FUTURE MCM STUDY

Study Group Presentation to

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FUTURE MCM STUDY

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PRESENTATION OUTLINE

Section 1:
- **Study Background**
  - **overview of goals and approach**
  - **motivating premise**
  - **scenarios**
  - **underlying study assumptions**

Section 2:
- **Notional Concepts**
  - **original list of concepts**
  - **down-selected, 3 system types**
  - **supporting ideas/concepts/tactics (used, tabled, discarded)**

Section 3:
- **Assessment Process**
  - **Rules-of-Thumb; Study Workbook**
  - **Sensor Assessments**
    - **performance**
    - **weight, volume, power, cost**
- **Vehicle Assessments**
  - **endurance, weight, volume, cost**
- **System Assessments**
  - **ACR, mission times, weight, volume, cost**

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Section 4: • **Final Six System Concepts**
- component vehicles and sensor configurations
- mission profiles
- mission tactics

Section 5: • **Assessment Results**
- intermediate parameter trade-offs
- system level MOEs for each concept (w/ excursions)

Section 6: • **Enabling Technologies & Enabling Demonstrations**
- physical components
- specific search or contact prosecution tactics
- processing capabilities
- demonstration sequences
- prioritizations

Section 7: • **Discussions & Summaries**

• **Appendices**

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Section 1: Study Background

- overview of goals and approach
- motivating premise
- scenarios
- underlying study assumptions

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STUDY OVERVIEW

- **Study goal[1]**
  - **develop and evaluate new MCM system-of-systems concepts to provide seamless MCM capability**
  - **provide full system level analysis**

- **System Design Performance Goal**
  - **provide "complete" MCM system solution**
    - **deployment to execution to recovery**
    - **survey: detect, discriminate, classify, identify, localize, neutralize, sweep**

- **System Concept Goal**
  - **"system-of-systems"**
  - **many "small" vehicles with moderate capabilities**
  - **expendable (or nearly so)**
  - **deployable from multiple host assets**
  - **compatible with existing MCM system**
    - **as host, side-by-side, or incorporated within system-of-system concept**

- **Study Group**
  - **Applied Research Laboratories, The University of Texas at Austin (ARL:UT)**
  - **Johns Hopkins University, The Applied Physics Laboratory (JHU/APL)**
  - **NSWC Dahlgren Division, Coastal System Station (CSS)**

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[1] See "Study of Future MCM System Alternatives, Problem Definition, Missions, Threats, MOEs/MOPs, and Baseline Capabilities", Appendix P

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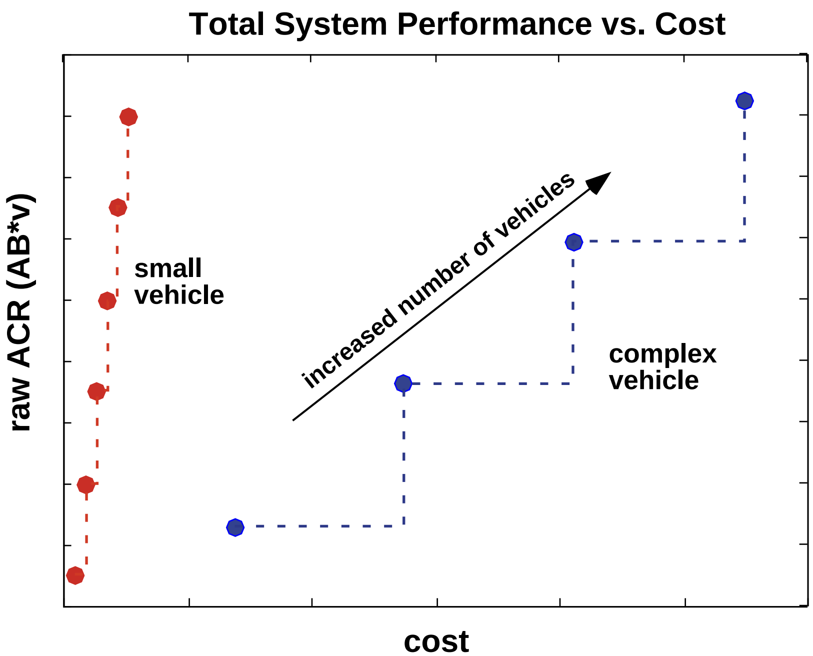
STUDY'S MOTIVATING PREMISE

Study Premise

Based on first order performance assessments, many small vehicles are more cost effective than one large (or a few moderate sized) vehicle(s).



- **Not Included in this first order assessment**
  - vehicle endurance
  - transit times between host and operation area
  - vehicle turn times
  - navigation errors
  - false call prosecution times

Study Investigation

- **Investigate the underlying premise**
- **Develop and evaluate numerous "system-of-systems" concepts**

Approach

- **Assess sensors and vehicles with a consistent methodology**
- **Develop system-of-systems concepts composed of multiple vehicles of varying sizes**
- **Assess the full systems to determine mission level MOEs (e.g. mission time)**
- **Evaluate mission level MOEs vs. cost, weight, volume, complexity, ...**

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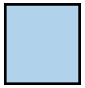
EVALUATION SCENARIOS[2]

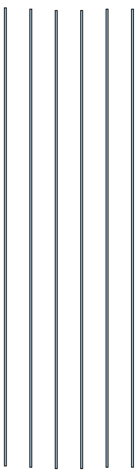


MDA
- mine danger area
- 4 x 4 nm
- search level: 95%
- goal mission time: 11 hrs
- threshold time: 32 hrs
- depths: 40 ft and 120 ft
- 30 mines

CVBG
- large area
- search level: 54%
- mission time: 14 days
- goal area size: 40 x 60 nm
- threshold size: 30 x 30 nm
- depth: 120 ft
- no mines

small area

large area



6 lanes

AOA
- 6 assault lanes
- 165 yd x 24 nm
- search level: 95%
- goal mission time: 4 hrs
- threshold time: 12 hrs
- depths: 40 ft and 120 ft
- 8 mines

(areas drawn to scale)

SLOC
- sea lane
- 0.5 x 100 nm
- search level: 68%
- goal mission time: 2 days
- threshold time: 6 days
- depths: 200 ft and 600 ft
- 47 mines

2: See "Study of Future MCM System Alternatives, Scenario Descriptions", Appendix P

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UNDERLYING STUDY ASSUMPTIONS

- **Technology Maturity**
  - **- primarily near term technologies**
  - **- current practices or extensions of current practices**
  - **- no "extensions of physics"**

- **Deployment in 10^+ Years**
  - **- assume natural extensions of current "state-of-the-art"**
  - **- e.g. significant processing power increase (Moore's Law)**
    - **- 10 years -> 100 fold increase, 15 years -> 1000 fold increase**
  - **- e.g. discrete electronic circuitry decrease in weight, volume, & power, 0% -> 50%**
  - **- e.g. autonomy for mission execution, G&C, obstacle avoidance, CAD/CAC/CAI**
    - **- difficult to define a measure or assess**
    - **- assumed the required capability is available**
    - **- defined by each tactic and mission**

- **All MOPs/MOEs should be derived in a consistent manner**
  - **- start with "first principles" -> sensor parameters -> sensor performance (MOP)[3]**
  - **- system MOE**
    - **- common assessment model[4]**
    - **- same model parameter inputs**

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3 See "Sonar Performance Assessment Process: Target Detection and Close-Tethered Target Discrimination", Appendix P11

4 See "Future Mine Countermeasure Study, Cost and Affordability Appendix", Appendix P12

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Section 2: Notional Concepts

- original list of concepts
- down-selected, 3 system types
- supporting ideas/concepts/tactics
  - used within these system concepts
  - tabled for some future use
  - discarded on rule-of-thumb (ROT) assessments

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NOTIONAL SYSTEM CONCEPTS

- ~15 Notional System-of-systems concepts were developed
  - 4 to 7 per lab
  - all included some sort of larger host-like platform
  - large vehicles included submersibles, surface-craft, and aircraft
  - "natural missions" included covert recon to in-stride detection-thru-neutralization
  - simple to complex "missions" for individual UUVs
  - included low to high levels of autonomy
  - included low to high levels of computer detection/classification/identification
  - most included some option to report back intermediate results (search thru neutralization)

- Not included in the 15 concepts
  - completely small UUV options
  - search-thru-neutralization small vehicles
  - random or nearly random search schemes
  - search schemes based on "self organizing networks of small vehicles"
  - significant levels of inter UUV comms

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NOTIONAL SYSTEM CONCEPT SUMMARY

- **LV w/ a small set of "bird-dog" SVs**
  - **LV sensor searches the area**
  - **SVs are directed to contacts to class/ID/mark**

- **Surface Craft w/ a small set of "bird-dog" SVs**
  - **surface craft sensor searches the area**
  - **MCM like craft**
  - **SVs are directed to contacts to class/ID/mark**

- **LV transports and recovers SVs**
  - **SVs search/class/ID/mark**
  - **SVs return to LV for data upload and transport back to host**

- **LV transports disposable SVs**
  - **SVs search/class/ID/mark**
  - **SVs comm back to LV or host**

- **Set of medium sized vehicles**
  - **vehicles transit to area**
  - **vehicles coordinate/search/class/ID/mark**
  - **vehicles return and transit back to host**

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NOTIONAL SYSTEM CONCEPT SUMMARY (cont.)

- In-stride surface platform
  - SVs are ballistically launched to pepper area out in front of surface craft
  - SVs search/class/ID/mark (1 per target) short track, comms back to surface craft
  - Neutralizer SVs are launched to markers

- Deployed multiple central nodes
  - nodes provide nav, comms, mission orders, energy
  - SVs search/class/ID/mark
  - SVs return to nodes

- Operational search cell of small vehicles (SVs)
  - SVs are air dropped in groups of 5 (1 for comms, 4 for search)
  - search SVs search/class/ID/mark each sub-area
  - SVs return to comm SV
  - data relayed to host

- Multi-vehicle type, Multi-staged system
  - area is searched in a series of steps (detect, class, ID) by different vehicle types
  - autonomous extension of current organic approach

- High-Speed High Volume SVs deployment
  - SVs area air dropped along a full lane (via a B52)
  - each SV search/class/marks small overlapping sub-area

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NOTIONAL SYSTEM CONCEPTS
DOWN-SELECTION and TYPE DEFINITION

• After Review the initial notional concepts were categorized and down-selected to 3 types

• Type definition depended upon the capability of the small vehicles and their interaction with the large vehicle

Type I: Large Vehicle(s) with directed SVs ("Bird-Dogs")

- **large vehicle conducts <u>search</u>**
- **SV directed individually by LV to <u>classify</u> & <u>ID</u> contacts**
- **option: large vehicles can be <u>surface</u>, <u>semi-submersible</u>, or <u>submerged</u>**
- **option: SV may <u>mark</u> or <u>neutralize</u> contacts**

Type II: Many Vehicles in a coordinated group operation with large vehicle "supervisor"

- **many SVs (or MV) conduct <u>search</u> to <u>ID</u>**
- **large vehicle transports SVs**
- **option: large vehicles can be <u>surface</u>, <u>semi-submersible</u>, <u>submerged</u>, or <u>moored</u>**
- **option: large vehicle <u>directs</u> or <u>monitors</u> the SV search group**
- **option: SV may <u>mark</u> and/or <u>neutralize</u> contacts**

NOTIONAL SYSTEM CONCEPTS
DOWN-SELECTION and TYPE DEFINITION
(cont.)

Type III: Many Vehicles in stand alone Group Operations

- **many SVs (or MVs) conduct search to ID to neutralize contacts**
- **no large vehicle used during operation**

- **option: SVs are transported via aircraft or ballisticly launched**
- **option: complete autonomy for decision to neutralize vs. host supervised decision to neutralize**
- **option: coordinated search vs. uncoupled search**

FMCM SYSTEM-of-SYSTEM TYPES

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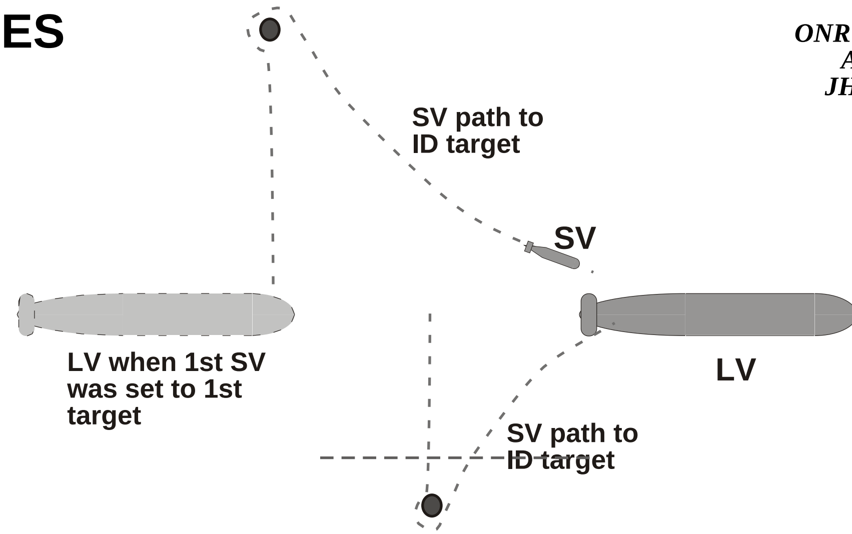
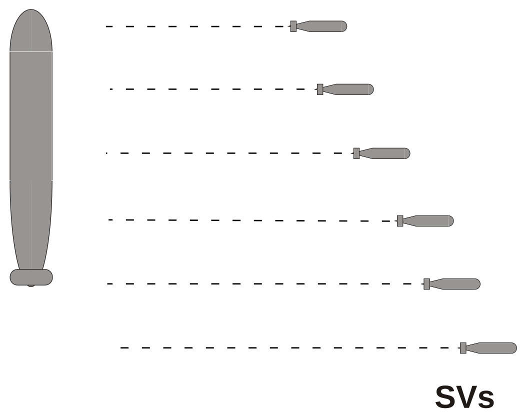
TYPE I SYSTEM CONCEPT

- LV provides search function
- SVs are individually directed to prosecute (class. & ID) targets





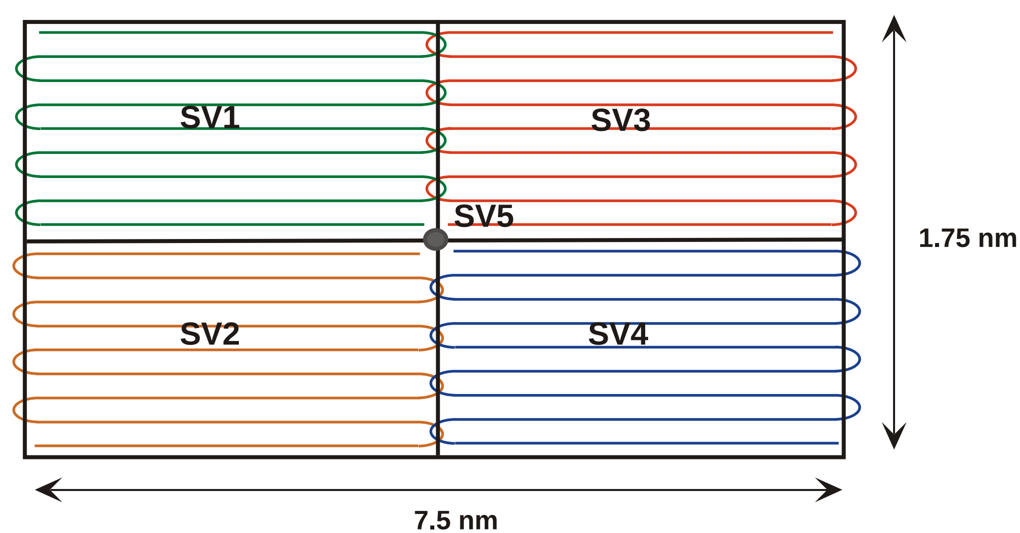
TYPE II SYSTEM CONCEPT

- LV provides SV transportion or coordination
- SVs search thru ID

TYPE III SYSTEM CONCEPT

- “no” LV
- SVs search thru ID

Single Packet (5 SV) Search Area



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NOTIONAL SYSTEM CONCEPTS
STANDARDIZED OPTIONS

- A set of “standardized” component options were selected
  - focus of concepts was utilization of vehicles and not necessarily specific optimized types
  - system concepts were not necessarily restricted to these standard options
  - set of small and large UUV
  - sets of acoustic sensors optimized for vehicle sizes (& missions)
  - set of battery options
  - set of “other” sensors
  - set of auxiliary vehicle components (e.g. nav.)

- Small Vehicle Options
  - 4.875” (Sonobuoy & EMAT)
  - 7.5” diam. (REMUS sized)
  - 12.75” diam (Mark 46)

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NOTIONAL SYSTEM CONCEPTS
STANDARDIZED OPTIONS
(cont.)

- **Large Vehicle Options (Type I & II Concepts)**
  - **large UUVs (21”, 36”, and 54” diams (LMRS size to ASDS size))**
    - **delivery, search, guidance, coordination, and/or communications**
  - **large stationary nodes**
    - **storage & delivery**
    - **central reporting, direction, communications back to host, energy**
  - **AUV & USV (multi-stage operation)**
    - **search, class, & marking**
    - **delivery for small vehicles to class->ID and to neutralize**

- **Large Vehicles (Type III)**
  - **P3 (large area recon)**
  - **B52 (AOA multi-pass delivery)**
  - **gun launched**

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NOTIONAL SYSTEM CONCEPTS
STANDARDIZED OPTIONS
(cont.)

- **Sensors**
  - **- ALS (deep & shallow water options)**
  - **- SAS (deep & shallow water options)**
  - **- close range SLS & SAS sensors**
  - **- ID (current commercial configurations)**

- **Batteries**
  - **- primary and secondary types**
  - **- Li/thionyl Chloride, Silver Oxide, Zinc/Air**
  - **- lead acid, Lithium-ion, Lithium-polymer, Nickel-Cadium, Nickel-metal hydride, Silver-oxide, Silver Zinc**

- **Navigation Packages**
  - **- low, medium, and high performance/cost options**

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FMCM SYSTEM CONCEPTS
SUPPORTING IDEAS

- **During the study and the development & assessment of the system concepts, numerous sub-component ideas or concepts were generated**

- **Including physical components (hardware, sensors, …)**

- **Including vehicle tactics and/or deployment schemes**

- **Some ideas were used in the final concepts**

- **Some ideas were not used but "tabled" for some future concept**

- **Some ideas were discarded for practicality or no feasible approaches identified**

- **Used to establish core of the Technology Roadmap**

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LIST OF SUPPORTING IDEAS
(some used, some tabled, and some discarded)

- **Close range sensing**
  - **- "take the sensor to the object"**
  - **- enable numerous sensing approaches**

- **Dual mode ALS**
  - **- long range detect & close range class in one sensor**

- **Small marker**
  - **- mark for target reacq. and possibly area navigation**

- **Pop-up communication device**
  - **- provide one-time contact ID info. or neutralization comfirmation**

- **En-masse SV navigation**
  - **- simple control mechanism for parallel SV tracks**

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LIST OF SUPPORTING IDEAS (cont.)
(some used, some tabled, and some discarded)

- **Close range RF sensor**
  - **detection of electronics in target**
- **Close range smell sensor**
  - **detection of characteristic chemical traces**
- **LV/bird-dog combination**
  - **match special sensing & endurance capabilities of each platform**
- **Cell of SVs**
  - **mixture of specific SV types to search a small area**
- **Central, stationary host node for SVs**
  - **provide central station for SV guidance, mission dispatch, comms back to host, energy**

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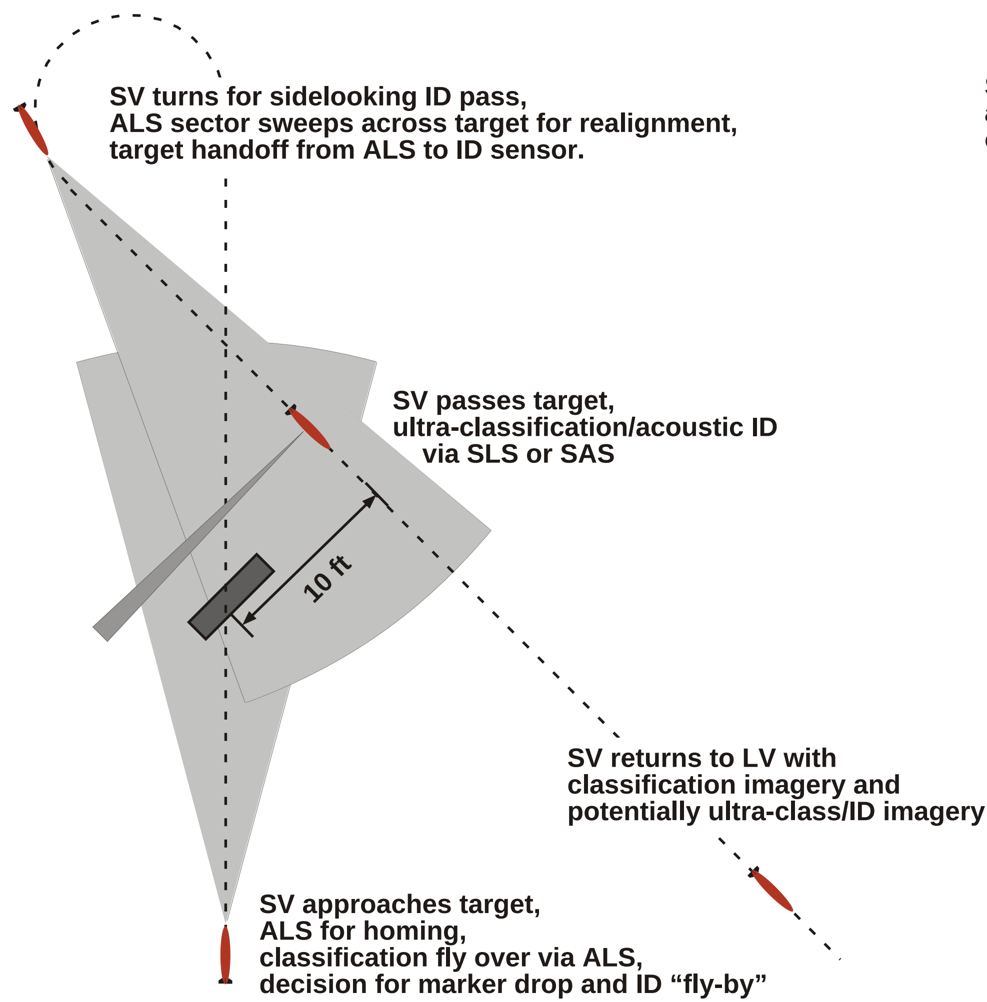
LIST OF SUPPORTING IDEAS (cont.)
(some used, some tabled, and some discarded)

- **Efficient wideband RF antenna**
  - **small, efficient, low cross-sectional area high bandwidth antenna**
- **Precision guidance of SVs**
  - **local grid, precision guidance to enable complete are coverage and data reconstruction**
- **Close range neutralization device**
  - **simplification of long range concepts**
- **Ballistic launched SVs**
  - **fast, efficient approach for SV deployment**
- **High speed, high volume SV deployment**
  - **maximizes deployment speed of SV to pepper a search area**
- **Very small vehicles**
  - **simplest vehicle for target reacquisition and neutralization (diam < 3”)**

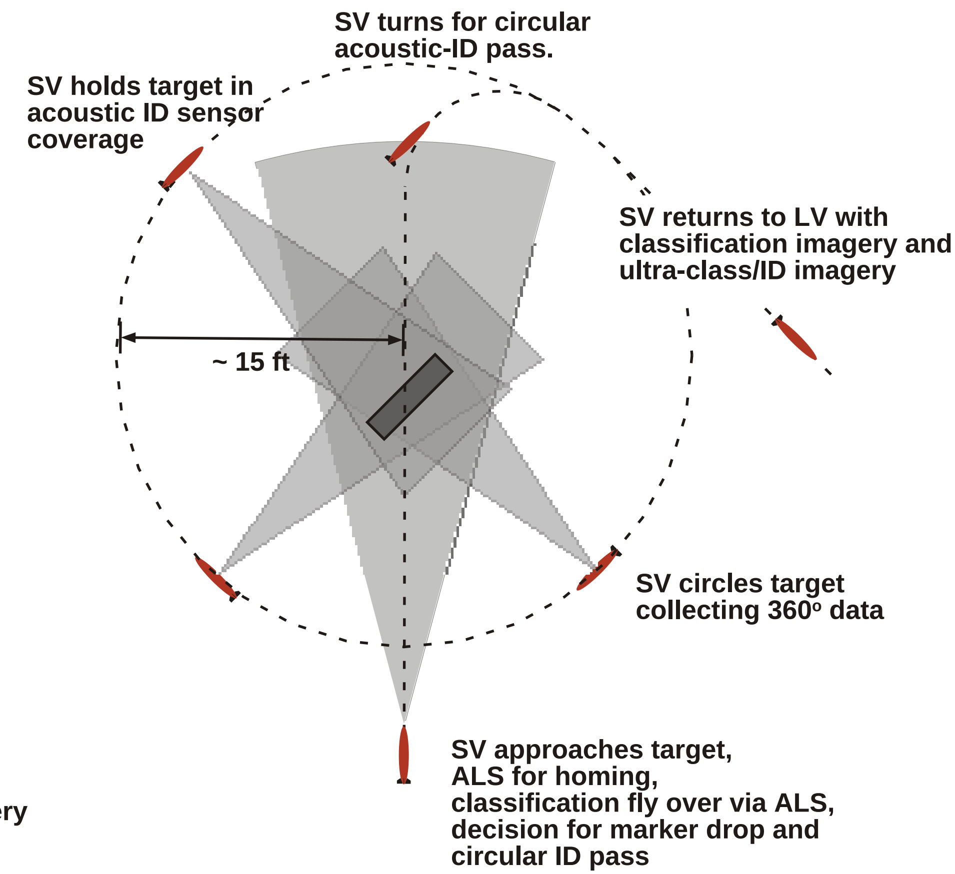
FMCM STUDY: SUPPORTING IDEAS

CLOSE RANGE SENSING
SMALL VEHICLE (SV) MANEUVERING OPTIONS

Single Pass ALS class w/ Linear ID Maneuver
- multi-ping, multi-image ALS classification data
- single pass (or a few) ultra-class/ID SLS or SAS data



Single Pass ALS class w/ Circular ID Maneuver
- multi-ping, multi-image ALS classification data
- circular SASdata for ultra-class imagery



**Long range ID sensing is difficult.
Moving the acoustic-ID (ultra-classification) sensor to the target greatly simplifies the ID sensor and processing while providing unique sensing opportunities**

FMCM STUDY: SUPPORTING IDEAS

CLOSE RANGE SENSING CONCEPTS
NON-TRADITIONAL SENSING OPTIONS

- **Close Range Sensing Enables**
  - utilization of non-traditional forms of sensing
    - light, RF, and magnetic
    - electronics detection
    - chemical (smell/taste)
    - texture/touch
  - complexity or impossibility of long range versions can be eliminated in short range versions
  - some of these may have very unique signatures
    - simple classification algorithms
    - very low false alarm rates

Close Range Optical Imagery

Benefits
- significant reduction in turbidity loses
- significant simplification in system complexity
  - electronic still camera w/ flash
- simple identification by operator review

Issues
- turbidity is still an issue (< 2 ft can be "common")
- data sizes are large for low bandwidth comms
- computer ID algorithms are still challenging

Close Range RF/electronics detection

Benefits
- active and/or passive electronics is a very unique man-made signature
- simple detection algorithm
  - "if RF emissions" then MLO & neutralize
  - "if PN junctions" then probably MLO
- very low false alarm rate
  - mine, sensor, comm node, or ?

Issues
- unknown sensing options
- SV electronics interference
- unknown operating envelope

Broadband Acoustic Target Discrimants

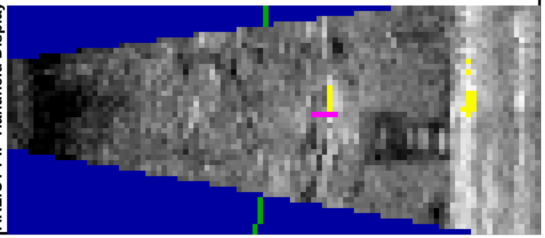
Benefits
- close range enables 5+ octave operations
- excite & estimate non-specular responses
  - low ka body/material resonances
    - material discriminants
  - high ka shell resonances
    - shell thickness & material discriminants

Issues
- understanding underlying physics
- detection/estimation algorithms

Step1: Object detection (yellow)

Step2: Discrimination as a thinned shell (probably man-made) obect (pink)

ARL:UT PIP-Handheld Display



FMCM STUDY: SUPPORTING IDEAS

CLOSE RANGE SENSING CONCEPTS
NON-TRADITIONAL SENSING OPTIONS
(cont.)

Close Range Chemical Sensing

Benefits
- unique signature
  - "if explosive" then probably a mine or at least dangerous
- potential for long range by via a plume

Issues
- in water sensing options
- non-omni response (down wind)
- physical contact for "taste"

Close Range Magnetic Sensing

Benefits
- magnetic fields ~ 1/r^3
- close range should significantly reduce complexity
- somewhat unique man-made signature

Issues
- not a unique mine signature
- natural fields interference
- moderate false alarm rate
  (many man-mades are magnetic)

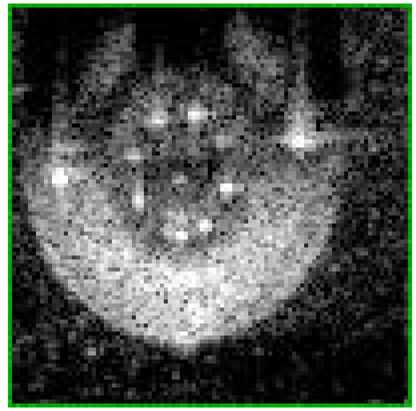
Texture/Touch Sensing

Benefits
- simple device & electronics

Issues
- very indirect characterization
- non-unique signatures
- physical contact with object

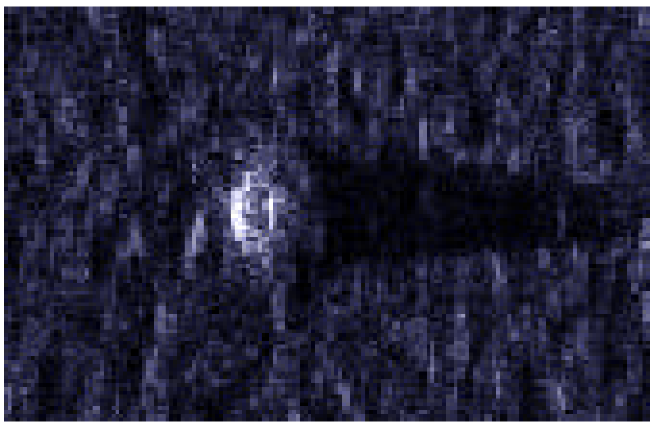
FMCM SUPPORTING IDEAS
CLOSE RANGE SENSING
ACOUSTIC ULTRA-CLASSIFICATION

- Close Range Sensing Enables
  - simple sensors
  - ultra-classification level imagery
  - non-traditional sensing techniques
- Ultra-classification Acoustic Images
  - very-high resolution
  - near-ID quality
- All examples of acoustic data from real targets



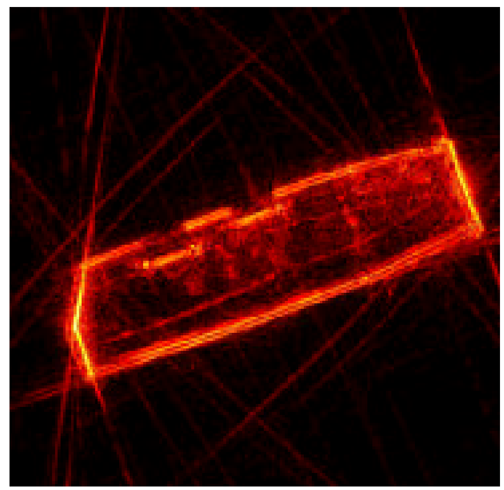
from ARL:UT

Diver Handheld Example
Real Aperture
- 5yd
- 1“ pixel
- lab tank
- high fo



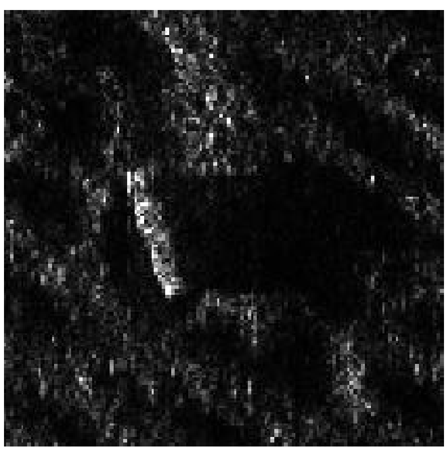
from NAVSEA Panama City, CSS

SAS example
- ~20 yd
- 1“
- 25ft
- sandy bottom
- mid-fo



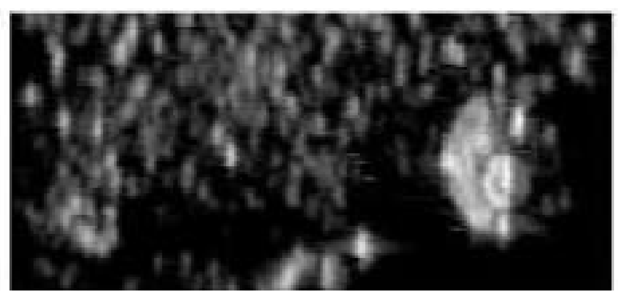
from ARL:UT

Circular SAS example
(concept test data)
~ 100 ft range
- < 1“ pixel size
- rotating platter
- low fo
- very wide bandwidth



from NAVSEA Panama City, CSS

SAS example
- ~37 yd
- 1“
- mid-fo



from ARL:UT

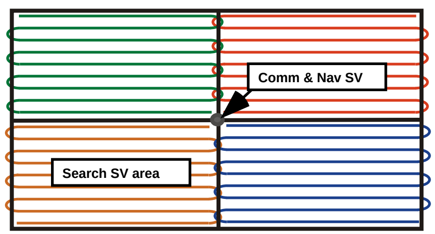
3D imagery (real aperture)
- 100 yd range
- 4“ x 1” pixel size
- ~100 ft water
- very rocky bottom
- high fo
- 3D processing enhances target contrast (“TS”) against high bottom backscatter

FMCM SUPPORTING IDEAS

SMALL VEHICLE DEPLOYMENT CONCEPTS

- SV's limited endurance requires a deployment in the operation area
- Number of deployment concepts were considered
- Optimized a variety of criteria
  - covertness or speed or volume delivered or maintaining comms or maintaining control or LV/SV autonomy capability
- Enable a particular SV tactic and mission
  (e.g. complete AOA lane SV search-to-neutralization in a few hours)

- Operational cells of SVs
  - deploy a small group SVs to search an area
  - distribute the capabilities among the SVs
    - e.g. one with comss & nav others with search sensors
  - simple SVs mission and simple host deployment strategies



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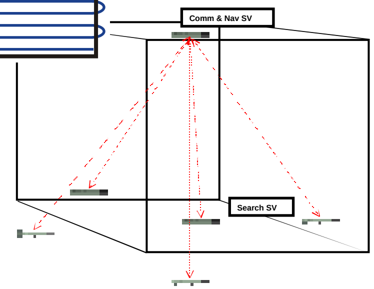
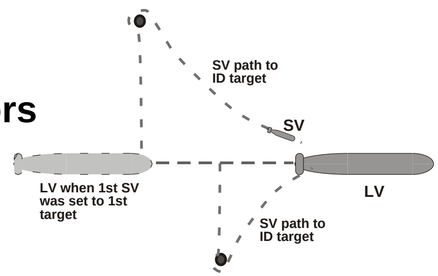


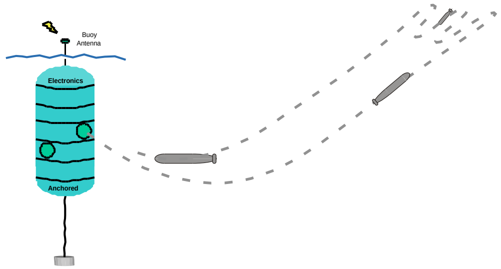
- Search LV w/ directed SVs ("bird-dogs")
  - utilize long range LV detection swath
  - send SVs for close range ID w/ simple sensors
  - SV sorties are simple missions



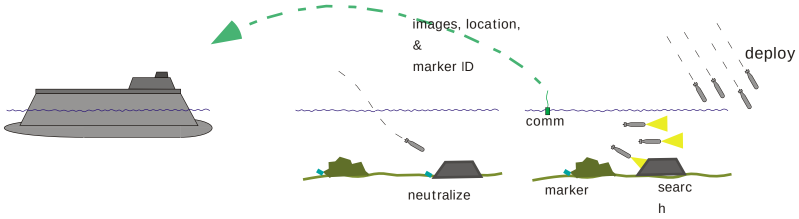
FMCM SUPPORTING IDEAS

SMALL VEHICLE (SV) DEPLOYMENT CONCEPTS (cont.)

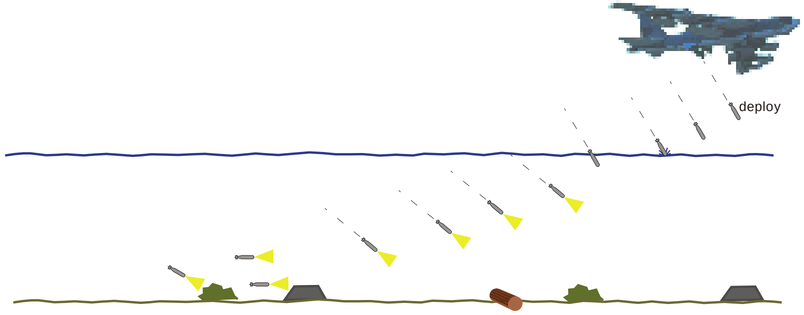
- **Central Node "LV"**
  - **a large central stationary node**
  - **node provides energy, comms, SV mission instructions**
  - **potential for SV guidance from node**
  - **SV search area and ID contacts**



- **Ballistic Launched SV**
  - **area SV peppering**
  - **SV neutralizer placement**
  - **long range efficient SV deployment**
  - **host maintains significant stand-off range**
  - **mortar or artillery**



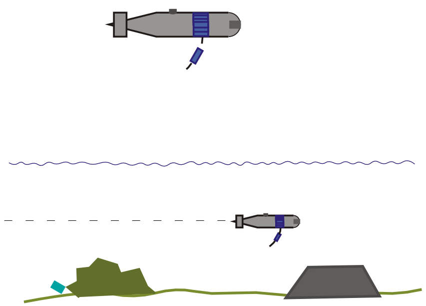
- **High Volume Aircraft Launched SV**
  - **rapid AOA lane coverage**
  - **high volume (10,000$^+$ SVs) single pass**
  - **two staged search SV then neutralizers**



FMCM SUPPORTING IDEAS

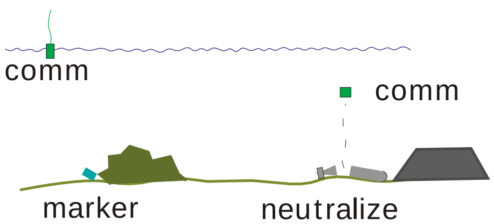
ADDITIONAL SUPPORTING CONCEPTS

Small SV Deployed Markers



- small device ~1“ x 3”
- low power mode & alerted mode
- internal low power DSP
- contains unique ID & target information
  - e.g. location, target class, ...
- commands:
  - wake-up, ID’d response, all respond, percentage response
- provides: rapid reacquisition
- provides: location reference frame navigation
- Notional Design: 100^{+} yd rng, ___/___ endurance

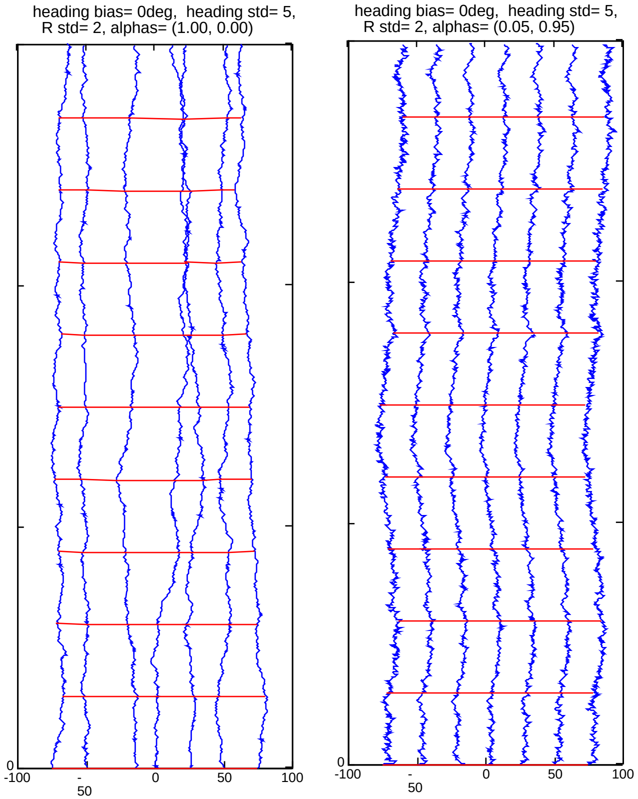
One Time Comms Device



- multiple mission events require a report back to the host/cmdr
- e.g. report the class. & marking of a target
- e.g. verification of intent-to-neutralize

- could be a simple short range device
- transmit until verification then scuttle
- transmit target image or discriminants or marker ID or locations

En-masse Navigation of SVs

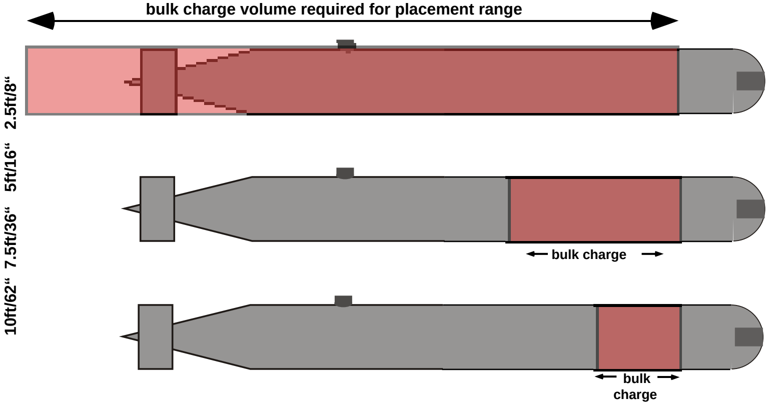


- heading only navigation of SVs
  - uneven & overlapping tracks
  - non-uniform clearance coverage
- heading w/ spacing navigation
  - simple distance measure to nearest neighbor
  - simple first order control scheme
  - maintains ~parallel tracks w/ composite heading error

FMCM SUPPORTING IDEAS

SV NEUTRALIZATION SUMMARY

Bulk Charge Payload (6“ diam. vehicle)



volume for 100% farther placement

volume for typical EOD placement

volume for 50% closer placement

* volumes based on EOD rule-of-thumb and maintaining shock-factors at each range

- neutralization charge requires a significant payload section
- charge payload significantly limits endurance
- a complete search-to-neutralization seems infeasible
- multiple bulk charges per vehicle seems infeasible
- deploying numerous “additional mines” into an area is a concern
- Endurance for three options from a few hours to 0 hrs

Small Neutralization Device

- shaped-charge or close-range projectile
- requires precision placement
- “terminal homing” is difficult
- no known simple, reliable attachment scheme
- w/o attachment, target must be neutralized immediately
- multiple devices per vehicle not practical

Target Spoofing or Jamming

- may be feasible to jam or the mine’s detection mechanism
- may require significant knowledge the target
- may require precision placement
- must be very reliable (no confirmation mechanism)
- requires follow-on force acceptance

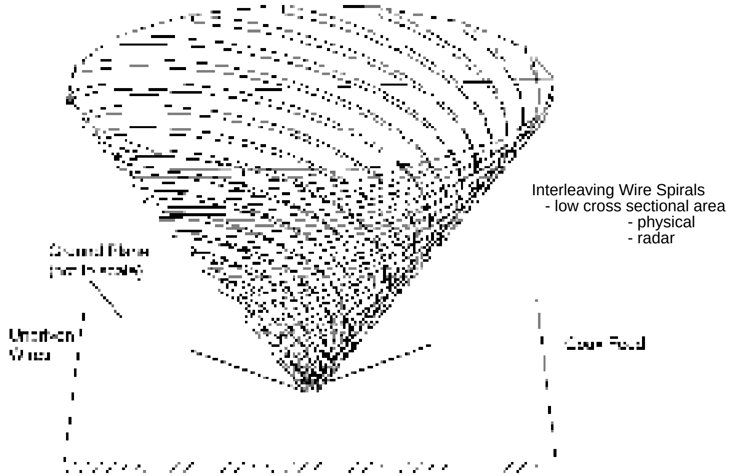
Only Neutralization Option Identified

- bulk charge, one vehicle per target
- follow-on vehicle after detect/class/ID screening
- target neutralizations should be confirmed

FMCM SUPPORTING IDEAS

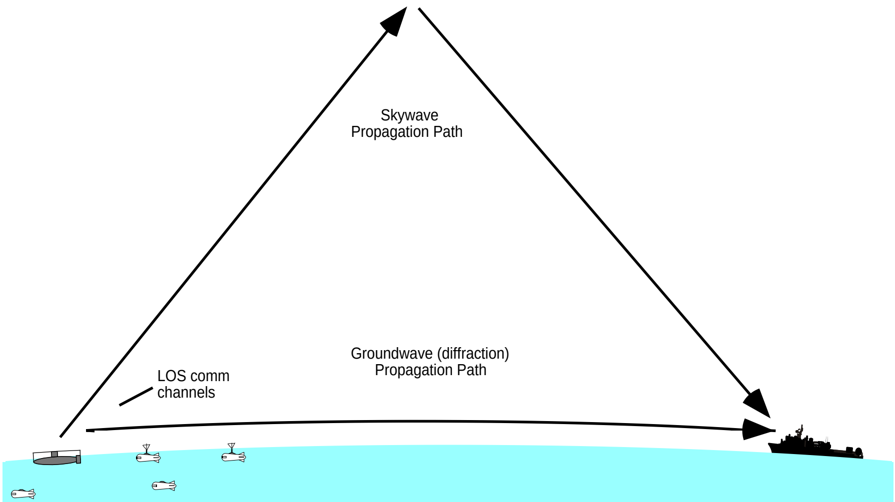
ARL
The University of Texas at Austin

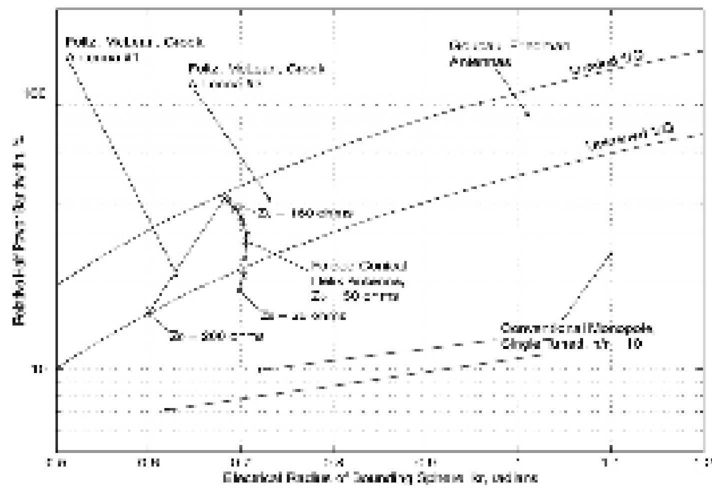
Folded Conical Helix Antenna



Features

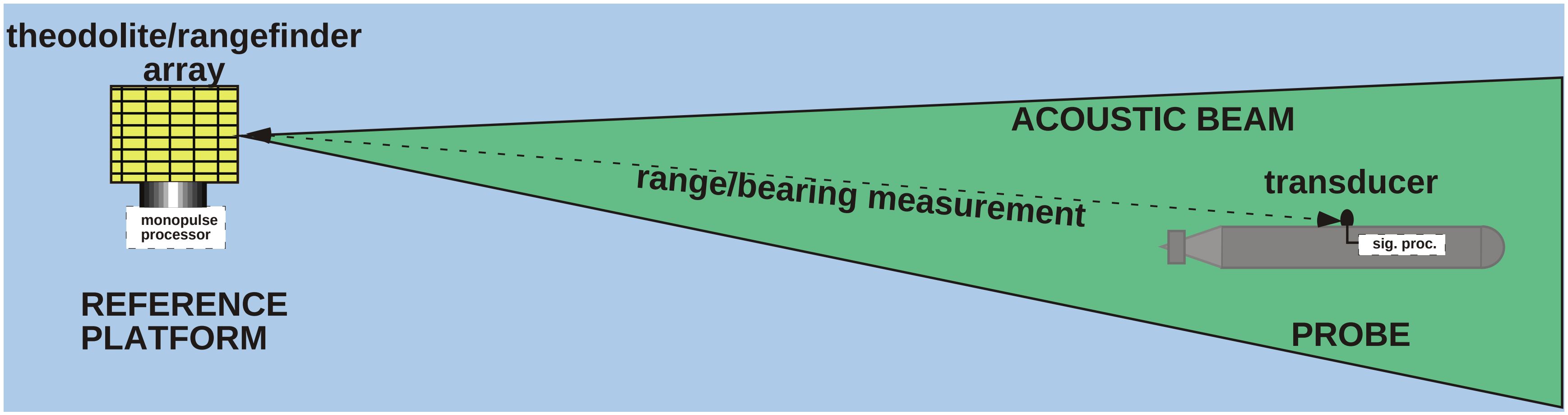
- Electrical Small - Less than 0.1l
- Wide Relative Bandwidth - over 30 percent
- High Efficiency > 90 percent
- Can optimize for smaller sizes with high efficiency
- All wire antenna - robust against wave splash
- Inherently low RCS geometry
- Mechanically Collapsible





FMCM SUPPORTING IDEAS

FAST ACOUSTIC NAVIGATION OF EXPENDABLE PROBES FROM A SINGLE REFERENCE PLATFORM



- Probe carries simple omni transducer and single-channel signal processor
- Precision acoustic theodolite/rangefinder on reference platform
  - Range measurement error < 1inch (100 kHz transmission bandwidth)
  - Bearing measurement error < 0.02° , crossrange error < 6 in at 500 yds
- IF REFERENCE PLATFORM TRANSMITS:
  - Probe knows its range/bearing at the instant of reception
- IF PROBE TRANSMITS:
  - Reference platform knows probe's range/bearing at the instant of transmission
- METHOD FOR MEASURING BEARING SO PRECISELY:
  - Broadband monopulse processing (i.e., gradient receiver with limited beamwidth)
  - Array aperture provides 1° beamwidth, processing gives > 50:1 subdivision
  - Large time-bandwidth transmissions (with pulse compression) minimize angle noise
  - Array must apply two shading patterns simultaneously
- SPECIFIC MCM APPLICATIONS:
  - Platform-guided "kamikaze" attack on mine
  - Navigation reference for merging map data from low-cost, close-in, survey probes

FMCM Supporting Concepts

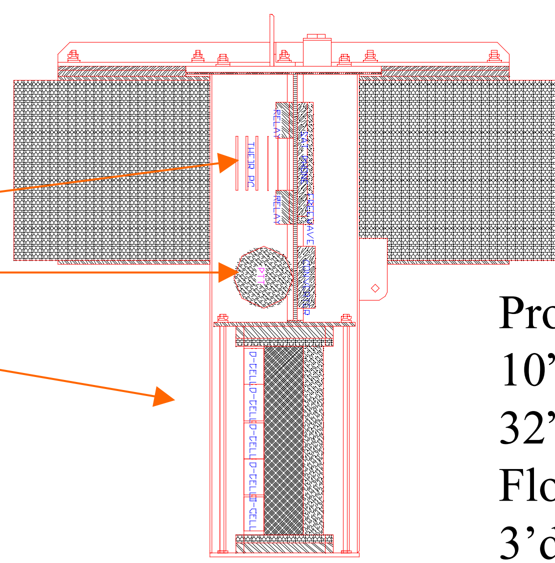
Prototype Sensor System

(as tested Oct 00)

Multi-mission surveillance sensor funded by CNO N774

- Autonomous operations with OTH SATCOM and high data rate LOS spread spectrum for UAV relay
- Acoustic ,COMINT and Camera sensor packages hosted on a single buoy
- Internal pentium computer hosts automated acoustic and COMINT processing algorithms
- Long Lived operability (2 month life)

SASS Buoy Internal Layout



Prototype dimensions
10" diameter
32" length
Flotation collar: closed cell foam
3'diameter & 14" height
Antenna height: 1' above water line
Freeboard :6" above waterline

FUTURE MCM STUDY

Section 3: Assessment Process

- **Rules-of-Thumb; Study Workbook**
  - **basis for notional concept developments**
- **Sensor Assessments**
  - **performance**
  - **weight, volume, power, cost**
- **Vehicle Assessments**
  - **endurance, weight, volume, cost**
- **System Assessments**
  - **ACR, mission times, weight, volume, cost**
- **Example**

FUTURE MCM STUDY

Example: Notional System Assessment

- Formulate System Concept of Operations
  - Conduct Mine Reconnaissance Survey, Detection & Discrimination Only
  - Single Large UUV vs. Few Medium UUVs vs. Many Small UUVs
    - Large UUV: Execute Ladder Search Survey
    - Many UUVs: Launched/Recovered from Large UUV to Execute Ladder Search Surveys
- Define Sensor Configurations
  - Select Sensor Package: Forward-Looking Sonar (FLS)
    - Moored/Close-Tethered/Bottom MLO Detection & Discrimination
    - Bathymetry Measurement
  - Optimize Configuration for Selected Vehicle Size
    - Determine Sensor Performance
    - Determine Sensor Physical (Mechanical/Electrical) Requirements
    - Evaluate Sensor Integrated w/ UUV System
- Determine System MOEs

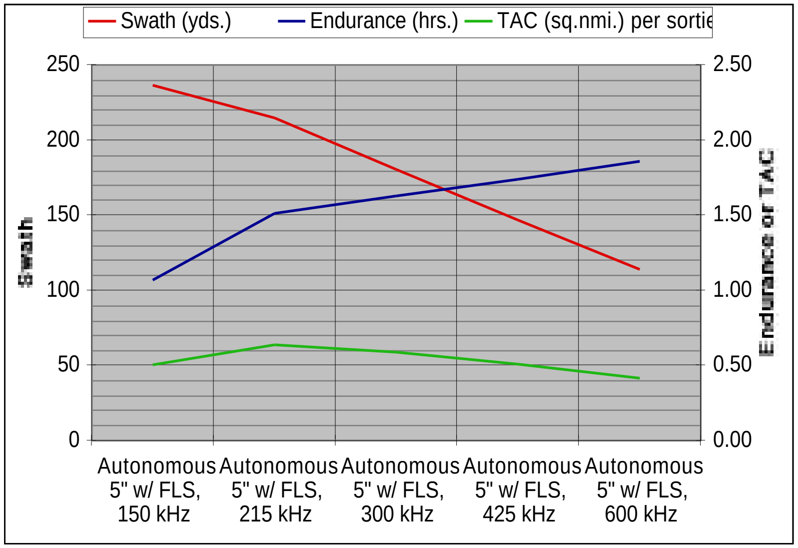
FUTURE MCM STUDY

Example: Notional System Assessment Configuration Definition

Small UUV (5”x36”) Design

- FLS Located On Nose
  - 3” Horizontal Aperture
  - 3 Element Vertical Monopulse
  - 150-600 kHz
  - 5 deg V x 150 deg H Sector
- Mineray Performance Predictions
  - Shallow Water, 30’
  - Tough Bottom, Sandy Gravel
  - Tough Target, -30 dB TS
  - Swath Estimation
- Implementation
  - Current HF Technology
    - Signal Conditioning & Array
    - Signal Processing
  - Volume/Weight/Power Estimation
- System Integration
  - Max. Allowable Batteries
  - Simple UUV Controller
  - Endurance Estimation
- MOE: Total Area Coverage (TAC) per Sortie

	Volume (cu.in.)	Weight (lbs.)	Power (W)	Swath (yds.)	Endurance (hrs.)	TAC (sq.nmi.) per sortie
Autonomous 5" w/ FLS, 150 kHz	287	9	73	237	1.06	0.50
Autonomous 5" w/ FLS, 215 kHz	271	8	67	214	1.51	0.64
Autonomous 5" w/ FLS, 300 kHz	268	8	64	181	1.63	0.58
Autonomous 5" w/ FLS, 425 kHz	266	8	61	147	1.74	0.51
Autonomous 5" w/ FLS, 600 kHz	264	8	58	113	1.86	0.42



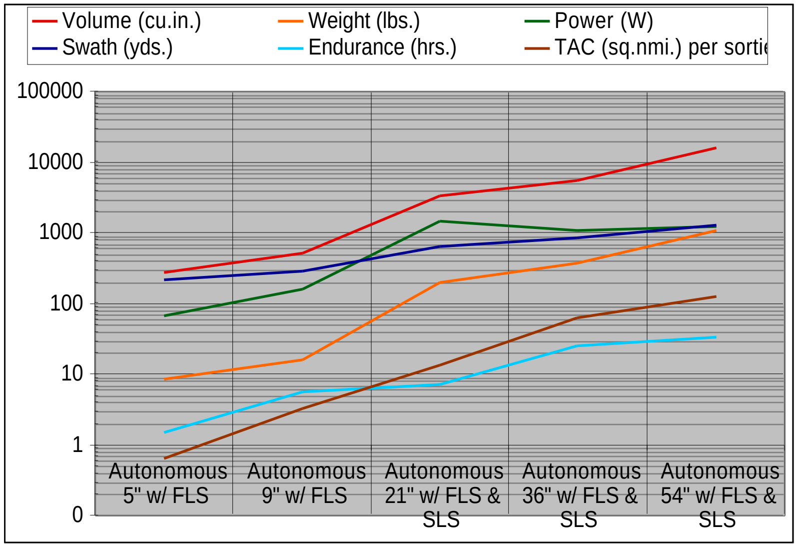
FUTURE MCM STUDY

Example: Notional System Assessment

Large vs. Medium vs. Small UUV Comparison

- Large Vehicles
  - Three Vehicle Sizes: 21”x240”, 36”x254”, 54”x254”
  - Sensor Package Includes FLS and SLS
  - Implementation Estimation w/ Scaled 1993 Technology & LMRS COEA Spreadsheet
    - Ceramic transducer material
    - Hybrid signal conditioning
    - Transputer/DSP56k signal processing
    - Zn-AgO Batteries
  - Endurance & TAC Increase w/ Vehicle Size
- Med./Sm. Vehicles
  - Two Vehicle Sizes: 5”x36”, 9”x65”
  - Sensor Package Includes FLS Only
  - Implementation Estimation w/ Scaled 1998 Technology
    - 1-3 composite transducer material
    - ASIC signal conditioning
    - SHARC/PPC signal processing
    - Lithium Ion Batteries
  - Multiple Vehicles Match 21” UUV TAC
    - 4 9” UUVs
    - 21 5” UUVs

	Volume (cu.in.)	Weight (lbs.)	Power (W)	Swath (yds.)	Endurance (hrs.)	TAC (sq.nmi.) per sortie
Autonomous 5" w/ FLS	271	8	67	214	1.51	0.64
Autonomous 9" w/ FLS	514	16	160	294	5.62	3.26
Autonomous 21" w/ FLS & SLS	3388	202	1452	630	7.30	13.63
Autonomous 36" w/ FLS & SLS	5520	366	1067	840	25.10	62.64
Autonomous 54" w/ FLS & SLS	16124	1088	1235	1260	33.10	123.82



FUTURE MCM STUDY

Preparation For Future Notional System Assessments

- Complete Definition of Sensors Assessment Process
  - Finalize procedures for detection and HAB classification (from RMS Sensors Study)
  - Select appropriate SLS/SAS classification techniques (out of 4 in PCCurve software)
  - Formulate Magnetic sensor assessment process
  - Formulate optical sensor assessment process (rules of thumb)
- Complete Generic Environment (derived from Scenarios) Definitions
  - Range of bottom type conditions (APL type 4, 9, and 15?)
  - Range of sea state conditions (SS2-SS4)
  - Simple SVPs w/o acoustic propagation anamolies
- Generate "Grab-Bag" of Standard Sensor Configurations (vs. veh. Size)
  - All sensor types: FLS, SLS/SAS, Magnetic, Optical
  - Physical (mech./elect.) definitions and Processing requirements
  - Measures of performance for generic environments
- Finalize UUV System Definition Worksheets
  - Review/Simplify LMRS COEA worksheets for large UUVs
  - Review/Simplify APL-UW worksheets for med./small UUVs
- Formulate Generic CONOPs per notional concept
  - MCM functions performed
  - Measures of Effectiveness (based on MEM, UCPLAN, etc.)

ASSESSMENT TOOLS

- **Set of Rules-of-Thumb**
  - **provided basis for initial notional system concept developed and assessment**
  - **FMCM Workbook[5]**

- **Sensor Assessments**
  - **ALS**
    - **given: sensor and environment parameters**
    - **MINERAY3 provides SNR for targets throughout the water column**
    - **MINERAY3 extensions provide Pd_vs_range, swath (A), and effective Pd (B) MOPs**
  - **SLS & SAS**
    - **given: sensor and environment parameters**
    - **SWAT provides SNR for targets throughout the water column**
    - **SWAT modified runs provide non-ideal SAS preformance estimates**
    - **model provide Pd_vs_range, swath (A), and effective Pd (B) MOPs**

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[5] See Appendix W

FUTURE MCM STUDY

ONR 321-TS
ARL:UT
JHU:APL
CSS

- EOID
    - market survey provides basic parameters
    - assumed to always be used at close range

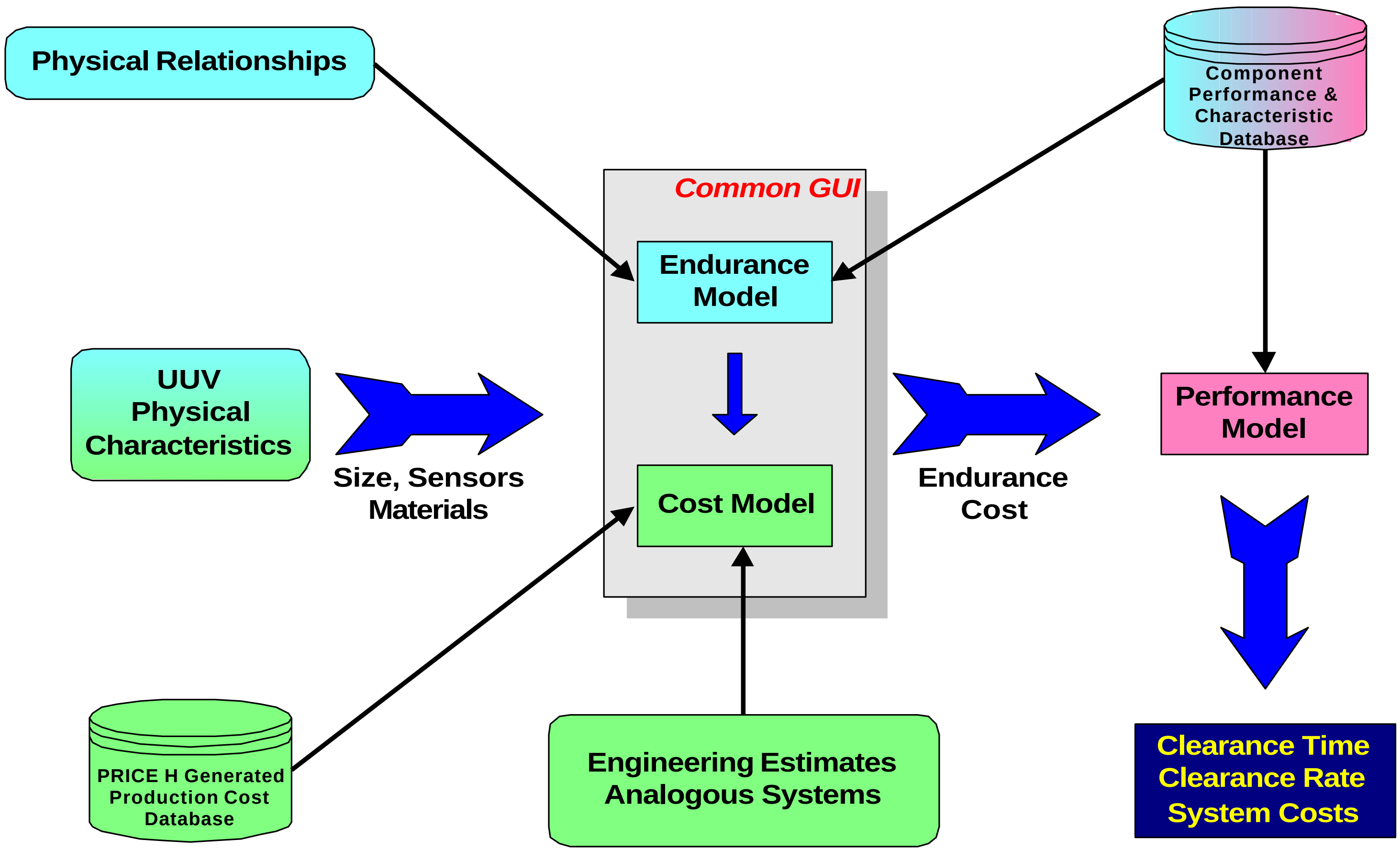
• Magnetic

• Vehicle Assessment
- "Vehicle Worksheet" provides endurance for a set of configurations
    - options: vehicle diameter, battery type, sensor package, speed of operation
    - worksheet linked to costing database
        - provides R&D and production cost estimates

• System Level Assessment
- Matlab model implementation to estimate mission level MOEs using PEO-MIW 3370
- Excel Spreadsheet implementation of PEO-MIW 3370 instructions for conventional MCM tactics
- other scripts compute or import system cost, weight, volume, ACR/$, …

Future MCM Study

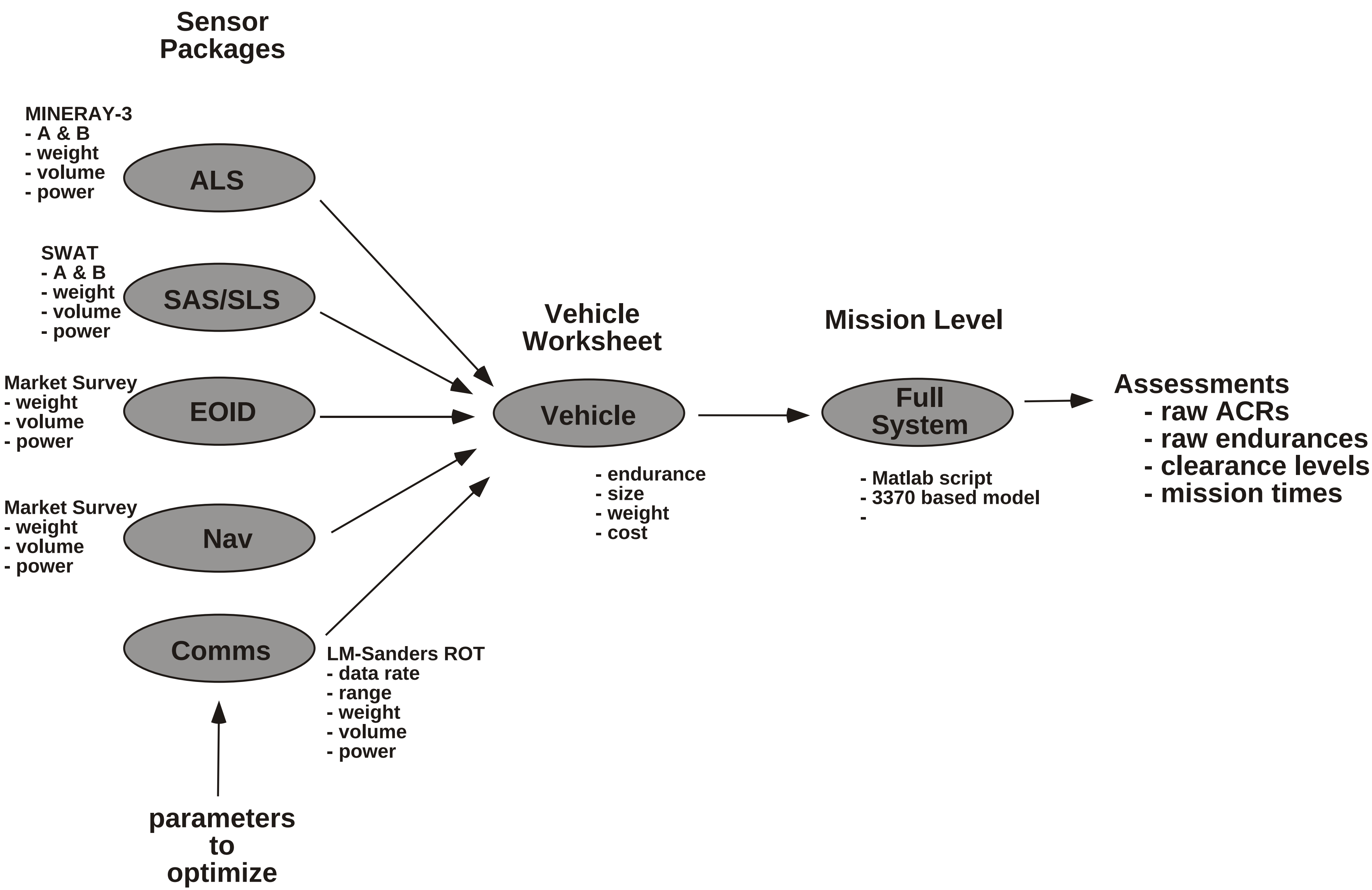
Model Hierarchy



FUTURE MCM STUDY

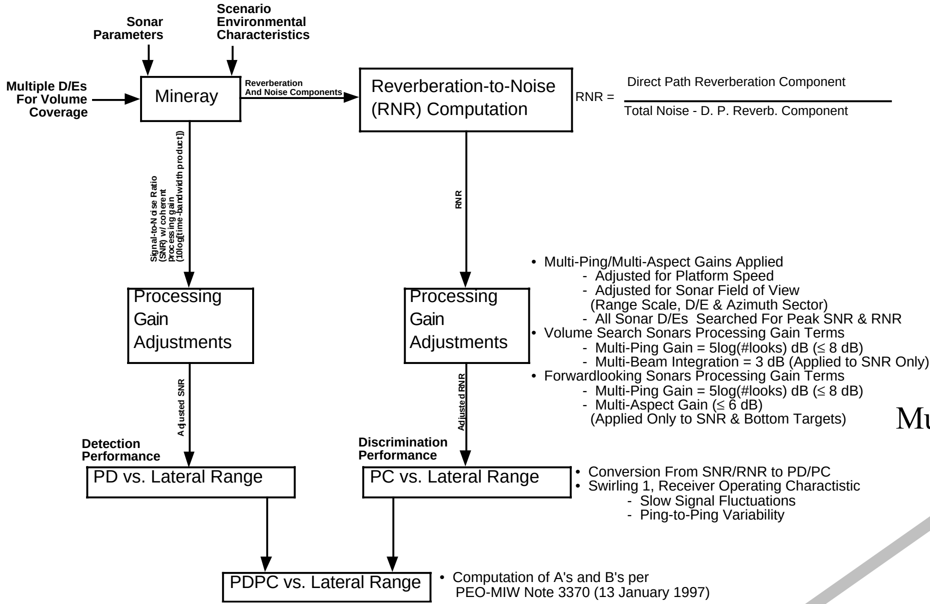
NOTIONAL SYSTEM ASSESSMENT PROCESS

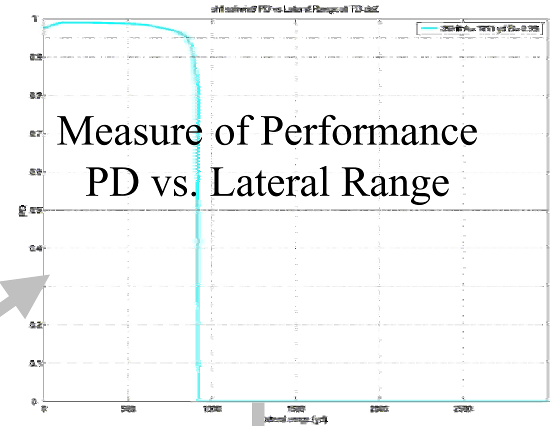
ONR 321-TS
ARL:UT
JHU:APL
CSS



FUTURE MCM STUDY

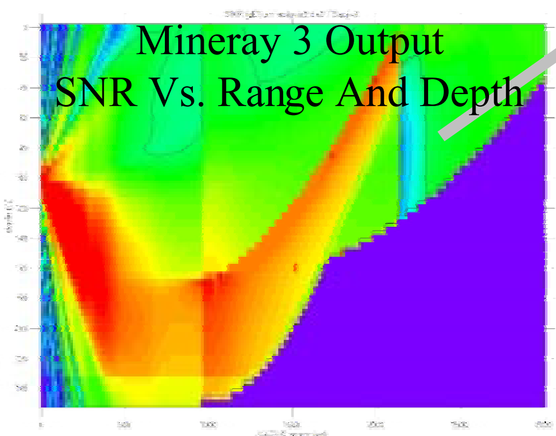
ALS Performance Assessment Process Using Mineray 3





Multi-Ping, Multi-Aspect Detection ROC

A s and B s



UUV Size	Bottom Type	40 ft	120 ft	200 ft	600 ft	1000 ft	
54" NARROW	APL-4	3108	3434	3575	3575	3571	A
		0.91	0.98	0.98	0.98	0.99	B
	APL-9	3106	3431	3574	3580	3578	A
		0.91	0.98	0.99	0.99	0.99	B
54" WIDE	APL-4	2427	508	581	1125	1675	A
		0.39	0.73	0.89	0.97	0.98	B
	APL-9	2231	1534	1819	2059	2351	A
		0.63	0.79	0.82	0.94	0.98	B
36" NARROW	APL-4	2582	2823	2880	2875	2874	A
		0.92	0.97	0.98	0.98	0.98	B
	APL-9	2585	2819	2879	2877	2877	A
		0.92	0.99	0.99	0.99	0.99	B
36" WIDE	APL-4	1817	437	525	1090	1624	A
		0.36	0.70	0.88	0.96	0.97	B
	APL-9	1820	1271	1464	1695	2039	A
		0.63	0.79	0.83	0.97	0.99	B
21" NARROW	APL-4	1804	1953	1968	1975	1978	A
		0.92	0.96	0.96	0.96	0.97	B
	APL-9	1816	1949	1968	1976	1979	A
		0.94	0.99	0.99	0.99	0.99	B
21" WIDE	APL-4	1021	521	588	1107	1339	A
		0.46	0.72	0.88	0.96	0.96	B
	APL-9	1170	1029	1076	1251	1353	A
		0.75	0.84	0.90	0.99	0.99	B

Water Depth: 40 ft, 120 ft, 200 ft, 600 ft, 1000 ft

UUV Size	Bottom Type	40 ft	120 ft	200 ft	600 ft	
12.75" NARROW	APL-4	1313	1415	1419	1424	A
		0.90	0.96	0.96	0.97	B
	APL-9	1328	1417	1422	1427	A
		0.94	0.99	0.99	0.99	B
12.75" WIDE	APL-4	626	476	554	885	A
		0.51	0.85	0.93	0.97	B
	APL-9	780	739	760	896	A
		0.79	0.91	0.96	0.99	B
7.5" NARROW	APL-4	1029	1251	1274	1274	A
		0.88	0.95	0.96	0.96	B
	APL-9	1110	1258	1280	1280	A
		0.94	0.99	0.99	0.99	B
7.5" WIDE	APL-4	460	422	514	514	A
		0.62	0.89	0.95	0.95	B
	APL-9	678	663	679	679	A
		0.81	0.92	0.97	0.97	B
4.875" NARROW	APL-4	768	870	869	869	A
		0.94	0.97	0.98	0.98	B
	APL-9	812	877	879	879	A
		0.97	0.99	1.00	1.00	B
4.875" WIDE	APL-4	401	409	475	475	A
		0.77	0.93	0.97	0.97	B
	APL-9	513	522	537	537	A
		0.90	0.96	0.99	0.99	B

Water Depth: 40 ft, 120 ft, 200 ft, 600 ft

FUTURE MCM STUDY

ALS Weight/Volume/Power Assessment Using LMRS COEA Spreadsheet

	A	B	C	D	E	F	G	J	K	L	M
1				uuv 36in n							
2			*INPUT PARAMETERS*								
3			FREQ (KHZ)	BW (KHZ)	SOURCE LVL	PULSE (MSEC)	RNG SCALE (YD)				
4			60	24	220	10.42	1500				
5			TR VER (DEG)	TR HOR (DEG)	CHAN NUM		SLS DISPLAY KPIX				
6			2.5	150	45.84		1310				
7			REC VER (DEG)	REC HOR (DEG)	CHAN NUM	BEAM NUM	D RATE TM (MB/S)				
8			2.5	1.85	5271.6	81.0810811	7591.104				
9			NUM EDM	ARRAY WIDTH	ARRAY HEIGHT	ARRAY DEPTH	D RATE BM (MB/S)				
10			2	57.50	22.92	0.00	155.6756757				
11				A WIDTH XMIT	A HEIGHT XMIT	A WIDTH REC	A HEIGHT REC				
12				14.38	22.92	57.50	22.92				
13											
14		VEHICLE OB			REFERENCE						
15	ITEM	CONTROL	CALCULATION	VOL (CU IN)	WT (LBS)	PWR (W)	ARL K$ REC	ITEM	VOL (CU IN)	WT (LBS)	PWR (W)
16	ARRAY BLOCK	0	*W*H	2	0.198						
17	ARRAY TONPLIZ	0	*W*H	2	0.48						
18	ARRAY PDVF/BLOCK	1	*WT*HT+WR*HR	2	0.00653						
19	ARRAY PDVF/TONPL	0	*WT*HT+WR*HR	2	0.00653				*OUTPUT PARAMETERS*		
20	ARRAY	1	*SYS	2	1	[illegible]	*SYS	ARRAY	5183.74	102.13	0.00
21	PREAMP	1	*CH	0.33	0.014	[illegible]	[illegible]CH	PREAMP	1739.63	73.80	948.89
22	PA	1	*TV*TH*(SL)	0.67	0.012	0.047	[illegible]	PA	114.60	5.50	20.63
23	A/D,MUX	1	*CH	0.08	0.005	0.12	[illegible]	A/D,MUX	421.73	26.36	632.59
24	TM	1	*CH	0.13	0.003	0.08	*CH	TM	685.31	15.81	421.73
25	PA PR SUP(LOAD)	1	*PL*TV*TH*(RS)*(SL)	0.0061	0.000235	0.0066	[illegible]	PA PR SUP(LOAD)	7.56	[illegible]	8.18
26	PA PR SUP(SS)	1	*SYS	30	8.1						
27	BEAMFORMER	1	*BM*BW	0.19	0.007						
28	CONTROL	1	*SYS	58	2.13						
29	CORRELATOR	1	*(BW)^2*PL*BM	0.00042	0.000014						
30	CORRELATOR (25)	0	CORR*25/(BW*PL)	0.00042	0.000014						
31	CAD (SIMPLE)	0	*RS*BM/2	0.00348	0.0001208						
32	CAD (3D)	1	*RS*BM/2 (CORR REQ)	0.0016	0.000057						
33	LRC	1	*.2*CAD	0.2	0.2						
34	CAC	0	*.5*CAD	0.5	0.5						
35	TERR	1	*.2*CAD	0.2	0.2						

Aheadlooking Sonars

Sonar Configuration

	SONAR	54in_n	36in_n	21in_n	12.75in_n	7.5in_n	4.875in_n	54in_w	36in_w	21in_w	12.75in_w	7.5in_w	4.875in_w
	FREQ (KHZ)	50	60	80	105	110	160	50	60	100	150	170	245
	BW (KHZ)	20.00	24.00	32.00	36.00	44.00	64.00	20.00	24.00	40.00	50.00	68.00	98.00
	SOURCE LVL	220	220	220	220	220	220	220	220	220	220	220	220
	PULSE (MSEC)	12.50	10.42	7.81	5.95	5.68	3.91	12.5	10.42	6.25	4.17	3.68	2.55
	RNG SCALE (YD	[illegible]	1500	[illegible]	750	600	500	2000	1500	1000	750	600	500
	TR VER (DEG)	[illegible]	2.5	[illegible]	4	6.25	6.75	10	10	10	10	10	10
	TR HOR (DEG)	[illegible]	150	[illegible]	150	150	150	150	150	150	150	150	150
	CHAN NUM	46	46	[illegible]	29	18	17	11	11	11	11	11	11
	REC VER (DEG)	2.5	2.5	[illegible]	4	6.25	6.75	40	40	40	40	40	40
	REC HOR (DEG	1.45	1.85	[illegible]	2.93	4.81	5.03	1.45	1.85	1.88	2.04	3.02	3.28
	CHAN NUM	6601	5272	[illegible]	2034	807	696	412	329	320	292	194	183
	BEAM NUM	103	81	63	51	31	30	103	81	80	74	50	46
	ARRAY WIDTH	86.40	57.50	33.38	20.29	12.00	7.69	86.40	57.50	42.00	29.14	18.55	12.00
	ARRAY HEIGHT	27.50	22.92	13.22	8.19	5.00	3.18	6.88	5.73	4.30	3.27	3.13	2.15
	ARRAY DEPTH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A WIDTH XMIT	21.60	14.38	8.34	5.07	3.00	1.92	21.60	14.38	10.50	7.29	4.64	3.00
	A HEIGHT XMIT	27.50	22.92	13.22	8.19	5.00	3.18	6.88	5.73	4.30	3.27	3.13	2.15
	A WIDTH REC	86.40	57.50	33.38	20.29	12.00	7.69	86.40	57.50	42.00	29.14	18.55	12.00
	A HEIGHT REC	27.50	[illegible]	13.22	8.19	5.00	3.18	1.72	1.43	1.07	0.82	0.78	0.54
VOL (CU IN)	ARRAY	10741.1	5183.7	1412.2	444.4	156.0	51.4	2685.3	1295.9	498.2	207.4	118.0	44.3
	PREAMP	2178.3	1739.6	1035.6	671.3	266.2	229.7	135.9	108.5	105.7	96.3	64.2	60.4
	PA	114.6	114.6	88.2	101.0	157.8	170.4	252.4	252.4	252.4	252.4	252.4	252.4
	A/D,MUX	528.1	421.7	251.1	162.7	64.5	55.7	32.9	26.3	25.6	23.3	15.6	14.6
	TM	858.1	685.3	408.0	264.4	104.8	90.5	53.5	42.8	41.6	37.9	25.3	23.8
	Total	**14420**	**8145**	**3195**	**1644**	**749**	**598**	**3160**	**1726**	**924**	**617**	**475**	**396**
WT (LBS)	ARRAY	218.7	102.1	26.2	7.7	2.7	0.8	54.7	25.5	8.7	3.2	1.8	0.6
	PREAMP	92.4	73.8	43.9	28.5	11.3	9.7	5.8	4.6	4.5	4.1	2.7	2.6
	PA	5.5	5.5	4.2	3.4	2.8	3.1	4.5	4.5	4.5	4.5	4.5	4.5
	A/D,MUX	33.0	26.4	15.7	10.2	4.0	3.5	2.1	1.6	1.6	1.5	1.0	0.9
	TM	19.8	15.8	9.4	6.1	2.4	2.1	1.2	1.0	1.0	0.9	0.6	0.5
	Total	**369.4**	**223.6**	**99.5**	**55.9**	**23.2**	**19.2**	**68.2**	**37.3**	**20.3**	**14.2**	**10.6**	**9.1**
PWR (W)	ARRAY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PREAMP	1188.2	948.9	564.9	366.1	145.2	125.3	74.1	59.2	57.7	52.5	35.0	32.9
	PA	20.6	20.6	15.9	12.9	11.1	12.0	17.7	17.7	17.7	17.7	17.7	17.7
	A/D,MUX	792.1	632.6	376.6	244.1	96.8	83.5	49.4	39.5	38.4	35.0	23.3	22.0
	TM	528.1	421.7	251.1	162.7	64.5	55.7	32.9	26.3	25.6	23.3	15.6	14.6
	Total	**2529.0**	**2023.8**	**1208.4**	**785.9**	**317.5**	**276.5**	**174.2**	**142.7**	**139.4**	**128.6**	**91.6**	**87.3**

A and B Predictions for SAS vs. Vehicle Size

- PCSWAT 6.0 was used for all performance predictions
  - It is an energy sonar prediction model with outputs of echo-to-reverberation ratios (ER), return signal strengths, bottom, surface and volume reverberations levels and a variety of others
  - Accurately predicts the ER, based on verification with a number of minehunting sonars
  - Accurate prediction of the ER allows for the easy prediction of Pd and Pfa
- Each of the Six SAS's take advantage of the vehicle size and length
  - Sonar Array Length = 75% of total length of the vehicle
  - Vehicle Length was Assumed to be 10x the diameter
  - Each sonar was designed to for 1 inch resolution when the center frequency would support the bandwidth
  - Bandwidth was calculated to be 25% of the center frequency
  - Assumed constant angular resolution of 0.01 degrees
- Environment consisted of two bottom types – sand and gravel – and a isovelocity SVP
- Results and examples are contained in the SAS section of the "MCM Future Systems Study Workbook"

Simplified Equation for Determining Array Length

- Let ACR denote Area Coverage Rate (nmi^2/hr) and AL denote Array Length (ft). The constant 0.24 nmi^2/hr is related to the speed of sound and an array length of 1 ft.

$$ACR = \left(\frac{0.24 nmi^2/hr}{1ft}\right)(AL)$$

- Again, let ACR denote Area Coverage Rate, V the speed (nmi/hr) and R (nmi) denote the one sided detection radius.

$$ACR = 2VR$$

- Set both equations equal to each other and solve for the variable of interest. In this case it is Array Length

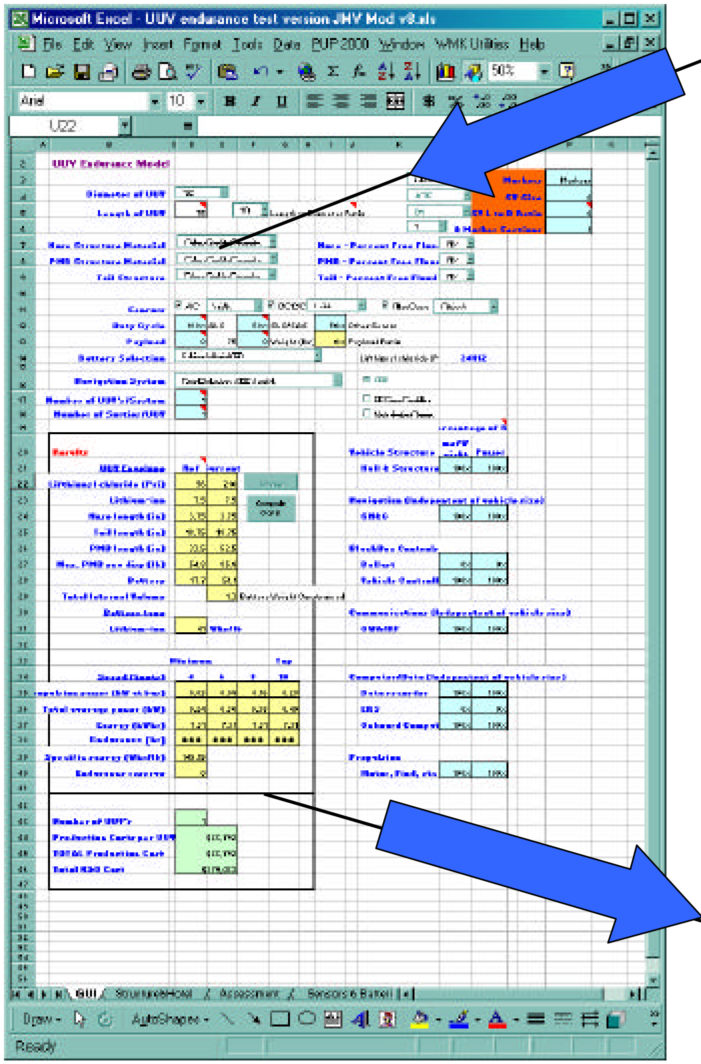
$$AL = \frac{2VR(1ft)}{0.24 nmi^2/hr}$$

Simplified Equation for Determining Array Length - Example

- Here, let V = 20 nmi/hr and R = 200 yds (~0.099 nmi) denote the one sided detection radius. Then ….

$$AL \approx \frac{2(20\text{nmi/hr})(0.099\text{nmi})1\text{ft}}{0.24\text{nmi}^2/\text{hr}} = 16.5\text{f}t$$

Combined Cost / Endurance Model



Inputs -- UUV Physical Characteristics
Size; Material; Sensors; Payload

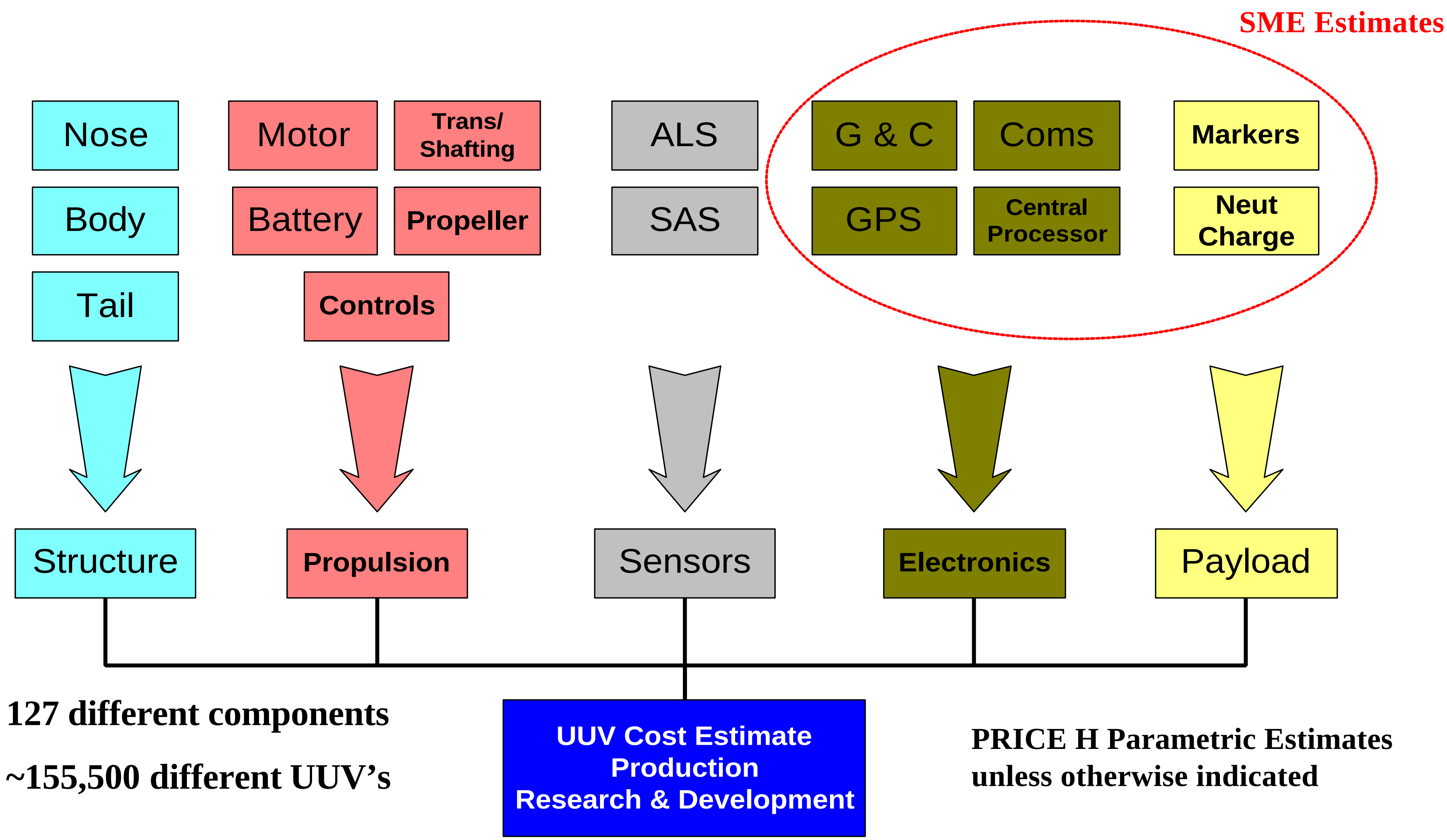
The UUV's physical characteristics (diameter, length, hull material) along with its sensor suite (ALS, SAS, ID Sensor) determine its electrical load and the size of the battery, which leads to endurance estimates after taking any size reduction for smaller UUV's which might be carried by the larger UUV into account. Packing factors and neutral buoyancy assumptions help determine endurance.

Physical characteristics are linked to a database of components costs which are combined to determine cost estimates.

Outputs -- Endurance at 4-6-8-&10 Kts,
Unit Production Costs, R&D Costs

Future MCM Study

Cost Estimating Structure



Cost Estimate Assumptions

- Lot Size and Prototypes
  - 36 & 54 inch: 10 per lot, 2 prototypes
  - 21 inch: 20 per lot, 2 prototypes
  - 12.75 & 7.5 inch: 100 per lot, 10 prototypes
  - 4.875 inch: 1000 per lot, 10 prototypes
- Production
  - Start 2010
  - Complete 2015

- UUV's only
- Linear technology progress assumed
- Battery estimates based on projected results based on automotive applications
- 3 Levels of Navigation sophistication (accuracy and cost)
- All data processing resides on a single common module

Types of Costs

- Procurement (expendable)

  Costs expended each time the system is used

  – Expendable UUV's, Primary battery batterypacks

- Procurement (non expendable)

  Costs spread over multiple system deployments

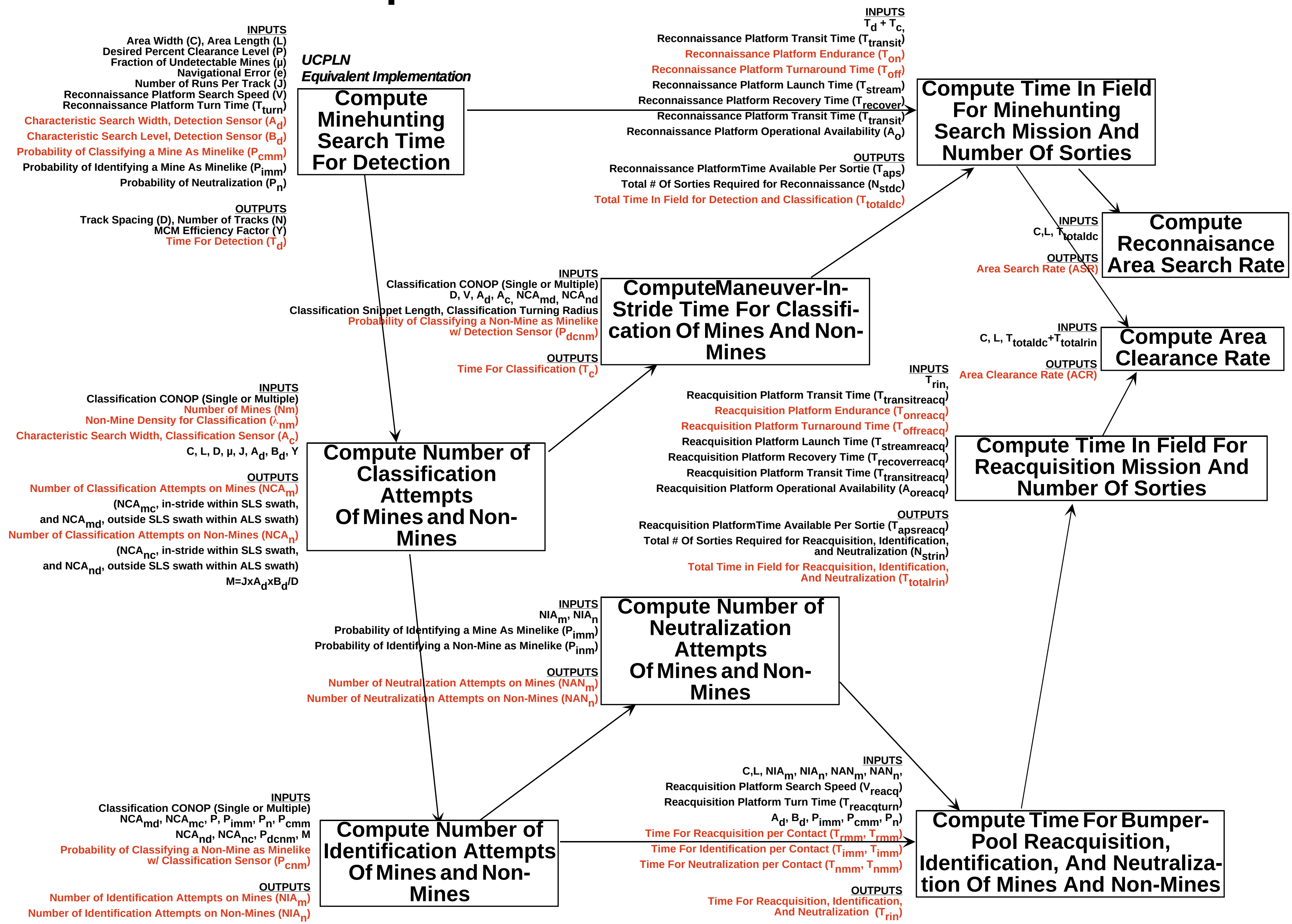
  – Recoverable UUV's

- Supporting Systems Costs

  Relevant costs are "opportunity costs": What mission is not accomplished so the assets are available for MCM?

  – Non MCM dedicated support systems
    - Surface craft
    - Submarines
    - Aircraft
    - UAV's

FUTURE MCM STUDY
Matlab Model Implementation Of PEO-MIW Instruction 3370

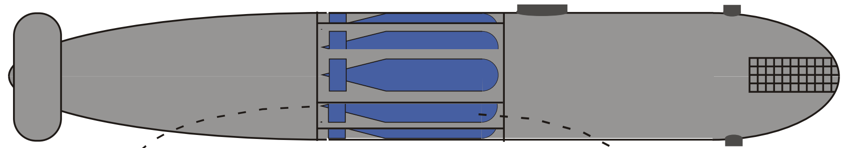


Section 4: Final Six System Concepts

- Type I’s, Type II’s, & Type III’s: two each
- component vehicles and sensor configurations
- mission profiles
- mission tactics

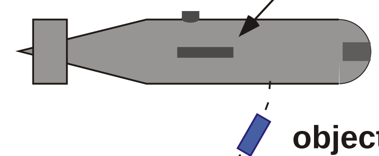
HIGH LEVEL SYSTEM CONCEPTS DESCRIPTIONS

TYPE I SYSTEM CONCEPT
search vehicle w/ small "bird dog"vehicles for class/ultra-class/ID/marking



Large Vehicle (LV)

- wide swath search vehicle
- host for SVs
- launches SVs for close target inspection ("bird dogs")
- options include submerged and surface vehicle
  - 3 sub-surface vehicles were modeled
    - 21“, 36”, 54“
    - hosting 4 to 28 SVs
  - submerged vehicle provide covert BSP pre-neutralization missions
- sensors
  - ALS
    - wide area search
    - OAS
    - object detection/discrimination
    - two options per vehicle
    - swath: (1029 yds -> 3578 yds)
    - bottom lock nav.
  - GPS when near surface
  - homing beacon for SVs
  - close range comms with SVs
- SVs are docked in a ring around perimeter of LV
- speed: 4 to 10 kts



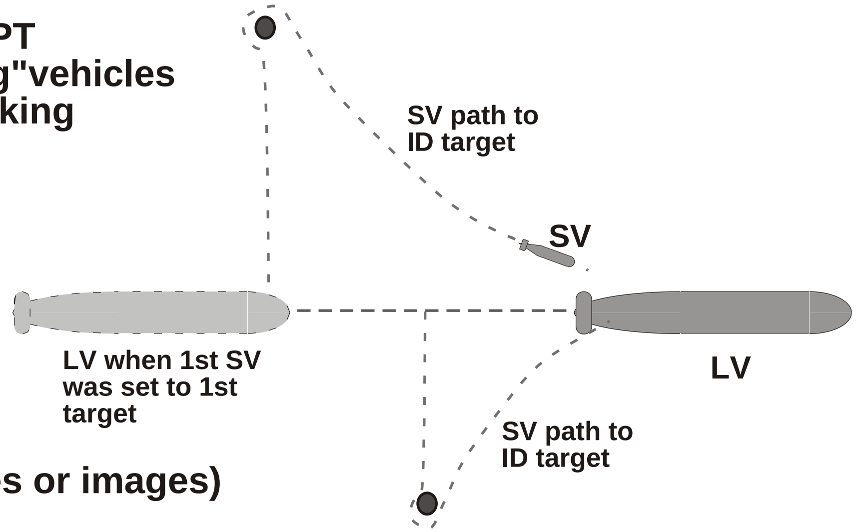
Small Vehicle (SV)

- ultra-class/ID vehicle
- submerged vehicle
- bird dogs for LV
- Sensors
  - ALS
    - object localization
    - OAS
    - classification on approach
    - swath: (513 yds -> 1427 yds)
    - beacon follower on return
  - sidelooking array
    - short range SLS or SAS
    - ultra-classification or ID
- Nav
  - INS and beacon follower
- markers dropped at MLO
- Launch/recovery (TBD)

• covert (w/ submerged LV option)
• matches vehicle endurances w/ tasks
• matches sensor ranges w/ vehicle tasking
• high ACR ~ LV search rate
• supports BSP mode for exploratory search
• matches other platform’s sensors configs.

HIGH LEVEL SYSTEM CONCEPTS DESCRIPTIONS

TYPE I SYSTEM CONCEPT
search vehicle w/ small "bird dog"vehicles
for class/ultra-class/ID/marking



Mission Profile

- Host launches LV
- LV transits to op. area @ 4 to 8 kts
- LV searches/detects/discr. MLOs
- LV launches an SV and vectors to contact
- SV relocates and class/ID objects
  - records discr./class/ID data (e.g. discr. clues or images)
- SV may drop a marker for MLO
  - unique ID number
  - grid location
  - acknowledges marker functionality & set to "stand by"
- SV returns to LV with ultra-class/ID data
  (for full recovery or for re-vectoring)
- LV, at end-of-track or area (options)
  - transmit data to host
- LV returns to host
- Final data upload

- Nav (LV)
  - GPS fixes and/or bottom lock
  - SVs return via LV-beacon or LV-ALS detection
  - GPS nav fix at least start & finish

OPArea ACR: 162 to 415 nm^2/day

Required # SVs

Factors
- LV swath width
- contact density
- LV & SV velocities
- LV ALS w/ good discrimination

Estimate: ~8 SVs (< 16)

Issues

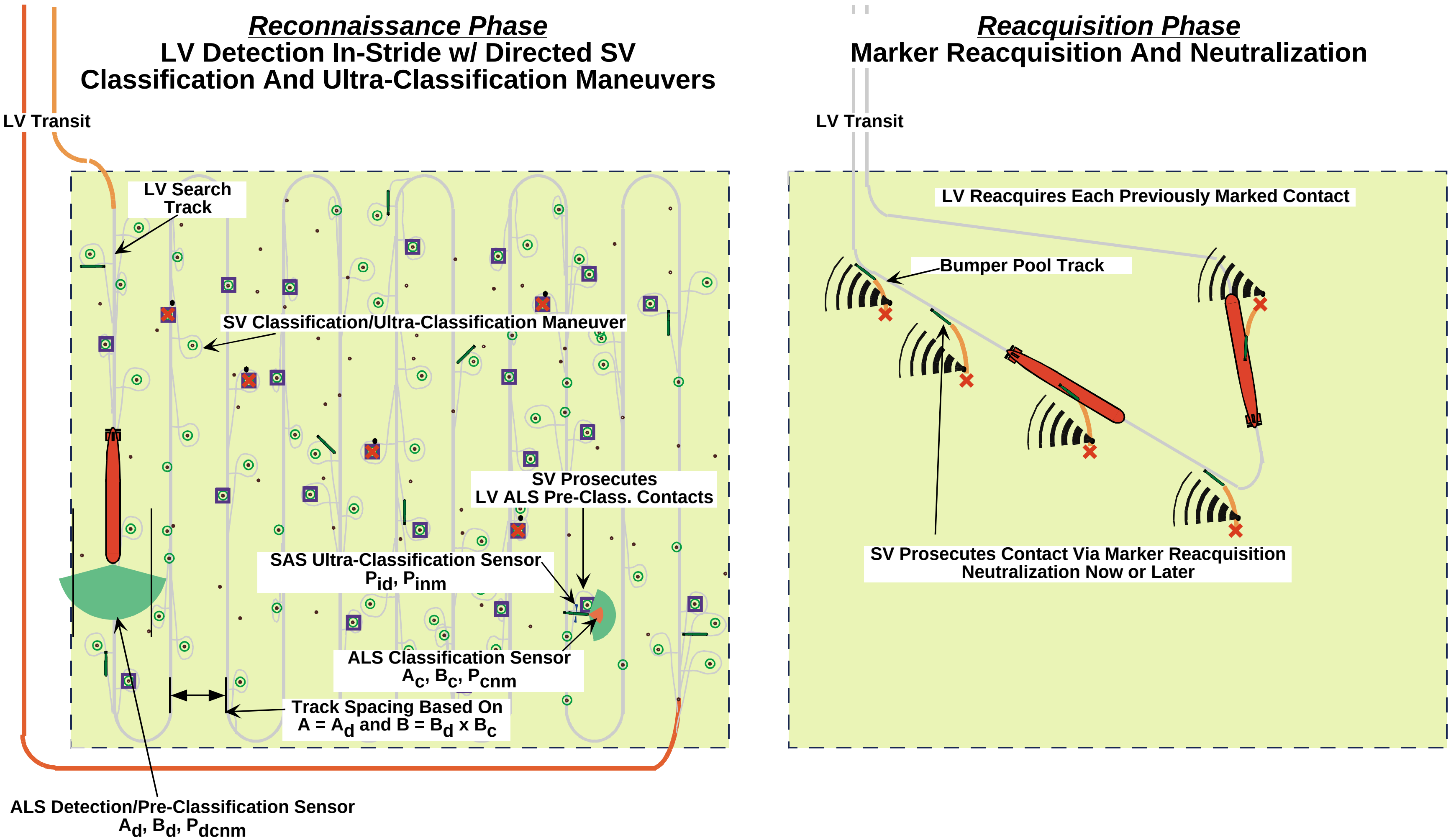
- handling too many contacts
- minimizing # markers dropped
- maximizing LV search performance
- energy management between LV & SVs
- L&R of SVs

"least cost selection"

	ACR	
	Threshold	Objective
CVBG (54%)	244	250
MDA (95%)	17	50
SLOC (95%)	22	52
AOA (95%)	1.6	5

Type I System CONOPS

Autonomous Undersea Vehicle w/ Bird Dog UUVs



Symbol Legend: MILCs, Mines, Markers

- LV ALS Detection
- LV ALS Preliminary Classification
- SV ALS Classification
- SV SAS Ultra-Classification
- SV Dropped Marker

Reconnaissance Mission Time Includes:

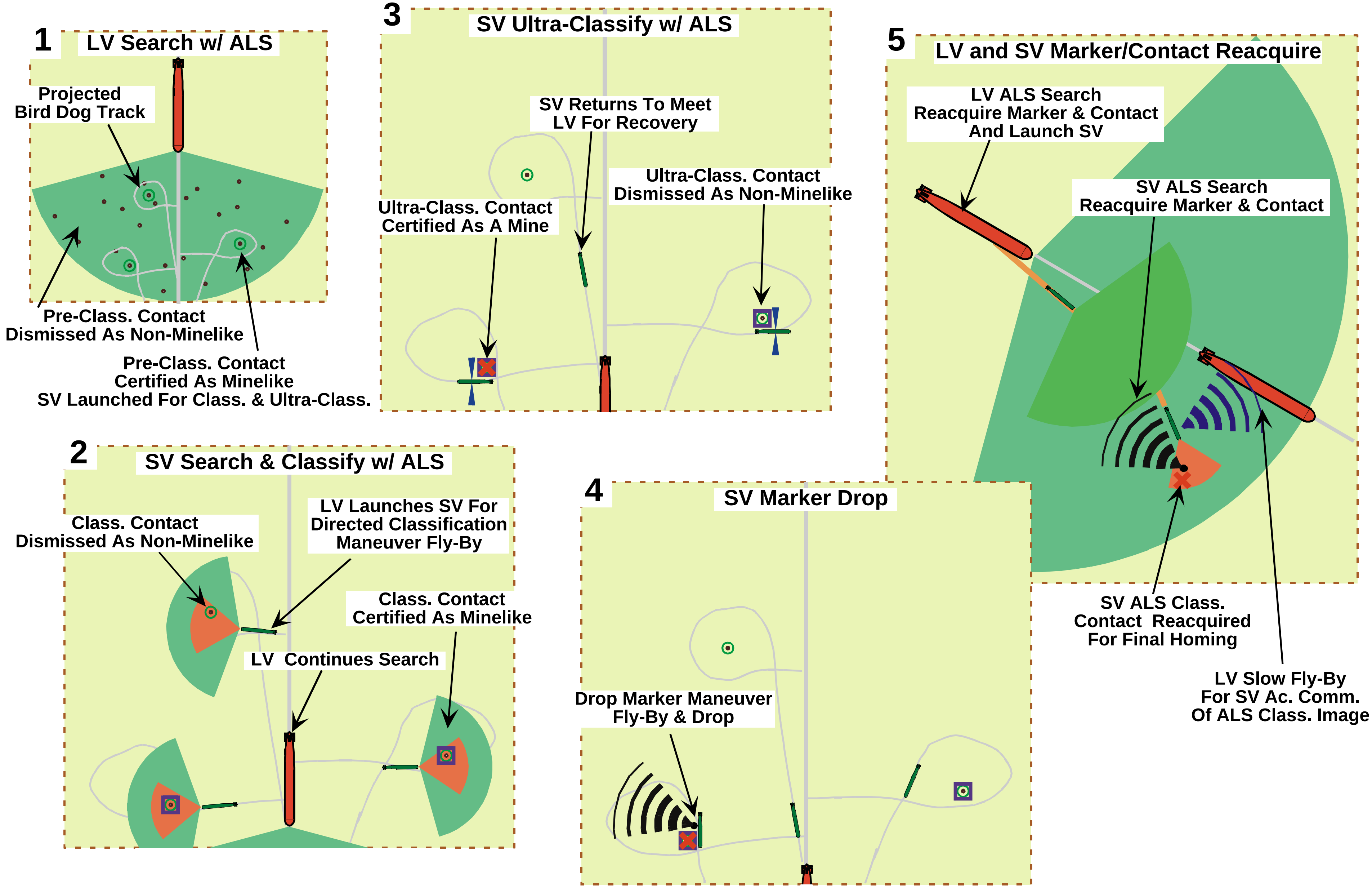
- LV Launch And Recovery By Host
- LV Two Way Transit
- LV Search

Reacquisition Mission Time Includes:

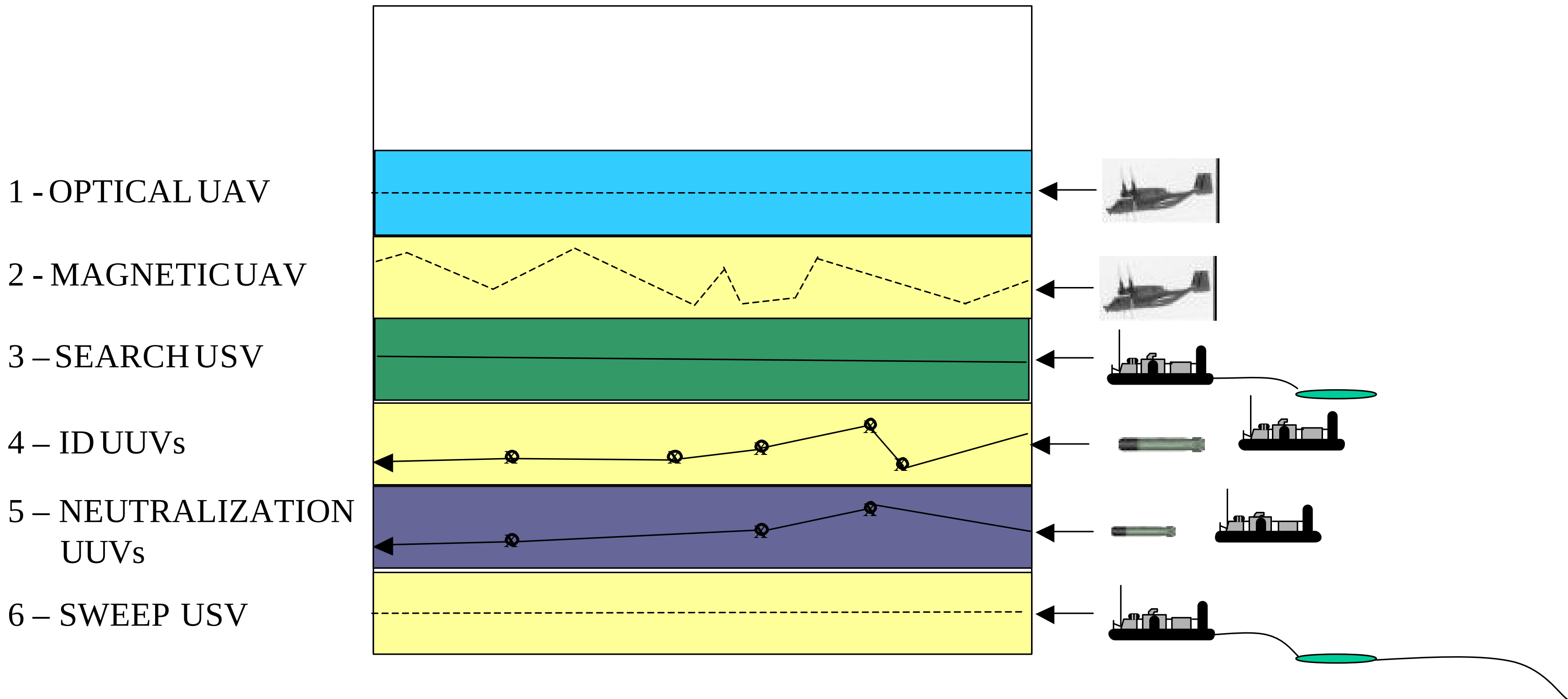
- LV Launch And Recovery By Host
- LV Two Way Transit
- LV Bumper Pool Between Contacts
- SV Launch, Marker Reacq., & Ac. Comm.

Type I System, LV and SV CONOPS Stages

Autonomous Undersea Vehicle w/ Bird Dog UUVs



FUTURE MCM STUDY
Type I System Concept
Multiple Unmanned Vehicle Types



FUTURE MCM STUDY
Type I System Concept
Multiple Unmanned Vehicle Types

Mission Profile:

1. Optical UAV:
    - First UAV to Optically Search for Near Surface Mines
2. Magnetic UAV:
    - Second UAV Uses Super Conducting Gradiometer (SCG) to "bumper pool" Optical Contacts
3. Search USV
    - SAS/ALS to Detect and Classify Volume and Bottom Mines
        - GPS Navigation and RF Communications With Fleet
        - Launch and Recovery Capability for UUVs
4. Identification UUVs
    - Reacquire Contact and If Identified as a Mine, Place Marker
5. Neutralization UUVs
    - 4.875" or 7.5", Bulk Charge to Neutralize Mines (~60 lbs)
6. Sweep USV
    - USV Sweeps Area for Undetectable Mines

FUTURE MCM STUDY
Type I System Concept
Multiple Unmanned Vehicle Types

Concept:

Unmanned Air Vehicles (UAVs), Unmanned Surface Vehicles (USVs), and Small Unmanned Underwater Vehicles (UUVs)

1. Detect & Classify: UAVs - near surface mines; USVs - bottom and volume mines
2. ID & Mark: UUVs to "Bumper Pool" Contacts
3. Neutralization: UUV Uses Bulk Charge

Description:

- UAV - Endurance: 8 hours, Search Speed: 60 knots for Optical, 200 knots for Magnetic
- USV - Endurance: 36 hours, Search Speed: 20 knots
- UUV - Endurance: 4.875" x 36", 4 hours, Search Speed: 4 knots

Sensors:

- UAVs – A: Electro-Optical (E-O) Sensor Package; B: Super Conducting Gradiometer (SCG)
- USV - Towed SAS for Detect & Classify
- UUVs – A: ID with 3 Element High Frequency SAS; B: Bulk Charge for Neutralization

Communications & Navigation:

- RF Link to Exchange Data With Fleet
- GPS Navigation

Measures of Performance:

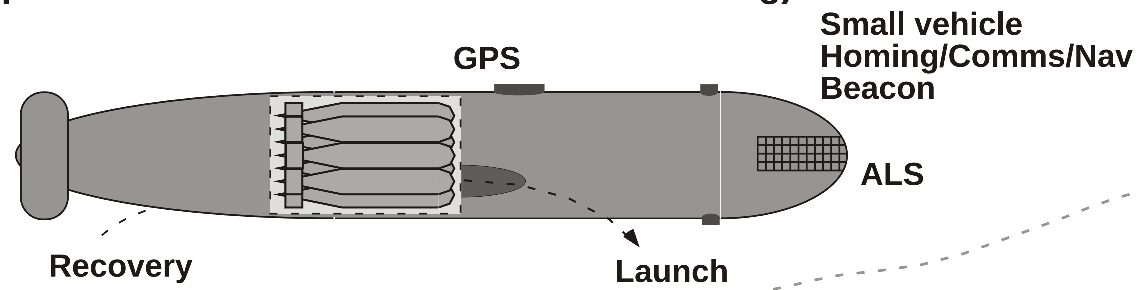
Operations Area	ACR per Mission, nm^2/hr	Number Required
CVBG	UAV: 10.9 @ 95% USV: 6.6 @ 54%	UAV: 4 USV: 2 UUV: 119
SLOC	UAV: 9.4 @ 95% USV: 5.0 @ 68%	UAV: 4 USV: 2 UUV: 74
AOA – 40/120 (1 Lane)	UAV: 4.9 @ 95% USV: 1.6 @ 95%	UAV: 2 USV: 1 UUV: 8

Issues:

- Mission Planning to Coordinate Multiple Vehicle Usage in Optimal Fashion
- Availability of LCAC for Mission or Alternative (11 m. RHIB, etc)
- Deck Space for Launch of UAVs (Amhpibs or CV host)
- Launch and Recover of UUVs by USVs

HIGH LEVEL SYSTEM CONCEPTS DESCRIPTIONS

Type II SYSTEM CONCEPT
(transport w/ small vehicles for search/ID/marking)

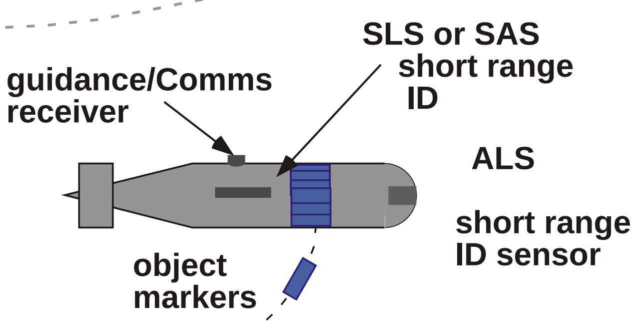


Large Vehicle (LV)

- primarily transport for SVs
- may provide guidance to SVs
- launch SVs as a group
- options include submerged and surface vehicle
  - 3 sub-surface vehicles were modeled
    - 21“, 36”, 54“
    - hosting 8 to 91 SVs
  - submerged vehicle provide covert BSP
- ALS
  - OAS
  - wide area search in volume target areas
  - high AG receiver for SVs comms
  - swath: (1029 yds -> 3578 yds)
- nav
  - periodic or continuous GPS when near surface
  - bottom lock when engaging the sea floor
- speed: 4 to 10 kts

Small Vehicle (SV)

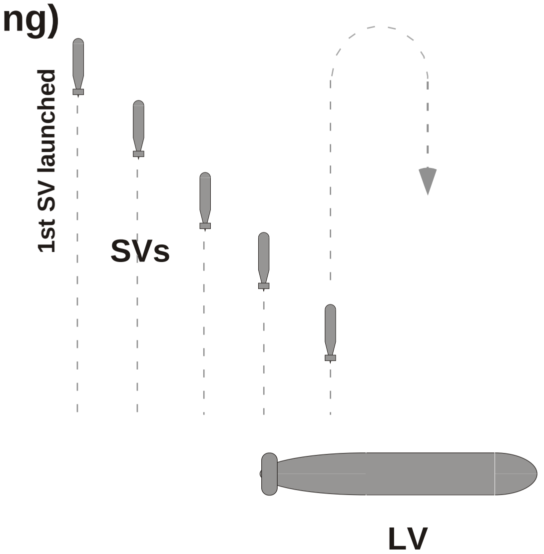
- submerged vehilce
- search/ultra-class/ID & mark
- search parallel tracks
- ALS
  - OAS
  - object detect/discr
  - class (dual mode)
  - swath: (513 -> 1427 yds)
  - beacon follower on return
- Sidelooker: ALS or SAS
  - short range
  - ultra-class/ID
- Nav
  - INS
  - beacon return to LV
- Launch/recovery (TBD)



- covert (w/ submerged LV option)
- high ACR: multiple SV search vehicles
- supports BSP mode for exploratory search
- matches other platform’s sensors configs.

HIGH LEVEL SYSTEM CONCEPTS DESCRIPTIONS

Type II SYSTEM CONCEPT
(transport w/ small vehicles for search/ID/marking)



Mission Profile

- Host launches LV
- LV transits to op. area
- LV launches SVs in parallel tracks
- SV search/detect/discr./class/ID objects
  - records discr./class/ID data (e.g. discr. clues or images)
  - records grid location
- SV drops marker
  - unique ID number
  - grid location
  - acknowledges marker functionality & set to "stand by"
- SV transmits to LV drop data
  - partial immediately
  - full when capable
- At end-of-track or end-of-marker-supply
  SV returns to LV via homing beacon
- Final data up load
- LV transmits data to host
- LV returns to host

Op Area ACR: ~ 65 to 348 nm^2/day

"least cost selection"

	ACR Threshold	ACR Objective
CVBG (54%)	76	184
MDA (95%)	18	37
SLOC (95%)	21	52
AOA (95%)	1.6	4.7_

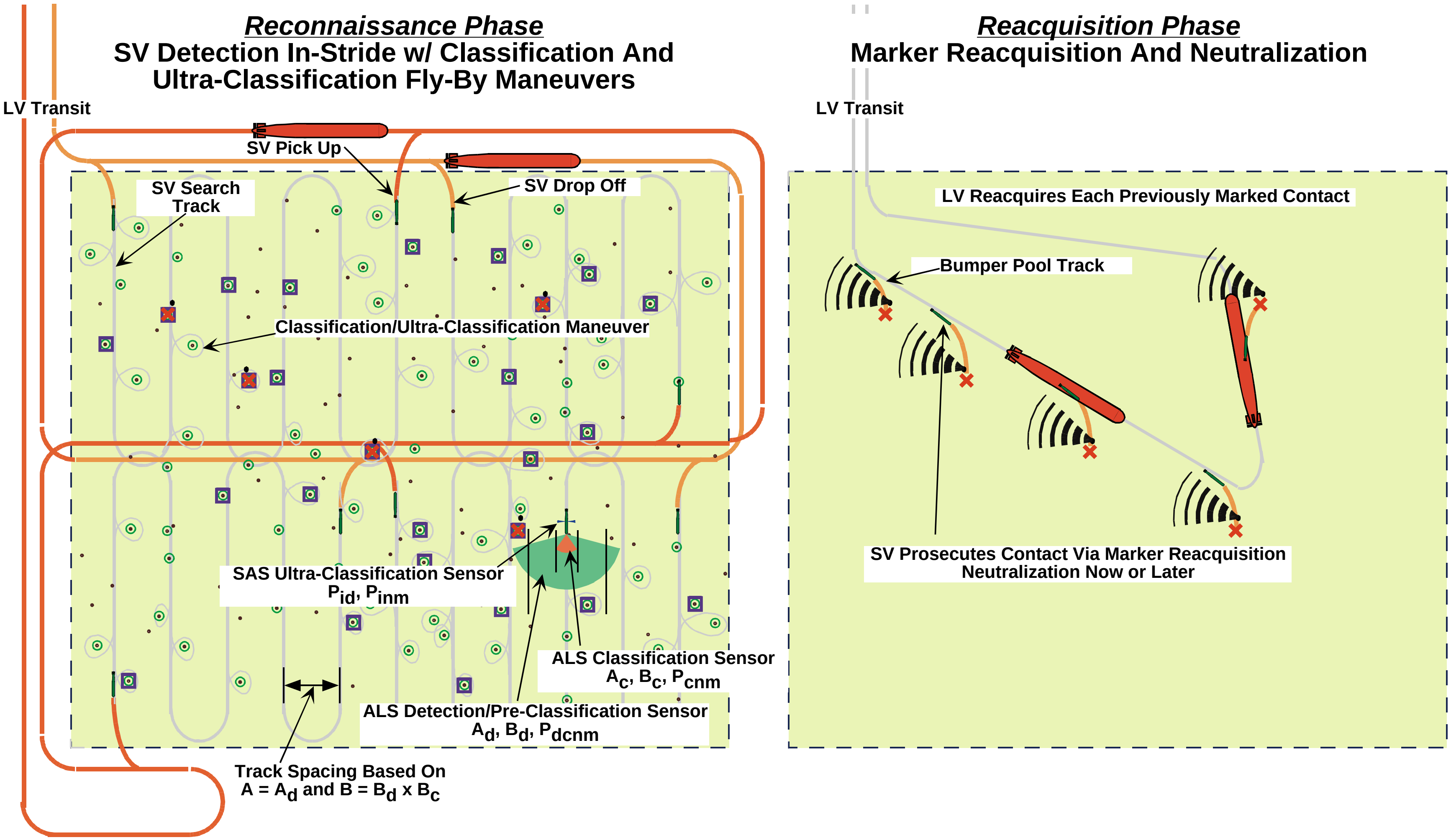
Mission Profile (Deep Water Areas)

- Host launches LVs
- LVs transit to op area
- LV searchs/detect/discr objects
  - when FC/nm is low
- Nav: periodic GPS or bottom lock
- LV records locations
- LV transmits data to host
- LV returns to host

Issues
- SV coordinated nav
- minimizing # markers dropped
- L&R of SVs

Type II System CONOPS

Coordinated Multiple Undersea Reconnaissance Vehicles



Symbol Legend: MILCs, Mines, Markers

- SV ALS Detection
- SV ALS Preliminary Classification
- SV ALS Classification
- SV SAS Ultra-Classification
- SV Dropped Marker

Reconnaissance Mission Time Includes:

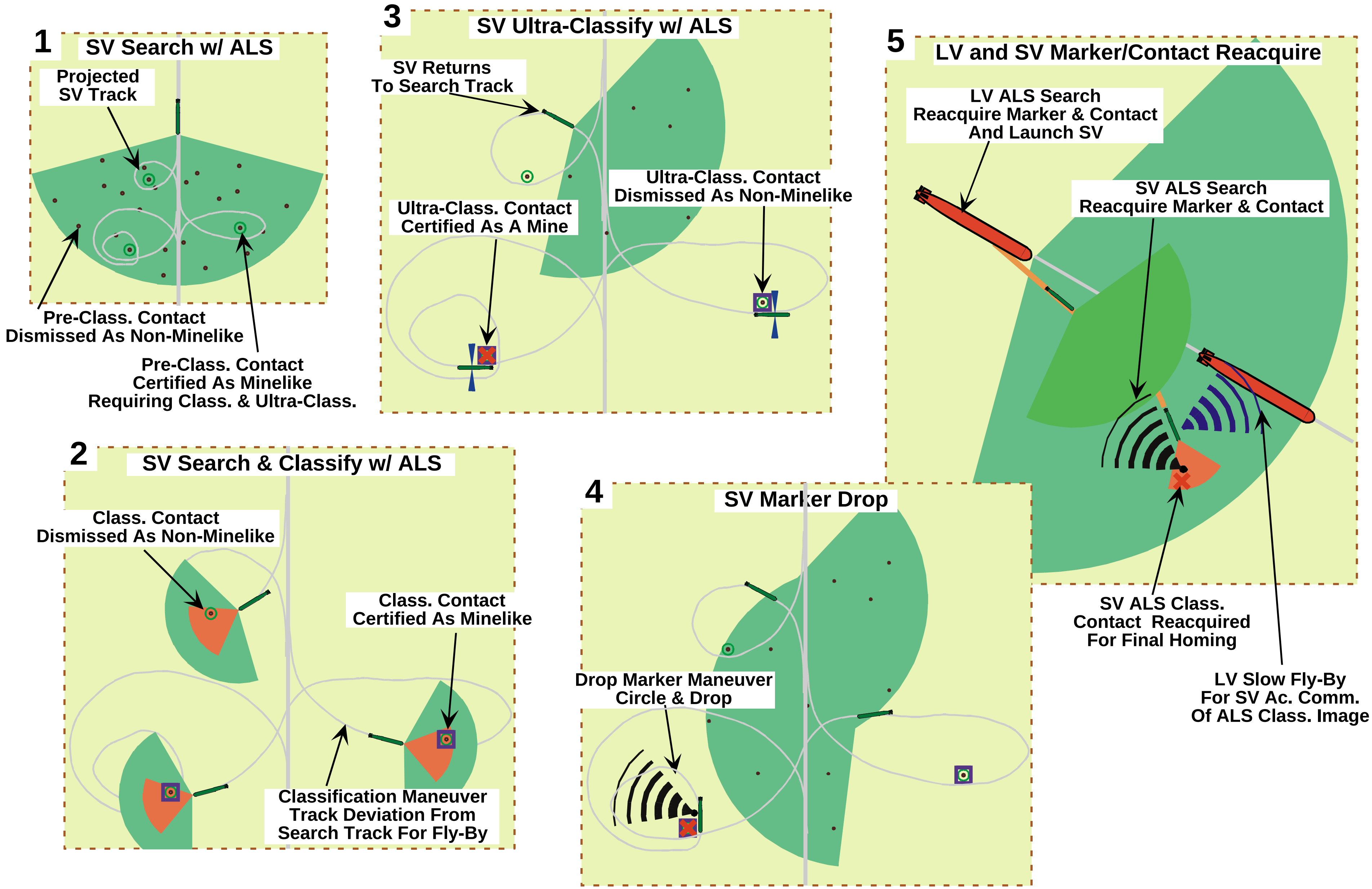
- LV Launch And Recovery By Host
- LV Two Way Transit
- LV Transit Between SV Drop Off And Pick Up
- SV Launch And Recovery By LV
- SV Search
- SV Class. and Ultra-Class. Maneuver
- SV Marker Launch

Reacquisition Mission Time Includes:

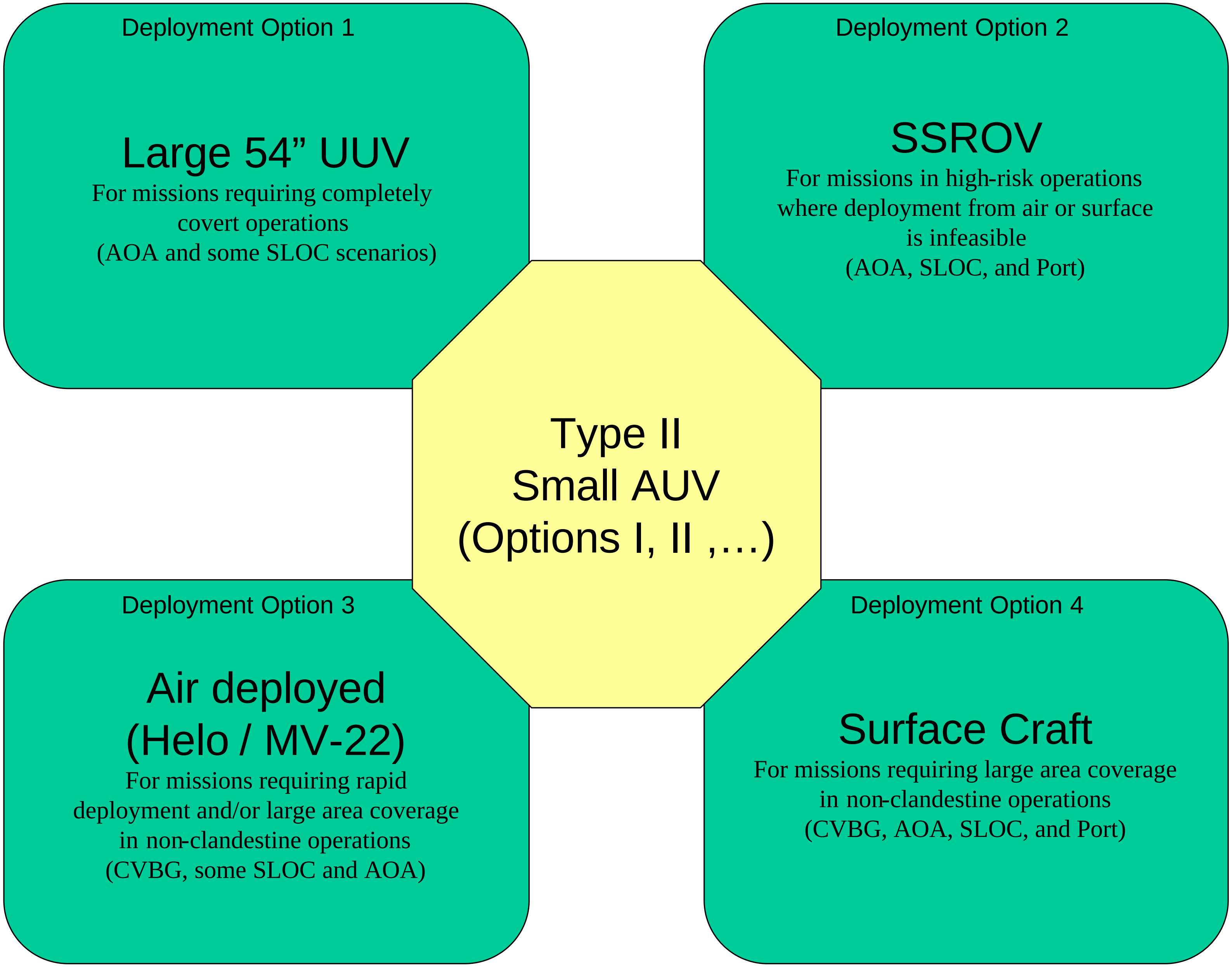
- LV Launch And Recovery By Host
- LV Two Way Transit
- LV Bumper Pool Between Contacts
- SV Launch, Marker Reacq., & Ac. Comm.

Type II System, LV and SV CONOPS Stages

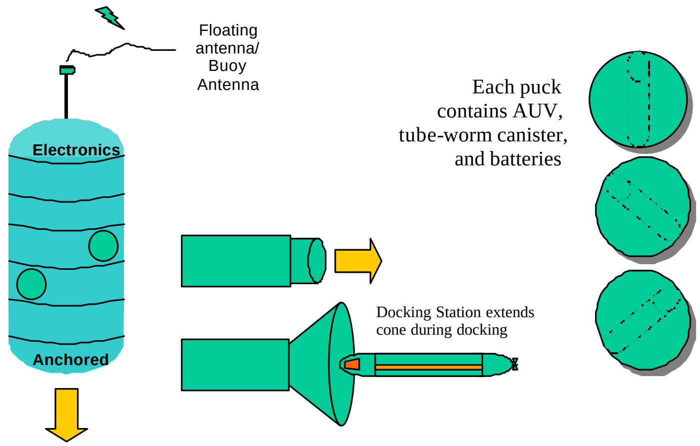
Coordinated Multiple Undersea Reconnaissance Vehicles



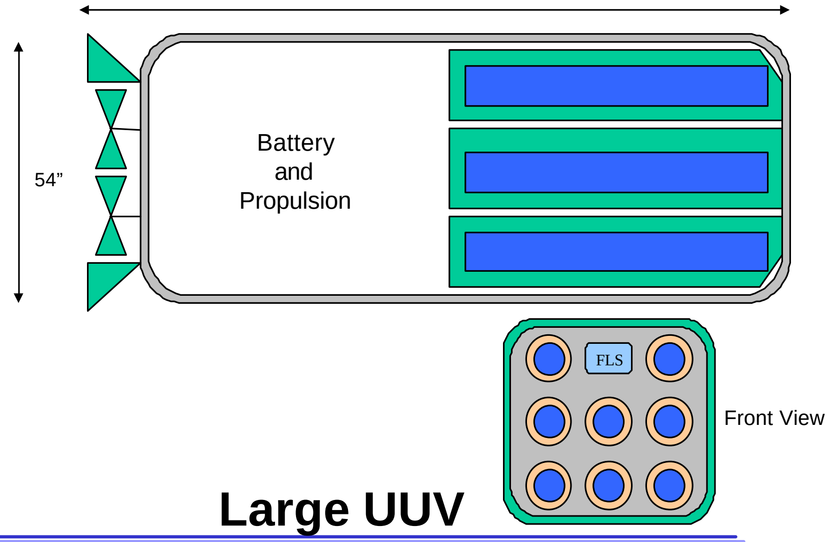
FUTURE MCM STUDY
TYPE II COVERT AND OVERT TRANSPORT VEHICLES WITH ROBUST SMALL UUVS



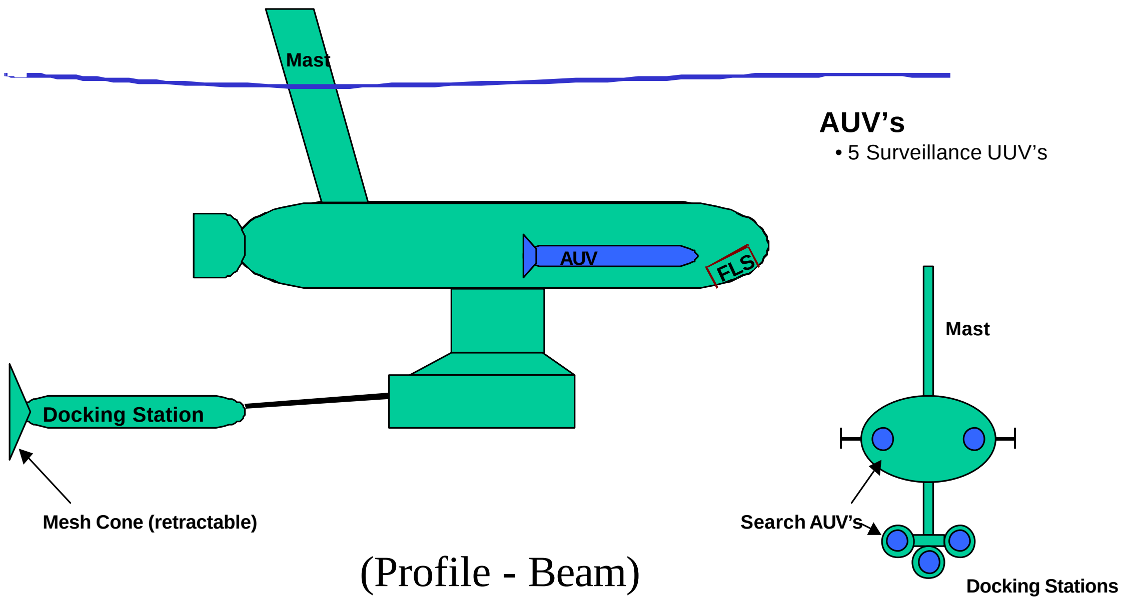
FUTURE MCM STUDY
TYPE II COVERT AND OVERT TRANSPORT VEHICLES WITH ROBUST SMALL UUVS



Airlift



Large UUV



(Profile - Beam)

SSROV

FUTURE MCM STUDY
TYPE II COVERT AND OVERT TRANSPORT VEHICLES WITH ROBUST SMALL UUVS

Delivery Platform: Large UUV, 21" UUV, SSROV, Air Lift, Surface Craft Non-Expendable UUVs

Delivery Platform

#	5"	7"	12"
Large UUV	24	16	10
21" UUV	8	6	na
SSROV	na	5	na
Air Lift	58	21-25	6
Surface	58	21	6

- Platform Deployment Speeds
  10 kts ~ Large UUV
  10 kts ~ SSROV
  150 kts ~ Aircraft

- Recharge Capability

- Communications Capability

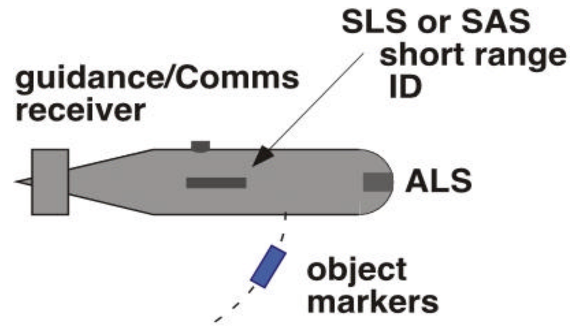
Summary

- Range from covert (UUV) and slow to OVERT (A/C) and fast

- Replenish Power Supply

Systems

- 5" DIA (15:1)
- 7" DIA (8:1 and 10:1)
- 12" DIA (8:1 and 10:1)



Comms/Recharge Node

- Large UUV ~ Internal
- 21" UUV ~ Internal
- SSROV ~ Internal
- Air Lift ~ Deployed Pod
- Surface ~ Drogue or Onboard

UUVs

Search/Detect/Classify/ID
Deploy Markers
ALS (Wide)
SAS (Narrow/Wide)

Robust NAV
Rechargeable
Speeds 4 to 10 kts

FUTURE MCM STUDY
TYPE II COVERT AND OVERT TRANSPORT VEHICLES WITH ROBUST SMALL UUVS

Delivery Platform: Large UUV, 21" UUV, SSROV, Air Lift, Surface Craft
Non: Expendable UUVs

Mission Profile

- **Large 54" UUV**
  Missions requiring covert 10 kt delivery
- **21" UUV**
  Missions requiring covert 10 kt delivery
- **Air Delivered Host**
  - Rapid deployment/long starting time
    - Overt
    - 150 kt delivery
- **Swath/Surface Ship**
  - Human intervention
  - Overt
  - 20 kt delivery
- **SSROV**
  - Long endurance
  - Covert
  - 10 kt delivery

NAV

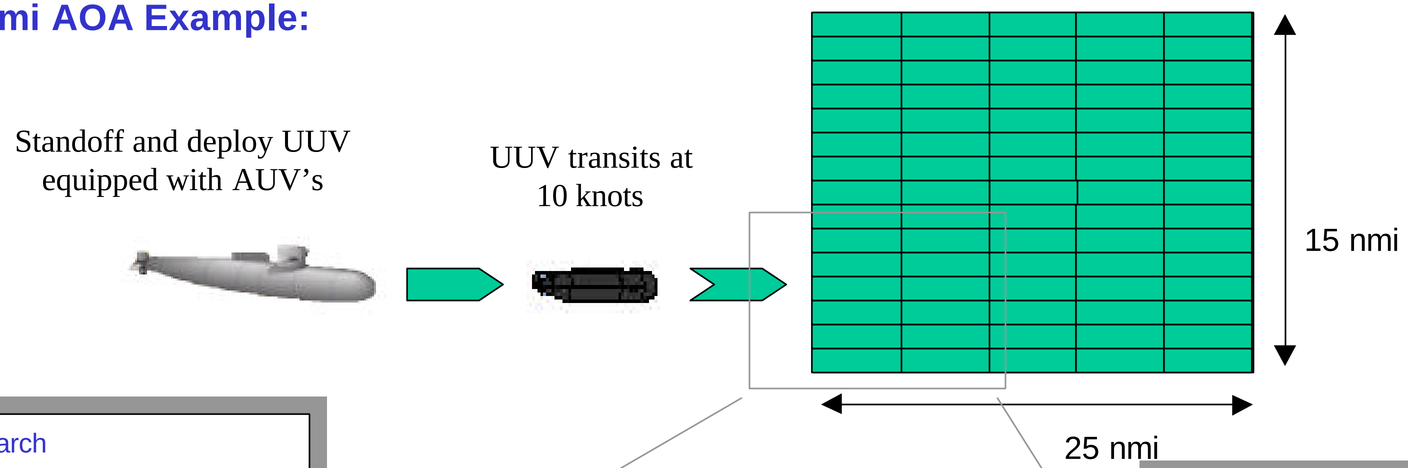
- GPS initial fix
- Updates from Comms node
- Battery recharge during Comms
- INU
- GPS at completion
- UUV returns to docking bay at conclusion

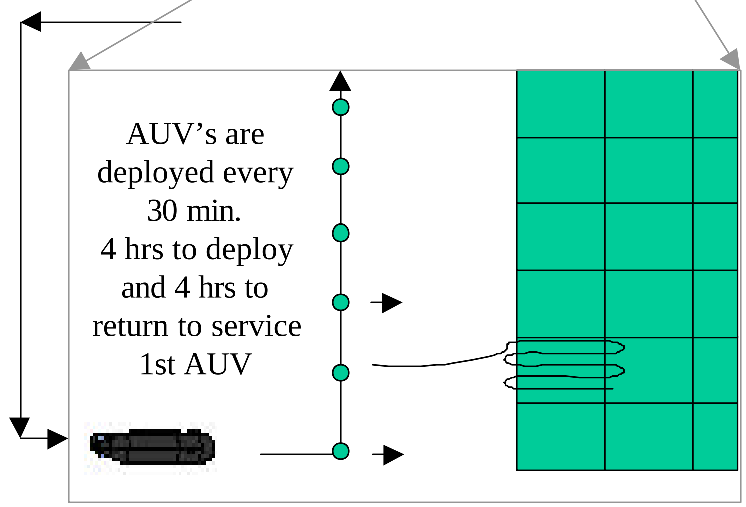
Required Number of UUVs

- **Non-Expendable**
- **Search ® ID**
  Mark
  Neutralize
- **Factors**
  - BT 4/9
  - NOMBO density (10/30)
  - Endurance
    - Battery (primary/secondary)
    - Payload
- **Issues**
  - Number of contacts
  - Mission planning

FUTURE MCM STUDY
TYPE II COVERT/OVERT TRANSPORT VEHICLES WITH ROBUST SMALL UUVS
CONOPS: AOA MINEHUNTING EXAMPLE

- **15 x 25 nmi AOA Example:**





- Bottom mine search
  - **15x25 nmi AOA**
  - **53% Clearance**
  - **A: 200 yds, B: 0.80 (assume SAS)**
  - **Speed 6 knots**
- UCPN Results
  - **75 AUV missions, 1 per 1x5 box**
  - **6.5 hr recon + 1.5 hr transit and 5 hr recharge, total mission time is ~120 hrs using 8 recon UUV's**
  - **For 25 nmi transit, total time is 130 hours to perform recon at 53% clearance level of effort**

- Volume mine search
  - **15x25 nmi AOA**
  - **53% Clearance**
  - **A: 360 yds, B: 0.95**
  - **Speed 6 knots**
- UCPN Results
  - **38 AUV missions, 1 per 2x5 box**
  - **7 hr recon + 1 hr transit and 5 hr recharge, total mission time is ~65 hrs**
  - **Total time is 75 hours to complete**

FUTURE MCM STUDY
TYPE II TRANSPORT VEHICLE DATA

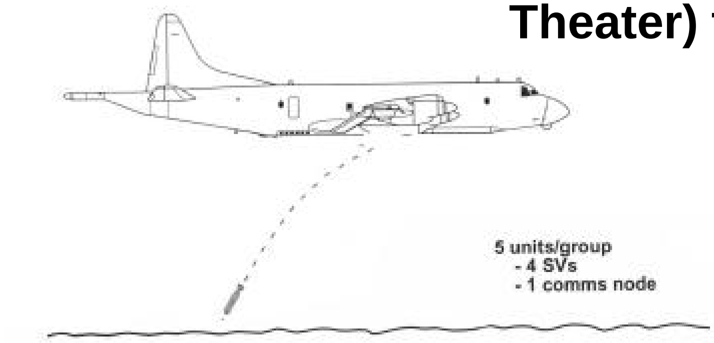
				Transport Vehicle Parameters									
				Covert						*Non-Covert*			
				Lg UUV		SSROV		Med UUV		Surf Craft		comm/recharge node	
				volume: 429.4		*volume:* 289		*volume:* 42		*volume:* varies w/ UUV		*volume:* 450	
Small UUV Dimensions				*dis. (lbs):* 40460		*dis. (lbs):* 14000		*dis. (lbs):* 2379		*dis. (lbs):* varies w/ UUV		*dis. (lbs):* varies w/ UUV	
width (in)	ratio	vol. (ft^3)	dis. (lbs)	capacity	endurance (hrs)	capacity	endurance (hrs)	capacity	endurance (hrs)	capacity	endurance (hrs)	capacity	endurance (hrs)
4.875	15	0.85	46.6	24	198.92	-	-	8	51.35	58	unl	58	unl
7.5	8	1.90	83.9	16	191.64	-	-	6	38.68	25	unl	25	unl
7.5	10	2.20	108.4	16	181.19	5	24	6	17.97	21	unl	21	unl
12.75	8	6.30	412.0	10	123.19	-	-	-	-	6	unl	6	unl
12.75	10	7.90	532.6	10	93.56	-	-	-	-	6	unl	6	unl
21	8	33.7	1840.8	-	-	-	-	-	-	1	unl	1	unl
21	10	42	2379.6	-	-	-	-	-	-	1	unl	1	unl

FUTURE MCM STUDY
TYPE II SYSTEM COMMENTS

- Optimum systems
  - In 7.5” to 12.75” diameter range
    - 5” systems have low endurance
    - 21” systems are costly using ACR as metric
  - Deployed from an existing platform
    - Cost of Large UUV transport is high
    - Availability of assets an issue
  - Use SAS Wide option (versus Narrow)
  - Operate most efficiently (ACR and Cost) in 6-8 knot range
- No clear trend on benefit of expendable and non-expendable systems (varies by scenario)

FUTURE MCM STUDY
TYPE III RAPIDLY DEPLOYED EXPENDABLE SMALL UUVS
STATIONARY NODE CONOPS

Delivery Platform: Small expendable UUV's (released from asset in Theater) for Search/Detect/Classify/ID/Mark



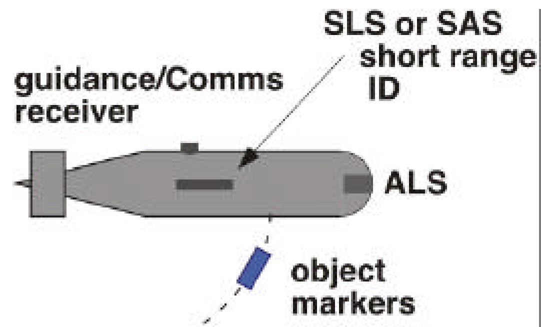
Delivery Vehicle
- Aircraft (Rapid deployment)
- Surface platform
- SSN

Deployed From
- Sonobuoy tubes (plane)
- Bomb-bay (plane)
- Over-side, 5" launcher (boat)
- 5" launcher, TDU SSN

Payload
- UUVs per sortie
- Comms node deployment
- Dependent on delivery platform

Summary
- Large payload (dependent on platform) rapid deployment
- Capable of re-seeding
- Deliver Comms relay

Systems
- 5" DIA (15:1)
- 7" DIA (8:1 and 10:1)
- 12" DIA (8:1 and 10:1)



Comms/Recharge Node
- Acoustic to UUV
- RF to A/C relay or satellite relay to host
- GPS initiation

UUVs
- Search/Detect/Classify/ID
- Deploy markers
- ALS (wide)
- SAS (narrow/wide)
- Robust NAV

FUTURE MCM STUDY
TYPE III RAPIDLY DEPLOYED EXPENDABLE SMALL UUVS
STATIONARY NODE CONOPS

Delivery Platform: Small expendable UUV's (released from asset in Theater) for Search/Detect/Classify/ID/Mark

Mission Profile

- **A/C transits to area**
- **A/C deploys UUVs**
- **UUVs searches/detects/classifies/IDs**
- **UUV deploys marker**
  - Unique ID
  - GRID location
- **UUV communicates with Comms node**
- **Comms node collects input from local UUVs**
- **Data relayed from Comms node to host via RF/SATCOM**

NAV

- GPS initial fix
- Updates from Comms node
- INU
- GPS at completion
- UUV scuttles

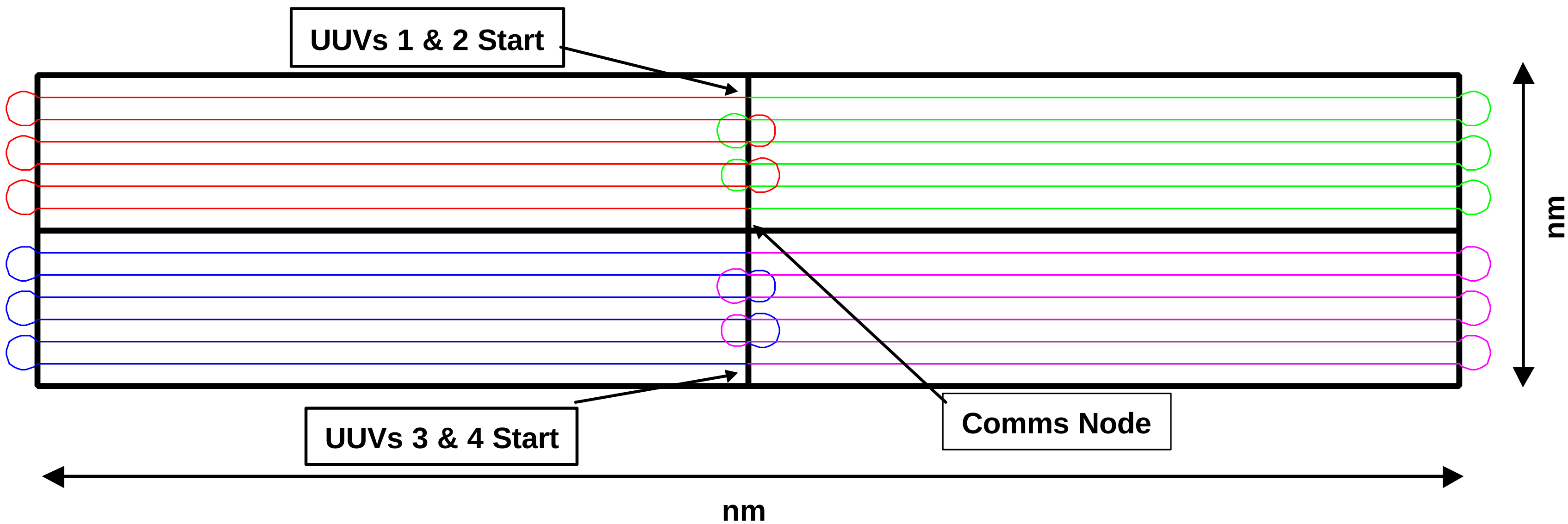
Required Number of UUVs

- **Factors**
  - BT 4/9
  - NOMBO density (10/30)
  - Endurance
    - Battery (Primary/Secondary)
    - Payload
- **Issues**
  - Number of contacts
  - Identifying failures/re-seeding
  - Data fusion
  - Mission planning
  - Track overlap (+/-)

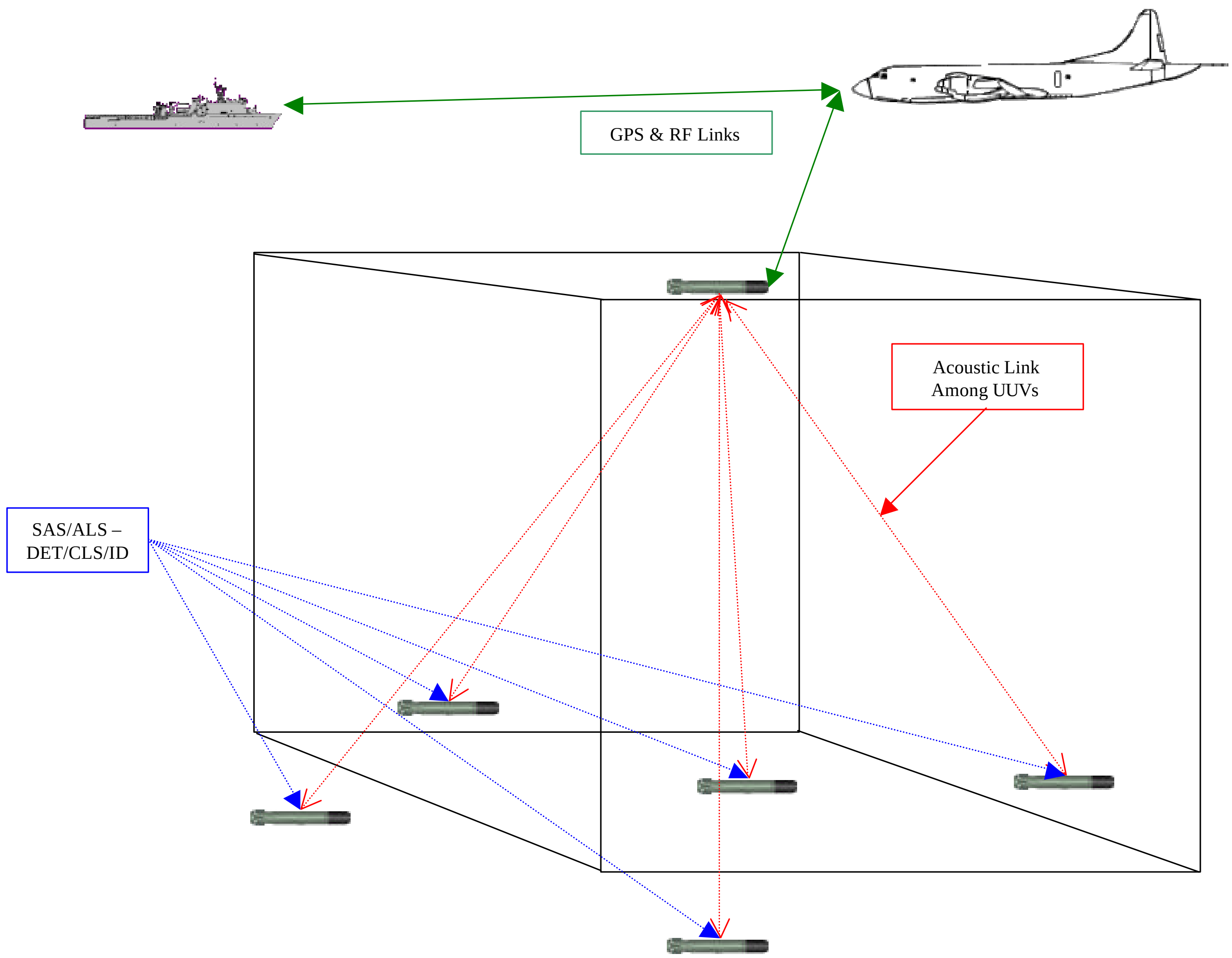
:

FUTURE MCM SYSTEMS
TYPE III RAPIDLY DEPLOYED EXPENDABLE SMALL UUVS
STATIONARY NODE CONOPS

- **Aircraft deployed system of small UUVs**
  - **4.875”, 7.5” or 12.75” diameter UUVs**
- **Search area using a subsystem of four small UUVs and a single Comms Node**



FUTURE MCM STUDY
Type III System Concept
Small Unmanned Underwater Vehicles (SSUVs)



FUTURE MCM STUDY
Type III System Concept
Small Unmanned Underwater Vehicles (SSUVs)

Mission Profile:

1. Aircraft Launches Search & Classify UUVs into Operations Area
2. UUVs Search Operations Area to Detect, Classify & ID Mine Like Objects
   - Near Surface UUV for Navigation & Near Surface Mines
   - Bottom Following UUVs for Bottom/Volume Mines
   - Acoustic Communications are Used for Bottom Navigation & Data Transfer
3. Contact Data is passed to Aircraft
4. Contact Data is Passed Back to Fleet for Analysis
5. Aircraft Launches Neutralization UUVs with Bulk Charge for Identified Mines
6. UUVs Neutralize Selected Mines as Ordered
7. Aircraft Transmit Results of Mission Back to Fleet
8. Search UUVs Scuttle

FUTURE MCM STUDY
Type III System Concept
Small Unmanned Underwater Vehicles (SSUVs)

Concept:

- All UUVs Deployed via Aircraft
  1. Detect/Classify/Identify: UUVs D/C/I Bottom and Volume Contacts
  2. Neutralization: Separate UUVs Carry Bulk Charge (~50 lbs) for Neutralization

Description:

- SAS/ALS/ID UUV: 7.5” x 75”, Speed: 4 knots, Endurance: 8 hours (**Excursion**: With 31 hr endurance based on primary battery of Lithium Thionyl Chloride: UUVs Required reduced to **60** for CVBG Scenario)
- Neutralization UUV: 4.875” x 36”, Speed: 4 knots, Endurance: 4 hours

Sensors:

- SAS to Detect and Classify Bottom Contacts/ALS to Detect Volume Mines
- Acoustic Imaging Sensor for Contact Identification

Communications & Navigation:

- Acoustic Communication Between UUVs for Data Transfer & Navigation Update
- RF Link to Exchange Data With Fleet
- GPS Navigation

Measures of Performance:

Scenario	Area Coverage Rate*	UUVs Required	Cost ($M)
CVBG	1.23 - 1.59	227	6.5
SLOC	0.64 - 0.83	23	0.6
AOA – 40 (6 lanes)	0.14 – 0.15	144	3.7
AOA – 120 (6 lanes)	0.27 – 0.30	78	2.0

Issues:

- Multiple-way Underwater Acoustic Communications Among UUVs
- Detect/Classification of Near-Surface Mines
- Detection of Buried Mines
- Retrieval System for UUV’s Vice Scuttling
- Mission Planning for Drop-off Points of UUVs

* ACR range of values are based upon a SAS with A=545 yards, B=0.999, with ID sensor, and FCD (lambda) = 10 or 30, (except for AOA-40 scenario where B=0.869)

FUTURE MCM STUDY
NEUTRALIZATION CONCEPT

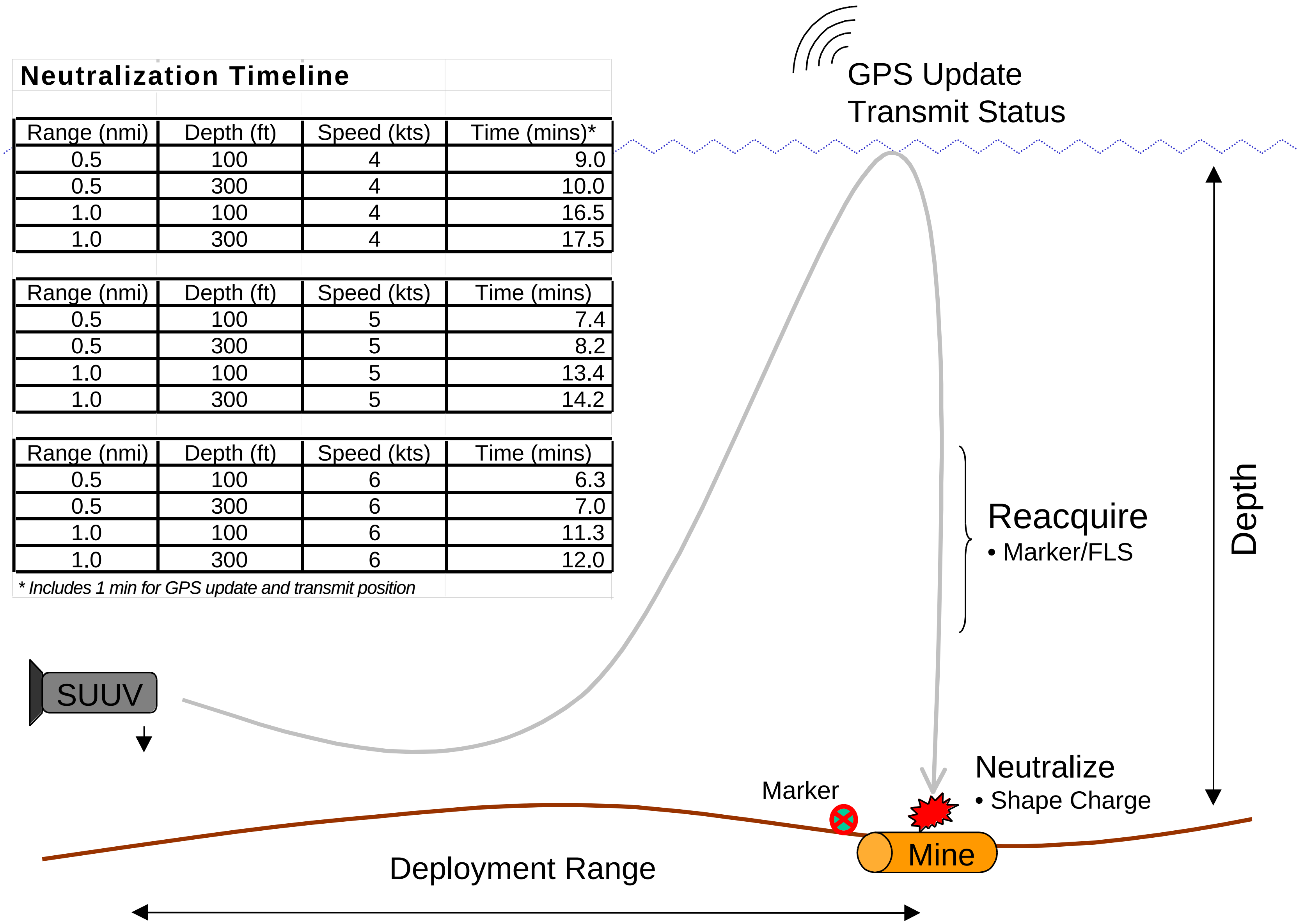
Neutralization Timeline

Range (nmi)	Depth (ft)	Speed (kts)	Time (mins)*
0.5	100	4	9.0
0.5	300	4	10.0
1.0	100	4	16.5
1.0	300	4	17.5

Range (nmi)	Depth (ft)	Speed (kts)	Time (mins)
0.5	100	5	7.4
0.5	300	5	8.2
1.0	100	5	13.4
1.0	300	5	14.2

Range (nmi)	Depth (ft)	Speed (kts)	Time (mins)
0.5	100	6	6.3
0.5	300	6	7.0
1.0	100	6	11.3
1.0	300	6	12.0

** Includes 1 min for GPS update and transmit position*

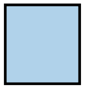


Section 5: Assessment Results

- intermediate parameter trade-offs
- system level MOEs for each concept (w/ excursions)

FUTURE MCM STUDY

EVALUATION SCENARIOS[2]

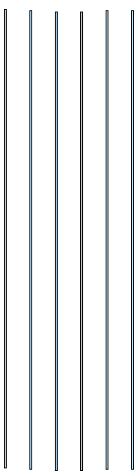


MDA
- **mine danger area**
- **4 x 4 nm**
- **search level: 95%**
- **goal mission time: 11 hrs**
- **threshold time: 32 hrs**
- **depths: 40 ft and 120 ft**
- **30 mines**

CVBG
- **large area**
- **search level: 54%**
- **mission time: 14 days**
- **goal area size: 40 x 60 nm**
- **threshold size: 30 x 30 nm**
- **depth: 120 ft**
- **no mines**

small area

large area



6 lanes

AOA
- **6 assault lanes**
- **165 yd x 24 nm**
- **search level: 95%**
- **goal mission time: 4 hrs**
- **threshold time: 12 hrs**
- **depths: 40 ft and 120 ft**
- **8 mines**

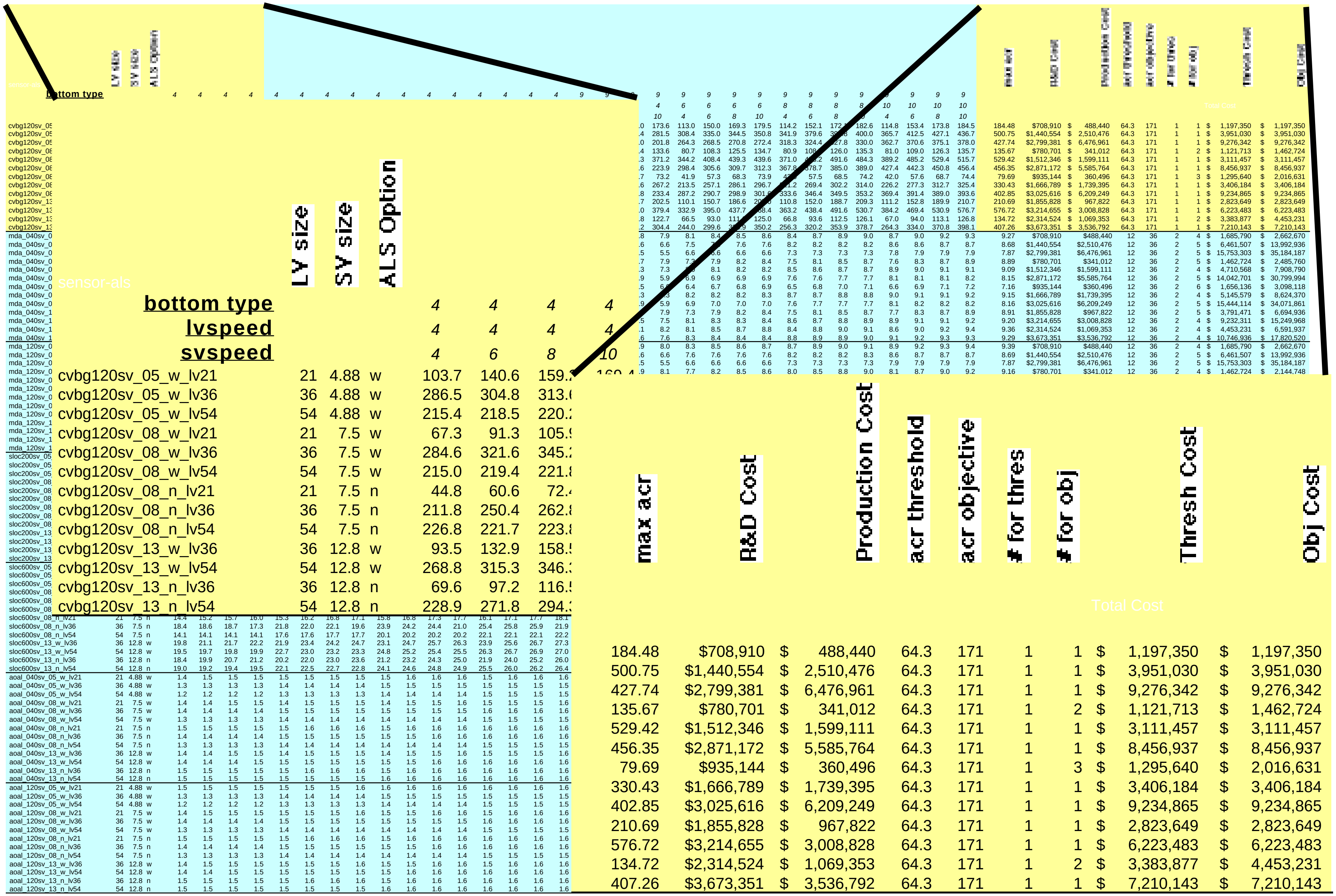
(areas drawn to scale)

SLOC
- **sea lane**
- **0.5 x 100 nm**
- **search level: 68%**
- **goal mission time: 2 days**
- **threshold time: 6 days**
- **depths: 200 ft and 600 ft**
- **47 mines**

2: See “Study of Future MCM System Alternatives, Scenario Descriptions”, Appendix P

FUTURE MCM STUDY

Performance Assessment Worksheet Example



sensor-als	LY size	SV size	ALS Option				
bottom type				4	4	4	4
lvspeed				4	4	4	4
svspeed				4	6	8	10
cvbg120sv_05_w_lv21	21	4.88	w	103.7	140.6	159.	
cvbg120sv_05_w_lv36	36	4.88	w	286.5	304.8	313.	
cvbg120sv_05_w_lv54	54	4.88	w	215.4	218.5	220.	
cvbg120sv_08_w_lv21	21	7.5	w	67.3	91.3	105.	
cvbg120sv_08_w_lv36	36	7.5	w	284.6	321.6	345.	
cvbg120sv_08_w_lv54	54	7.5	w	215.0	219.4	221.	
cvbg120sv_08_n_lv21	21	7.5	n	44.8	60.6	72.	
cvbg120sv_08_n_lv36	36	7.5	n	211.8	250.4	262.	
cvbg120sv_08_n_lv54	54	7.5	n	226.8	221.7	223.	
cvbg120sv_13_w_lv36	36	12.8	w	93.5	132.9	158.	
cvbg120sv_13_w_lv54	54	12.8	w	268.8	315.3	346.	
cvbg120sv_13_n_lv36	36	12.8	n	69.6	97.2	116.	
cvbg120sv_13_n_lv54	54	12.8	n	228.9	271.8	294.	

max acr	R&D Cost	Production Cost	acr threshold	acr objective	# for thres	# for obj	Thresh Cost (Total Cost)	Obj Cost
184.48	$708,910	$ 488,440	64.3	171	1	1	$ 1,197,350	$ 1,197,350
500.75	$1,440,554	$ 2,510,476	64.3	171	1	1	$ 3,951,030	$ 3,951,030
427.74	$2,799,381	$ 6,476,961	64.3	171	1	1	$ 9,276,342	$ 9,276,342
135.67	$780,701	$ 341,012	64.3	171	1	2	$ 1,121,713	$ 1,462,724
529.42	$1,512,346	$ 1,599,111	64.3	171	1	1	$ 3,111,457	$ 3,111,457
456.35	$2,871,172	$ 5,585,764	64.3	171	1	1	$ 8,456,937	$ 8,456,937
79.69	$935,144	$ 360,496	64.3	171	1	3	$ 1,295,640	$ 2,016,631
330.43	$1,666,789	$ 1,739,395	64.3	171	1	1	$ 3,406,184	$ 3,406,184
402.85	$3,025,616	$ 6,209,249	64.3	171	1	1	$ 9,234,865	$ 9,234,865
210.69	$1,855,828	$ 967,822	64.3	171	1	1	$ 2,823,649	$ 2,823,649
576.72	$3,214,655	$ 3,008,828	64.3	171	1	1	$ 6,223,483	$ 6,223,483
134.72	$2,314,524	$ 1,069,353	64.3	171	1	2	$ 3,383,877	$ 4,453,231
407.26	$3,673,351	$ 3,536,792	64.3	171	1	1	$ 7,210,143	$ 7,210,143

FUTURE MCM STUDY

Least Cost Winner, Type II Coordinated Multiple Undersea Reconnaissance Vehicles

Scenario	Water Depth	Non-Mine Density	LV Size	SV Size	ALS w or n	Unit System Cost, R&D	Unit System Cost, Production	#Systems	Total ACR	Total Cost	Total Mission Time	Mission Package Weight (in lbs)	Mission Package Volume (in cu. Ft.)	Replenishible, Weight (in lbs)	Replenishible, Volume (in cu. Ft.)	Replenishible, Cost
cvbg	120	10	21	5	w	$ 708,910	$ 488,440	1	184.48	$ 1,197,350	13.01	2,380	33	1,221	12	$ 35,033
cvbg	120	30	21	5	w	$ 708,910	$ 488,440	2	223.78	$ 1,685,790	10.72	4,759	65	2,442	25	$ 70,065
cvbg	120	100	21	8	w	$ 780,701	$ 341,012	5	185.51	$ 2,485,760	12.94	11,898	164	6,404	66	$ 180,882
mda	40	10	21	8	w	$ 780,701	$ 341,012	5	44.45	$ 2,485,760	0.36	11,898	164	6,404	66	$ 180,882
mda	40	30	21	8	w	$ 780,701	$ 341,012	5	43.35	$ 2,485,760	0.37	11,898	164	6,404	66	$ 180,882
mda	40	100	21	8	w	$ 780,701	$ 341,012	6	37.66	$ 2,826,771	0.42	14,278	196	7,685	79	$ 217,058
mda	120	10	21	8	w	$ 780,701	$ 341,012	4	36.64	$ 2,144,748	0.44	9,518	131	5,123	52	$ 144,705
mda	120	30	21	8	w	$ 780,701	$ 341,012	5	44.60	$ 2,485,760	0.36	11,898	164	6,404	66	$ 180,882
mda	120	100	21	8	w	$ 780,701	$ 341,012	6	38.39	$ 2,826,771	0.42	14,278	196	7,685	79	$ 217,058
sloc	200	10	21	8	w	$ 780,701	$ 341,012	2	51.77	$ 1,462,724	1.16	4,759	65	2,562	26	$ 72,353
sloc	200	30	21	8	w	$ 780,701	$ 341,012	2	41.15	$ 1,462,724	1.46	4,759	65	2,562	26	$ 72,353
sloc	200	100	21	8	w	$ 780,701	$ 341,012	2	30.36	$ 1,462,724	1.98	4,759	65	2,562	26	$ 72,353
sloc	600	10	21	8	w	$ 780,701	$ 341,012	2	51.77	$ 1,462,724	1.16	4,759	65	2,562	26	$ 72,353
sloc	600	30	21	8	w	$ 780,701	$ 341,012	2	41.15	$ 1,462,724	1.46	4,759	65	2,562	26	$ 72,353
sloc	600	100	21	8	w	$ 780,701	$ 341,012	2	30.36	$ 1,462,724	1.98	4,759	65	2,562	26	$ 72,353
aoal	40	10	21	8	w	$ 780,701	$ 341,012	3	4.76	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	40	30	21	8	w	$ 780,701	$ 341,012	3	4.74	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	40	100	21	8	w	$ 780,701	$ 341,012	3	4.68	$ 6,918,912	0.42	7,139	98	3,842	39	$ 108,529
aoal	120	10	21	8	w	$ 780,701	$ 341,012	3	4.84	$ 6,918,912	0.40	7,139	98	3,842	39	$ 108,529
aoal	120	30	21	8	w	$ 780,701	$ 341,012	3	4.82	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	120	100	21	8	w	$ 780,701	$ 341,012	3	4.74	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529

Lowest Cost System Which Meets The Objective Performance

FUTURE MCM STUDY

Replenishible, Weight (in lbs)

Replenishible, Volume (in cu. Ft.)

Replenishible, Cost

Best Value Winner, Type II Coordinated Multiple Undersea Reconnaissance Vehicles

Scenario	Water Depth	Mine Density	LV Size	SV Size	ALS w or n	Unit System Cost, R&D	Unit System Cost, Production	#Systems	Total ACR	Total Cost	Total Mission Time	Mission Package Weight (in lbs)	Mission Package Volume (in cu. Ft.)	Replenishible, Weight (in lbs)	Replenishible, Volume (in cu. Ft.)	Replenishible, Cost
cvbg	120	10	21	8	w	$ 780,701	$ 341,012	2	271.34	$ 1,462,724	8.84	4,759	65	2,562	26	$ 72,353
cvbg	120	30	21	5	w	$ 708,910	$ 488,440	2	223.78	$ 1,685,790	10.72	4,759	65	2,442	25	$ 70,065
cvbg	120	100	21	5	w	$ 708,910	$ 488,440	4	202.97	$ 2,662,670	11.82	9,518	130	4,885	49	$ 140,131
mda	40	10	21	8	w	$ 780,701	$ 341,012	5	44.45	$ 2,485,760	0.36	11,898	164	6,404	66	$ 180,882
mda	40	30	21	8	w	$ 780,701	$ 341,012	5	43.35	$ 2,485,760	0.37	11,898	164	6,404	66	$ 180,882
mda	40	100	21	8	w	$ 780,701	$ 341,012	6	37.66	$ 2,826,771	0.42	14,278	196	7,685	79	$ 217,058
mda	120	10	21	8	w	$ 780,701	$ 341,012	4	36.64	$ 2,144,748	0.44	9,518	131	5,123	52	$ 144,705
mda	120	30	21	8	w	$ 780,701	$ 341,012	5	44.60	$ 2,485,760	0.36	11,898	164	6,404	66	$ 180,882
mda	120	100	21	8	w	$ 780,701	$ 341,012	6	38.39	$ 2,826,771	0.42	14,278	196	7,685	79	$ 217,058
sloc	200	10	21	8	w	$ 780,701	$ 341,012	2	51.77	$ 1,462,724	1.16	4,759	65	2,562	26	$ 72,353
sloc	200	30	21	8	w	$ 780,701	$ 341,012	2	41.15	$ 1,462,724	1.46	4,759	65	2,562	26	$ 72,353
sloc	200	100	21	8	w	$ 780,701	$ 341,012	2	30.36	$ 1,462,724	1.98	4,759	65	2,562	26	$ 72,353
sloc	600	10	21	8	w	$ 780,701	$ 341,012	2	51.77	$ 1,462,724	1.16	4,759	65	2,562	26	$ 72,353
sloc	600	30	21	8	w	$ 780,701	$ 341,012	2	41.15	$ 1,462,724	1.46	4,759	65	2,562	26	$ 72,353
sloc	600	100	21	8	w	$ 780,701	$ 341,012	2	30.36	$ 1,462,724	1.98	4,759	65	2,562	26	$ 72,353
aoal	40	10	21	8	w	$ 780,701	$ 341,012	3	4.76	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	40	30	21	8	w	$ 780,701	$ 341,012	3	4.74	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	40	100	21	8	w	$ 780,701	$ 341,012	3	4.68	$ 6,918,912	0.42	7,139	98	3,842	39	$ 108,529
aoal	120	10	21	8	w	$ 780,701	$ 341,012	3	4.84	$ 6,918,912	0.40	7,139	98	3,842	39	$ 108,529
aoal	120	30	21	8	w	$ 780,701	$ 341,012	3	4.82	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	120	100	21	8	w	$ 780,701	$ 341,012	3	4.74	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529

System Which Meets The Objective Performance And Provides Best Value In ACR Per $

FUTURE MCM STUDY

Replenishible, Weight (in lbs)

Replenishible, Volume (in cu. Ft.)

Replenishible, Cost

Best Performance Winner, Type II Coordinated Multiple Undersea Reconnaissance Veh

Scenario	Water Depth	Mine Density	LV Size	SV Size	ALS w or n	Unit System Cost, R&D	Unit System Cost, Production	#Systems	Total ACR	Total Cost	Total Mission Time	Mission Package Weight (in lbs)	Mission Package Volume (in cu. Ft.)	Replenishible, Weight (in lbs)	Replenishible, Volume (in cu. Ft.)	Replenishible, Cost
cvbg	120	10	54	13	w	$ 3,214,655	$ 3,008,828	1	576.72	$ 6,223,483	4.16	40,461	589	25,609	262	$ 723,269
cvbg	120	30	54	13	w	$ 3,214,655	$ 3,008,828	1	350.35	$ 6,223,483	6.85	40,461	589	25,609	262	$ 723,269
cvbg	120	100	54	8	w	$ 2,871,172	$ 5,585,764	1	207.72	$ 8,456,937	11.55	40,461	611	22,426	238	$ 605,320
mda	40	10	36	13	n	$ 2,314,524	$ 1,069,353	4	37.43	$ 6,591,937	0.43	47,953	656	29,921	302	$ 860,545
mda	40	30	21	5	w	$ 708,910	$ 488,440	4	36.68	$ 2,662,670	0.44	9,518	130	4,885	49	$ 140,131
mda	40	100	54	13	w	$ 3,214,655	$ 3,008,828	5	44.30	$ 18,258,796	0.36	202,303	2,946	128,046	1,312	$ 3,616,343
mda	120	10	36	13	n	$ 2,314,524	$ 1,069,353	4	37.86	$ 6,591,937	0.42	47,953	656	29,921	302	$ 860,545
mda	120	30	21	5	w	$ 708,910	$ 488,440	4	37.13	$ 2,662,670	0.43	9,518	130	4,885	49	$ 140,131
mda	120	100	54	13	w	$ 3,214,655	$ 3,008,828	5	44.56	$ 18,258,796	0.36	202,303	2,946	128,046	1,312	$ 3,616,343
sloc	200	10	54	13	w	$ 3,214,655	$ 3,008,828	2	53.86	$ 9,232,311	1.11	80,921	1,178	51,219	525	$ 1,446,537
sloc	200	30	54	13	w	$ 3,214,655	$ 3,008,828	2	52.80	$ 9,232,311	1.14	80,921	1,178	51,219	525	$ 1,446,537
sloc	200	100	54	13	w	$ 3,214,655	$ 3,008,828	2	49.38	$ 9,232,311	1.22	80,921	1,178	51,219	525	$ 1,446,537
sloc	600	10	36	13	w	$ 1,855,828	$ 967,822	2	54.58	$ 3,791,471	1.10	23,977	328	15,377	155	$ 442,683
sloc	600	30	54	13	w	$ 3,214,655	$ 3,008,828	2	52.60	$ 9,232,311	1.14	80,921	1,178	51,219	525	$ 1,446,537
sloc	600	100	36	8	w	$ 1,512,346	$ 1,599,111	2	49.11	$ 4,710,568	1.22	23,977	338	14,699	152	$ 409,518
aoal	40	10	36	13	w	$ 1,855,828	$ 967,822	3	4.84	$ 19,276,617	0.40	35,965	492	23,066	233	$ 664,024
aoal	40	30	36	13	w	$ 1,855,828	$ 967,822	3	4.81	$ 19,276,617	0.41	35,965	492	23,066	233	$ 664,024
aoal	40	100	21	5	w	$ 708,910	$ 488,440	3	4.76	$ 9,500,830	0.41	7,139	98	3,664	37	$ 105,098
aoal	120	10	21	8	w	$ 780,701	$ 341,012	3	4.84	$ 6,918,912	0.40	7,139	98	3,842	39	$ 108,529
aoal	120	30	21	8	w	$ 780,701	$ 341,012	3	4.82	$ 6,918,912	0.41	7,139	98	3,842	39	$ 108,529
aoal	120	100	54	13	w	$ 3,214,655	$ 3,008,828	3	4.75	$ 57,373,565	0.41	121,382	1,768	76,828	787	$ 2,169,806

System Which Meets The Objective Performance And Provides The Highest ACR

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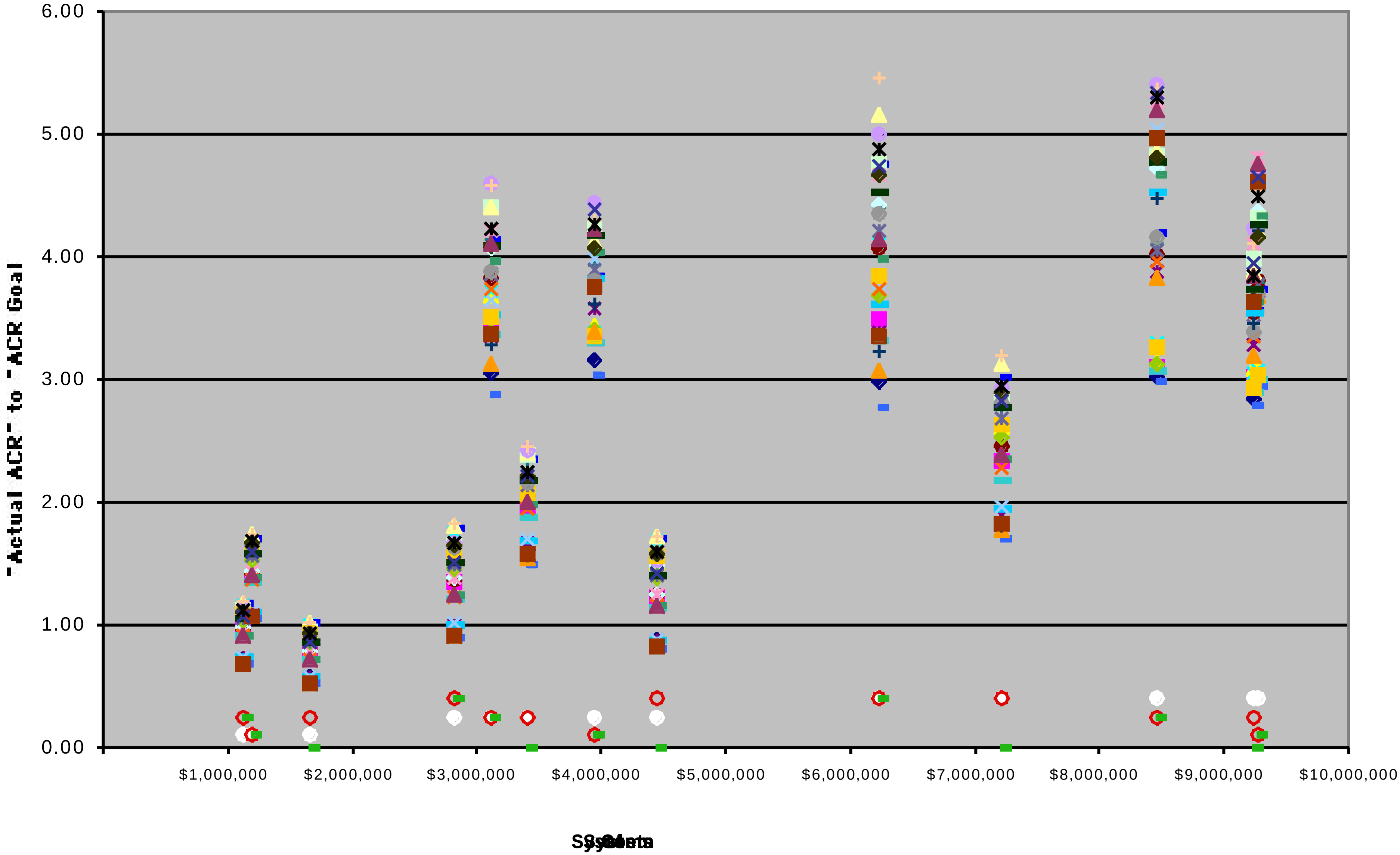
Performance Assessment, ACR vs. Cost, Chart Example



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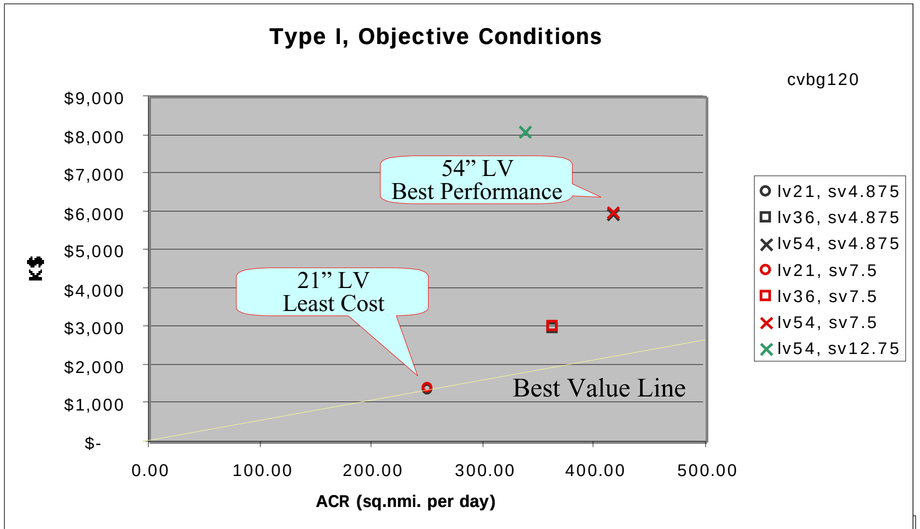
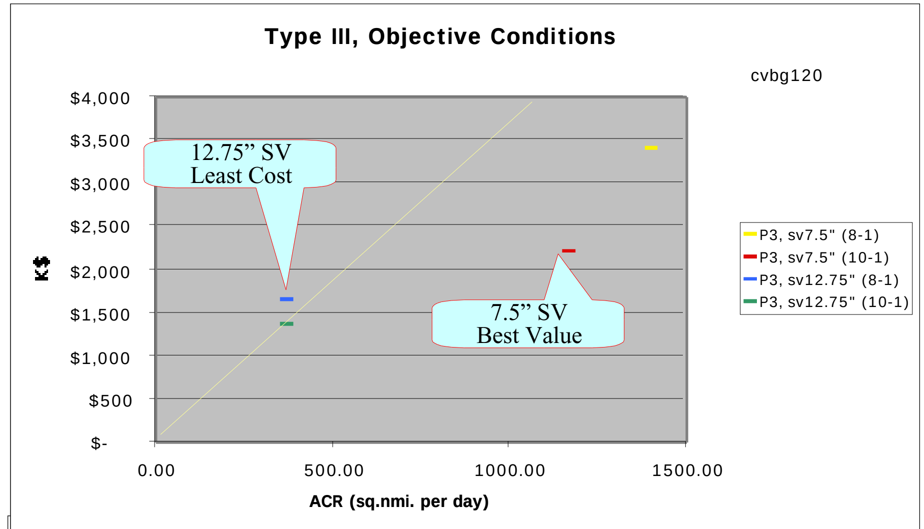
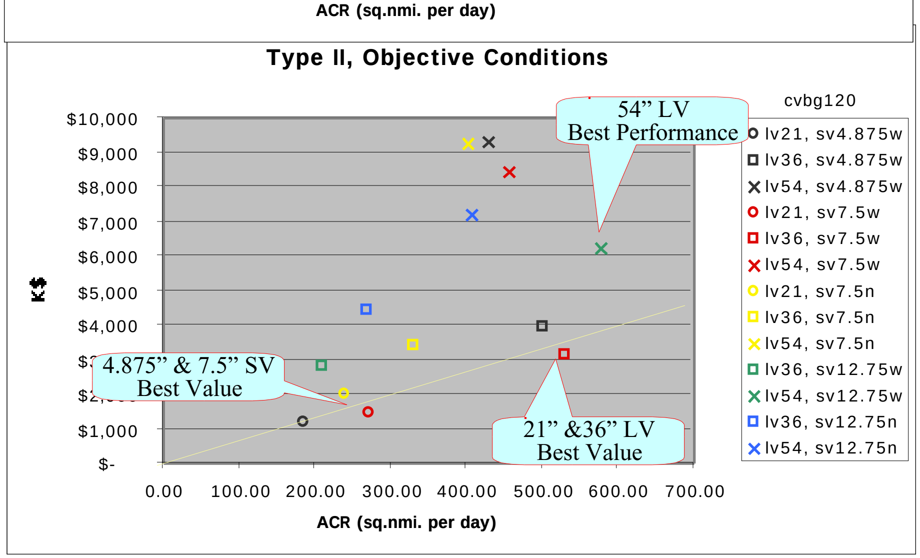
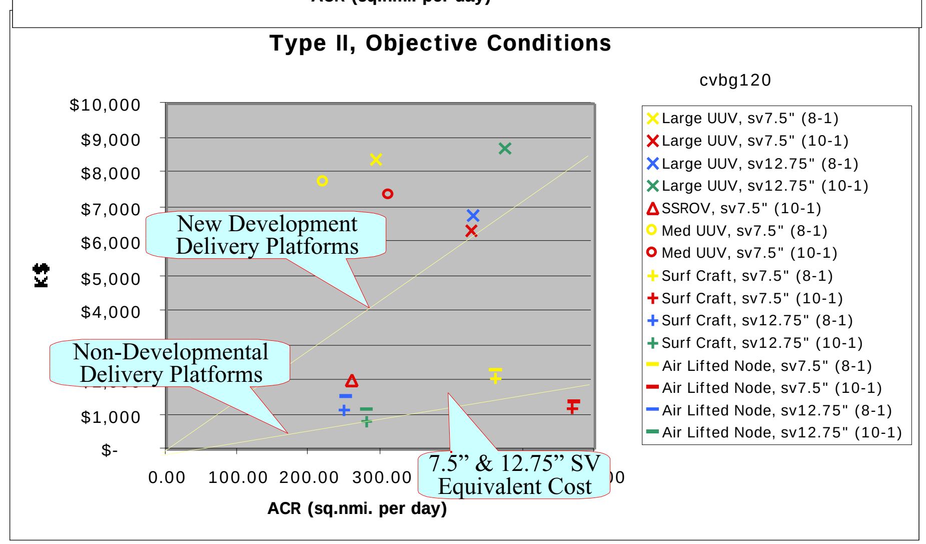
Performance Assessment Summary, CVBG Op Area Scenario









NOTES:
* ACR For System Of Systems (Multiple UUVs)
* K$ Cost For UUV R&D And Production Cost Only
* Non-UUV Delivery Platform Cost Not Included
* Type III System Is Expendable

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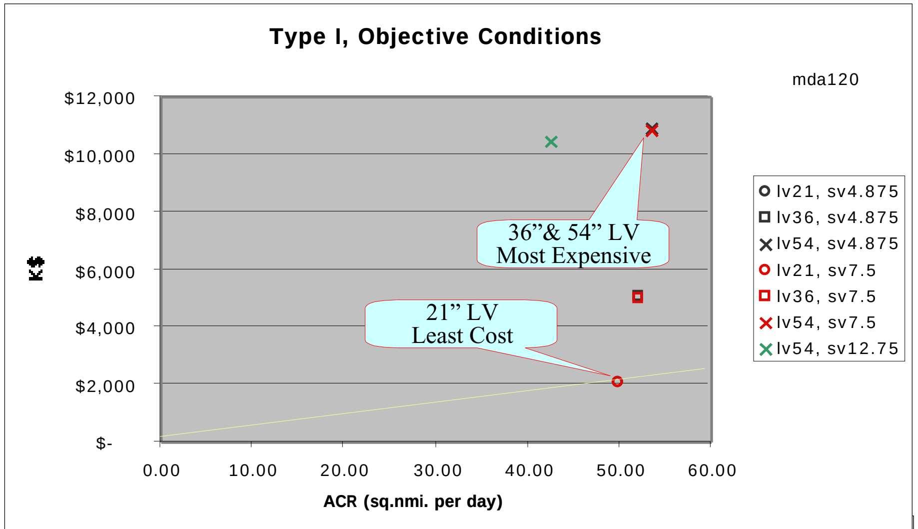
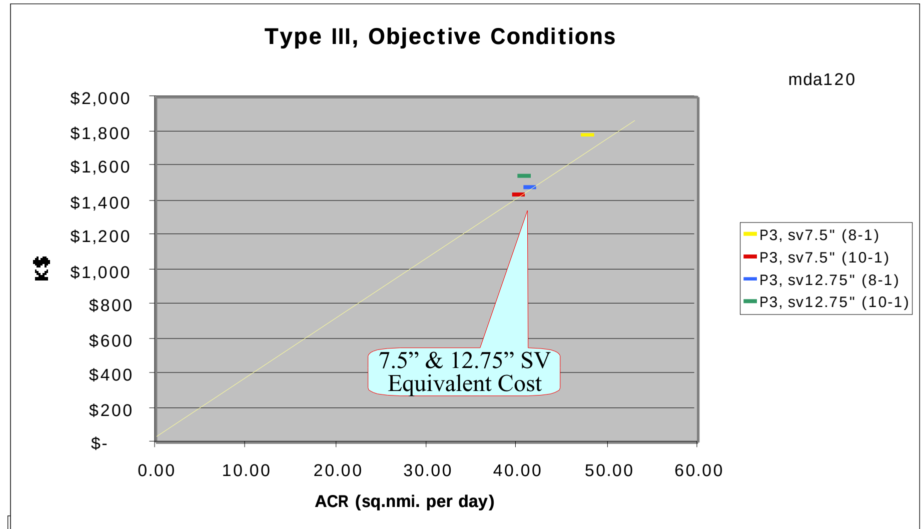
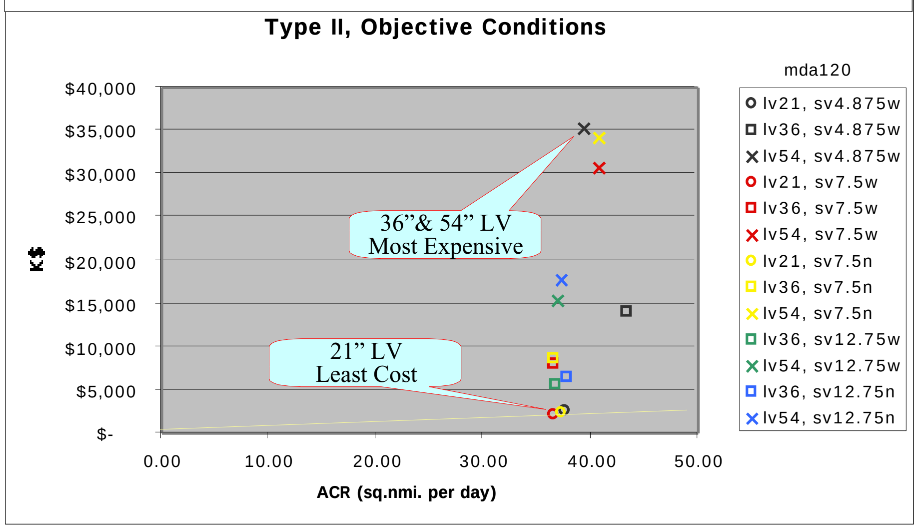
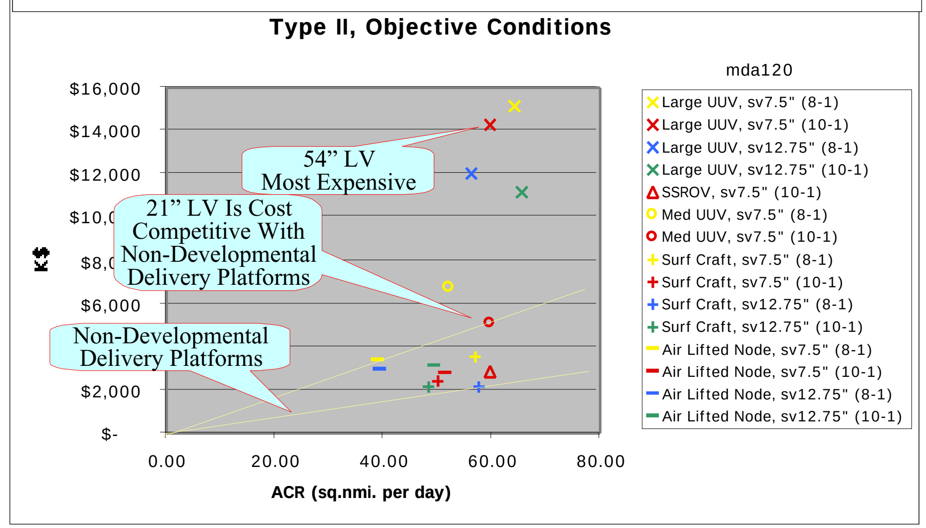
Performance Assessment Summary, MDA Scenario





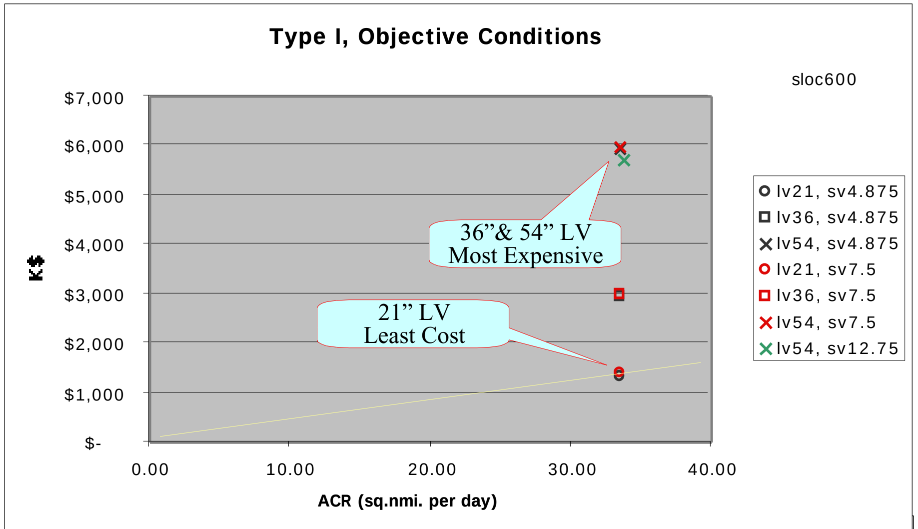


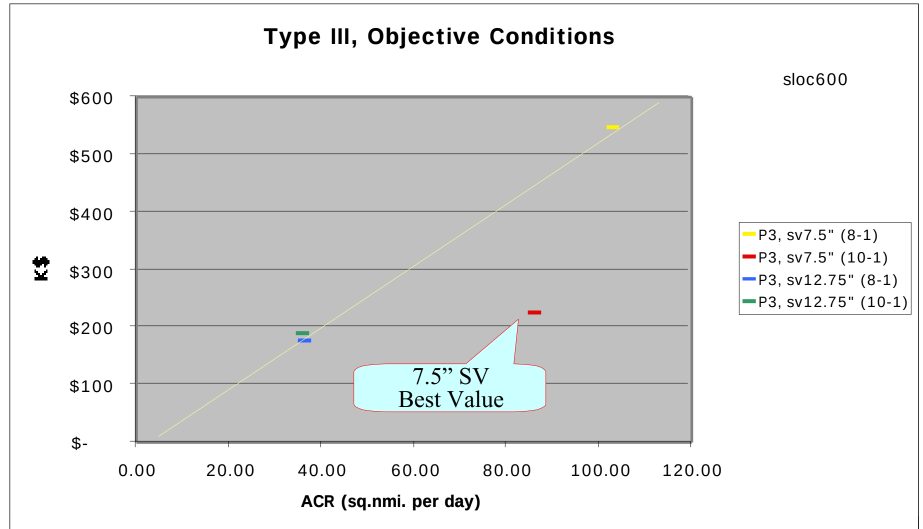


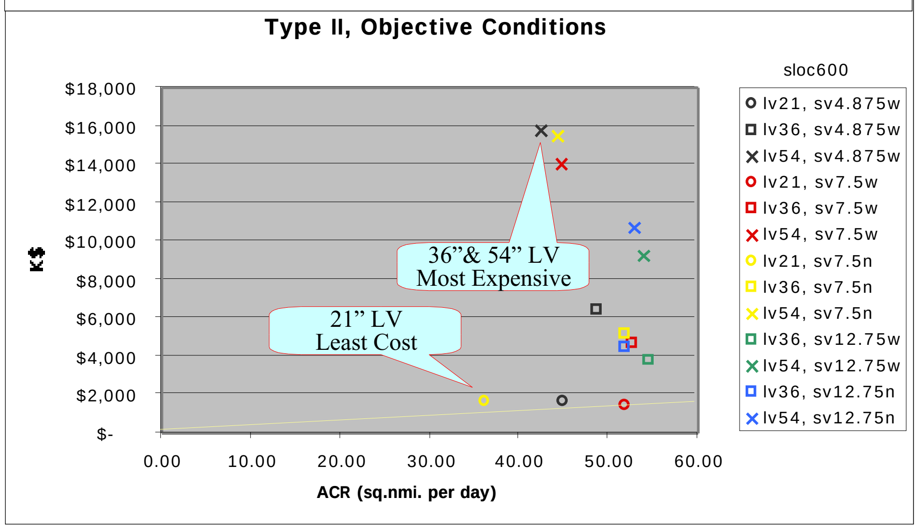
NOTES:
* ACR For System Of Systems (Multiple UUVs)
* K$ Cost For UUV R&D And Production Cost Only
* Non-UUV Delivery Platform Cost Not Included
* Type III System Is Expendable

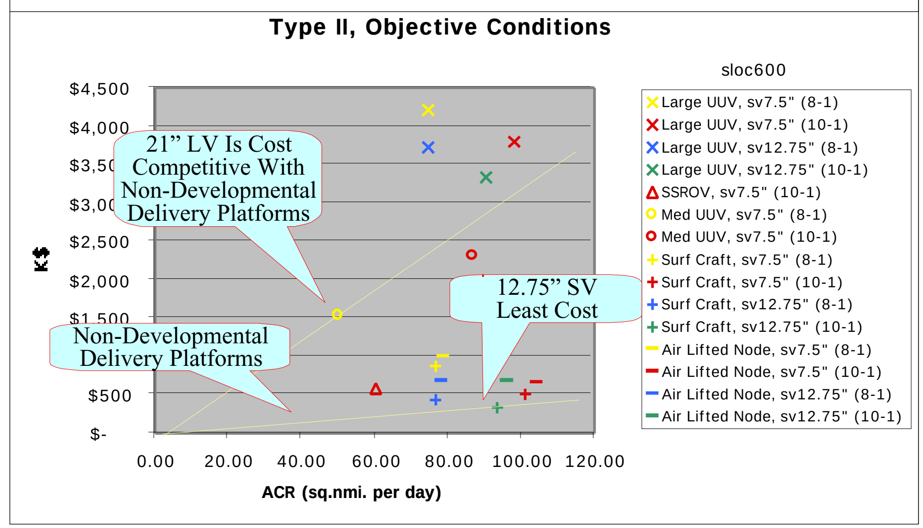
FUTURE MCM STUDY

Performance Assessment Summary, SLOC Scenario









NOTES:
* ACR For System Of Systems (Multiple UUVs)
* K$ Cost For UUV R&D And Production Cost Only
* Non-UUV Delivery Platform Cost Not Included
* Type III System Is Expendable

FUTURE MCM STUDY
Performance Assessment Summary, Conclusions

General

- System of Systems Performance Varies Per Scenario
- LVs or SVs With Either ALS Or SAS Wide Options (versus Narrow) Can Meet Threshold And Objective Performance Goals With Reasonable Cost
- Non-Developmental Delivery Platform (versus LV) Provides Lowest Cost, If Available For Dedicated MCM Missions
- An Effective System Of Systems Can Be Composed Of 21” LVs & 7.5” SVs

Type I

- Most Cost Effective Birddog Reconnaissance Platform Is 21” LV UUV
- Small SV Size Doesn’t Really Matter

Type II

- All LV Sizes (21”-54”) Make Good Delivery Platforms In CVBG Scenario
- Most Cost Effective Delivery Platform For All Scenarios Is 21” LV UUV
- All SV Sizes (4.875” - 12.5”) Are Cost Effective Reconnaissance Platforms

Type III

- Expendable 7.5” SV UUV Is A Cost Effective Reconnaissance Platform

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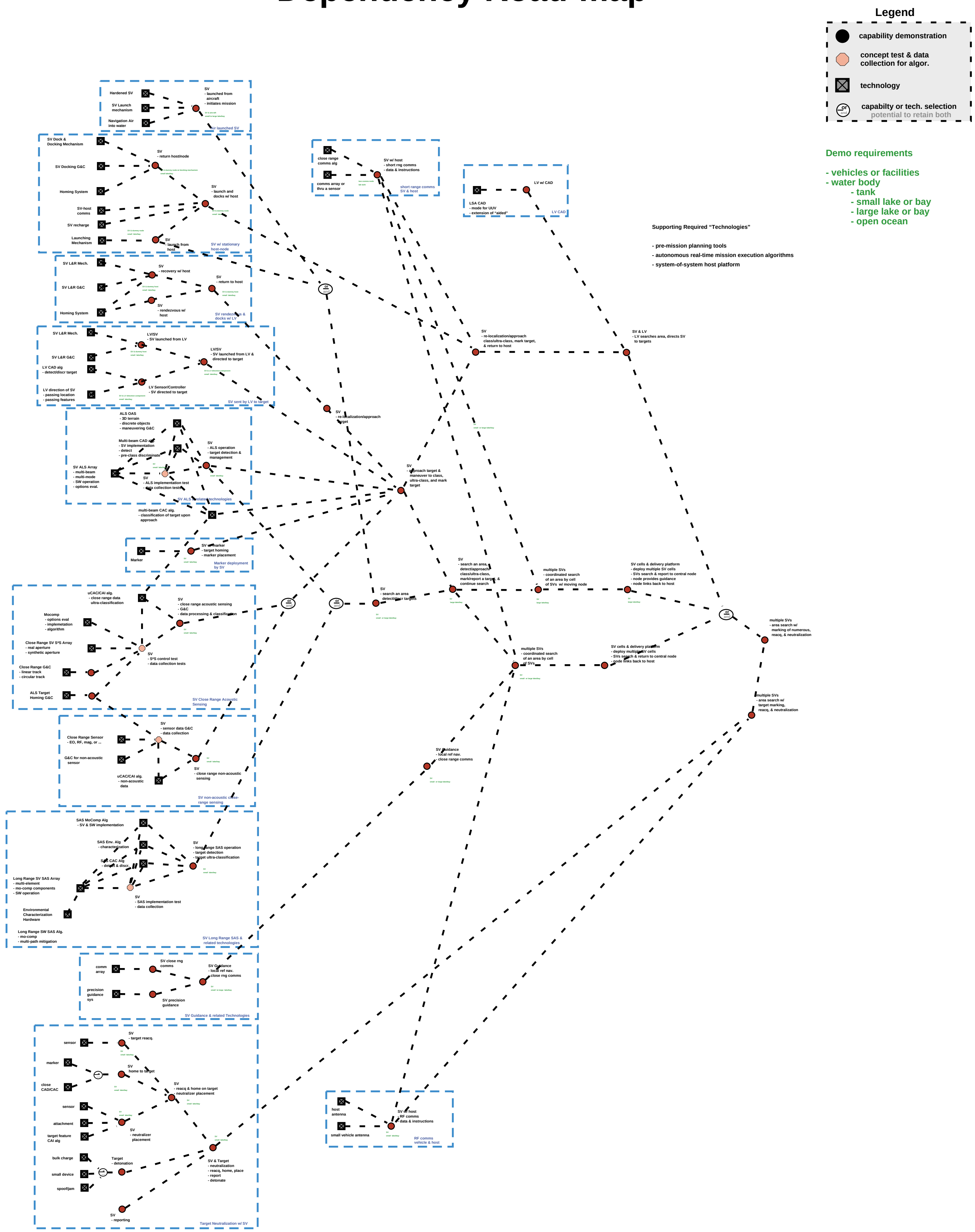
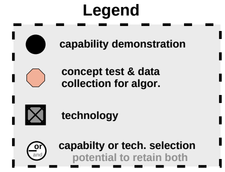
Section 6: Enabling Technologies & Enabling Demonstrations

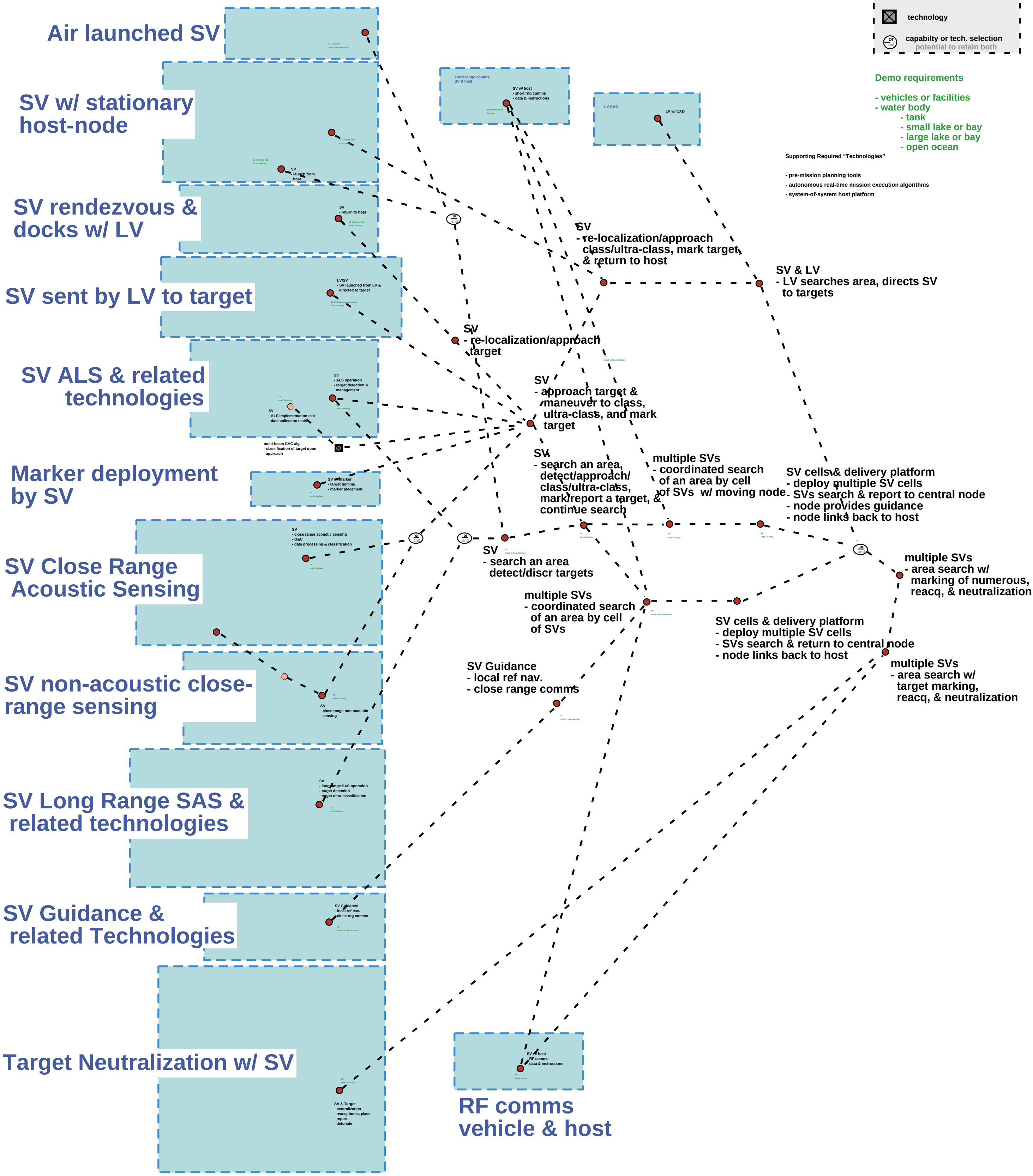
- physical components
- specific search or contact prosecution tactics
- processing capabilities
- demonstration sequences
- prioritizations

FMCM Technology and Demonstration Dependency Road-map

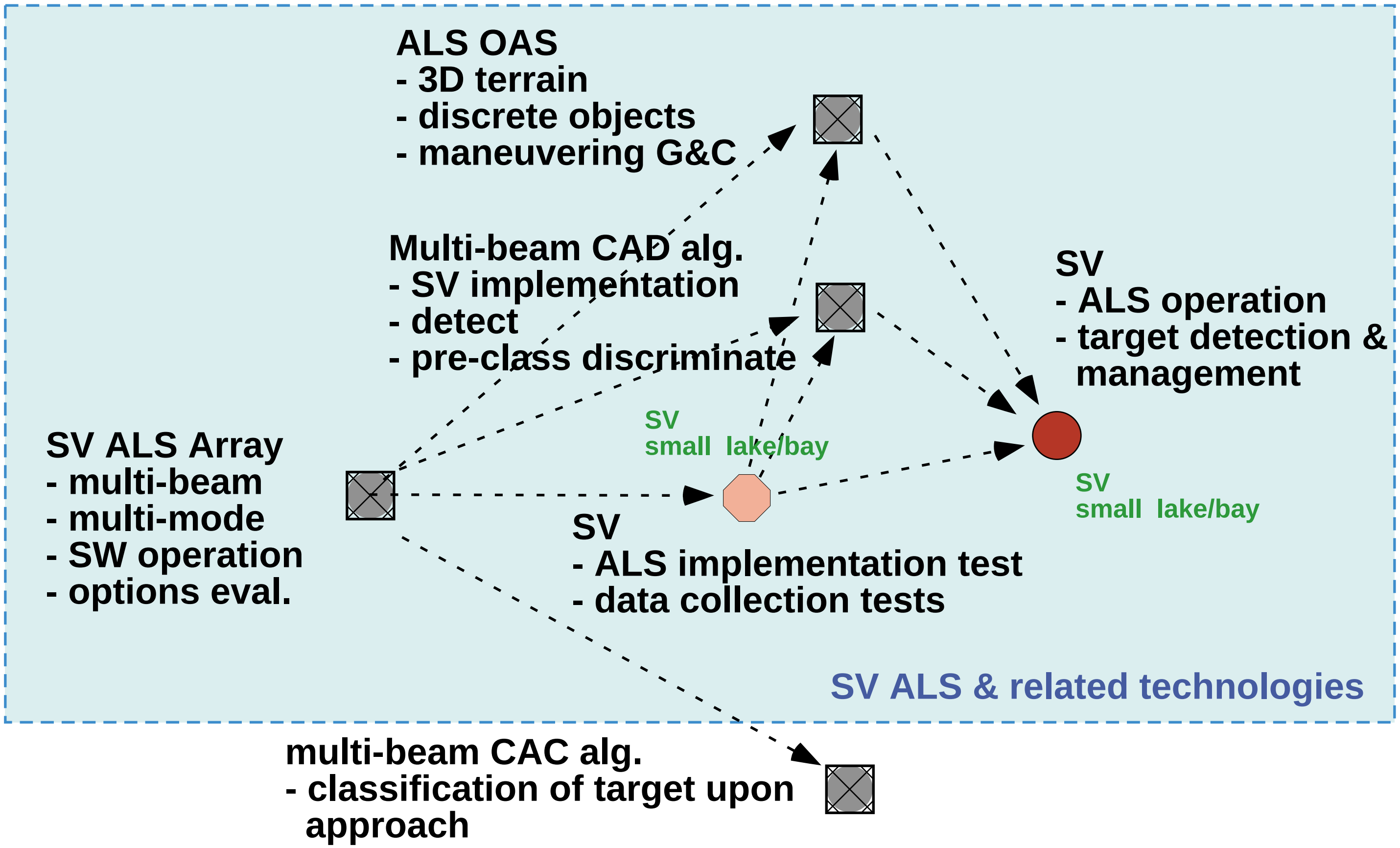


FMCM Technology and Demonstration Dependency Road-map

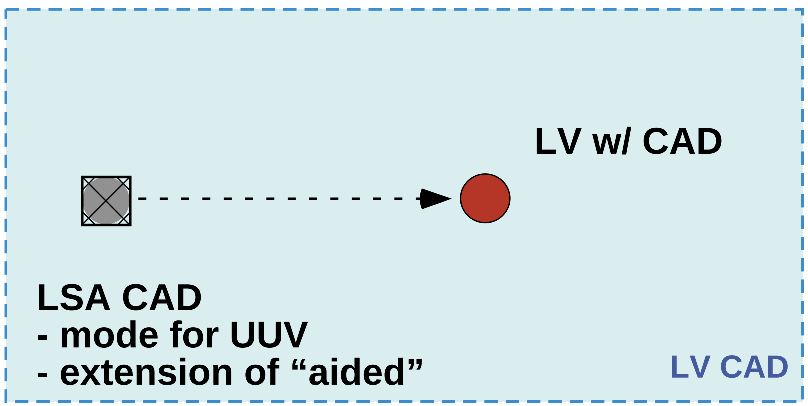




FMCM STUDY ROADMAP TECHNOLOGIES & DEMONSTRATION COMPONENTS



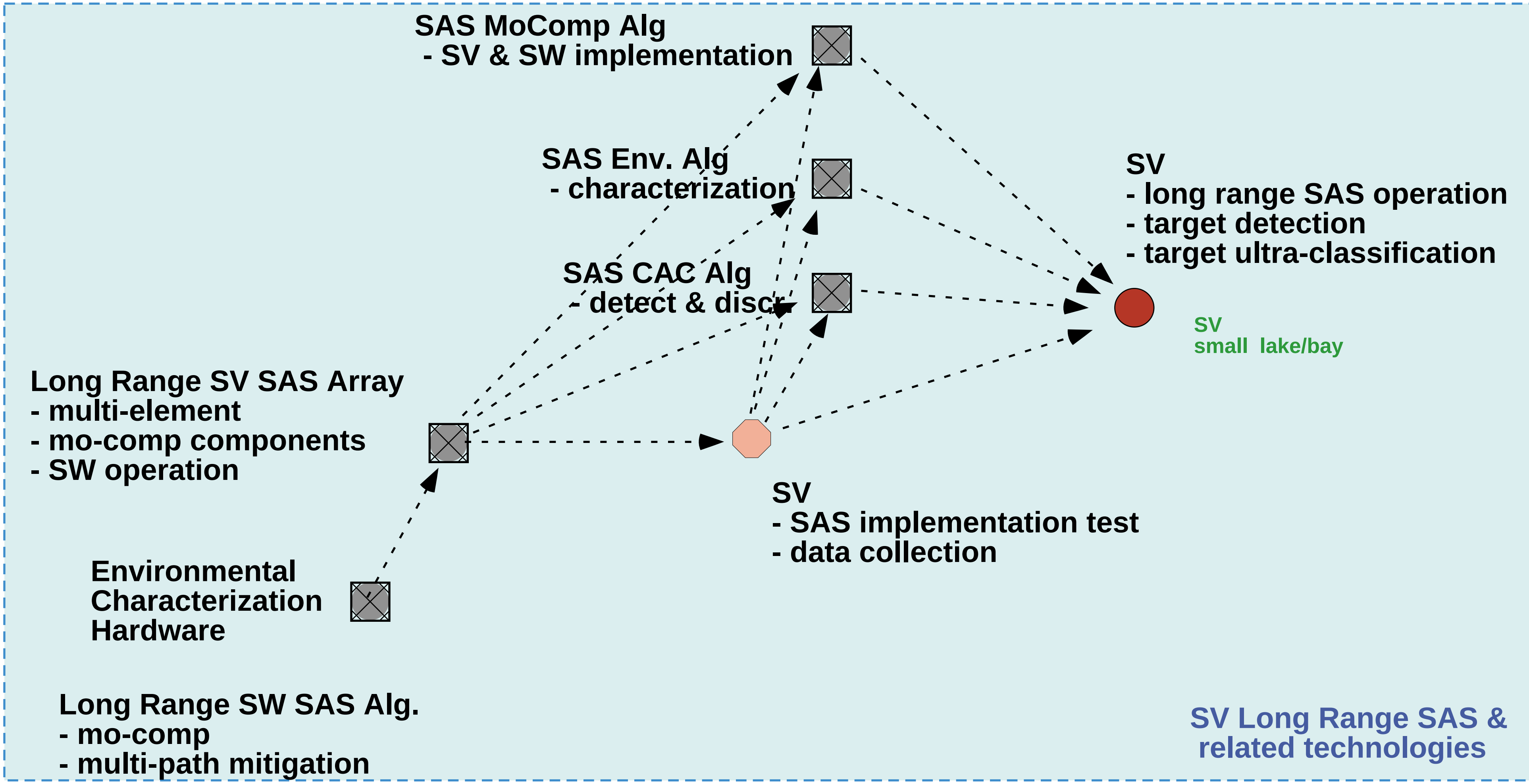
- SV ALS & CAD
- Low Power & Volume Implementation
- Extend CAD to SV Configurations
- Adapt for Target Appraoch G&C



- LV CAD for High Pd low FC Search
- Adapt from other programs
- Extend Autonomous mode demonstrated on DARPA UUV

FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS

- **Long Range SAS**
- **Develop and Demonstrate Long Range SAS**
- **Develop and Demonstrate Long Range SAS on a SV**
  - **SV specific motion compensation**
- **Develop and Demonstrate Autonomous SAS CAD & CAC**

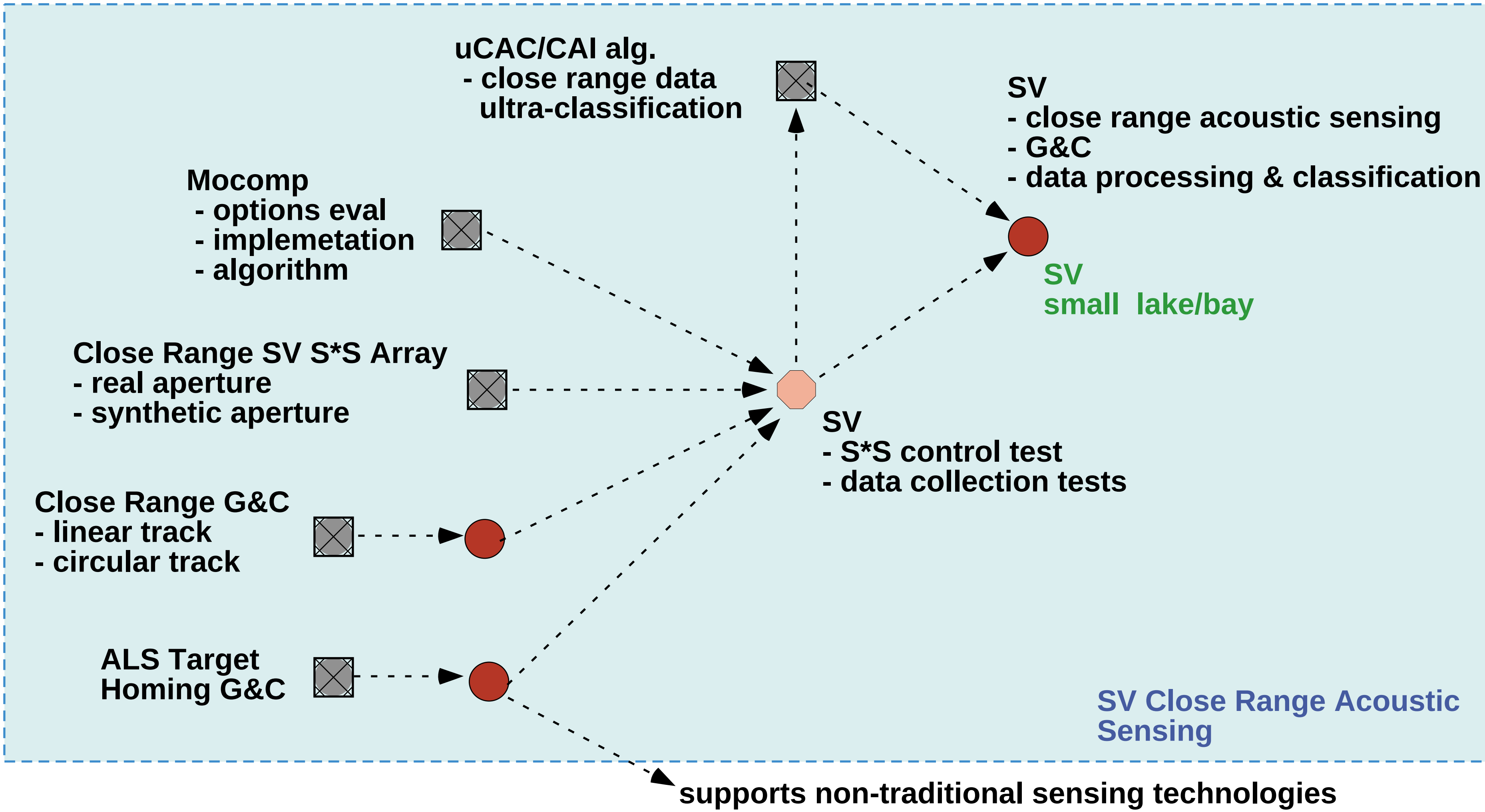


FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS

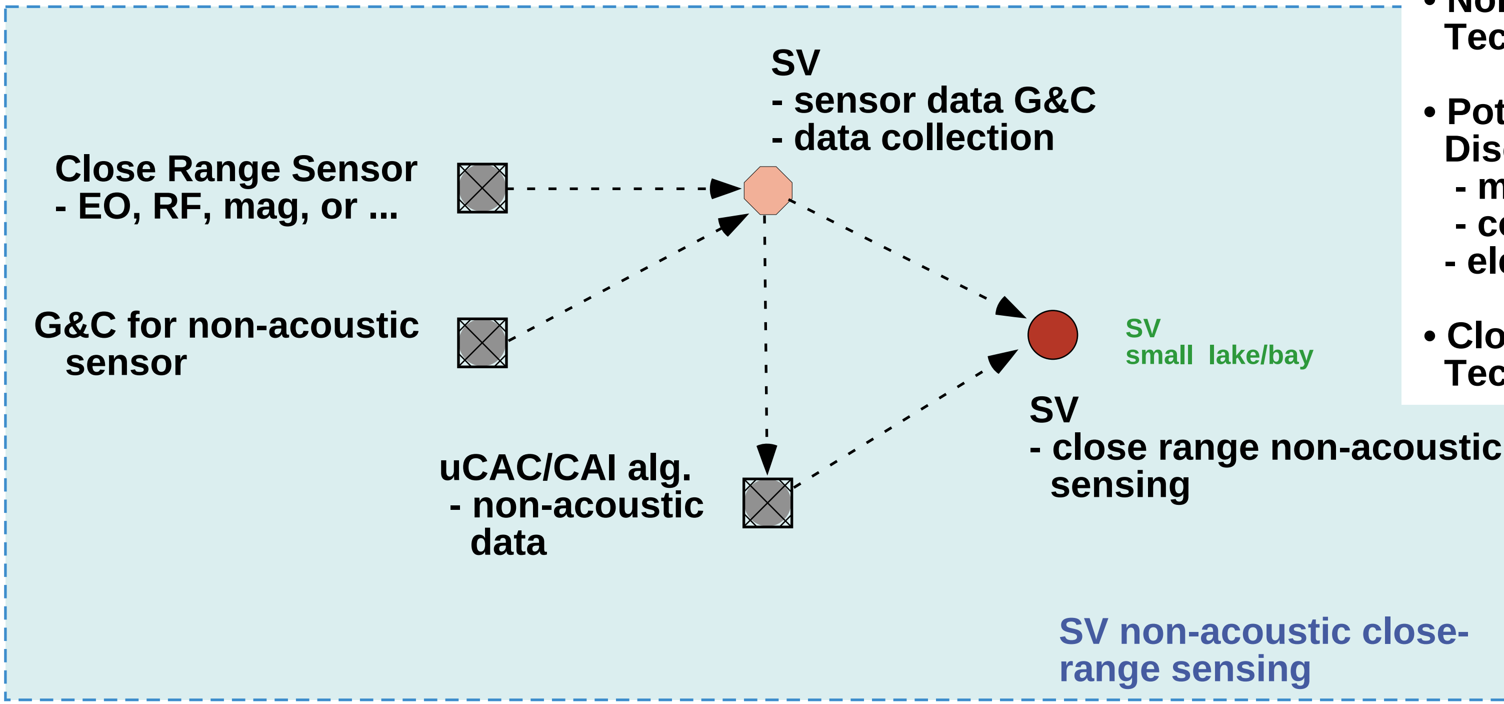
- **SV Close Range Acoustic Sensing Technologies and Demonstrations**

- **Develop the capability to maneuver a SV near a contact**
  - **G&C for approach and track**

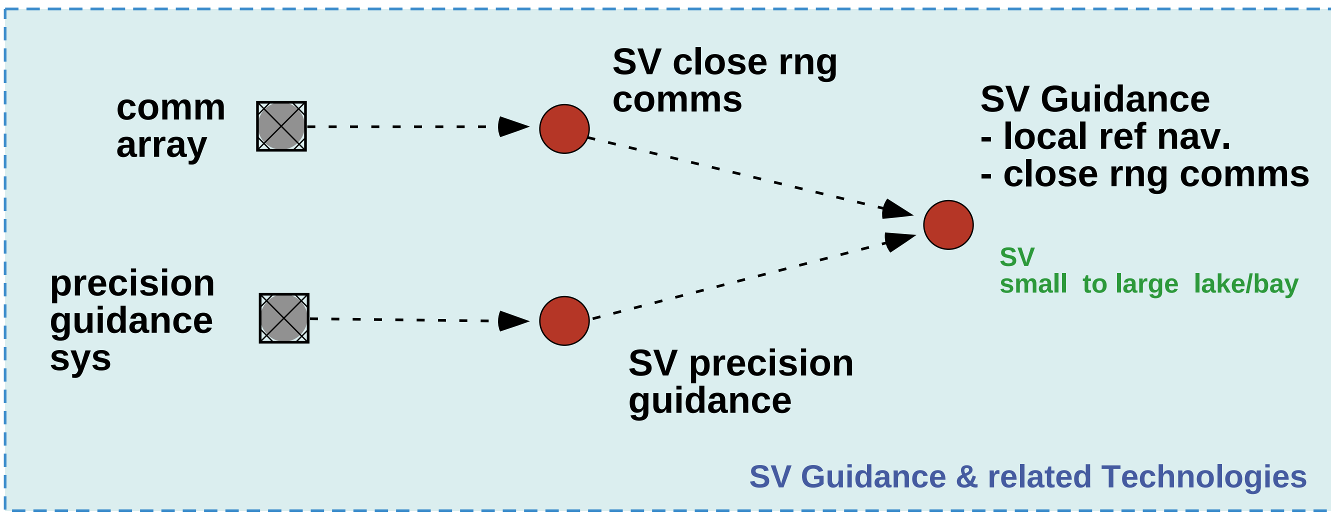
- **Develop Close Range Sensors and Processing Algorithms**
  - **optimized for ultra-classification**
  - **develop in conjunction with maneuvering track**



FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS



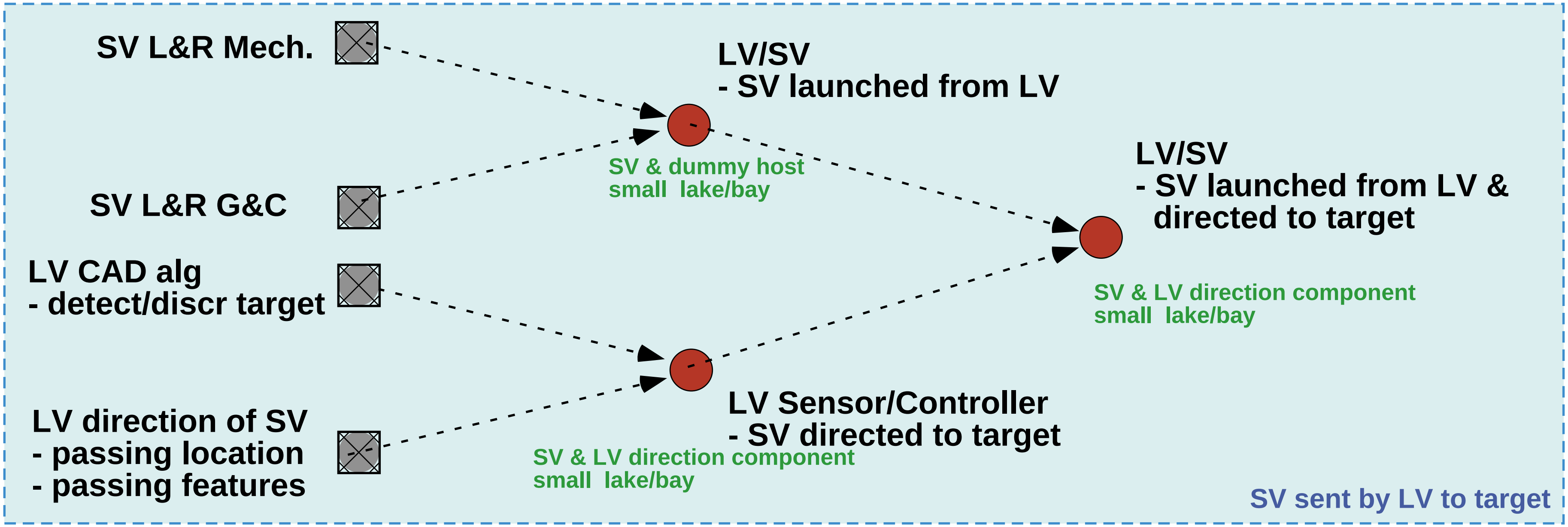
- Non-Traditional Sensing Technologies
- Potential of Target Specific Discrimination Clues
  - materials
  - construction
  - electronics
- Close Range Sensing Technologies



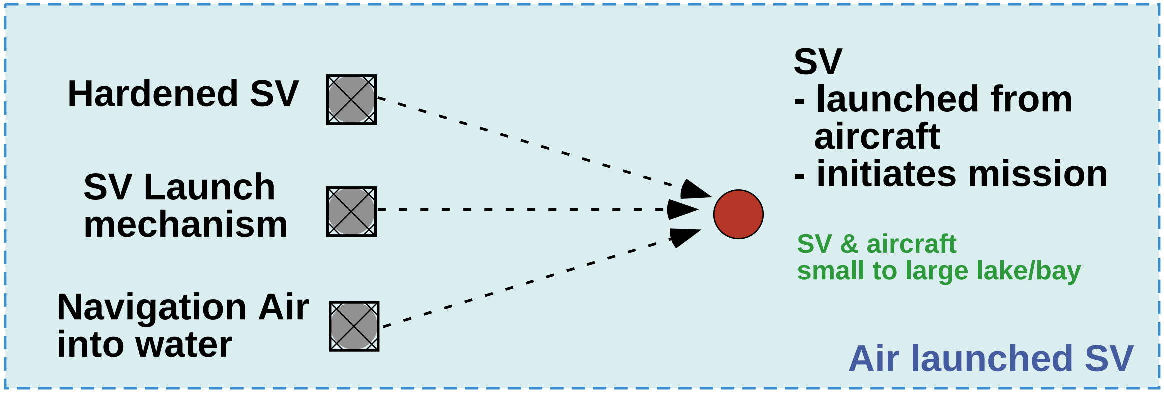
- Short-to-Moderate Range SV Communications and Guidance
- Low Bandwidth Data Rates
- For Small Operational Units of SVs

FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS

- **LV directing a SV toward a contact**
- **Develop and Demonstrate Launching of SV from LV**
- **Develop and Demonstrate Initial Guidance of SV by LV**
  - before launch download & post launch vectoring
- **Develop and Demonstrate Autonomous LV CAD to Select Contact and Vector SV**

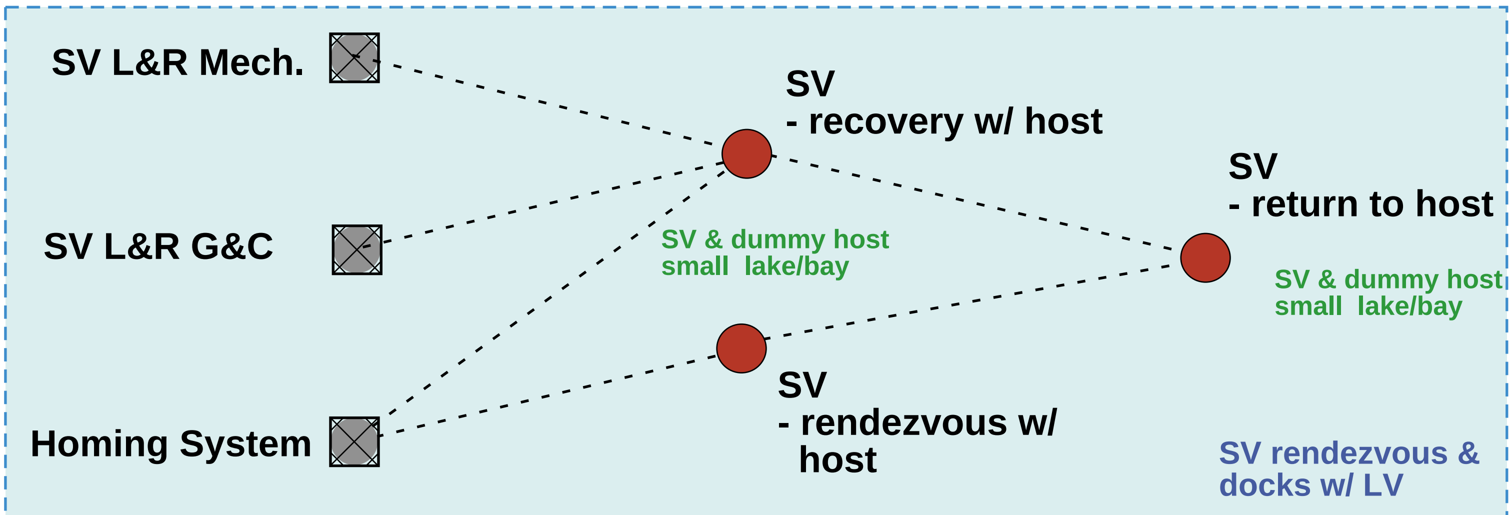


FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS

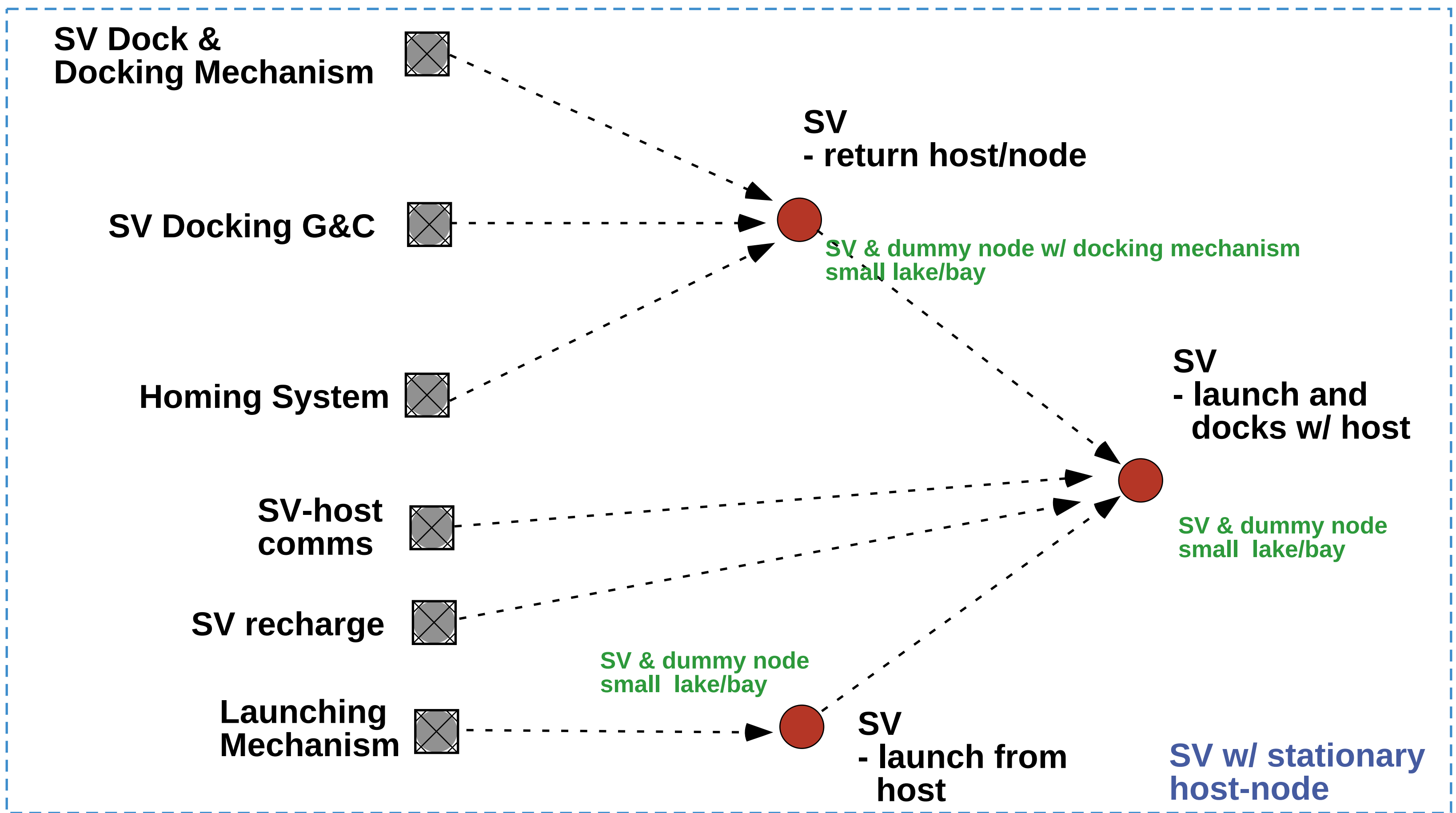


- Air Deployment of SVs Technologies & Demonstration
- Develop SV Launching and Hardening
- Develop Air/Water G&C and tracking

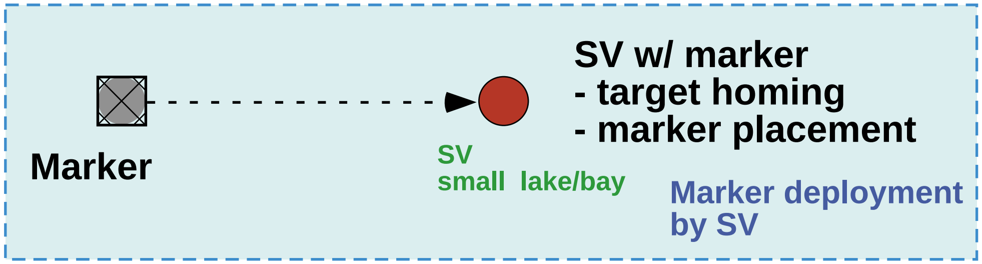
- Return of SV to LV
- Develop L&R Mechanism
- Develop Homing System on SV & LV
- Final Approach G&C



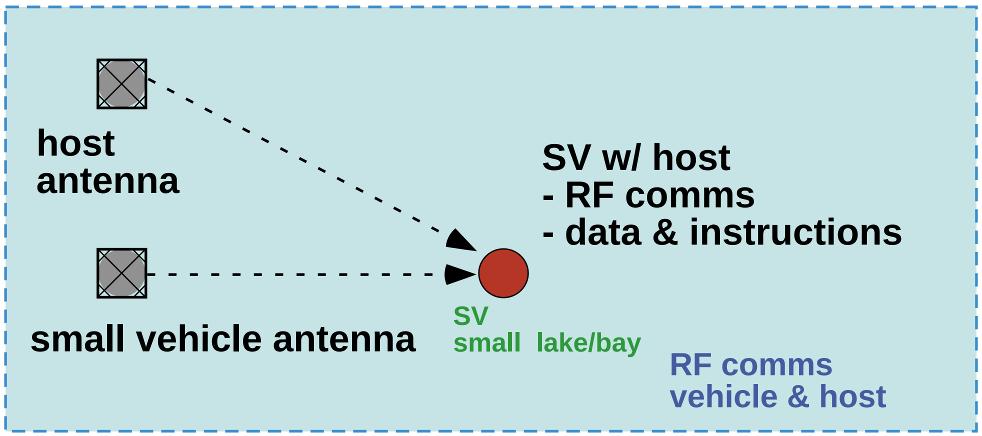
FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS



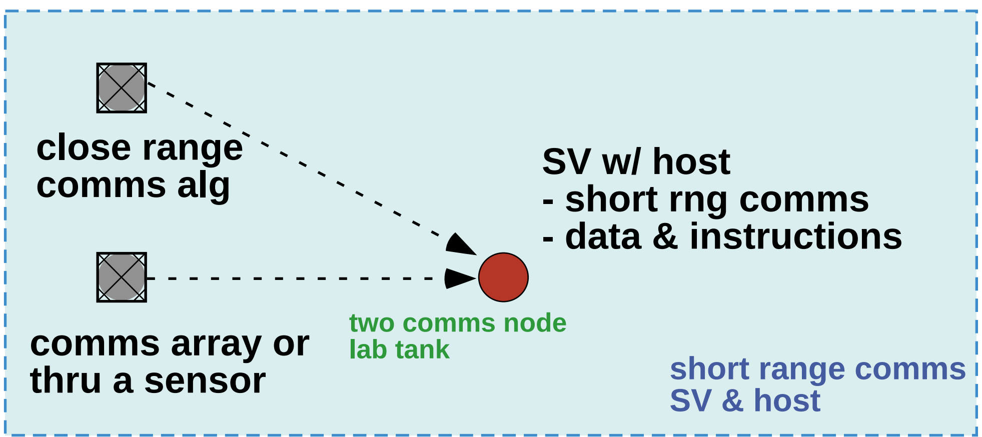
FMCM STUDY ROADMAP
TECHNOLOGIES & DEMONSTRATION COMPONENTS



- Small, Short-Term Target Marker
- Reacquisition Marker
- Navigation Marker



- Moderate Range SV RF Communications
- Near Water Surface Operation
- Robust Availability



- High Bandwidth Short-Range Acoustic Communications
- SV to LV Data Transfers
- Utilize Existing Sensor Arrays

Technologies Needs and Demonstrations

- Sensors
  - ALS
    - Long range shallow water design
      (most modeled ranges have been demonstrated)
    - ALS's for small vehicles
      - power management
      - simplicity of design/manufacture
      - supports auto dectect/discrimination
      - supports swallow water vertical processing
  - SAS (search/classification)
    - long range, small object performance
    - long range shallow water design
    - on small to medium sized vehicle (less stable)
    - power management & design simplicity
    - processing efficiency
  - SAS (close range)
    - small vehicle close range high ping rate operation
    - small vehicle motion
    - ultra-classification imagery

• Computer Detection/Discrimination/Classification/ID algorithms
  (most algorithms have only been run in an “aided” mode)
  - high Pd
  - low FC (from Pd on: < 10/nm^2)
  - sufficient confidence to send SV (Bird-dog Type I System)
  - sufficient confidence to auto-mark targets

• Markers
  - small low power markers
  - w/ unique ID
  - wake-up modes
  - individual & group responds
  - use as homing marker
  - use as nav-grid

• Bird-dog Small vehicles maneuvering
  - locating the selected target after initial vectoring
    (potential in-route vectoring)
  - classification approach via ALS
  - ultra-classification/ID fly-by via sidelooker
  - marking if MLO
  - homing on LV
  - L&R with LV
  - close range comms w/ LV
  - Bird-dog vehicle support of other platforms & missions
  - high accuracy localization for marker placement

- Full search Small Vehicles
    - SV that execute “typical” MCM conop
        - search, maneuver to ultra-class/ID, & continue search
        - marking if MLO
    - sufficient nav. to support complete multi-vehicle coverage
    - sufficient nav. to support reacq.
    - High Pd/low FC Detection sensors w/ associated platform stability
    - class & ultra-class sensors w/ associated platform stability

- Small Vehicles
    - in-expensive/reliable design techniques
    - energy sources
        - high energy density
        - fast recharge
        - LV/SV energy sharing in bird-dog option

- Neutralization
    - reacq via markers
    - reacq via acoustic CAD/CAC/CAI & scene recognition
    - reacq w/o markers (but “good” nav)
    - payload placement

- Acoustic ID
    - replace optical sensors, turbid water operation
    - high-high resolution imaging
    - 3D sensing of sensor

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OBSERVATIONS

- **Multiple Vehicle Sizes are Necessary for Full End-to-End Capability**
  - **multiple stages to each mission**
    - **transit, search (detect, classify, identify), mark, reacquire, neutralize, …**
  - **no single vehicle type has the endurance, search capabilities, nor payload capacity to perform all stages in an effective manner**

- **Every Concept Required a Larger Vehicle (LV)**
  - **transport smaller vehicles to operational area**
  - **provide wide area search sectors and highest area search rates**

- **Some Large Vehicle Provided Both Transport and Large Area Search Capabilities**

- **Covert System-of-System Concepts Required a Large UUV**
  - **some type I and types II systems**

- **Non-covert System-of-System Concepts used a variety of Large Vehicles**
  - **UUV, USV, and manned aircraft**

- **Some of the concepts required rapid deployment by an aircraft (for high ACR)**
  - **types III systems**
  - **surface craft deployment was an option, but with lower ACR's**

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OBSERVATIONS
(cont.)

- **The 21” UUV was a near optimal size (among the Large UUVs)**
  - **always among the “best performers” (ACR, Cost, ACR/Cost)**
  - **Type I & II systems in multiple mission areas**

- **The 8” UUV was typically one of the best performers (among the small UUV’s)**
  - **Type I, II, & III systems**
  - **LV/Bird-dog type I system sometimes favored the smaller (5”) UUV**
  - **Type II systems sometimes favored the larger (12”) UUV**
  - **vehicle may be influenced by deployment options and CONOPS**

- **Close Range Sensing by the Small UUVs provides enormous benefits**
  - **significantly simplified acoustic sensor packages**
  - **ultra-classification images (near ID acoustic imagery)**
  - **simplified optical sensors (close range optics, cameras, and light sources)**

- **Close Range Sensing Provides the Potential to Employ Non-Traditional Sensing Options**
  - **ultra-broadband acoustic sensing for non-specular echo target discrimination clues**
  - **magnetic and RF discrimination clues**
  - **chemical discrimination clues**

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OBSERVATIONS
(cont.)

- **Multiple Sensor Configurations Provided a Variety of Robust Capabilities and Supported Multiple Mission Options**
  - **LV Ahead Looking Sonars (ALS): wide swath search**
    - **for pass off to next level sensor (either long range on LV or close range on SV)**
    - **for complete coverage in deeper environments with volume targets**
  - **SV ALS**
    - **ahead looking area search for initial coverage and pass-off to next sensor**
    - **for approach to target, single pass classification, or G&C during close range sensing maneuvers**
  - **SV Long Range Synthetic Aperture Sonar (SAS): wide area search and classification**
    - **side looking search for initial coverage and pass-off to next sensor on return path and reacquisition**
  - **SV Close Range SAS: ultra-classification sensing**
  - **SV Close Range Side-Looking Sonar (SLS): ultra-classification sensing**

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OBSERVATIONS
(cont.)

- **Most Versatile SV Sensor Configuration**
  - **ALS:**
    - **ahead looking area search**
    - **contact pass-off and vehicle vectoring**
    - **target approach**
    - **close range sensing G&C**
  - **Long range SAS**
    - **long range classification**
  - **Close Range Acoustic Sensor**
    - **ultra-classification imagery w/ safe stand-off distances**

- **Only Simple SV CONOPS Were Needed for All System Concepts**
  - **most systems concepts used very simple search strategies**
    - **no coordinated networks of UUVs**
    - **minimal inter-vehicle communication**
  - **mostly "out-and-back" or "search-a-confined-box" SV CONOPs**
  - **no random search SV CONOPs**
  - **one concept has a coordinating moving SV-node that communicates with a small set of search SVs over short ranges**

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OBSERVATIONS
(cont.)

- **Inter-vehicle Communications Were Employed in Select Situations**
  - close range (potentially in contact) SV data uploads and next mission plan downloads
  - SV to host RF long range communications for data transfer and mission plan updates
  - some low bandwidth LV to SV control and guidance

- **No underwater Communications Network was Necessary for These System Concepts**

- **Small Target Markers were useful in Nearly Every Concept**
  - minimizes reacquisition time
  - reduces reacquisition navigation accuracy requirements
  - could provide a local reference frame fix for reacquisition or follow-on avoidance assets

- **No New or Innovative Neutralization Option was identified**
  - no small charge, shape charge, or projectile was identified for disposable UUVs
  - first order review/analysis indicated that only bulk charge options appeared feasible
  - no multiple charge per SV was developed
  - all system concepts used a single follow-on SV per target

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OBSERVATIONS
(cont.)

- **Multiple Navigation Options Were Employed**
  - **long base line system**
    - **earth based reference frame**
    - **requires external pre-deployed units**
  - **surface GPS navigation node**
    - **earth based reference frame**
    - **requires communications with other vehicles**
  - **ground reference tracking**
    - **local bottom reference frame with GPS fix tie points**
    - **all based on the vehicle (no extra hardware) uses search sensor data**
    - **may provide bottom features for follow-on vehicles re-navigation**
  - **inertial**
    - **vehicle based reference with GPS fix tie points**
    - **all based on vehicle with standard navigation packages**
    - **may be sufficient for some system concepts (w/ short distance tracks)**
  - **marker assisted navigation**
    - **dropped by previous vehicle as navigation nodes**
    - **provides target lock**
    - **provides re-navigation on local reference frame**

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Recommendations for R&D and Testing

- Close Range Sensing should be developed and tested
    - immediately
        - small vehicle maneuvering
            - approach and fly-bys
        - simple acoustic sensor and processing (SAS, SLS, …)
        - simple non-traditional sensors (magnetic, optical)
    - near term
        - special path maneuvering (match sensor and processing and G&C characteristics)
        - more advanced acoustic sensors and processing (broadband, adaptive paths)
        - other non-traditional sensors (RF, ….)
    - far term
        - advanced sensor and processing (chemical, multi-sensor fusion,…)

- Small Vehicle Target Approach
    - for sensing fly-by, marker drop, and neutralization
    - starting with moderate navigation error
    - starting with vector and range
    - acoustically guided
    - with marker near target

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Recommendations for R&D and Testing
(cont.)

- **Small Vehicle Payloading in Large vehicles**
  - for efficient launching; underwater, surface, or aircraft
  - for recovery
    - one time, end of mission
    - multiple times through-out mission
  - for efficient packing and loading

- **Small Vehicle L or L&R from a UUV**
  - Covert Type I & II system configurations
  - evaluate with a large vehicle reconfigurable section

- **Small Vehicle Air Launch**
  - for search mission & neutralization mission
  - start search track and/or reacquire target

- **Low-Cost Small UUV**
  - investigate low cost components and fabrication techniques
  - single use (e.g neutralization) UUVs and multi-use missions (e.g. area search) UUVs
  - self disposing or destructing so as to not add to bottom clutter

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Recommendations for R&D and Testing
(cont.)

- **Inexpensive Short-Term Markers**
  - **target marker & renavigation**
  - **w/ low power and active modes**
  - **develop placement and launch from SV**

- **Low Power Compact Sensors**
  - **ALS, SAS, close range sensor arrays**
  - **ALS, SAS, close range sensor electronics**
  - **ALS, SAS, close range sensor processing**
  - **ALS, SAS, close range sensor data recording**