### Dr. John Osmundson
Faculty Advisor (Professor, Information Sciences)

### RADM (ret.) Rick Williams
Technical Advisor (NPS Chair of Mine and Expeditionary Warfare)

<table>
<thead>
<tr>
<th>Castaneda, Phil</th>
<th>Koh Wee Yung</th>
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<tbody>
<tr>
<td>Aviation (SH-60, USN)</td>
<td>Weaponry (MoD)</td>
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<td>Drennan, Jim</td>
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<td>SWO (USN)</td>
<td>Sensors (MoD)</td>
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<td>Emmeresen, Tracy</td>
<td>Lu Zheng Liang</td>
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<td>Intelligence/Infantry (SG ARMY)</td>
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<td>Perh Hong Yih Daniel</td>
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<td>Sor Wei Lun</td>
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<td>Chiam, David</td>
<td>Wong Chee Heng</td>
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<td>Operations Research (MoD)</td>
<td>Combat Engineer (SG ARMY)</td>
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<td>Zhu, Kelvin</td>
<td>Combat Engineer (SG ARMY)</td>
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</tbody>
</table>
SEA-17B has developed an Advanced Undersea Warfare System that enables control of the future Undersea Battlespace using superior weapons, sensors, AND communications.

• Flexible
• Scalable
• Tailorable
Section 1
- Tasking
- Methodology

Section 2
- Problem Statement
- Stakeholder Analysis
- CONOP
- Needs Analysis

Section 3
- Functional Analysis
- Alternative Generation
- DOE

Section 4
- Design Concept Overview

Section 5
- Analysis of Alternatives
  - Performance
  - Cost
  - Risk

Section 6
- Recommendations
  - Primary
  - Secondary
  - Hybrid

Section 7
- Project Insights
- Project Recommendations

Section 8
- Conclusions
Section 1

Tasking

Methodology
Define a system of capabilities that would be necessary to create and sustain an underwater operational picture of areas of interest and counter and engage adversary manned and unmanned systems when required.
**Systems Engineering Plan**

**SEA-17B Project Cycle**

### Problem Space

- Summer 2010
- Fall 2010
- Spring 2011

**Milestone A:**
- **Project Management Plan**
- **Decision Authority:** Project Advisor
- **Deliverable:** PMP

**Milestone B:**
- **Progress Review**
- **Decision Authority:** Project Advisor
- **Deliverable:** Statement of Requirements, and MOE, 25% draft report

**Milestone C:**
- **Progress Review**
- **Decision Authority:** Project Advisor
- **Deliverable:** IPR 1 Presentation, Alternative Selection, 75% draft report

### Solution Space

- TDSI Students arrive JAN 2011

### Need

**Preliminary Preparation Phase**
- Organization
- Preliminary Research
- Networking

**Research Phase**
- Deep Research
- Problem Definition
- Requirements Analysis

**Design Phase**
- Functional Analysis and Allocation
- Analysis of Alternatives
- Modeling and Simulation
- Cost Research and Analysis
- Risk Analysis
- IPR 1

**Deployment Phase**
- Verification and Validation
- Refinement and Implementation
- Presentation of Results
- IPR 2

**Capability**

### Milestone D:
- **Final Review**
- **Decision Authority:** SEA Chair
- **Deliverable:** FPR Presentation, Final Report
Systems Engineering Process

- Problem
  - Define
  - Solve
- Mission
  - Consider
  - Accomplish
- Need
  - Address
  - Identify
- Function
  - Perform
  - Analyze
- Evaluate
- Recommend

Physical Alternatives
- Physical Alternatives
- Physical Alternatives
- Physical Alternatives
Section 2
Problem Statement
Stakeholder Analysis
CONOP
Needs Analysis
Over the next twenty years the capacity and capability of USW platforms will not meet operational demands in non-permissive areas. Furthermore, the emergence of near-peer competitor navies, the distributed nature of the asymmetric maritime threat, and the development of autonomous undersea threats present a unique challenge that current platform-centric solutions are not ideally designed to confront.

Control the undersea battlespace with weapons and sensing superiority!
Future of USW in the Littorals
(if we maintain status quo)

- SHIPS
- AIRCRAFT
- SUBMARINES
- MINES
- DEPLOYED SENSORS

ASYMMETRIC (mines, diesel submarines,...)

CROSSOVER POINT

EMERGING TECHNOLOGY

NEAR-PEER COMPETITOR

US NAVY

THREAT

A Visual Representation

UNCLASSIFIED
Closing the Capability Gap

Future of USW in the Littorals

US NAVY

CAPABILITY + CAPACITY
- SHIPS
- AIRCRAFT
- SUBMARINES
- MINES
- DEPLOYED SENSORS
- AUWS

ASYMMETRIC (mines, diesel submarines,...)

Harness Technology

EMERGING TECHNOLOGY

NEAR-PEER COMPETITOR

Maintain Dominance

TIME
Considering Mission Areas

Limited resources, evolving threats, and emerging technologies all suggest leveraging the benefits of Mine Warfare in the undersea environment.

Technology is neutral!
## Stakeholder Matrix

<table>
<thead>
<tr>
<th>Internal</th>
<th>Decision Makers</th>
<th>Integrators</th>
<th>Implementers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>POTUS, SECDEF, SECNAV, CNO</td>
<td>COCOMs, CSG, ESG</td>
<td>CO, Wardroom, Crew</td>
</tr>
<tr>
<td>Industrial</td>
<td>CEO</td>
<td>Engineers</td>
<td>Technicians</td>
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<tr>
<td>Acquisitions</td>
<td>POTUS, Congress</td>
<td>DOD Acq</td>
<td>SUPPO/SK</td>
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<tr>
<td>RDT&amp;E</td>
<td>PEO</td>
<td>LSE</td>
<td>SME</td>
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<table>
<thead>
<tr>
<th>External</th>
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<tr>
<td>US</td>
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<td></td>
<td>Taxpayers</td>
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<tr>
<td>Friendly</td>
<td></td>
<td>Concerned Global Citizens and Governments</td>
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<tr>
<td>Neutral</td>
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<td>Concerned Global Citizens and Governments</td>
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<tr>
<td>Hostile</td>
<td></td>
<td>AFFECTED POPULATION AND GOVERNMENT</td>
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</tr>
</tbody>
</table>
Concept of Operations

0. Shape
- COVERT ISR
  - Clandestine insertion
  - Battlespace preparation
  - ISR for Intelligence Operations

1. Deter
- SMART “MINE” THREAT
  - Hold-at-risk
  - Early Warning
  - Show of force

2. Seize
- ENGAGEMENT
  - Engage hostile targets as directed

3. Dominate
- PERSISTENT ASSET
  - Area Denial
  - Maintain persistent presence

4. Stabilize
- FORCE MULTIPLIER
  - Protect friendly assets
  - Monitor area to contribute to COP
Needs Analysis

AUWS

Threat Discrimination

Platform Independence

Detection Avoidance

Operational Picture Development

Adjustable Autonomy

Enemy Prosecution (manned and unmanned)

Persistent Forward Presence

UNCLASSIFIED
Section 3

Functional Analysis
Alternative Generation
Design of Experiments
Controllable:
- Power Consumption
- Operator Inputs
- System Parameters
- Mission Data
- Training Methodology
- Peer System Input

Uncontrollable:
- Contact Signature
- Unknown Threat Tactics
- Weather
- Environmental

Intended:
- Threat Classification
- Threat Prioritized
- Mobilization of Kinetic Subsystem
- Automated Engagement of Threat
- Threat Elimination
- Sensor Data
- Communication with Command and Control
- BDA

By-Products:
- Unintended Casualties
- “Stray” Signals
- Impact to Ecosystem
Conduct AUWS Operations

1.1 Provide Structure

1.2 Provide Power
   - 1.2.1 Receive Power
   - 1.2.2 Store Power
   - 1.2.3 Manage Power
   - 1.2.4 Distribute Power
     - 1.2.4.1 Re-allocate Power
     - 1.2.4.2 Maintain Allocation
   - 1.2.5 Generate Power
     - 1.2.5.1 Conduct Recharge
     - 1.2.5.2 Omit Recharge

1.3 Perform C3
   - 1.3.1 Command
     - 1.3.1.1 Receive Order
     - 1.3.1.2 Process Status
       - 1.3.1.2.1 Receive Compon...
       - 1.3.1.2.2 Analyze Compon...
     - 1.3.1.3 Process ISR Data
       - 1.3.1.3.1 Receive ISR Data
       - 1.3.1.3.2 Analyze ISR Data
       - 1.3.1.3.3 Develop Environ...
       - 1.3.1.3.4 Develop Tactical Picture
     - 1.3.1.4 Analyze Order
     - 1.3.1.5 Execute Order
   - 1.3.2 Control
     - 1.3.2.1 Operate Autonomously
     - 1.3.2.2 Operate Semi-aut...
     - 1.3.2.3 Operate via Rem...
   - 1.3.3 Communicate
     - 1.3.3.1 Receive Communications
     - 1.3.3.2 Distribute Data
     - 1.3.3.3 Transmit Data Externally
     - 1.3.3.4 Transmit Data Internally

1.4 Maneuver
   - 1.4.1 Deploy
     - 1.4.1.1 Deploy from Surface Asset
     - 1.4.1.2 Deploy from Shore
     - 1.4.1.3 Deploy from Air
   - 1.4.2 Patrol
     - 1.4.2.1 Loiter
     - 1.4.2.2 Rove
     - 1.4.2.3 Sprint
     - 1.4.2.4 Transit
   - 1.4.3 Navigate
     - 1.4.3.1 Establish Location
     - 1.4.3.2 Propel
     - 1.4.3.3 Steer
   - 1.4.4 Recover
     - 1.4.4.1 Recover via Sub...
     - 1.4.4.2 Recover via Surface Asset
     - 1.4.4.3 Scuttle

1.5 Perform ISR
   - 1.5.1 Search
   - 1.5.2 Detect
   - 1.5.3 Track
   - 1.5.4 Classify
   - 1.5.5 Collect Intelligence
     - 1.5.5.1 Collect ACINT
     - 1.5.5.2 Collect COMINT
     - 1.5.5.3 Collect SIGINT
     - 1.5.5.4 Collect ELINT
     - 1.5.5.5 Collect EO/IR Data

1.6 Prosecute
   - 1.6.1 Monitor
   - 1.6.2 Deter
   - 1.6.3 Engage
     - 1.6.3.1 Employ Non-Leth...
     - 1.6.3.2 Employ Lethal Measures

1.7 Provide OPSEC
   - 1.7.1 Minimize Risk of Detection
     - 1.7.1.1 Provide EMCON
     - 1.7.1.2 Change Operation...
   - 1.7.2 Minimize Risk of ...
     - 1.7.2.1 Conduct Evasive Action
     - 1.7.2.2 Self-Neutralize
• 3 elements, 7-8 variants
  • Over 1 billion possibilities

• Eliminated infeasible, least promising variants
  • Warfare Innovation Workshop
  • 33,000 possibilities

• Made operational assumptions
  • 48 possibilities

• Work groups
  • 7 preliminary concepts

• Scoring and Screening
  • 4 concepts selected
• Used as a validation tool
  • Goal: adequately cover the design space

• Critical elements (Factors)
  • Weapons, sensors, and communicators

• Levels
  • Large/small
  • Centralized/distributed
  • Smart/dumb
  • Mobile/stationary
  • Combined/separate

• Led to a change from Swarm to LD-UUV
Section 4
Design Concept Overview
V-CAP
LD-UUV
Glider
Squid
Twin torpedo-shaped autonomous UUVs

**Power**
High-capacity Battery supplemented with wave-motion recharge unit

**Mobility**
Hybrid Electric/OTTO fuel propulsor

**Communications**
LOS RF, Iridium, and Acoustic modem (internal)

**Sensors**
Acoustic and EO sensors Deployable distributed sensor nodes

**Armament**
2x mini-torpedoes per Killer unit
V-CAP Deployment
V-CAP Employment
V-CAP Recovery
Large Diameter autonomous undersea payload delivery and engagement UUV

**Power**
High-capacity Battery

**Mobility**
Electric-drive propulsor

**Communications**
LOS RF, Iridium, and Acoustic modem (internal)

**Sensors**
Acoustic and EO sensors
Deployable distributed paired sensor nodes

**Armament**
4x lightweight torpedoes
LD-UUV Deployment
LD-UUV Employment
Networked Autonomous high-endurance UUVs

**Power**
Fuel cell with supplemental solar cell recharge

**Mobility**
Adjustable ballast and control surfaces with OTTO-fueled terminal homing propulsor drive

**Communications**
LOS RF, Iridium, and acoustic modem (internal)

**Sensors**
Passive sonar

**Armament**
10 kg HE shaped charge
Glider Deployment
Distributed network of stationary weapons and comms nodes, each with onboard sensors

**Power**
Non-rechargeable batteries

**Mobility**
N/A

**Communications**
LOS RF and Iridium (external) and acoustic modem (internal)

**Sensors**
Passive sonar mounted to Weapons and Comms nodes

**Armament**
Multiple 1 kg HE sub-munitions
Squid Employment
- Expendable design

- Disarm and Self-neutralize on command or via timer

Squid Recovery

High Volume of Units + No Internal Propulsion = Recovery not Feasible
Section 5
Analysis of Alternatives
Performance
Cost
Risk
AoA Methodology

TRACEABILITY

Recommended Alternative(s)
- Cost Analysis
- Risk Analysis
- Performance Analysis (OMOE)
- Factor Weighting

QFD

Functional Analysis
- AHP
- MOE
- Non-Stochastic Analysis
- M&S

Needs
- Stakeholder Preferences
- Quantitative Analysis
- Qualitative Analysis
Non-Stochastic Analyses

• MOE: Capability to Operate for a Minimum of 30 Days

<table>
<thead>
<tr>
<th>Concept</th>
<th>Endurance in Days</th>
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<tr>
<td>V-CAP</td>
<td>123</td>
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<tr>
<td>LD-UUV</td>
<td>126</td>
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<tr>
<td>GLIDER</td>
<td>987</td>
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<tr>
<td>SQUID</td>
<td>16</td>
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• MOE: Capability for Deployment from Current and Future Platforms

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<th>Capability Score (1-3)</th>
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<tr>
<td>GLIDER</td>
<td>1.0</td>
</tr>
<tr>
<td>SQUID</td>
<td>1.0</td>
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</table>

• MOE: Capability for Recovery by Current and Future Platforms

<table>
<thead>
<tr>
<th>Concept</th>
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<tr>
<td>LD-UUV</td>
<td>1.5</td>
</tr>
<tr>
<td>GLIDER</td>
<td>2.0</td>
</tr>
<tr>
<td>SQUID</td>
<td>0.0</td>
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• MOE: Capability to Avoid Detection

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<th>Capability Score (0-1)</th>
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<td>LD-UUV</td>
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<td>GLIDER</td>
<td>0.25</td>
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<tr>
<td>SQUID</td>
<td>0.5</td>
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</table>
Neutral/Friendly Surface Vessel
Threat Surface Vessel
Enemy Submarine

**Environmental Characteristics**
- Sea State: 2-3
- Winds: <30kts
- Currents: <5kts
- Depth: 300 ft
- Bottom Type: Mud, Sand

**Traffic Characteristics**
- Vessel Type: Various (merchants, tugs, fishing boats, small and large naval ships, and submarines)
- Average Speed: 15 kts
- Arrival Rate: 7 ships/hr
- Threat Frequency: 5%
- Position: Uniformly Distributed on Long Axis
- Ambient Noise: Heavy Traffic in Shallow Water
4 Killers with 2 CRAW torpedoes each, 1 Hunter with 8 sensor nodes

- Sensor Range: 2.7 nm
- Comms Range: 1.6 nm
- Kill Range: 3000 yds
- Hunter serves as gateway
- Sensor Nodes report all contacts and relay all messages
1 LD-UUV, 16 sensor nodes, 4 Mk-50 torpedoes

- Sensor Range: 2.0 nm
- Comms Range: 1.2 nm
- Kill Range: > 10 nm
- Cable: 1000 yds (8 pairs)
- At least 2 nodes required for classification
- Nodes “decide” which contacts to report (group based)
- UUV serves as gateway
17 Gliders

- Sensor Range: 2.7 nm
- Comms Range: 1.6 nm
- Speed: 2 kts
- Lateral Intercept Range: 0.55 nm (from Approaching Target Model)
- Coordinated Barrier Search (1.43 nm segments)
- Middle Gliders primarily for comms relay
- Gliders “decide” which contacts to report
- Gliders surface for external communications
SQUID Model

130 sensor/weapon nodes, 1 communications gateway

- Sensor Range: 1.35 nm
- Comms Range: 0.8 nm
- Kill Range: 50 yds
- Squid nodes randomly placed (e.g. artillery, air drop)
- Nodes must have path to gateway to be “in network”
- Must be in network to report contacts and engage threats
- 126 nodes in network on avg.
- Each node determines shortest path to Gateway
- Nodes report all contacts and relay all messages
### M&S Results

<table>
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<tr>
<th>Sensor Profile</th>
<th>Avg TTC (min)</th>
<th>$P_d$</th>
<th>$P_k$</th>
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<tbody>
<tr>
<td>Glider</td>
<td>13.3-15.0</td>
<td>0.74-0.75</td>
<td>0.16-0.22</td>
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<tr>
<td>LD-UUV</td>
<td>2.9-3.1</td>
<td>0.80-0.81</td>
<td>0.33-0.43</td>
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<tr>
<td>Squid</td>
<td>3.5-3.7</td>
<td>0.97-0.99</td>
<td>0.07-0.09</td>
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<tr>
<td>V-CAP</td>
<td>4.5-4.7</td>
<td>0.80-0.82</td>
<td>0.54-0.65</td>
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</table>

**Sensor Profile**

- **Probability of Detection**
- **Range of CPA**
Analytic Hierarchy Process

Need Area Weighting

<table>
<thead>
<tr>
<th>Need Area</th>
<th>Weighting</th>
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</thead>
<tbody>
<tr>
<td>Discrimination between Threats &amp; Non Threats</td>
<td>0.151</td>
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<tr>
<td>Avoid Detection</td>
<td>0.066</td>
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<tr>
<td>Achieve Adjustable Autonomy</td>
<td>0.031</td>
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<tr>
<td>Maintain Persistent Forward Presence</td>
<td>0.184</td>
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<tr>
<td>Engage Manned and Unmanned Assets</td>
<td>0.266</td>
</tr>
<tr>
<td>Provide Operational Picture</td>
<td>0.273</td>
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<tr>
<td>Be Platform Independent</td>
<td>0.029</td>
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</tbody>
</table>
Quality Functional Deployment

MOE Weighting

- Capability to Operate for Minimum of 30 Days: 0.162
- Average Message Completion Time: 0.221
- Capability for Deployment by both Current and Future Platforms: 0.082
- Capability for Recovery by both Contemporary and Future Platforms: 0.022
- Probability of Detection: 0.224
- Probability of Kill: 0.167
- Capability to Avoid Detection: 0.122
Performance Analysis Results

Non-Stochastic Analysis

QFD MOE Weighting

M&S

Performance Analysis Results

<table>
<thead>
<tr>
<th></th>
<th>V-CAP</th>
<th>LD-UUV</th>
<th>Glider</th>
<th>Squid</th>
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</thead>
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<tr>
<td>OMOE Score</td>
<td>0.705</td>
<td>0.656</td>
<td>0.406</td>
<td>0.436</td>
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</table>
20-yr Rough Cost Estimate

- **RDT&E Costs** - excluded
- **Production Costs**
  - Based on Component Costs
- **O&S Costs**
  - Consumables – Fuel, Warheads, Replacements
  - Personnel (excluded)
- **Disposal Costs** - excluded

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Cost (FY2011$M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-CAP</td>
<td>359</td>
</tr>
<tr>
<td>LD-UUV</td>
<td>690</td>
</tr>
<tr>
<td>GLIDER</td>
<td>75</td>
</tr>
<tr>
<td>SQUID</td>
<td>2418</td>
</tr>
</tbody>
</table>

- **V-CAP**: Good balance
- **LD-UUV**: High per-unit cost
- **GLIDER**: Low procurement & consumable cost
- **SQUID**: High cost due to large number of expendables
Risk Analysis Results

Overall Risk Factor Analysis

Consequence vs. Likelihood (Probability of Failure)

Risk Factor by Concept

Risk Factor for V-CAP, LD-UUV, GLIDER, and SQUID

Technical Risk, Schedule Risk, Cost Risk
Options for the given scenario

- Mines
- Surface Combatants
- Submarines

Superior performance

Cost is debatable

- Assume AUWS provides no LCC savings!

Operational risk is unacceptable

- $2B strategic asset and hundreds of lives at risk
- Even one SSN is “overkill”

AUWS can be scaled to balance risk with performance
Section 6

Concept Recommendations
Primary: V-CAP
Secondary: LD-UUV
Hybrid
Primary Concept: V-CAP

**Pros:**
- Best $P_k$
- Good $P_d$
- Ease of Deployment & Recovery
- Follow-on Salvo
- Cost

**Cons:**
- Slower Comms
- Shorter Endurance
Secondary Concept: LD-UUV

Pros:
• Rapid Comms
• Better Endurance

Cons:
• Limited Deployability
• Limited Recoverability
• Limited Salvo
• Cost
Hybrid Recommendation

- Double Deployment
- Improved $P_d$, $P_k$
- LD-UUV Paired Nodes
- Improved Comms
Section 7
Project Insights
Project Recommendations
**Flexibility**
- Network Integration
- Platform Integration
- Command & Control

**Scalability**
- Balance required w/ Cost & Performance
- Trade-off w/ Flexibility (Physical size of units)
- Unlike Current Systems

**Tailorability**
- Mission-reconfigurable modular design
- Optimal redundancy (heterogeneous vs. homogenous)
- Separation & distribution yield tactical advantage
AUWS Tradespace

- USN Mines
- Squid
- Glider
- LD-UUV
- V-CAP
- SSN

This is the AUWS goal!
Recommendations

• Near Term (FYDP 2012-2016)
  • Continue detailed analysis of superior AUWS concepts
  • Review and update doctrine (ROE, tactics, training, etc.)
  • Use this analysis to help ONR define Science and Technology Gap
  • ONR assigns Future Naval Capabilities Manager for AUWS concepts R&D
  • Get prototypes *of any kind* in the hands of sailors!

• Mid Term (FYDP 2016-2020)
  • Develop Initial Capability Document based on this analysis
  • Initiate AUWS Program of Record based on current best assessment of capability gap
  • Do not wait for technology to advance to optimal levels

• Far Term (FYDP 2020 →)
  • Maintain a goal of achieving AUWS full operational capability by 2030
Section 8
Closing Remarks
The undersea battlespace of the future is a complex, dynamic environment that cannot be divided neatly along platform or community lines.

Advanced Undersea Warfare Systems are just one element of a comprehensive, unified approach to maintaining and enhancing USW dominance in the future.