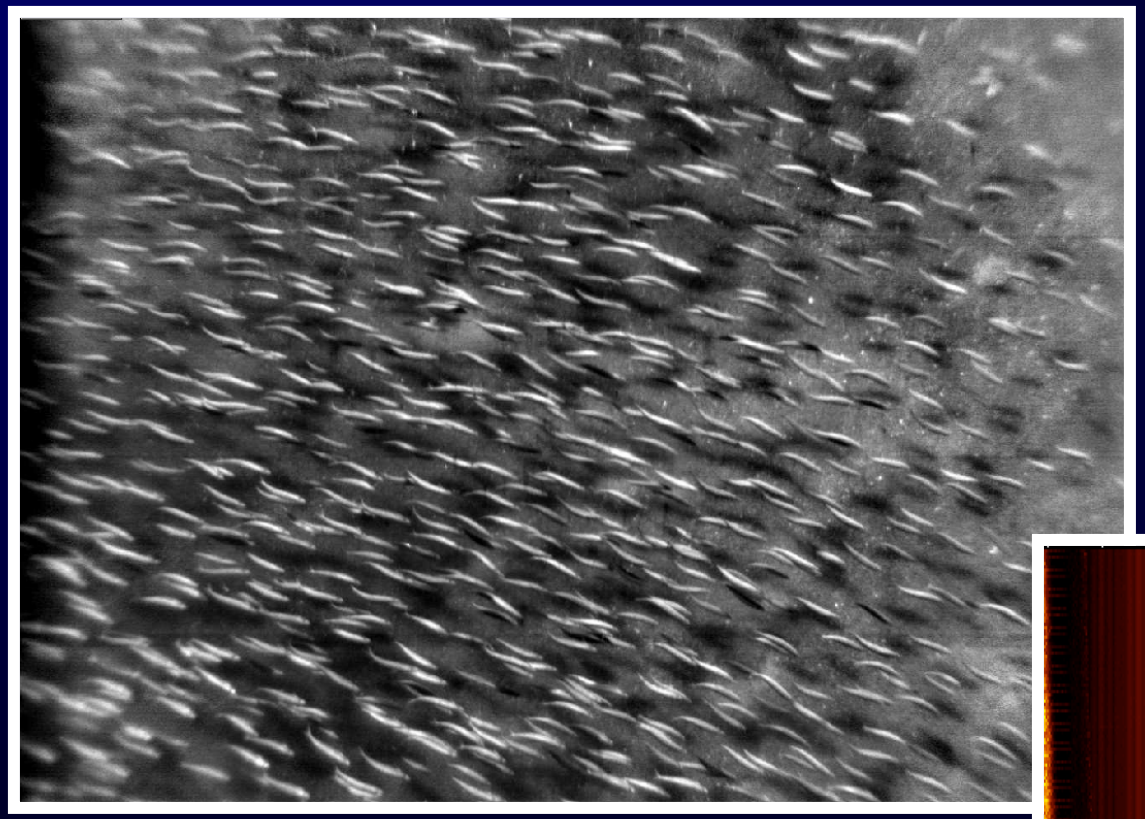
Descent Down the North Kaibab Trail



Rim	2,512	m
Colorado River	739	m
Depth	1,773	m
Trail Length	22,000	m
Slope	4.6 deg.	

Bright angel point

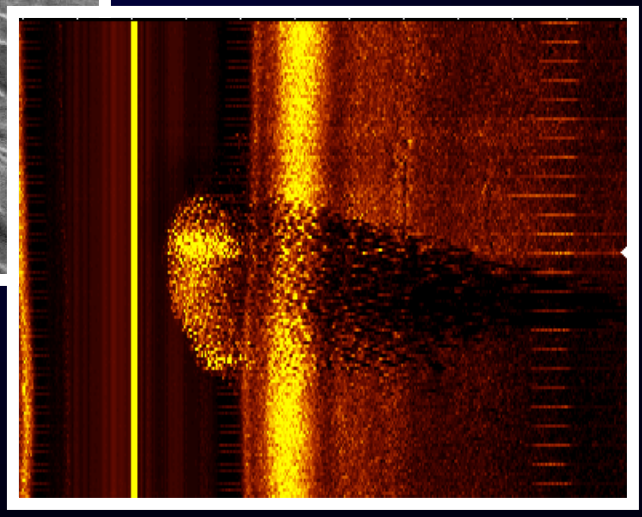
Shallow Low Altitude Imaging (4 meters)



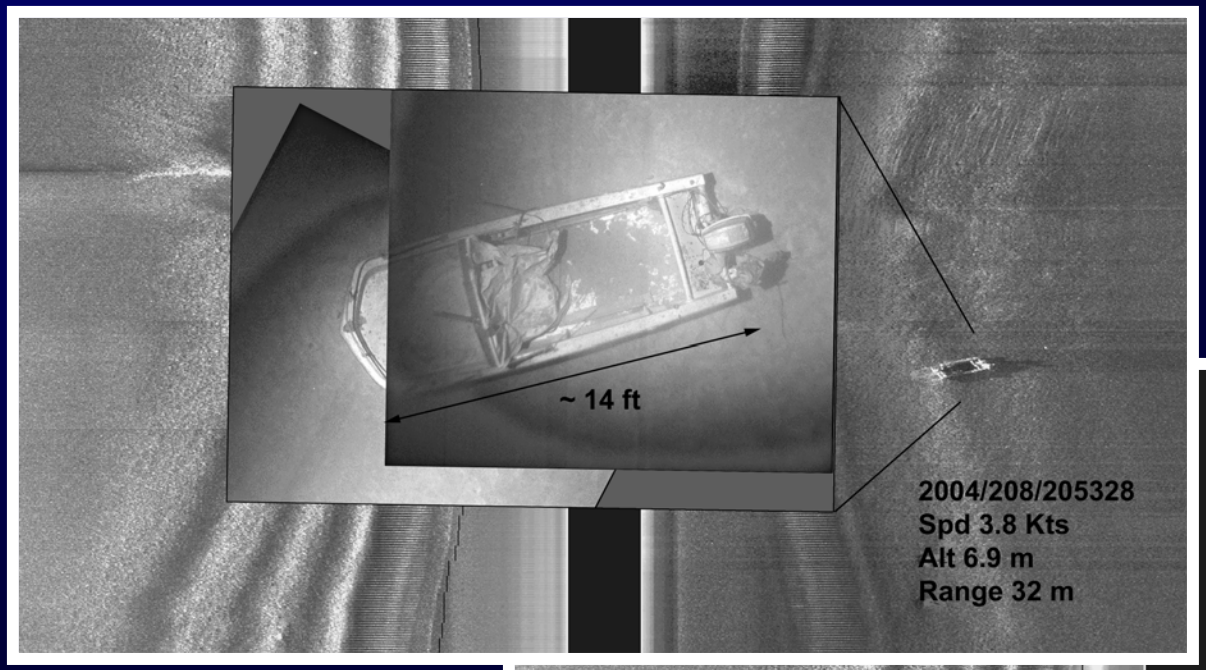
Electronic Still Image, with 200 W-S strobe illumination

Fish School off Charleston in 30 meters.

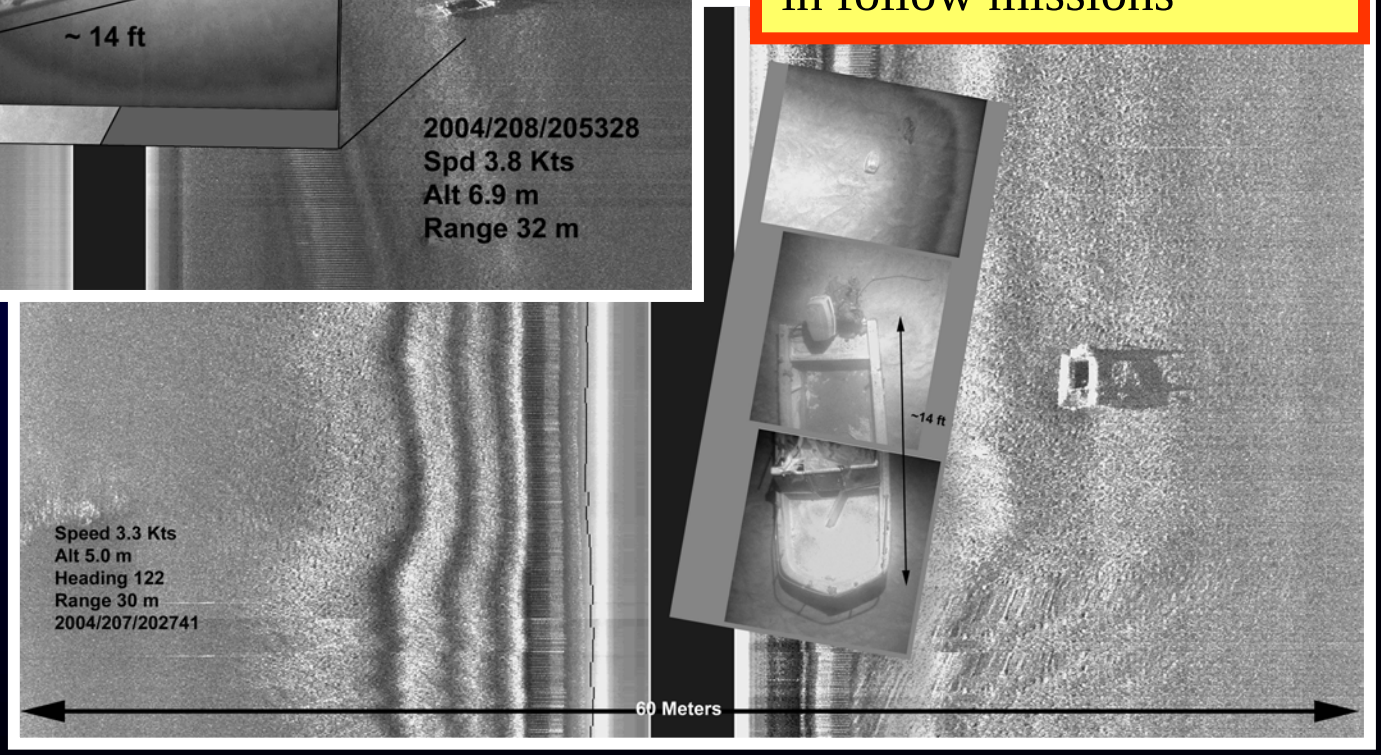
900 kHz Side Scan



Post Target Analysis



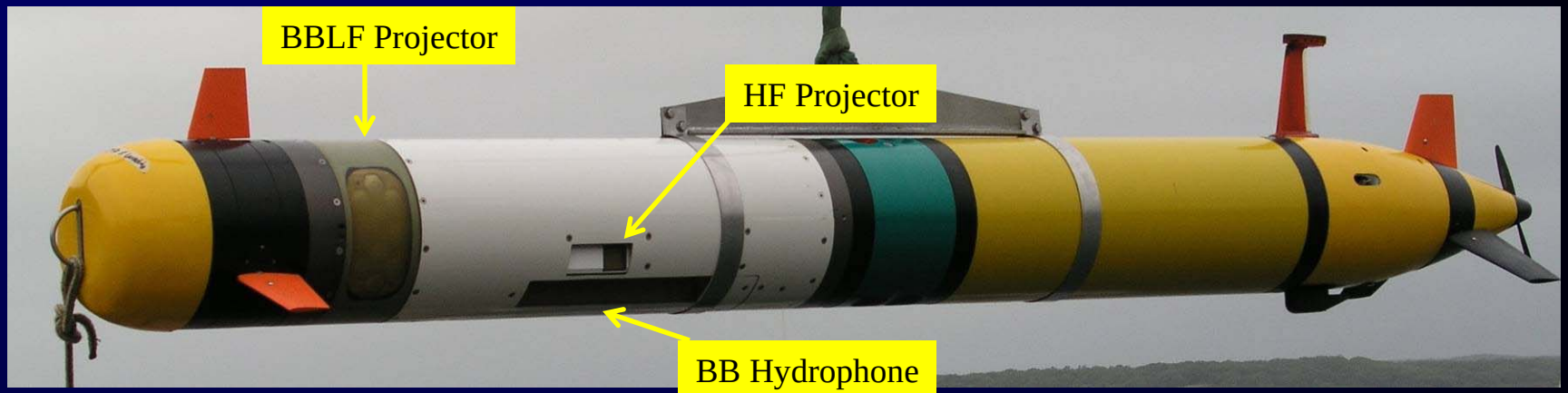
- Repeatedly returned to boat for imaging
- Redirected vehicle via modem to over fly target in follow missions



286565
DEP
WOODS HOLE OCEANOGRAPHIC INSTITUTION

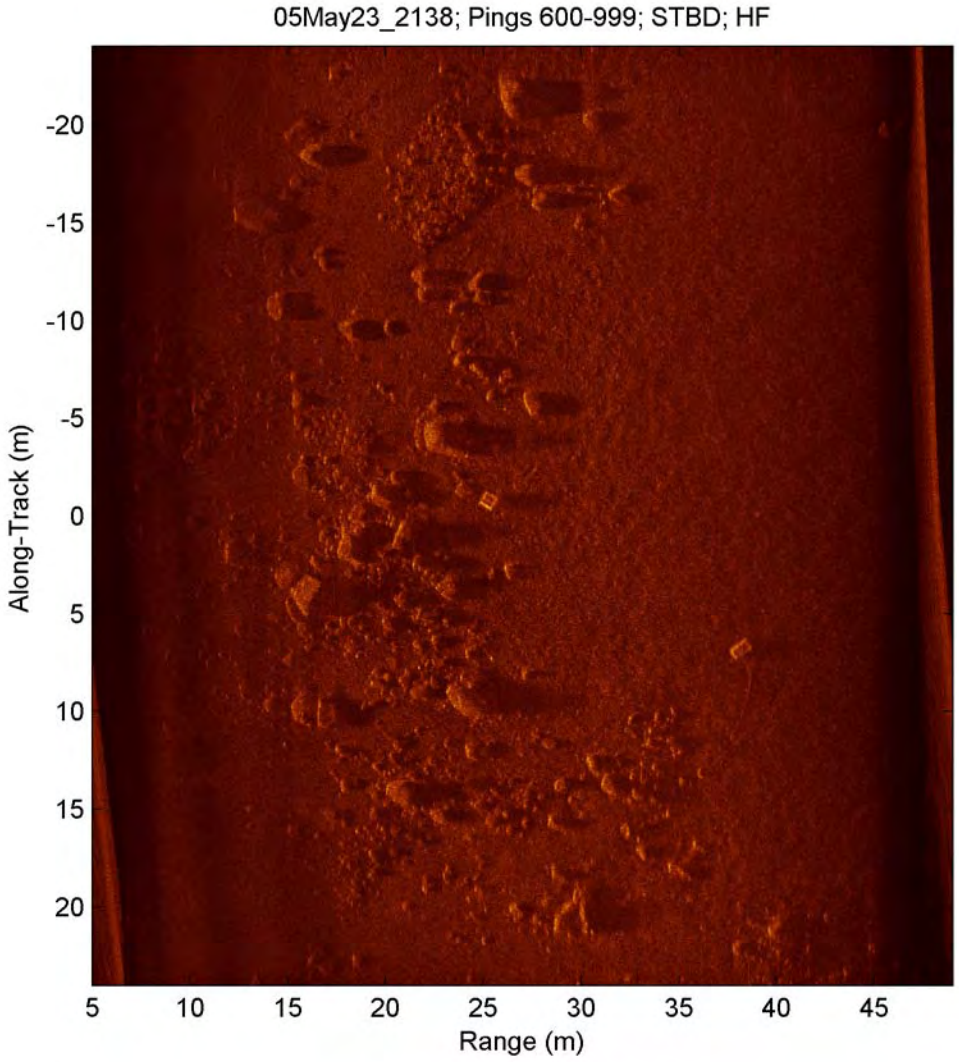
Light Weight Torpedo Class AUV

SSAM/Remus600 System (12.75” shell diameter class)

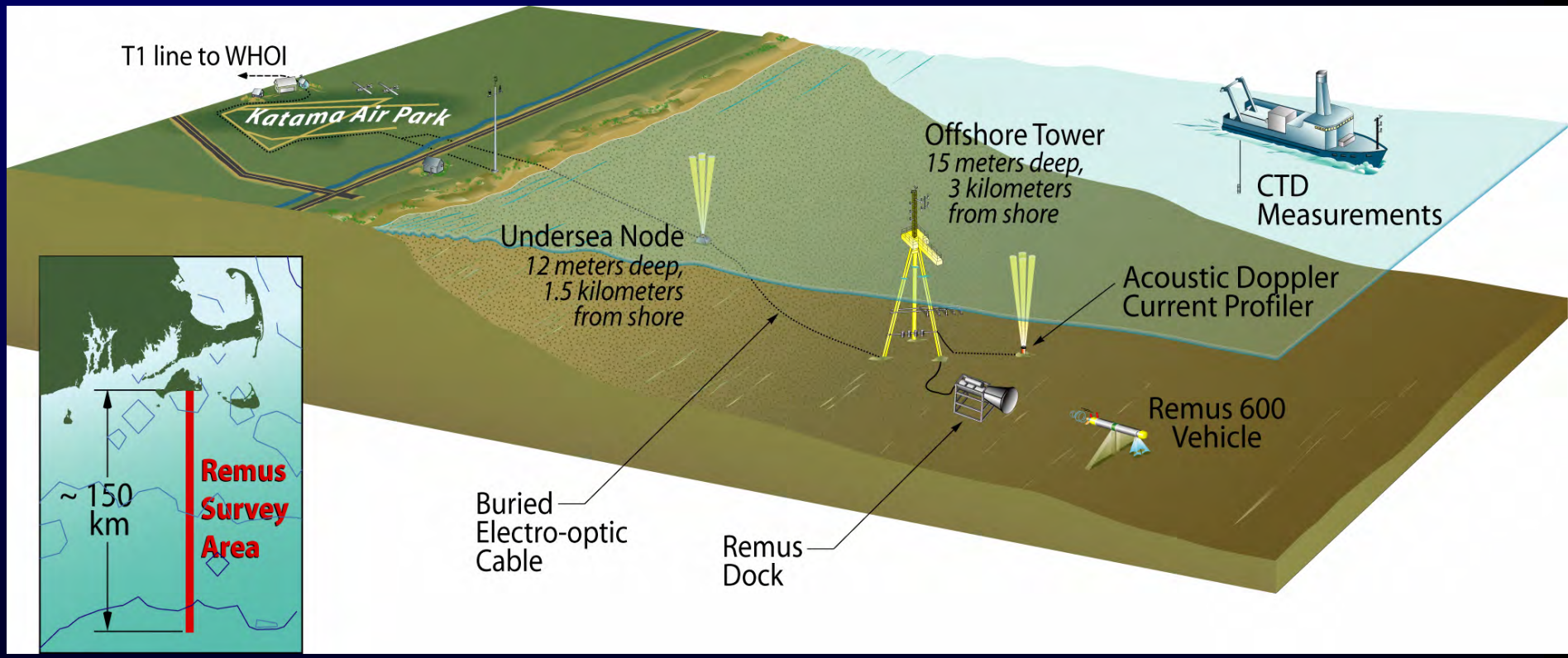


SAS Payload	UUV	Status	Team
SSAM •Simultaneous dual frequency band operation: HF band = 105 - 135 kHz, 1” x 1” res. LF Band = 8 - 52 kHz, 3” x 3” res. •DC Capabilities against proud & slightly buried targets. •Array elements used for MoComp = 2. •Range = 90/V (45 meters @ 2 m/sec). L_{SA} HF band = 11 meters L_{SA} LF band = 22 meters	WHOI Remus600	•Scheduled to participate in AUV FEST 05 (6-17 June).	Sponsor: ONR Tom Swean WHOI, ARL/PSU, VCT & NSWC-PC

SASS Images


05May23_2138; Pings 600-999; STBD; HF
Along-Track (m)
-20
-15
-10
-5
0
5
10
15
20
5
10
15
20
25
30
35
40
45
Range (m)

Repeated Autonomous Surveys of the Open Ocean thru shipping lanes



Repeated 300 km cross shelf transect from a seafloor docking station located at the end of cabled seafloor observatory

Subsurface observations are essential for properly constraining data assimilative models

REMUS Technology Demonstrated at AUV Fest 2005

- Multiple vehicle operations
- Dual frequency 900/1800 kHz Side Scan
- Dual Frequency SASS
- 600 KHz Phased Array DVL
- Kearfott T-16B INS
- LBL Nav on INS configured REMUS
- ACOMMS – high speed mode, image transfer
- Wet Labs BB2F
- Rockwell-Collins P Code GPS
- Iridium and WiFi Communications
- Simulated AUV Launch from a Dry Deck Shelter
- Autonomous Docking System for REMUS 100

Questions?

Customers: Fleet Operators

Naval Special Clearance Team ONE
and
EOD Mobile Units and Mobile Diving Salvage Units

EOD Fleet operators currently operating UUVs:

- EODGRU ONE
  - EODMU SEVEN
- EODGRU TWO
  - MDSU TWO

Mission focus on:

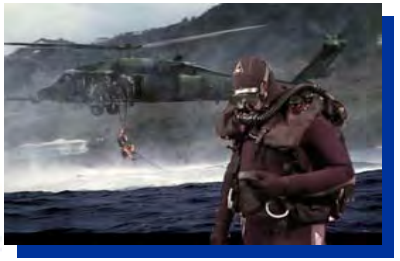
- Underwater Ordnance Detection
- Reacquisition
- Location
- Neutralization
- Recovery, and Exploitation Missions
- Salvage Operations

NSCT-1 charter combines 3 Communities:

- Naval Special Warfare
- USMC Reconnaissance
- Explosive Ordnance Disposal

Consists of <u>3 Platoons</u>:

– Marine Mammal Systems Platoon
– Unmanned System Platoon
– Diver Platoon



Navy UUV Master Plan
and the
Navy Small UUV Strategic Plan

The Navy
Unmanned Undersea Vehicle
(UUV)
Master Plan

DASN LMW
Nov 8 2004

A Navy Strategic Plan for
Small Unmanned Underwater Vehicles

Fielding Capability Packages to
Counter Unexploded Ordnance
in support of
Naval Expeditionary Warfare
28 June 2002

Acting Director, Expeditionary Warfare Division
Chief of Naval Operations (CNO N75)

Deputy and Chief of Staff (A), Atlantic Fleet

Program Executive Officer,
Mine and Undersea Warfare

Fleet Employment of UUVs

EOD FORCES
Operation IRAQI FREEDOM

- *"The arrival of a relief ship laden with emergency supplies at the port of Umm Qasr on Friday followed several days of allied mine clearing efforts… in support of Operation Iraqi Freedom. The operation marked…the initial operational launch of Navy unmanned underwater vehicles, according to Rear Adm. Paul Ryan, Commander of Mine Warfare Command."*

  Inside the Navy, 31 March 2003

- *"It's [NSCT-1 UUV Platoon] done a wonderful job for us over there in the Umm Qasr vicinity and we are looking forward to the end of the conflict to be able to tell the full story of the first operational deployment of UUVs."*

  RDML Paul Ryan, CMWC

  Inside the Navy , 31 Mar 2003

- ***"…[UUVs] gadgets were the main workhorses of the mine clearing effort… if one got blown up in the process, the relatively cheap price meant it would be no big deal."***

  LT Richard Haas, USN

  OIC, NSCT-1

  Inside the Navy ,31 Mar 2003

How should we further improve UMV testing and assessment capabilities, and at-sea experimentation support, to accelerate delivery of UMV systems to Fleet users?

- Emulate the fleet user (test personnel and procedures);
- Think system suitability (i.e. Human Systems Integration focus);
- Life cycle Simulation (e.g. system employment, accelerated aging, etc.)

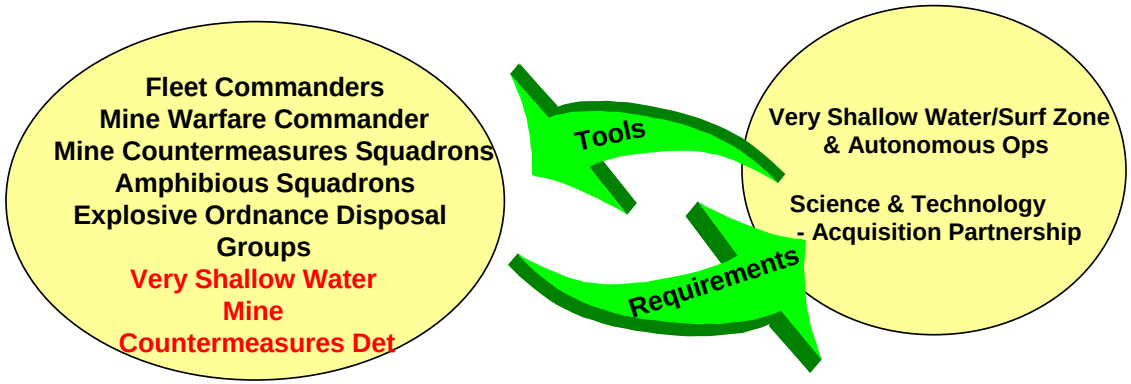
1st Generation VSW MCM Unmanned Underwater Vehicle Systems:

The "User Operational Evaluation Systems" Concept

- **"Fly-then-Buy" Concept**
- **User Operational Evaluation Systems were;**

  procured and provided to the Fleet to aid in:

  - Early engagement of Fleet in acquisition
  - Tactics evaluation and feedback on Fleet employment concepts
  - Requirements refinement
  - Affordability,suitability & logistics supportability concerns



Naval Undersea Warfare Center

Division Keyport

June 15th, 2005

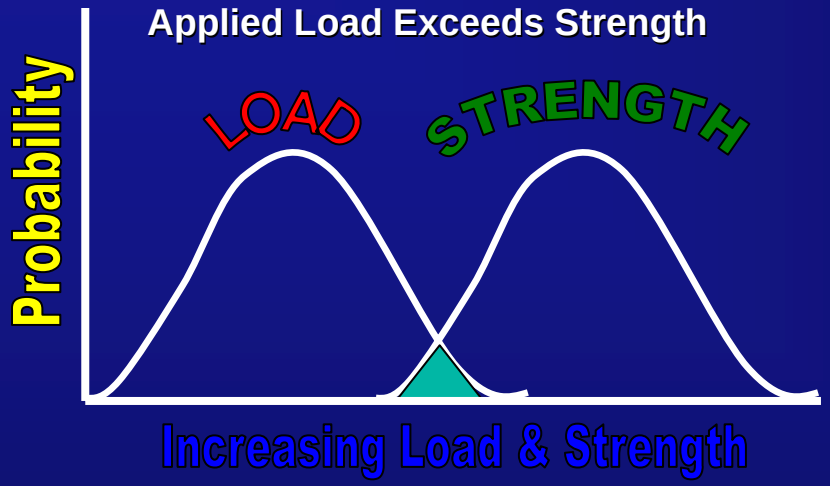
Durability Assessment using Accelerated Life Testing

Mr. Gary Zook
(360) 396-1217
gzook@ kpt. nuwc. navy. mil

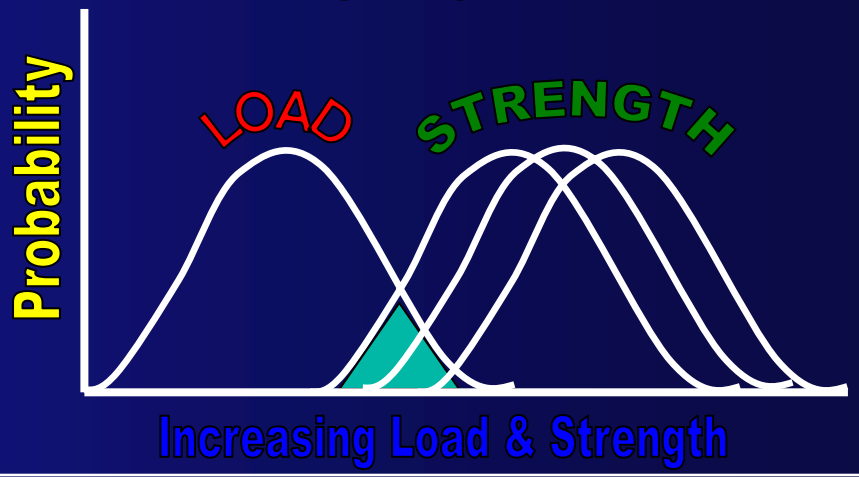
Accelerated Life Testing

NAVSEA KEYPORT
Undersea Warfare Center Division

Things Fail When Applied Load Exceeds Strength



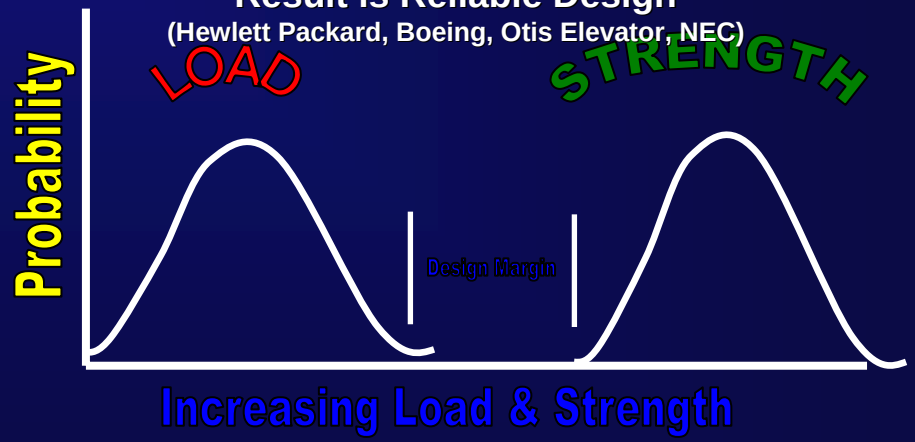
Product Strength Degradation with Time



Time Compression via Increasing Stresses

Result is Reliable Design

(Hewlett Packard, Boeing, Otis Elevator, NEC)

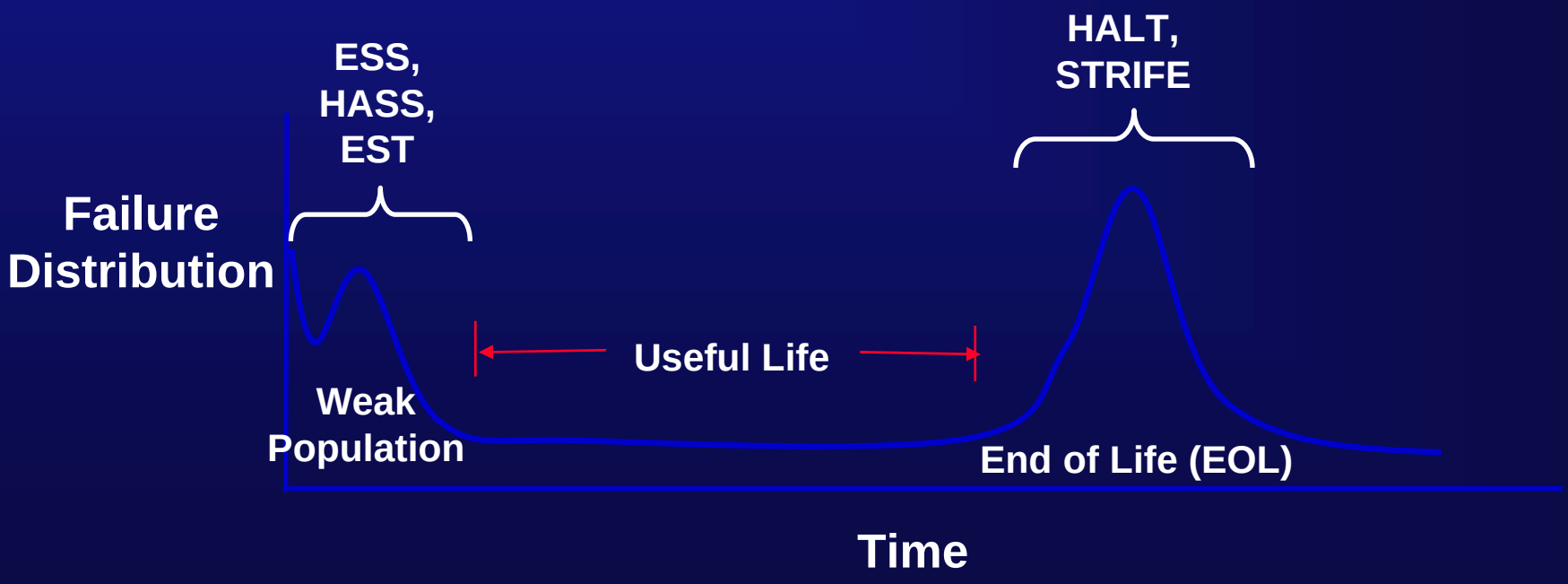


Accelerated Life Testing

- Highly Accelerated Life Testing (HALT)
  - Test to Failure (little concern about real environment)
  - Should be part of Design Effort
  - Industry has found this the most cost effective
- Highly Accelerated Stress Screening (HASS)
  - Non-Destructive
  - Removes Latent Defects
  - Test Levels determined from HALT
  - Can Migrate to Highly Accelerated Stress Audit (HASA)
- Environmental Stress Screening (ESS)
  - Non-Destructive
  - Removes Latent Defects
  - Typically based on Handbooks
- Environmental Stress Test (EST)
  - System Level ESS
  - Tested within Spec Levels
- Stressful Life Test (STRIFE)
  - Durability Assessment
  - Acceleration of Real Life Environments

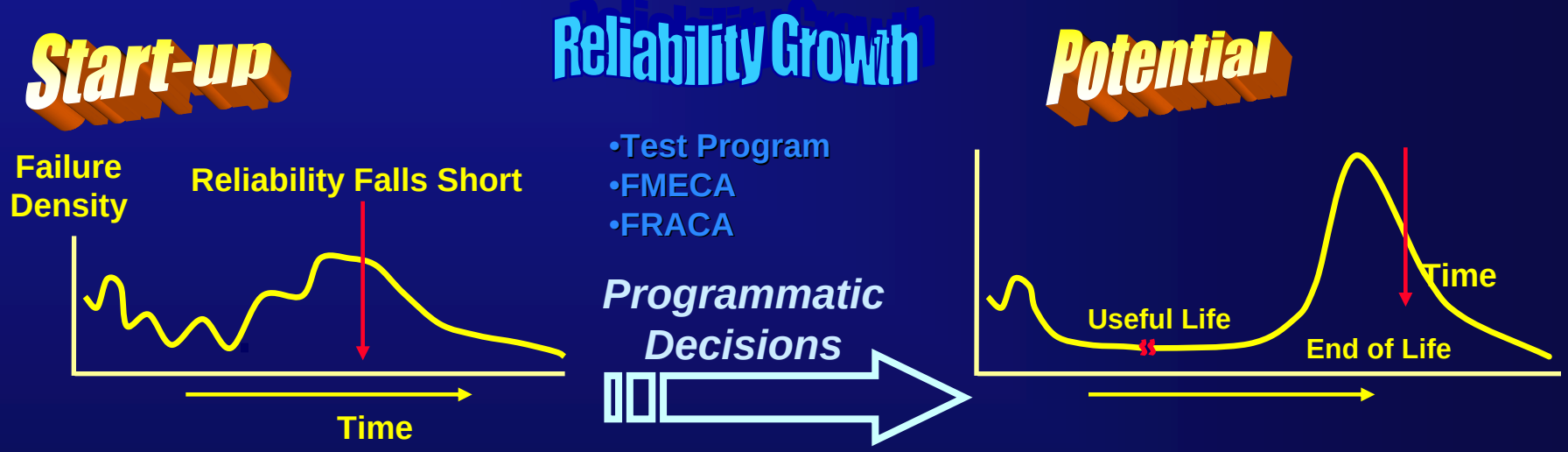
Failure Distribution Model

Failure Distribution Model



Accelerated Life Testing

Failure Distribution Model



Assume Tests Failures are Systemic Until Proven Otherwise

STRIFE Example (Durability Testing)

What is expected MTBF?

- Existing electromechanical Gyros replaced with solid state technology
- Existing MTBF 600 hours
- Calculated new MTBF 44,000 hours

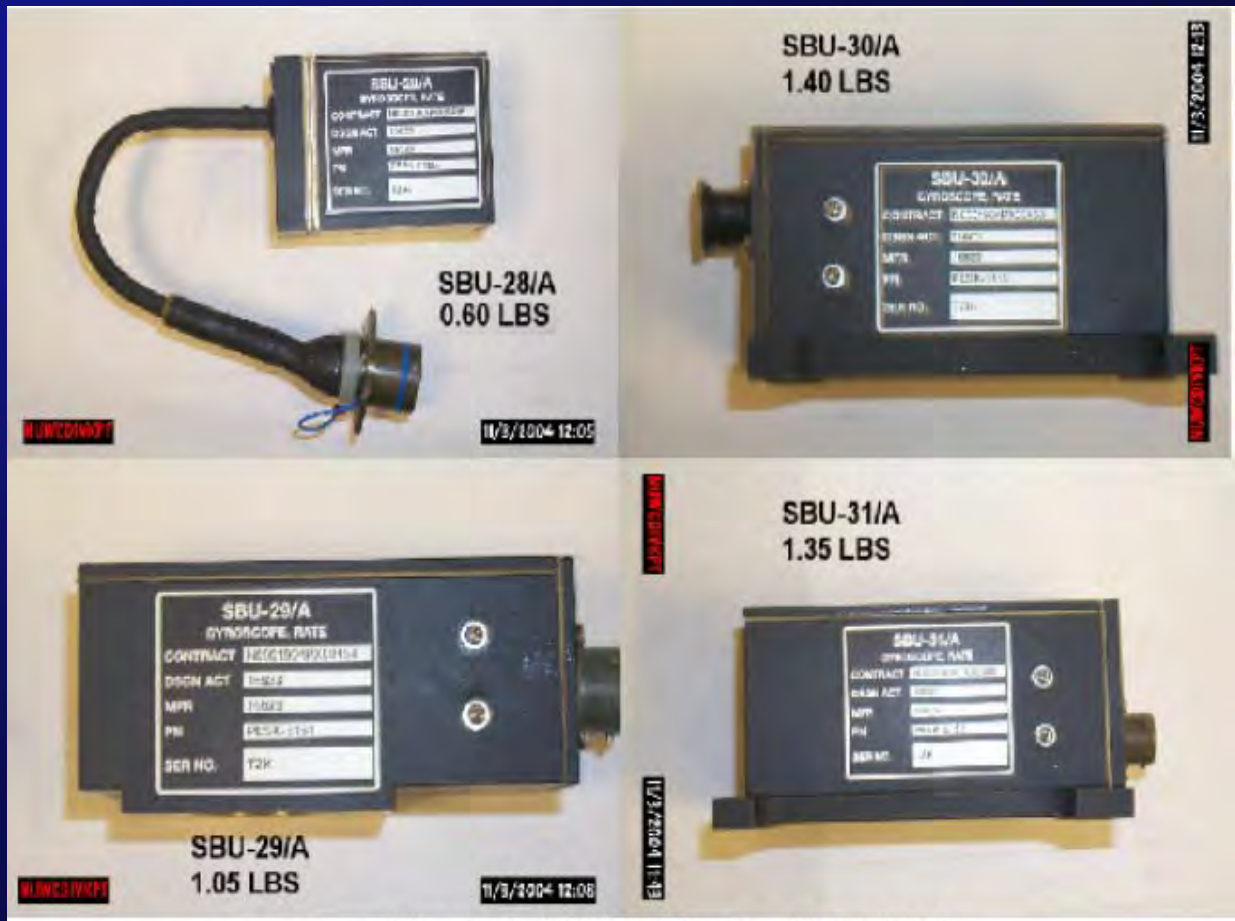


Figure 1. All Rate Gyros with weights

STRIFE Testing

- STRIFE (stressful life) is an approach to determine durability
- Goal was to simulate 44,000 hours of operation
- For Vibration:
  - MIL-STD-810F Fatigue Relationship
    - Inverse Power Equation

$$\left(\frac{W_0}{W_1}\right) = \left(\frac{T_1}{T_0}\right)^{\left(1/M\right)}$$

W_0: Baseline Vibration Level
W_1: Test Vibration Level
T_0 : Baseline Time
T_1 : Test Time
M : Material Constant

Material Constant Ranges from:
Kipp Company Paper M=2 (random Vib)
MIL-S-810 M=4-6
D.S. Steinburg M=6.4

For this example:
W_0= 4.2 g's RMS
T_0 = 44,000 hours
T_1 = 250 hours
M = 4 (connectors)

W_1 = 15.2 g's RMS

STRIFE Testing

- For Thermal:
  - Min and Max temps based on HALT
    - -75F and 175F
  - Ramping and dwell times based on equipment capability and functional test requirements
  - MIL-H-344 used for acceleration factor

$$D = N * S^{B}$$

D is Damage Index
N is Cycles
S is delta Temperature
B is Fatigue exponent (2.5 for solder)

For this example:
N = 750 test cycles
S = 250 delta F
D= 7.41e8

If actual environment is S=80 delta F:
D= 7.41e8 (same effective damage index)

N=12944 cycles for actual environment

STRIFE Testing

Combined Vibration and Thermal Testing with Liquid Nitrogen Assist

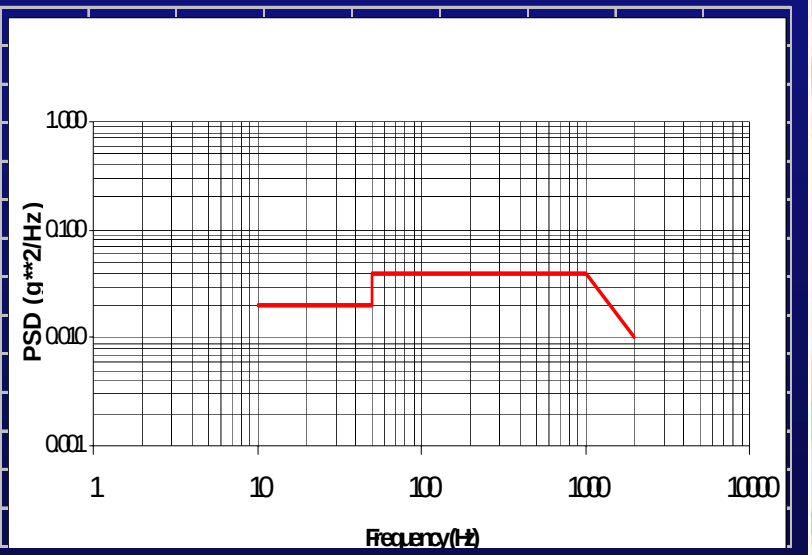


Figure 13. STRIFE Test Setup Example

STRIFE Testing

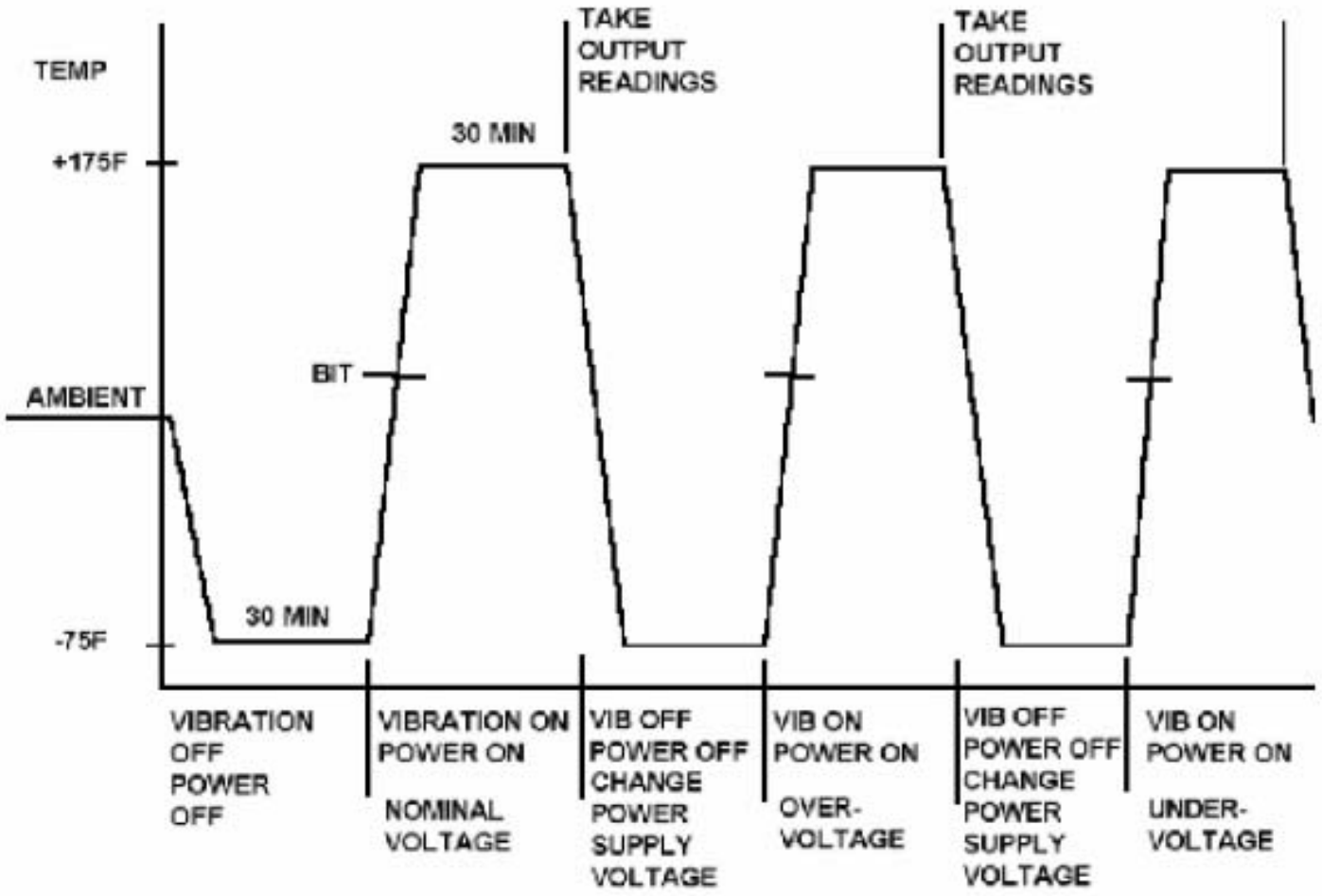


Figure 14. STRIFE profile (one complete cycle)

STRIFE Analysis

- **Using Assurance Tables from "Statistical Design and Analysis of Engineering Experiments", *Lipson and Sheth*, 1973, McGraw-Hill**

For a sample of two with no failures:

Vibration: 86.5% *Assurance* population will survive 44,000 hours at 4.2 g's
***or* 99.8% *Assurance* population will survive 14,667 hours at 4.2 g's**

Thermal: 86.5% *Assurance* population will survive 12944 cycles at 80 delta F
***or* 99.8% *Assurance* population will survive 4315 cycles at 80 delta F**

For comparison, one sample with no failures would give 63.2% assurance at 44,000 and 95.0% assurance at 14,667 for vibration

Assumption is that test samples adequately represent population

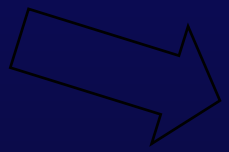
STRIFE Testing – UUV Example

- Real Environment
  - 0.5 G's
  - 2000 hours of Operation

$$\left(\frac{W_0}{W_1}\right) = \left(\frac{T_1}{T_0}\right)^{\left(1/M\right)}$$

W_0: Baseline Vibration Level
W_1: Test Vibration Level
T_0 : Baseline Time
T_1 : Test Time
M : Material Constant = 6 (general case)

Limit Test Vibration to 3 G's
W_1 = 3.0 g's RMS
W_0 = 0.5 g's RMS
T_0 = 2000 hours
T_1 = ? hours



T_1 = 1.54 Test Hours

Closing Thoughts

- Navy (DoD?) Environmental Test labs designed around 1960's technology and equipment
  - Steady state environments
  - Single axis vibration
  - Requirements based test design
- My Approach:
  - Upgrade equipment
    - Multi-axis vibration
    - High performance thermal systems (LN2)
  - Continue our education of accelerated life testing (HALT/HASS/STRIFE/ESS)

NAVSEA Keyport's 3-Axis Electro-dynamic Vibration Test System

Accelerated Life Testing is part of an Effective T&E approach