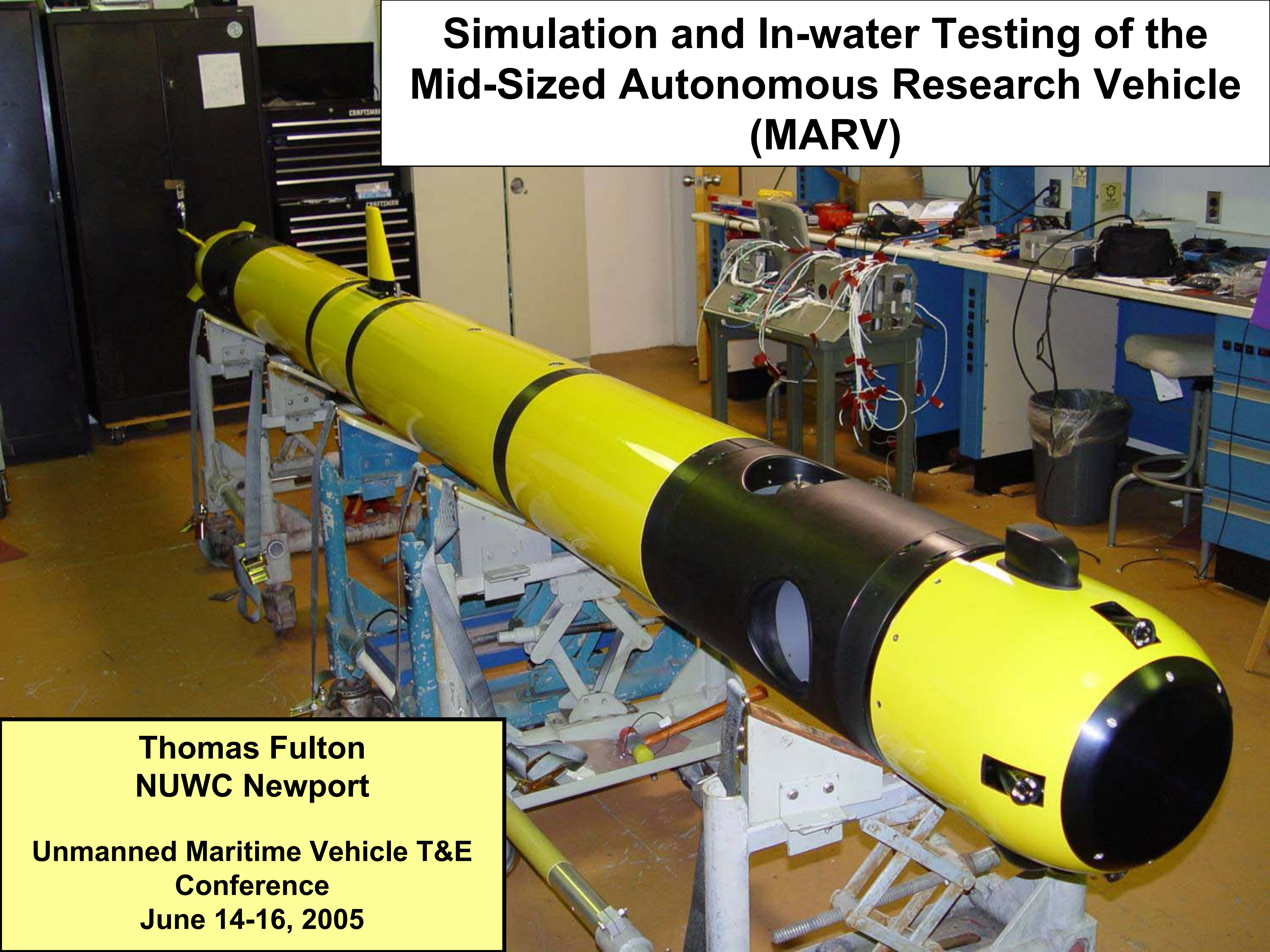
Simulation and In-water Testing of the Mid-Sized Autonomous Research Vehicle (MARV)



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

MARV
Mid-sized Autonomous Research Vehicle

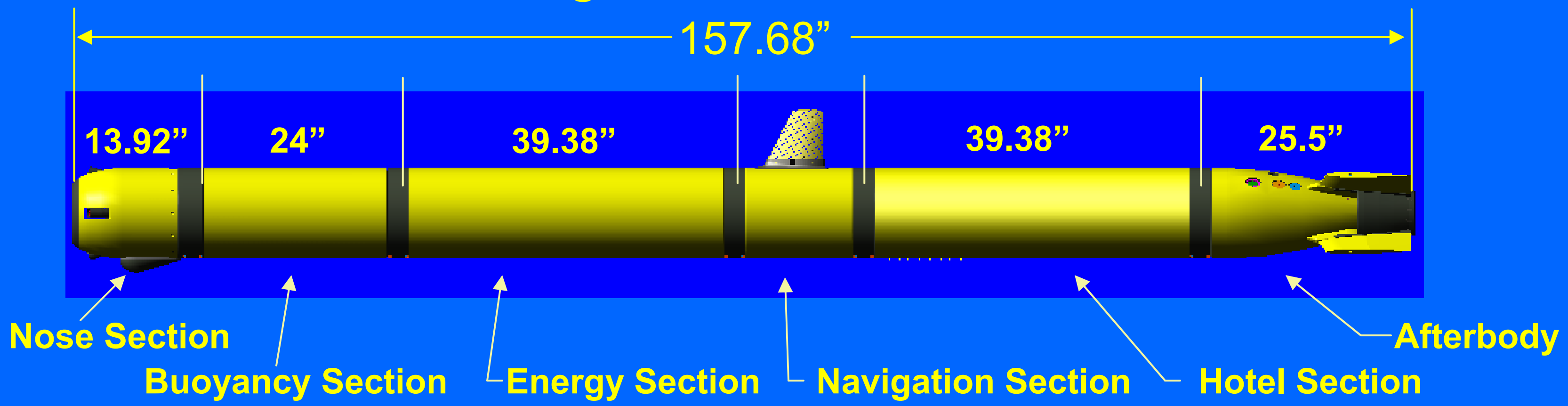
12.75" OD

Performance Specifications

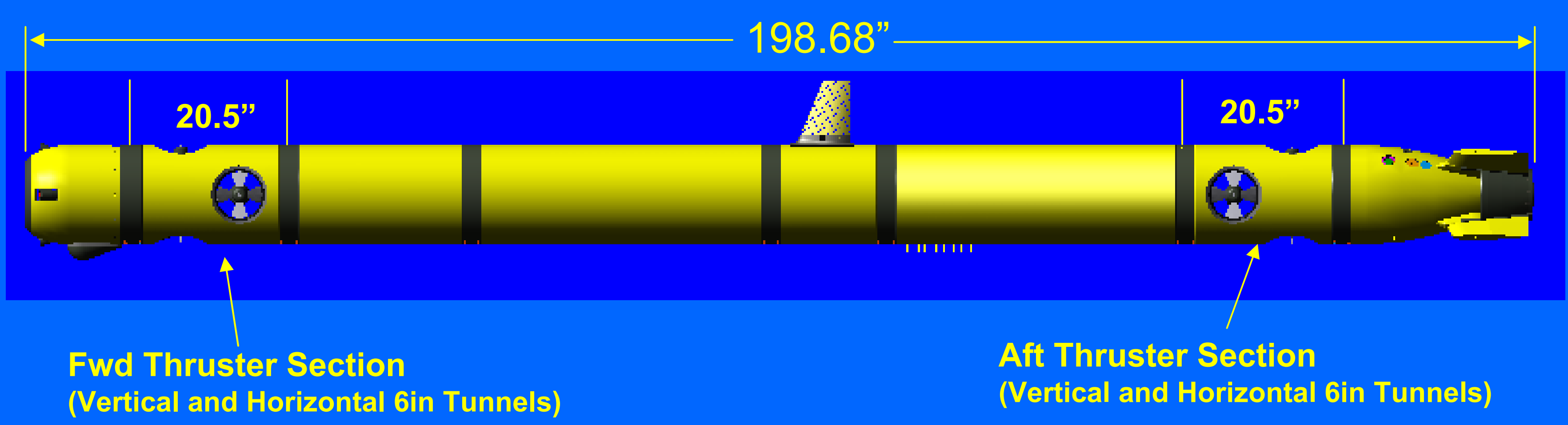
- **Operating Depth**
  - Surface to 1500 feet
  - Minimum water column depth: 20 feet
- **Operating Speed**
  - 2 - 5 knots forward/reverse (baseline configuration)
  - 0 - 1 knot forward / reverse / vertical / lateral / spar buoy (in thruster configuration)
- **Endurance**
  - 2.5 kWh available lead-acid, 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

UUV Layouts

Baseline Configuration, 652.45 lbs, 10.24 ft^3



Thruster Configuration, 860.37 lbs, 13.44 ft^3



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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

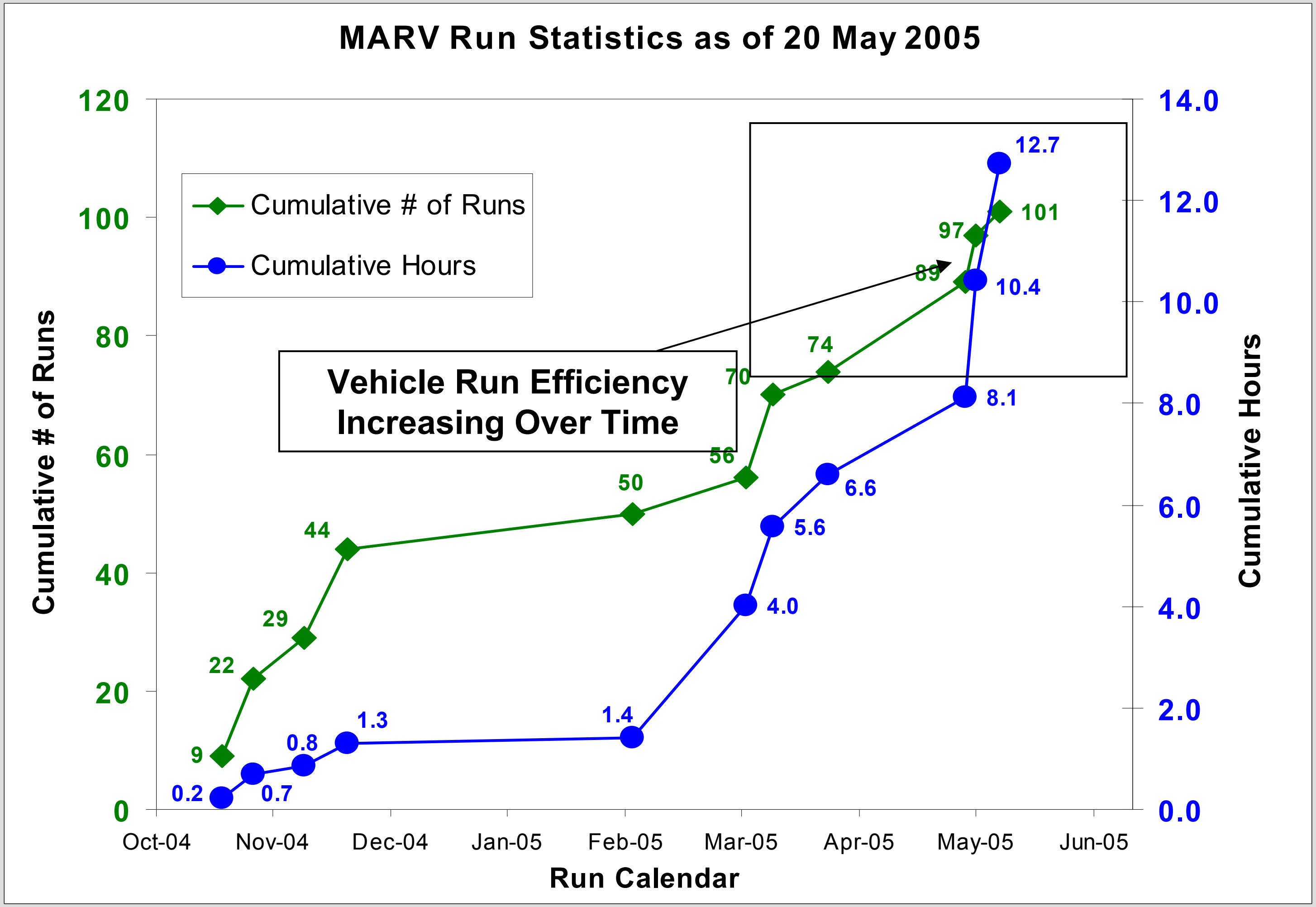
In-Water Test Status

- 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

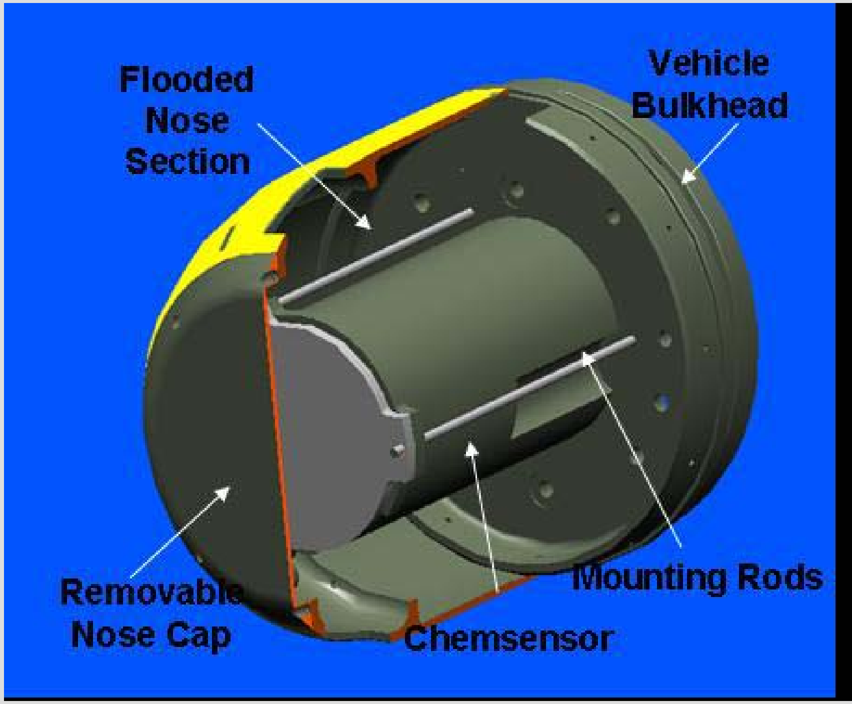
- Iterative cycles of
  - bench tests
  - in-water runs
  - troubleshooting fixes

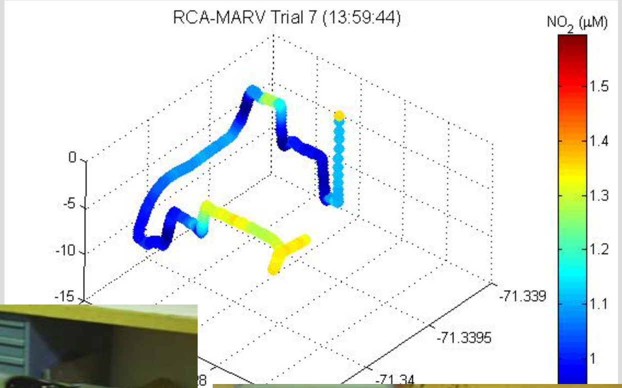
  have led to highly reliable vehicle
- Initial UUV troubleshooting is complete, vehicle missions in excess of 2 hours have been performed



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.



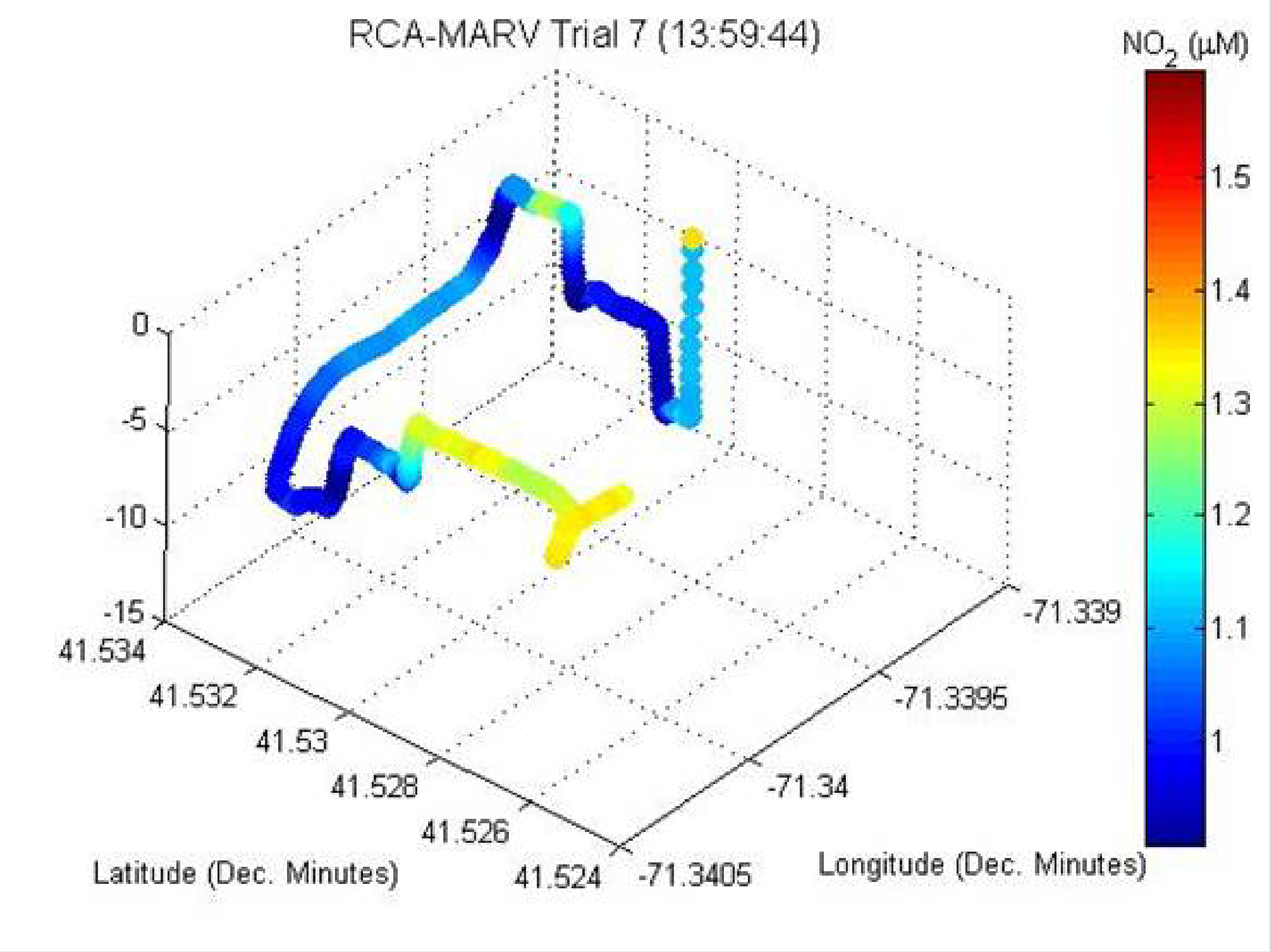


Sub Chem Systems, Inc.

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**



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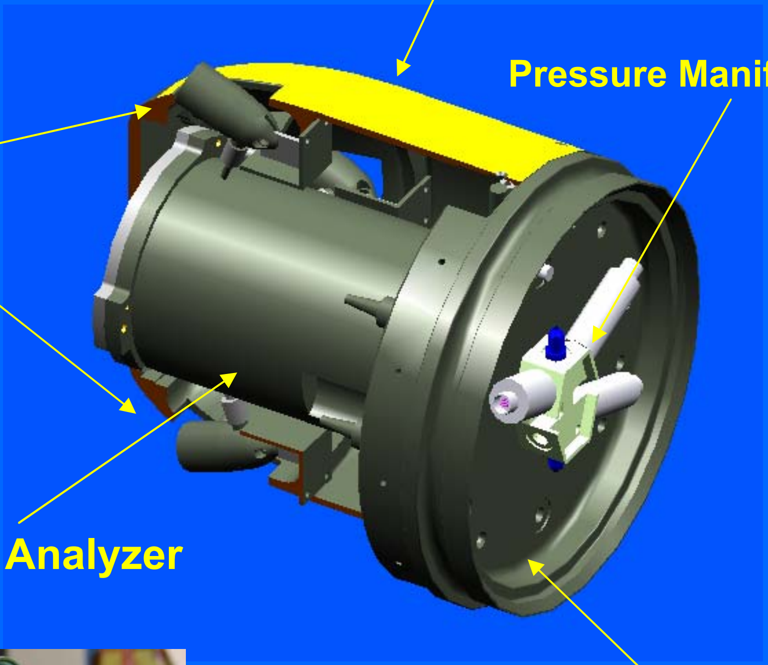
Video Camera Integration – Nose Section

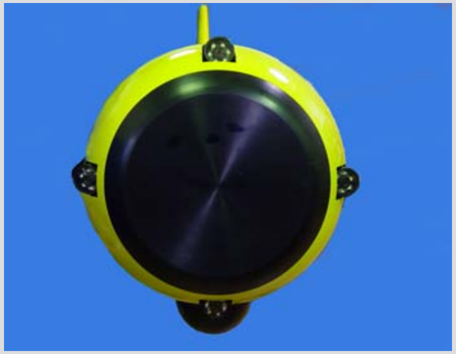
- Free Flooded Modified MK46 Nose Housing
- Up to four high resolution Underwater Cameras with up to 45° of pivoting
- Cameras equipped with LED array for lighting
- Tracking Transducer from ORE
- Pressure manifold adds multiple ports for pressure transducers and pressure switches
- Large Payload Area 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 75º 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

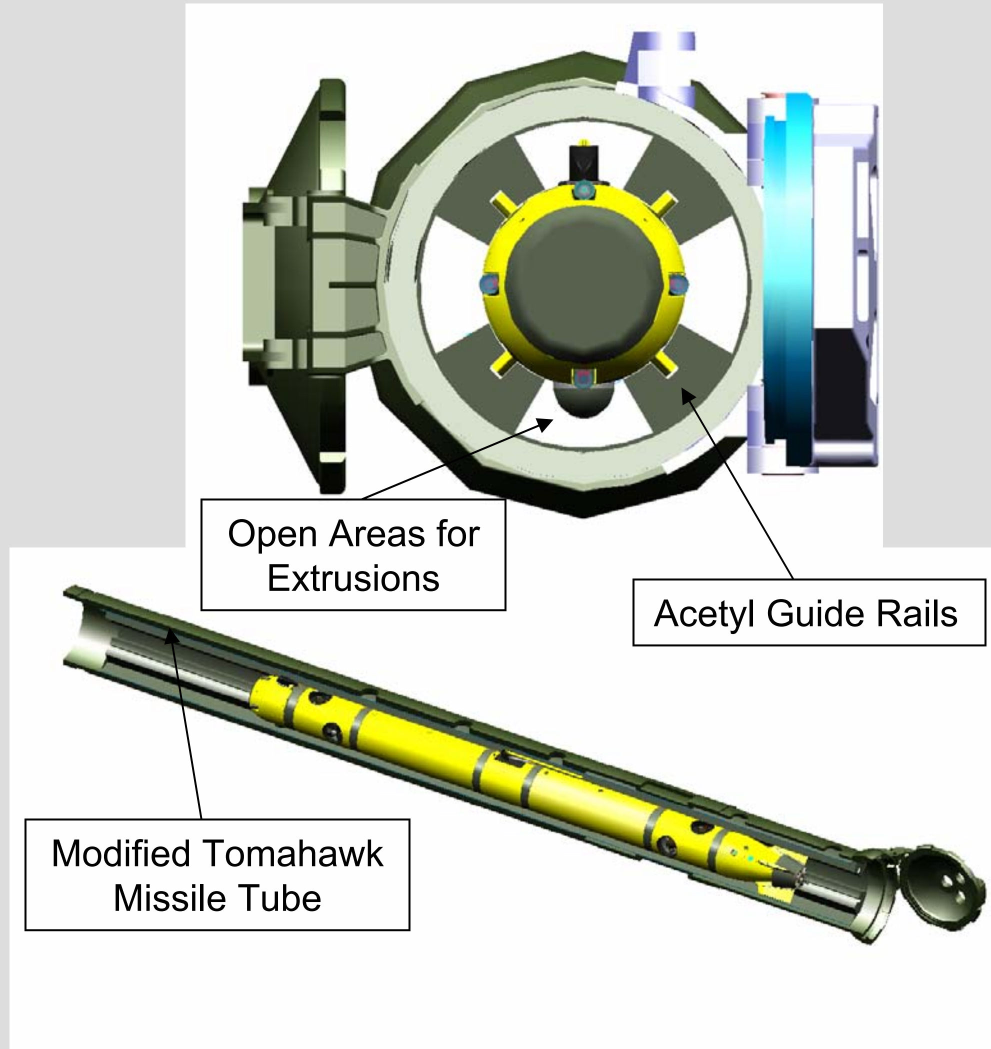
- **MARV is lightweight torpedo size in diameter but Torpedo tubes are designed for Heavyweights.**
- **Sleeve must be developed for MARV to be launch capable**
- **Two possible options have been researched:**

  - 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.

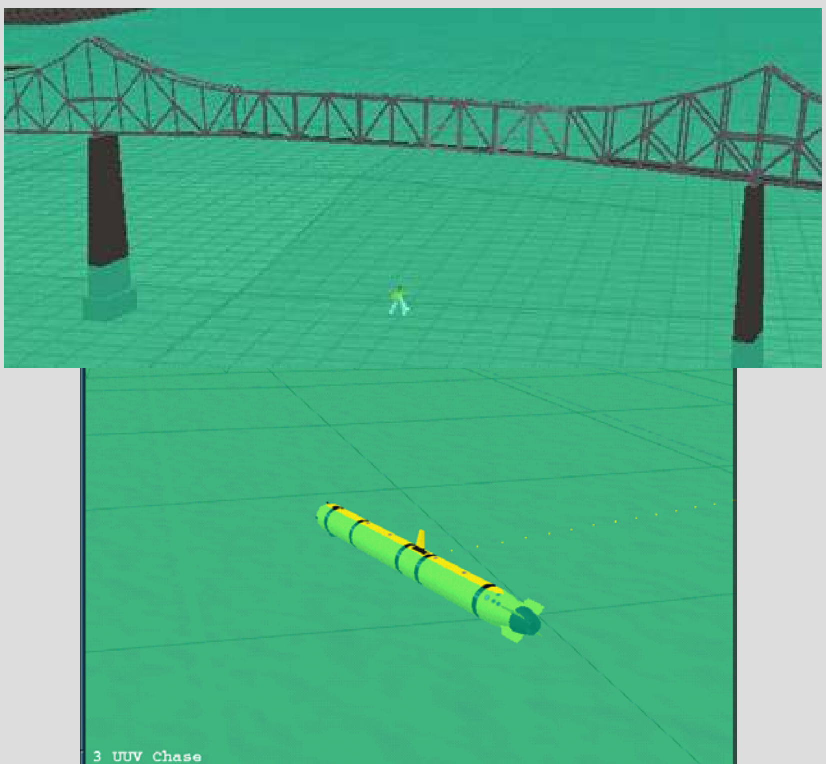


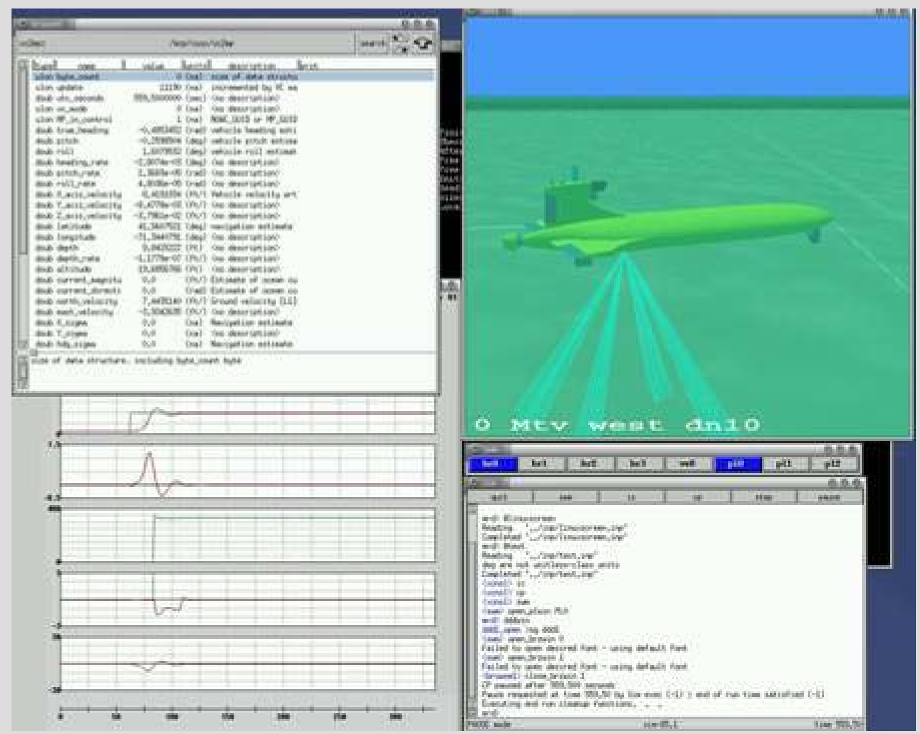
Computer Simulation

- 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

Vehicle System Models

Sensors
- Inertial navigation system
- Pressure depth
- Sonar altimeter
- Doppler velocity sonar
- Forward looking sonar
- Passive sonar

Vehicle Dynamics
- Mass properties
- Propulsion
- Hydrodynamics
- Fin actuators
- Vehicle state
  - position
  - attitude
  - linear & angular rates

Onboard Software
- Control
- Guidance
- Navigation
- Mission planning
- Path Planning
- Mapping
- Non-traditional navigation
- Obstacle avoidance

Environment Models

Ocean
- Sea state
- Currents
- Temperature
- Salinity

Earth
- Gravity
- Undersea terrain
- Navigational markers
- Surface & subsurface objects & obstacles

Computer Generated Imagery
- Real world view
  - Vehicle Position & attitude
  - Threat & obstacle position & attitude
  Sonar coverage
- Engineering graphics
  - System state display
  - Desired & actual trajectories
  - Relevant coordinate frames

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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

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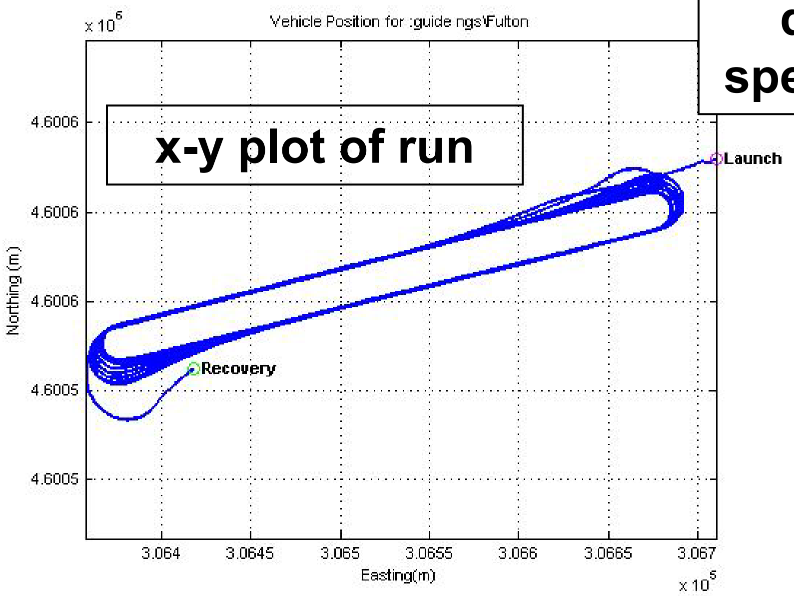
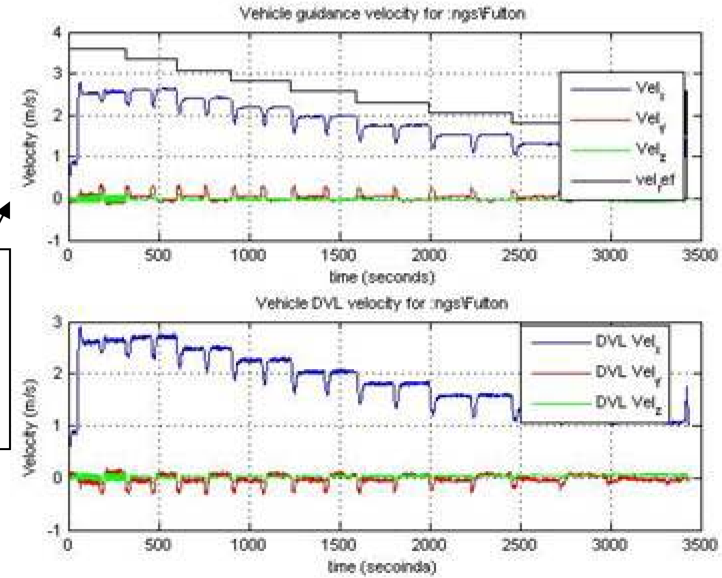
Post run mission evaluation

x-y plot of run

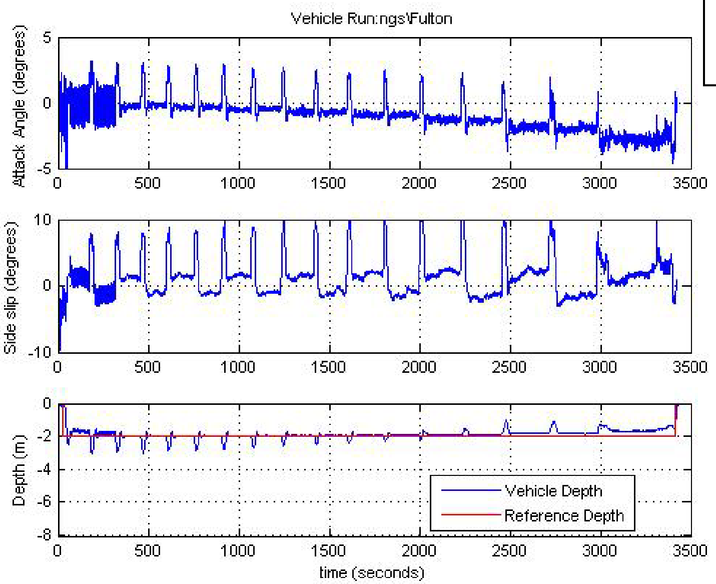


decreasing speed racetrack

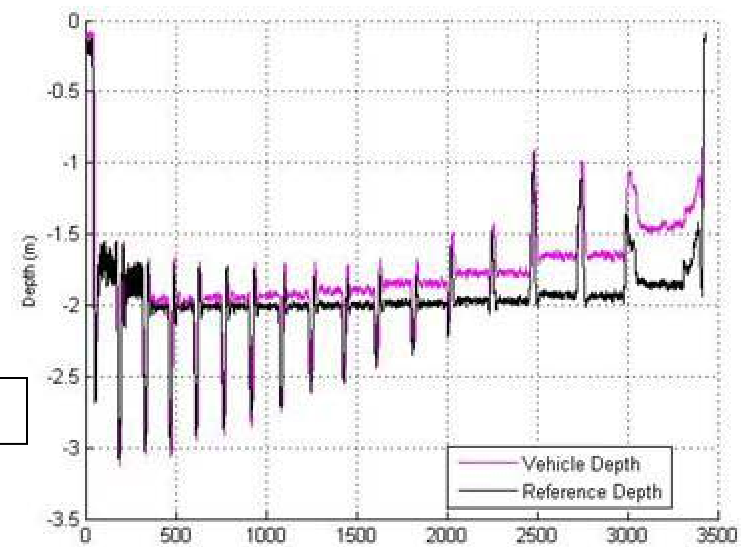
speed over ground, DVL data and controller data

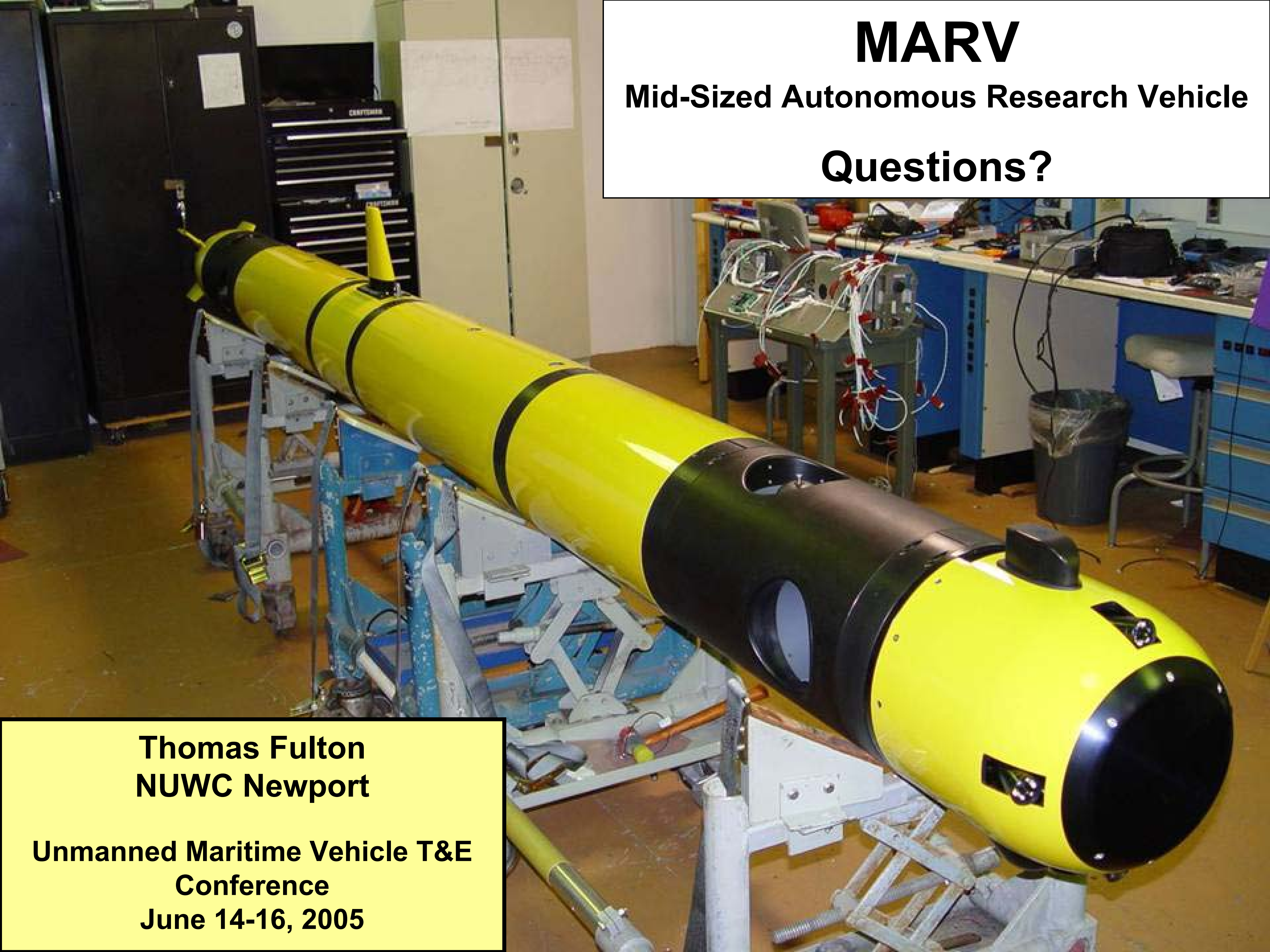


crabbing, pitch and depth



vehicle depth





MARV

Mid-Sized Autonomous Research Vehicle

Questions?

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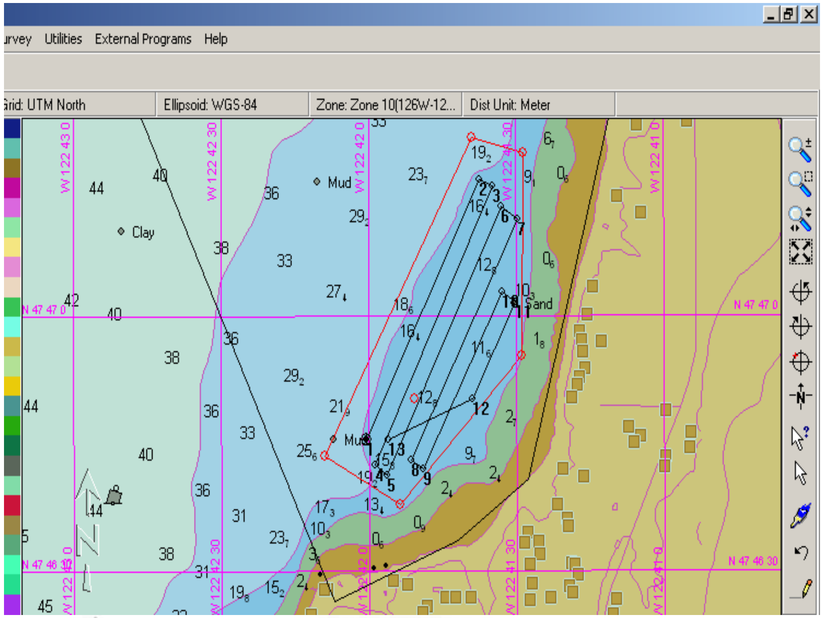
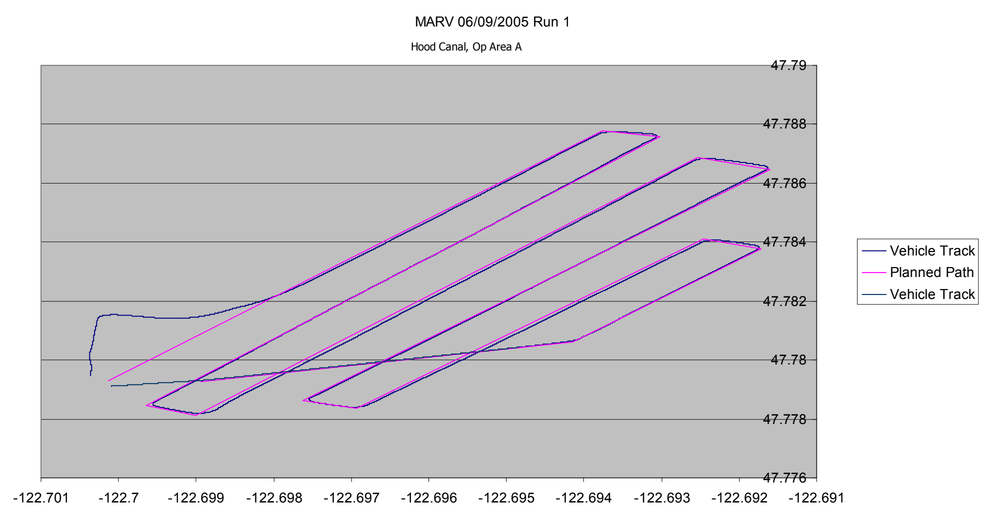
- BACKUP Slides

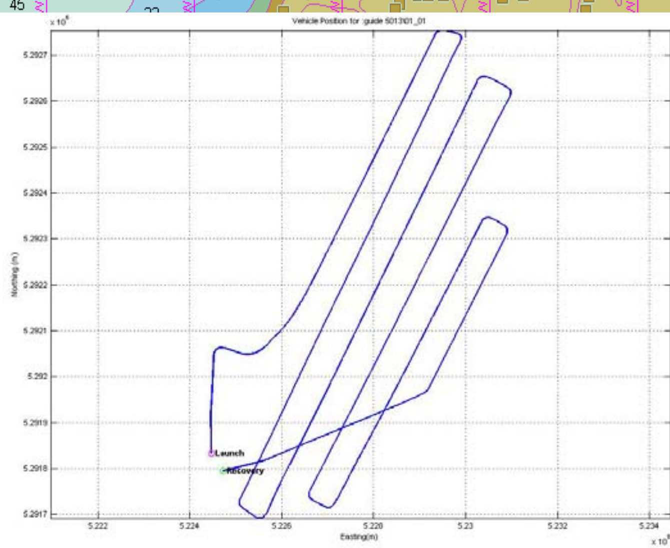
Run data – 6/9/05, run 1



Lawnmower mission, over-bottom tracking with cameras

- Depth limited to 11m
- Speed 3.5 kts





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Run data – 6/9/05, run 1

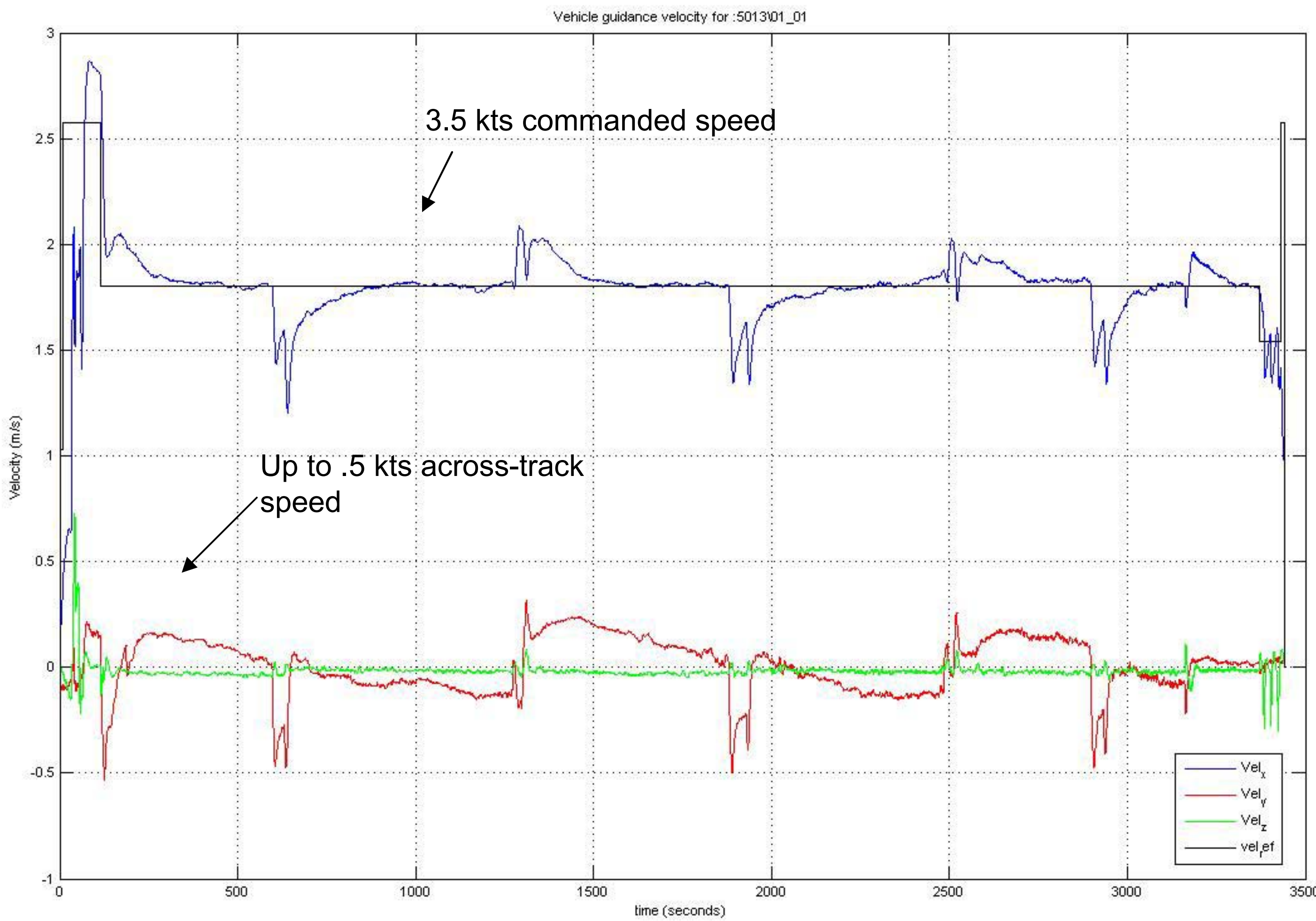
Velocity

Blue = x direction (forward)

Red = y direction (athwartships)

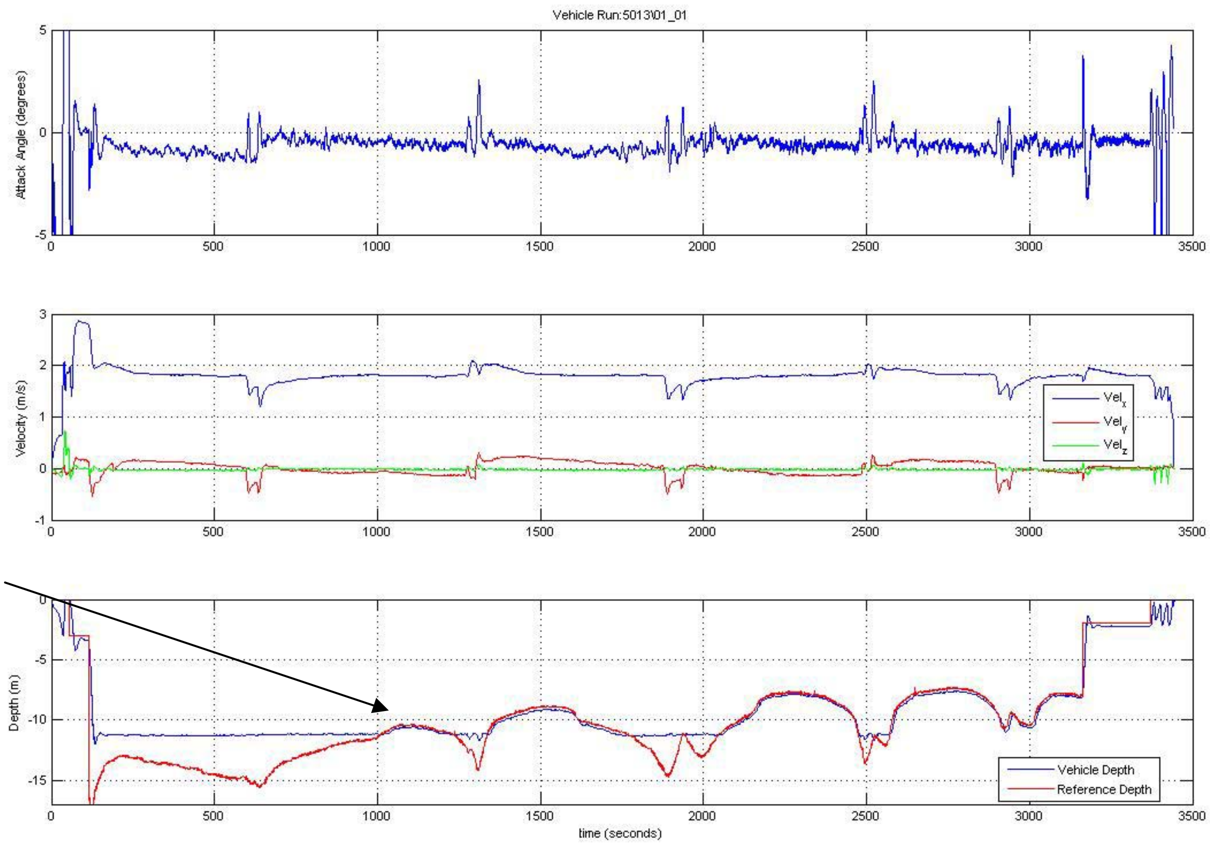
Green = z direction (vertical)

- 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

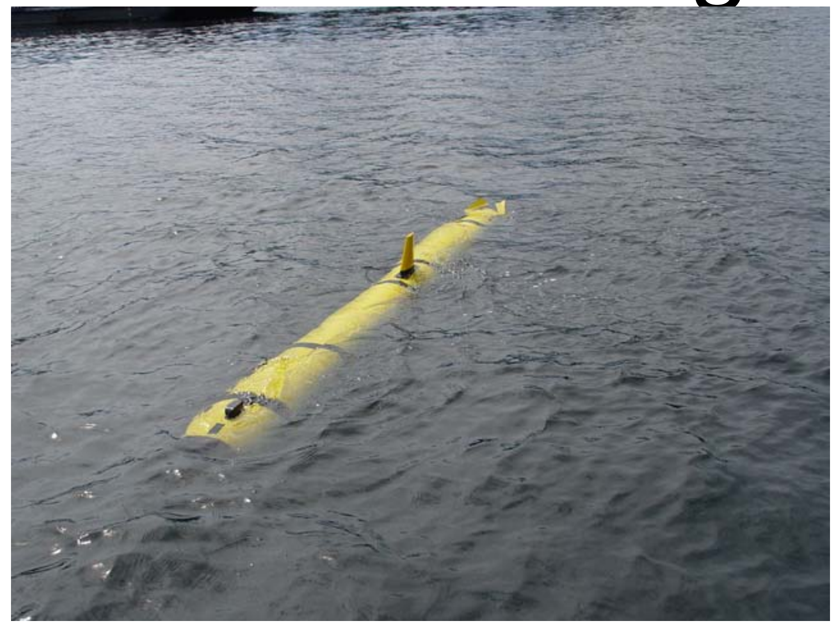
08:40 AM

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