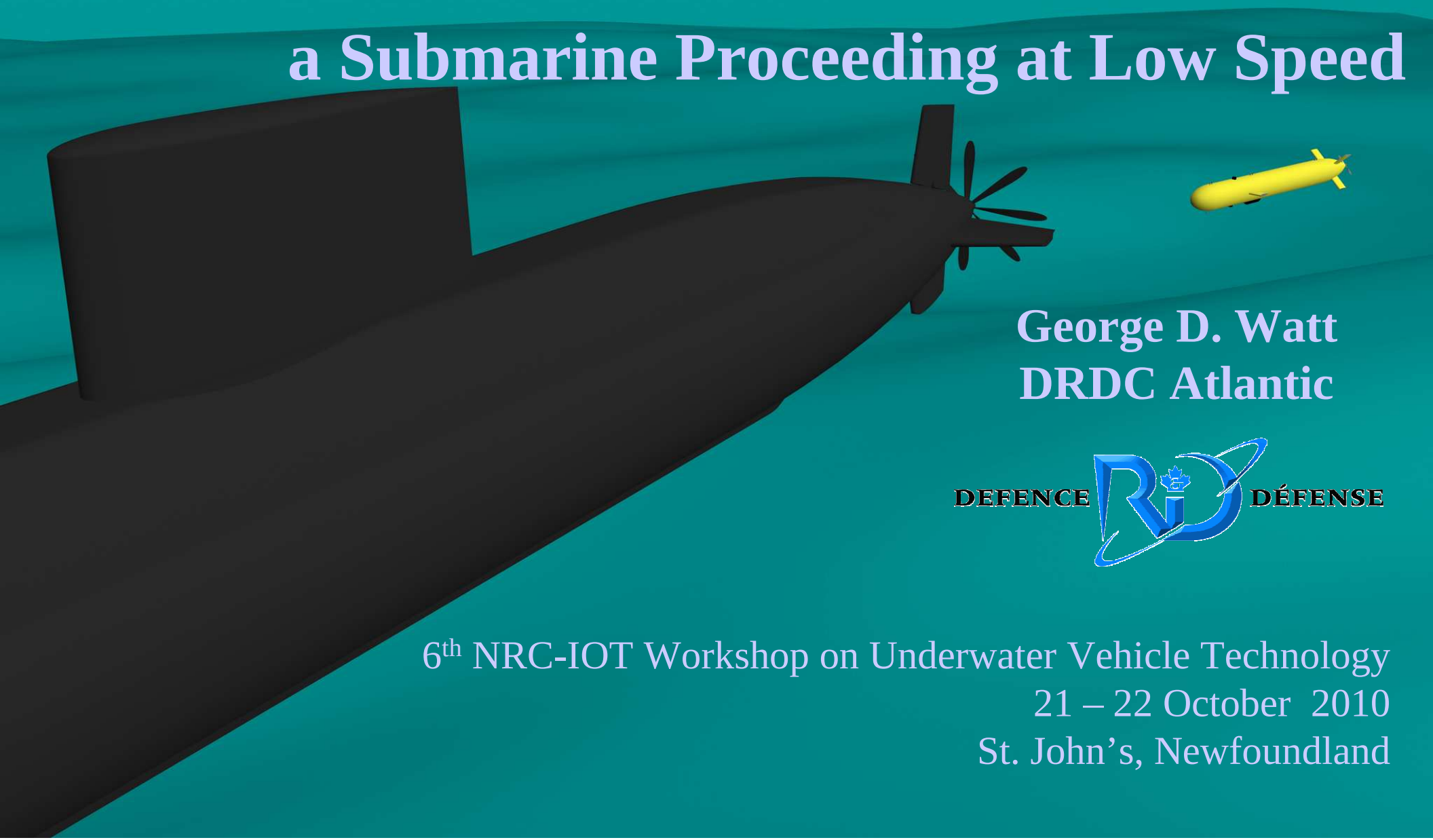
Unmanned Underwater Vehicle Docking with a Submarine Proceeding at Low Speed



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DEFENCE R&D DÉFENSE

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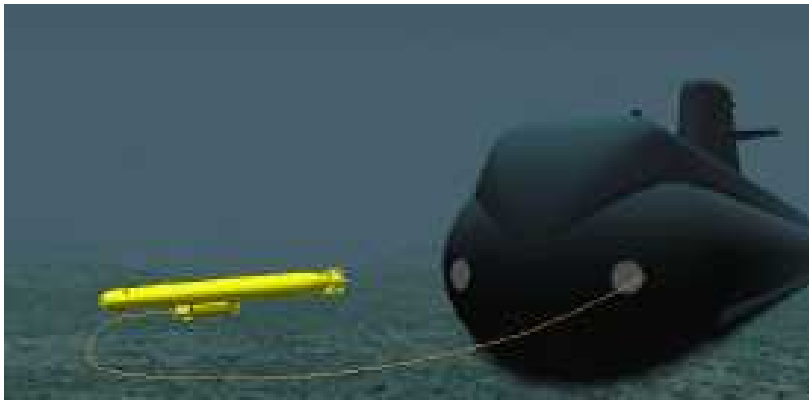
Motivation

UUV Docking Expands Sub/UUV Operational Envelopes

- Provides the submarine with deployable UUVs for
  - Personnel and Asset Protection
    - mine counter measures.
  - Intelligence, Surveillance, and Reconnaissance
    - command and control
    - weapons systems targeting.
    - battlefield awareness
  - Communications.
- Provides the UUV with
  - extended covert range and endurance.

Strong Defence Relevance

Current Methods for Recovering UUVs use the Torpedo Tubes

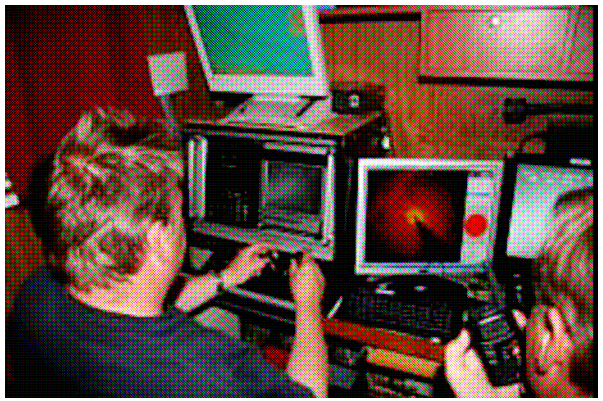


SAAB's AUV 62 system

- Sub and AUV sit on the bottom.

- ROV exits one tube, lassos the AUV, and inserts the AUV into a second tube.

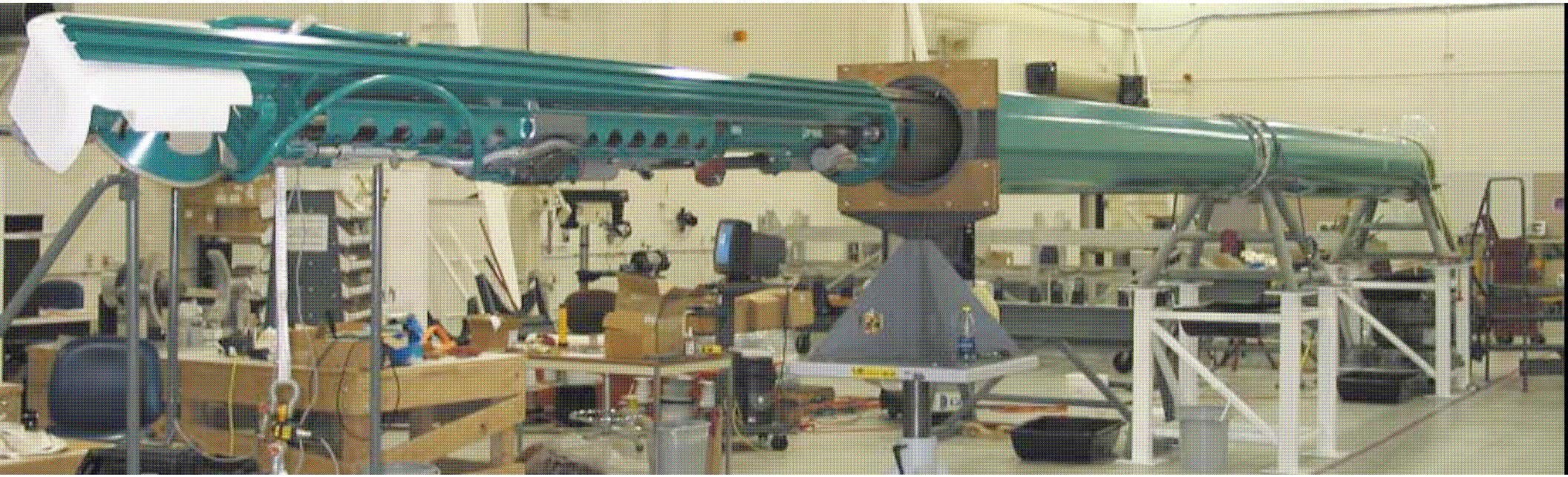
- ROV is operator controlled.



US Long-Term Mine Reconnaissance System (LMRS)

- Torpedo tube launched and recovered search and survey UUV.
- Recovery while underway at 1 to 3 knots.
- An arm extends out one tube, the UUV docks with it, the arm inserts the UUV in a second tube.
- Very expensive.

18 m Long Recovery Arm



Canadian Requirements

Submarine UUV docking should provide for:

- Deep water operations – must maintain headway.
- Littoral operations – dock off to side, away from disturbance above and hazards below.
- Stay away from non-uniform flow at ends of boat, and wake from the sail.
- Minimize collision hazard with tailplanes/propeller.
- Automation.
- Allow for a flexible choice of UUV – avoid torpedo tube restrictions.

UUVs that do not fit torpedo tubes

ISE Explorer successfully completed several 350 km under-ice mapping trips in the Arctic this spring.

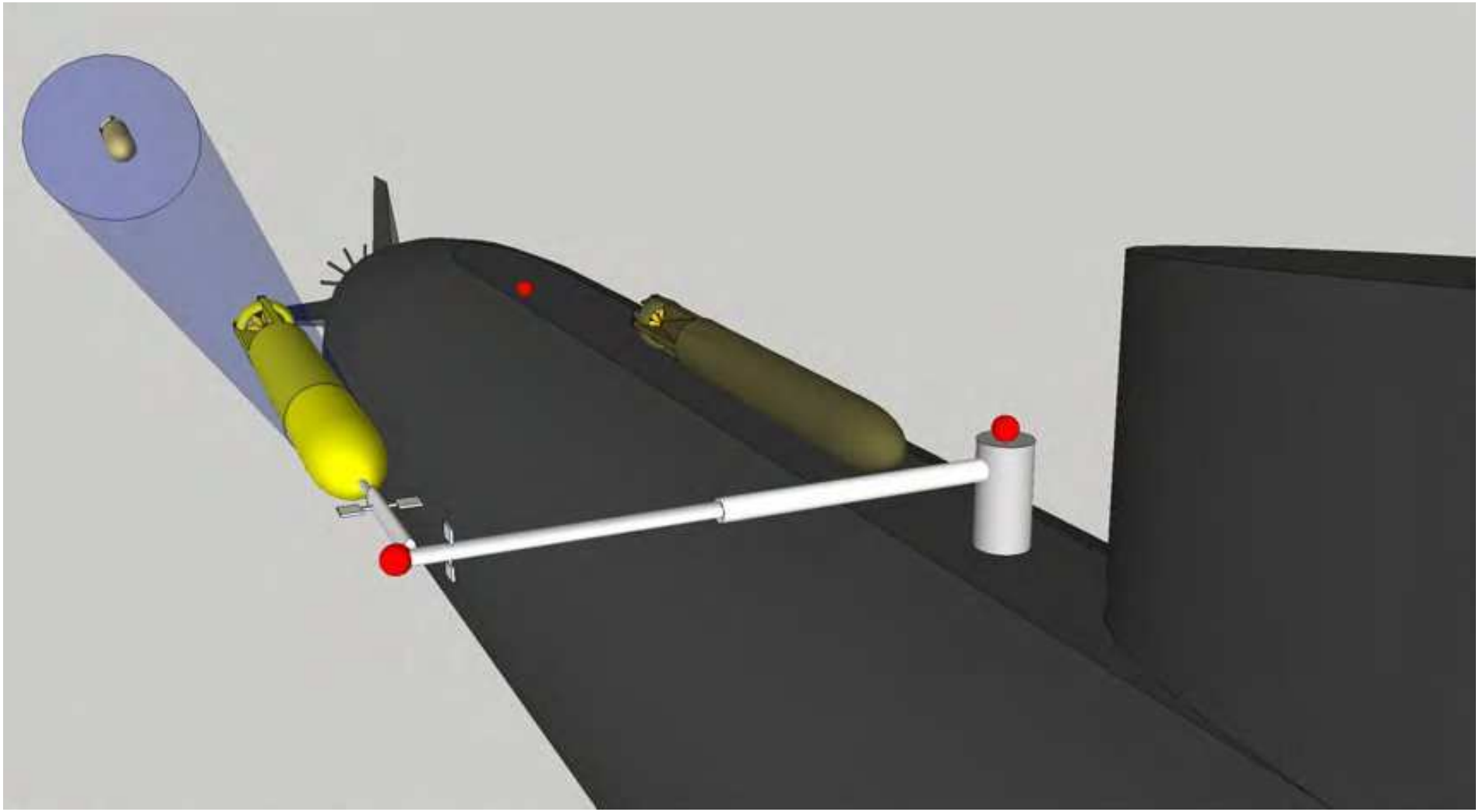
- 0.69 m (27”) dia hull
- 700 kg, 4.5 m long
- 450 km @ 1.5 m/s at up to 5000 m depth.

Endurance ~ Size

BAE Systems MCM UUV

Non-axisymmetric shape

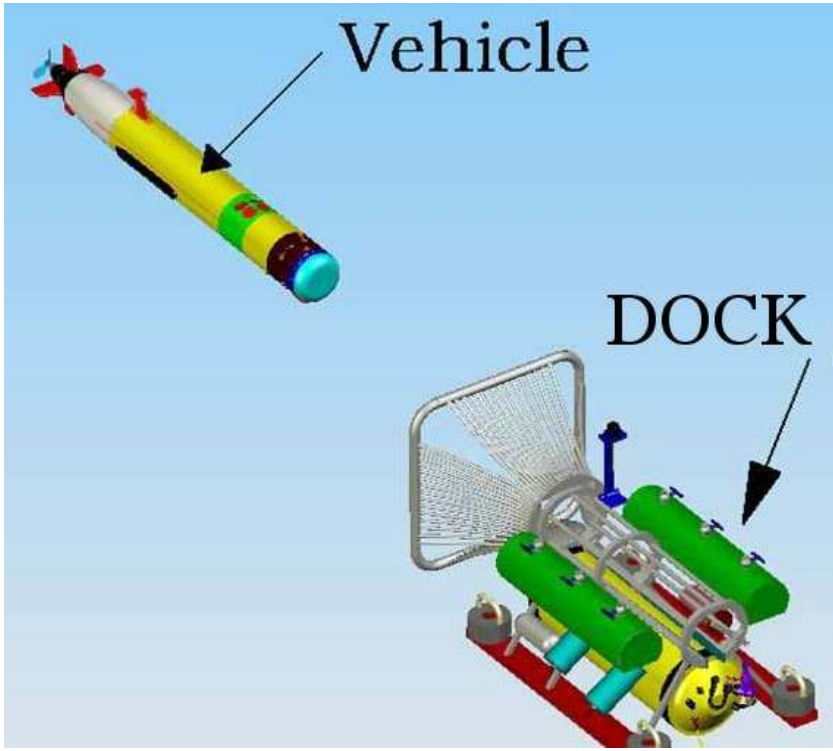
Notional Concept



Docking Scenario

- UUV has completed its mission and rendezvoused with sub.
- Submarine maintains straight and level flight at 2 – 3 knots.
- Submarine dock displays an acoustic transponder and the UUV homes in on it.
- The docking that follows must allow for:
  - inaccuracy in position sensing,
  - inaccuracy in heading and depth keeping ability,
  - uncontrolled vehicle motions (eg, roll),
  - different UUV and submarine responses to environmental disturbance.
- Effectively unpredictable relative motion → Positioning error.

Other UUV Docking Methods



- Woods Hole, Remus docking
  - dock fixed to ocean floor.
  - Ultra-Short Baseline Acoustic position sensing:
    - range to several hundred meters,
    - only ±0.5 m positioning accuracy.
  - 60% success rate per attempt, 90% for five attempts.
- Naval Command, Control and Ocean Surveillance Center
  - Optical terminal guidance
    - short range: down to 7 m in murky harbour water,
    - good position accuracy: ±0.01 m.
  - Success docking providing the target is acquired soon enough.

Main Research Issue: Precise Contact

How **accurately** and **reliably** can the UUV contact the Dock?

- Require position sensing with
  - **range** to enable a viable approach to be setup
  - **accuracy** for final docking.
- Require the maneuverability to overcome the
  - rates
  - amplitudes.

  of the relative motion between the UUV and dock due to
  - environmental disturbance
  - course/depth keeping error
  - random motion.

Proposed Solution: Active Dock

An Active Dock with:

- Supplementary, accurate optical tracking
  - requires light source(s) on the UUV.
- Exceptional transverse mobility for final docking:
  - UUV only retains control over longitudinal corrections
  - dock corrects for 2D offset in a transverse plane.
- Dock-to-UUV communication
  - dock is in charge (slow down, speed up, try again, etc).

Achieving Precise-Contact

Dock in uniform flow to side of sub, midway along its length.

Two-stage position sensing:

- UUV uses conventional acoustic sensing to home on dock
  - Transponder on dock → transceiver on UUV: one-way comms.
  - Good range for establishing a viable approach.
- UUV closes to within reach of dock, but somewhat aft of it.
- UUV activates strategically located LEDs on its nose and appendages.
- Dock uses accurate optical tracking to locate UUV
  - Fast update rates.

Achieving Precise-Contact (2)

Two-stage docking – decouple transverse, axial offset corrections

- Dock acquires UUV optically
  - commands UUV to deactivate transverse control
  - UUV slowly overtakes dock.
- Dock continually corrects for transverse position error
  - keeps itself centered on the approaching UUV
  - ➢ requires rapid transverse response
  - ➢ requires good reach.

Advantage: Consolidates specialized hardware and functionality in a single modular unit.

Disadvantage: Complexity.

Remaining Issue: Control

Control Strategy

- Independent submarine, UUV, and dock controllers.
- Master Controller.
- Tune controllers so system responses are complimentary.
- Fault tolerance required.
- **Design environment required**
  - Maximize operational scenarios at minimum cost.
  - Explore and trial hardware and control strategy options.
    - ➢ High fidelity computer simulation.

Computer Simulation

- Hydrodynamic/mechanical models of submarine, UUV, dock
  - three bodies, hydrodynamic interference.
- Position sensing model
  - error, range and turbidity limitations.
- Control systems
  - error and limitations.
- Environmental disturbance
  - sea state effects at depth, internal waves, random motions.
- Interface for control strategy development.

Limitations →Require dock and sensing hardware prototypes.

High Risk

Failure can occur if

- Dock reach and responsiveness are overwhelmed by the rate and/or amplitude of motion relative to the UUV
- Relative motion too complex to be anticipated by the kinematic information obtainable from the sensors.

… but High Pay-Off

DRDC's Technology Investment Fund (TIF)

- High risk projects with potential high payoff for the Forces.
- Allocated competitively with emphasis on
  - scientific impact
  - defence impact
- $500 – $750k over 3 years.
- Very competitive.

Just missed approval last year, trying again this year.

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