THE NAVY UNMANNED SURFACE VEHICLE (USV) MASTER PLAN

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EXECUTIVE SUMMARY

The nation is faced, currently and for the foreseeable future, with a multitude of military challenges that are unlike any seen in recent history. The enemy is diverse, not easily recognizable, and operates in atypical ways. These assymetic threats have the ability to do great harm to our maritime forces and infrastructure, and the Navy must have the ability to address and defeat them in support of national Defense objectives, while continuing to execute its traditional roles.

Unmanned systems have the potential, and in some cases the demonstrated ability, to reduce risk to manned forces, to provide the force multiplication necessary to accomplish our missions, to perform tasks which manned vehicles cannot, and to do so in a way that is affordable to the nation.

The Unmanned Surface Vehicle (USV) Master Plan was chartered by the Program Executive Officer for Littoral and Mine Warfare (PEO (LMW)). It provides the guide for USV development to effectively meet the Navy's strategic planning and Fleet objectives and the force transformation goals of the Department of Defense (DoD)to the year 2020.

Plan development was built on the results from Workshops conducted at the Naval War College and the Fleet ASW Training Center in late 2004 and early 2006, respectively, with major analysis, synthesis, and development efforts being conducted by a USV Master Plan Core Team.

THE VISION FOR USVs AND THE OBJECTIVE OF THE USV MASTER PLAN

The USV vision is:

> To develop and field cost-effective USVs to enhance Naval and Joint capability to support: Homeland Defense, the Global War on Terror, Irregular Warfare, and conventional campaigns. USVs will augment current and future platforms to deliver enhanced steady-state and surge capability to help deter the enemy at the regional, transnational, and global levels. USVs will be highly automated to reduce communication/data exchange requirements and operator loading. They will deploy and retrieve devices, gather, transmit, or act on all types of information, and engage targets with minimal risk or burden to US and Coalition Forces.

In support of this vision, the USV Master Plan has the following objectives:

- Define USV capabilities for the near, mid and far terms
- Establish levels of performance and USV ‘classes’ aligned with capabilities
- Evaluate technology needs to assess current readiness and recommend future investments

THE USV DEFINED

To clearly focus this plan on the required missions the following definitions were used in this plan:

- Scope of Plan - Tactical systems capable of air or sea transport
- Unmanned - Capable of unmanned operation. Can be manned for dual use or Test and Evaluation (T&E). Has varying degrees of autonomy.
- Surface Vehicle - Displaces water at rest. Operates with near continuous contact with the surface of the water. Interface of the vehicle with the surface is a major design driver.

For the purposes of this Plan, the following definitions are germane relative to USV autonomy:

- Manual – Man in loop continuously or near-continuously.
- Semi-autonomous – Some vehicle behaviors are completely autonomous (e. g., transit to station, activate sensors). Vehicle refers to its operator when directed by the operator or by its own awareness of the situation (e. g., for permission to fire).
- Autonomous or Fully Autonomous – The vehicle governs its own decisions and makes its own decisions from launch point to recovery point.

Most operations will likely be some combination of these three modes.

CRAFT TYPES

Many hull and craft types were examined since a major design driver is the interface of the USV with the sea surface.

(1) Semi-submersible Craft

(2) Conventional Planing Hull Craft

(3) Semi-planing Hull Craft

(4) Hydrofoils

(5) Other Craft types

MISSIONS

As a result of the analyses performed during development of this Master Plan, seven high-priority USV missions were identified that support the Joint Capability Areas (JCAs). The seven missions, in priority order, are:

- Mine Countermeasures (MCM)
- Anti-Submarine Warfare (ASW)
- Maritime Security (MS)
- Surface Warfare (SUW)
- Special Operations Forces (SOF) Support
- Electronic Warfare (EW)
- Maritime Interdiction Operations (MIO) Support

VEHICLE CLASSES

These seven USV Joint Capability Area missions can be accomplished in three standard vehicle classes and one non-standard vehicle class (Figure 1).

USV MP Priority	Joint Capability Area (JCA)	Seapower Pillar	USV Mission	X-Class (small)	Harbor Class (7M)	Snorkeler Class (7M SS)	Fleet Class (11M)
1	Battle Space Awareness (BSA) / Access/ Littoral Control	Sea Shield	Mine Countermeasures (MCM)		MCM Delivery, Search / Neutralization	MCM Search, Towed, Delivery, Neutralization	MCM Sweep, Delivery, Neutralization
2	BSA / Access/ Littoral Control	Sea Shield	Anti-Submarine Warfare (ASW)			Maritime Shield	Protected Passage and Maritime Shield
3	BSA, HLD, Non-Trad Ops, 7 Others	FORCEnet	Maritime Security		ISR/ Gun Payloads		7M Payloads
4	BSA / Access/ Littoral Control	Sea Shield	Surface Warfare (SUW)		SUW, Gun	SUW (Torpedo), Option	SUW, Gun & Torpedo
5	BSA / Access/ Littoral Control/ Non-Trad Ops	Sea Strike	Special Operation Forces (SOF) Support	SOF Support	SOF Support		Other Delivery Missions (SOF)
6	BSA, C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control	Sea Strike	Electronic Warfare		Other IO	High Power EW	High Power EW
7	BSA, Stability, Non-Trad Ops, Littoral Control	Sea Shield	Maritime Interdiction Operations (MIO) Support	MIO USV for 11M L&R	ISR/ Gun Payloads		

Primary Missions supported by			
X-Class	Harbor Class	Snorkeler Class	Fleet Class
Secondary Missions of each class that are possible			

Figure 1 - USV Classes

- The "X-Class" is a small, non-standard class of systems capable of supporting SOF requirements and MIO missions. It provides a "low-end" Intelligence, Surveillance, Reconnaissance (ISR) capability to support manned operations and is launched from small manned craft such as the 11m Rigid Inflatable Boat (RIB) or the Combat Rubber Raiding Craft (CRRC).
- The "Harbor Class" is based on the Navy Standard 7m RIB and is focused on the MS Mission, with a robust ISR capability and a mix of lethal and non-lethal armament. The "Harbor Class" USV can be supported by the majority of our Fleet, since it will use the standard 7m interfaces.
- The "Snorkeler Class" is a ~7m semi-submersible vehicle (SSV) which supports MCM towing (search) missions, ASW (Maritime Shield) and is also capable of supporting special missions that can take advantage of its relatively stealthy profile.
- The "Fleet Class" will be a purpose-built USV, consistent with the handling equipment and weight limitations of the current 11m RIB. Variants of the Fleet Class will support MCM Sweep, Protected Passage ASW, and "high-end" Surface Warfare missions.

FINDINGS AND RECOMMENDATIONS

The overall recommendations from the USV Master Plan are to:

- Wean from the bandwidth. Greater autonomy should be developed to reduce data requirements sent “to” the USV, and more advanced automated target recognition must be developed to reduce the data requirements “from” the USV.
- Align acquisition strategies/ approaches to the 4 classes of vehicles, with common core systems and interfaces to the greatest degree possible.
- Continue to deploy modules (non-standard) to Littoral Combat Ship (LCS) and other Fleet platforms to meet critical milestones and provide early operator feedback.
- Make use of the USV's ability to deliver capability in "crawl-walk-run" sequence. Deliver initial man-in-loop capabilities now, and use that experience to guide development of future semi-autonomous and fully autonomous upgrades.
- Conduct risk reduction for technology and operations
- For the weaponized USV options, investigate or develop the necessary rules of maritime law and law of war associated with operating autonomous armed vehicles. Apply these rules early and throughout the design and development process.
- Field systems in the Fleet with Sea Trials, before or in parallel with acquisition efforts.
- Invest in a balanced USV technology program, which includes five technical imperatives:
    - autonomy;
    - obstacle / collision avoidance;
    - coupled payloads / weapons;
    - launch and recovery; and
    - advanced hulls, mechanical, and electrical, systems.
- Develop USVs consistent with Navy and DoD guidance, including compliance with Joint Architecture for Unmanned Systems (JAUS).
- Comply with the PEO-LMW-chartered and industry-led unmanned systems standards being developed. Standardize the vehicle interface to the host as well as within the vehicle, with standards for each class and common vehicle functions leveraged among different classes.
- Continue the outreach to Navy operational, doctrine, and training commands to expand and refine employment concepts for USVs, to ensure they are integrated with the concepts of Navy transformation

Notes on the organization of this Plan:

Chapters are organized in the logical order in which the work was done. This does not necessarily correspond to the chronological order in which the review, discussion, and analysis were conducted and the conclusions drawn. Some of these processes were done in parallel and others were iterative in nature.

This Plan is derived from a Flag brief that has been reviewed and approved by the major stakeholders. All of the major issues from that brief and the resulting feedback is covered in the text. There may be, however, some additional and supplemental information in the figures that is not specifically highlighted in the text.

For the purposes of this Plan, the following definitions are germane:

- Near-term: present to 5 years
- Intermediate- or mid-term: 5 to ten years from present
- Far-term: beyond 10 years from present

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NAVY UNMANNED SURFACE VEHICLE MASTER PLAN

CHAPTER 1 – USV VISION

THE NEED FOR A USV MASTER PLAN

Our Nation is at war today, in what is described by many as the "long war". We are opposed by an enemy in the shadows, an asymmetric threat, whom we must and will defeat to preserve our way of life. Technology is advancing at a rapid pace, with the development and application of technology proliferating, rather than being concentrated in a small number of advanced nations. New and even more challenging peer competitors are a real threat in the coming decades.

Unmanned systems have the potential, and in some cases the demonstrated ability, to reduce risk to manned forces, to perform tasks which manned vehicles cannot, to provide the force multiplication necessary to meet this threat and continue to accomplish our missions, and to do so in a way that is cost-effective for the nation.

In consonance with this current and projected future global environment, the USV Master Plan Study Team was chartered by the Program Executive Officer for Littoral and Mine Warfare (PEO(LMW)) in reference (a). The Team's tasking was to develop the Department of the Navy's Unmanned Surface Vehicles (USV) Master Plan to guide USV development in effectively meeting the Navy's present and future needs in support of Sea Power 21 and Fleet requirements. The team was to address:

- Joint and Naval warfighting requirements;
- USV Platform and Payload (both emerging and available technologies);
- Joint interoperability and network connectivity;
- Modularity, host platform interfaces and Fleet integration issues;
- Compatibility with Office of the Secretary of Defense (OSD) guidance and plans, Joint doctrine and capability assessments, and Naval operational concepts as appropriate;
- Fleet lessons learned; and
- Affordability.

The use of unmanned vehicles in naval operations is not new…

Following World War II, Unmanned Surface Vehicles (USVs) were developed and used for purposes such as minesweeping and battle damage assessment (BDA). For example, in 1946, during Operation Crossroads, drone boats were used to obtain early samples of radioactive water after each of the Atomic Bomb Blasts (reference (b)).

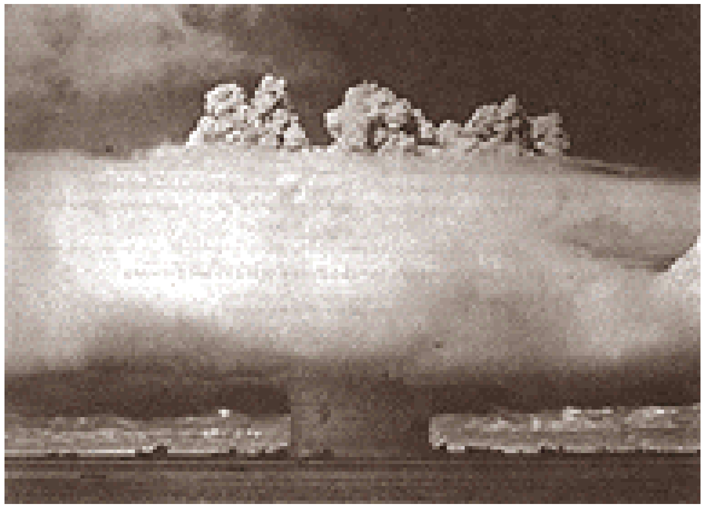

Figure 2 - Drone Boats on Bikini Atoll

Later, in the late 1960's, a 23-ft fiberglass hull, powered by a V-8 inboard gas engine, was modified to operate as a remotely controlled "chain drag" minesweeper (Figure 3). A number of these boats were assigned to Mine Division 113 at Nha Be, south of Saigon, for mine sweeping operations in Viet Nam.

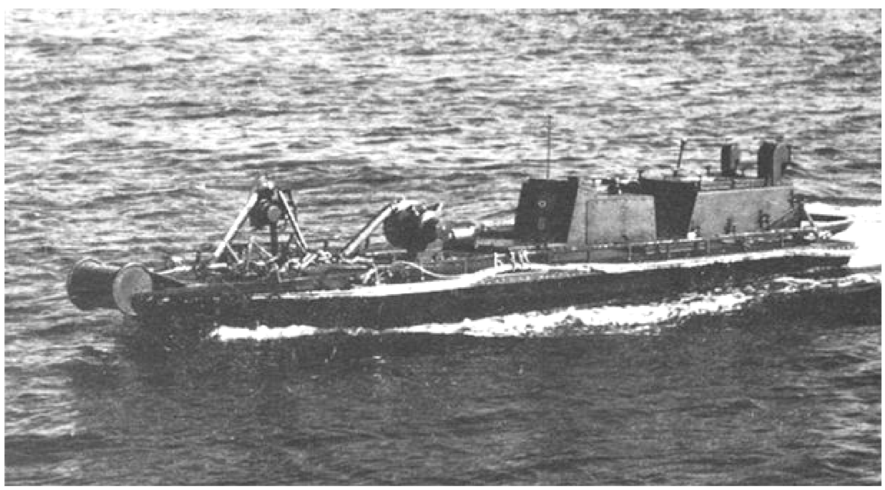

Figure 3 - Minesweeping Drone (MSD)

In the 1990's the Remote Minehunting Operational Prototype (RMOP) was operated from *USS Cushing* in the Persian Gulf. RMOP conducted 12 days of Minehunting operations in January/February 1997 in participation with the SHAREM 119 exercise (Figure 4).

Figure 4 - Remote Minehunting Operational Prototype (RMOP) in the Persian Gulf

More recently, Fleet experimentation and experience at war has validated the concepts of Fleet transformation and force multiplication via the use of unmanned systems. Unmanned Undersea Vehicles (UUVs) were considered the main workhorses of the mine clearing effort during Operation Iraqi Freedom in 2003, as shown in Figure 5 (reference (c)) .

Figure 5 - UUV during Operation Iraqi Freedom

The SPARTAN Advanced Capability Technology Demonstration (ACTD) USV was used at sea with USS Gettysburg (CG64) in the Persian Gulf, to demonstrate its ability to conduct ISR missions and for Fleet familiarization (Figure 6). The right-hand side of Figure 6 shows a demonstration of how a remote controller was used to steer a modified Rigid Inflatable Boat (RIB) USV (reference (d)).

Figure 6 – SPARTAN USV Demonstrating ISR Missions in Persian Gulf (reference (e))

It was the task of the USV Master Plan Study Team, then, to build on this rich background to forge a strategic path forward for the Navy's USV programs and supporting technology developments.

SUPPORTING THE DOD FORCE TRANSFORMATION INITIATIVE

This plan is designed to support Navy and DoD guidance in transforming our force structure by integrating the use of the USVs.

The Navy continues its transformation in order to provide the nation with rapid, flexible, and agile responses to current and potential future challenges. The Navy needs unmanned systems to reduce the vulnerability and multiply the effectiveness of manned platforms. Unmanned systems make sense from several perspectives (reference (f)):

- Cost - manned systems are far more expensive to operate than unmanned systems.
- Coverage - coverage rates and the ability to maintain constant awareness of the environment are improving as a result of technological advances in sensors and sensory systems.
- Productivity - leveraging of unmanned systems for intelligence surveillance and reconnaissance (ISR) missions enables mission planners to focus the manned platforms on other objectives.
- Persistence – dedicated, persevering threat observation can provide military planners with an understanding of long-term threat behavior patterns and trends that are not apparent from short-term "spot" observations.
- Vulnerability - Unmanned systems keep the people and the high-value manned platforms out of harm's way.

The Navy need for unmanned systems is validated by the priorities identified the following guidance: *Sea Power 21* (October 2002), *Quadrennial Defense Review* (QDR 2006), *National Strategy for Maritime Security* (September 2005), *National Plan to Achieve Maritime Domain Awareness* (October 2005), Combatant Commanders'

Integrated Priority Lists (i.e. Joint Forces Command (JFCOM), Special Operations Command (SOCOM)), *National Defense Strategy of the United States* (March 2005), *ASW Way Ahead* (March 2006), and the *Navy Strategic Plan* (June 2006).

The *Navy Strategic Plan* in particular identifies several recurring themes with emphases on jointness, sustainment, distribution of capabilities, and global maritime dominance.

The *Quadrennial Defense Review (QDR)* 2006 focuses on a Naval force with increased capability and capacity to assure access and support joint operations in blue, green, and brown waters (reference (g)). It confirms the Navy's resolve to sustain "Today's Navy" while preparing for the challenges of "Tomorrow's Navy" and the "Navy After Next". The Navy's future is not only about conventional campaigns; the final report focuses on steady-state and surge capabilities in three objective areas – homeland defense, the war on terror/irregular (asymmetric) warfare, and conventional campaigns – with force capabilities equally adaptive to all three areas.

USVs are not only effective in wartime, but can also make very valuable contributions to peacetime missions. USVs can contribute to maintaining international stability during peacetime operations. USVs can be used to aid in law and treaty monitoring, intervention, or enforcement as allowed by U.S. and international codes, as well as disrupting international criminal networks (i.e. piracy, smuggling of drugs, hazardous cargo and embargoed materials). Proactive security is far more cost-effective than armed conflict.

The *National Defense Strategy of the United States of America*, reference (h), emphasizes the importance of influencing events before challenges become more dangerous and less manageable. Different methods of responding to challenges are considered appropriate, depending on the vulnerability level and likelihood that the adversary capability or behavior will occur. This is illustrated in Figure 7, adapted from the National Defense Strategy.

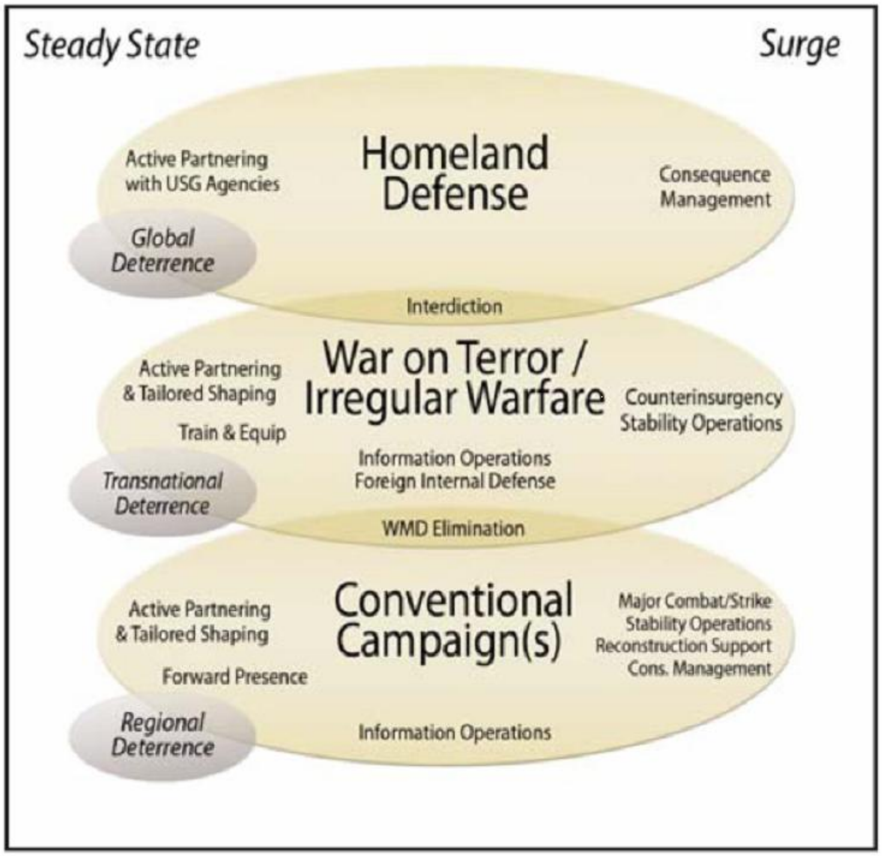

Figure 7 - Quadrennial Defense Review (QDR 2006)

The latest strategic plans show the Fleet structure in 2020 to be mainly comprised of Guided Missile Destroyers (DDG) 51/DDG(1000), Littoral Combat Ships (LCS), Attack Submarines (SSN), and Combat Logistics Force (CLF) class ships, reference (i). It is expected that over twenty percent (20%) of our 2020 Surface Fleet hulls will be LCS, the first ship class fielded with a significant portion of its warfighting capability tied to reconfigurable "Mission Modules". Many of these Mission modules have unmanned vehicle systems as primary or contributing components.

THE USV DEFINED

To clearly focus the USV Master Plan on its chartered tasks, the following definitions were adopted for the purpose of this plan:

- Scope of Plan - Tactical systems capable of air or sea transport (reference (j))
- Unmanned - Capable of unmanned operation. Can be manned for dual use or Test and Evaluation (T&E). Has varying degrees of autonomy.
- Surface Vehicle - Displaces water at rest. Operates with near continuous contact with the surface of the water.

Interface of the vehicle with the surface is a major design driver.

Although this definition includes hydrofoils and semi-submersible (i.e., continuously snorkeling) crafts, it specifically excludes UUVs operating at or near the surface, hovercraft, surface effect aircraft and target drones that are used exclusively for training or evaluation and are part of a separate legacy program (e.g., undersea and surface targets operated on an instrumented range as targets).

For the purposes of this Plan, the following definitions are germane relative to USV autonomy:

- Manual – Man in loop continuously or near-continuously.
- Semi-autonomous – Some vehicle behaviors are completely autonomous (e. g., transit to station, activate sensors). Vehicle refers to its operator when directed by the operator or by its own awareness of the situation (e. g., for permission to fire).
- Autonomous or Fully Autonomous – The vehicle governs its own decisions and makes its own decisions from launch point to recovery point.

Most operations will likely be some combination of these three modes.

VISION AND OBJECTIVES OF THE UNMANNED SURFACE VEHICLE MASTER PLAN

The USV vision is:

> To develop and field cost-effective USVs to enhance Naval and Joint capability to support Homeland Defense, the War on Terror/Irregular Warfare, and Conventional Campaigns. USVs will augment current and future platforms to deliver enhanced steady-state and surge capability to help deter the enemy at the regional, transnational, and global levels. USVs will be highly automated, to reduce communication and data exchange requirements, and will deploy or retrieve devices; gather, transmit, or act on a wide spectrum of information; and engage targets with minimal risk or burden to US and Coalition Forces.

In support of this USV vision, the USV Master Plan Study Team set forth the following objectives:

<u>Define the USV capabilities</u> needed in the near, mid and far term. These include mission descriptions and priorities, a high-level Concept of Operations (CONOPS) for each mission, and an assessment of candidate capabilities to determine whether they are appropriate for USVs or should be assigned to other assets.

<u>Establish Levels of Performance and a "Class"</u> for each USV capability to: (1) recommend a number of classes of vehicles required to efficiently group similar or complementary capabilities, (2) bound the proliferation of USV types and sizes in Navy programs, and (3) examines the level of modularity and commonality that should be established within and between classes.

<u>Evaluate USV Technology Needs</u> in order to assess their technological readiness and recommend the technology investments that should be made to enable the development of vehicles and payloads to accomplish the required USV capabilities.

The pursuit of the USV Vision should be conducted as an overall system integration process that takes into account all aspects of technology, engineering, Fleet experimentation, and life cycle support—including Doctrine, Organization, Training, Material, Logistics, Personnel and Facilities (DOTMLPF)—to realize effective capabilities (Figure 8). These capabilities should be allowed to evolve over time as the operators gain experience and confidence in the systems and the technologies advance. In this sense, USVs are ideally positioned for 'spiral' development of increasing Fleet capabilities: a rudimentary man-in-loop capability can be introduced early to provide timely Fleet mission enhancement, while also generating invaluable Fleet experience and feedback to the technical community in its development of the capability into partial and then full autonomy. This issue is discussed in greater detail in Chapter 4.

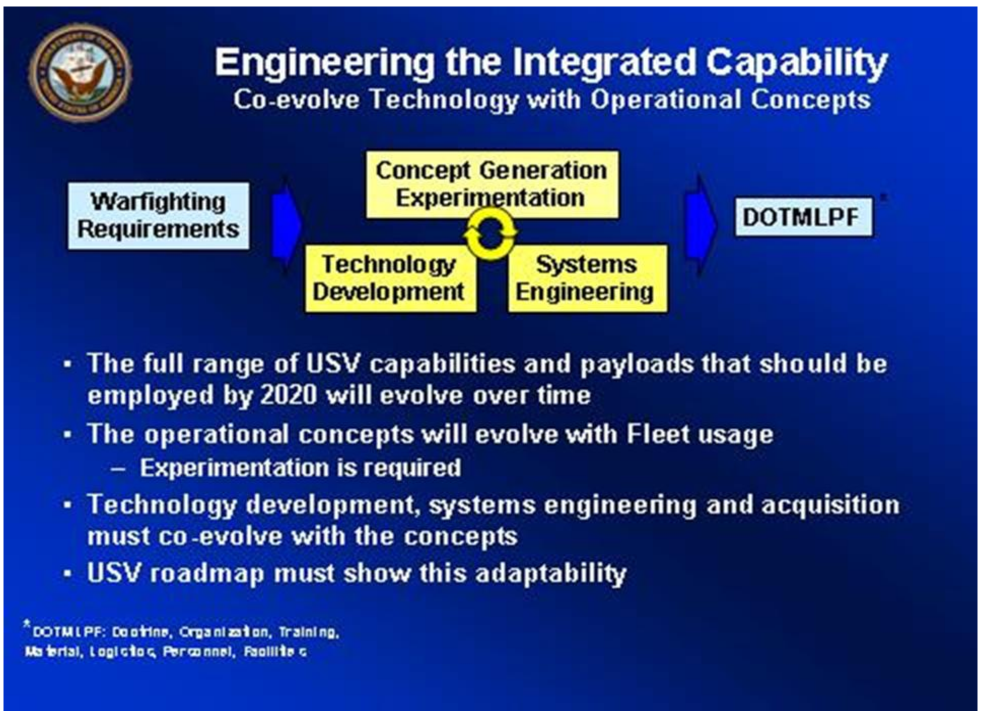

Figure 8 – Development of Integrated Capability

PROCESS

In executing these objectives in support of the Vision, the Study Team and its executive subset, the Core Team, determined to:

- Evaluate Navy and DoD guidance, as well as the Study Team chartering documentation, to craft a vision for the Plan and to ensure that the resulting product would meet Navy and DoD needs

- Gain an understanding of Fleet operational priorities, technical requirements, and practical limitations relative to USV operations, current and future
- Gain an understanding of the present state of USV development, and of the types of boat hulls that might be of use in current and future USV applications
- Review the current and likely future state of technologies available to assist in crafting reasonable, notional USV capability packages
- Conduct technical and operational analysis to the extent needed to gain a feel for practicability and potential military utility of notional USV capability packages
- Consider the full spectrum of DOTMLPF issues associated with vehicle ownership and operation throughout its life cycle.
- Forward recommendations to the technical development and acquisition communities to assist in making the desired USV capabilities a reality in the Fleet.

It was with this guidance in place that the Team took on its highest-priority issue, determining Fleet needs that could be mitigated or filled entirely by USVs.

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CHAPTER 2 - USV MISSION DESCRIPTIONS

DEVELOPING USV MISSION PACKAGES

Having reviewed Navy and DoD guidance, the Study Team then generated a set of high-payoff USV missions. This mission set was developed as a result of two major Workshops, substantial Core Team analysis and several Flag briefings. Details on the process used to develop this mission set are provided in Appendix C, but the process was heavily weighted toward Fleet input. For each of the desired missions, the Team developed a notional USV mission package including vehicle size/type, payload package, and probable utilization profile. In priority order, they are:

- Mine Countermeasures (MCM)
- Anti-Submarine Warfare (ASW)
- Maritime Security
- Surface Warfare (SUW)
- Special Operations Forces (SOF) Support
- Electronic Warfare (EW)
- Maritime Interdiction Operations (MIO) Support

This Chapter examines each of these missions in greater detail, including mission background and objective, concepts of operations (CONOPs), systems concepts for the employment of USVs in the mission, and technology and engineering issues for each. In this Chapter, "CONOPs" refers to the relationship, movement, and interaction of the major 'moving pieces' (host platform, USV, target or objective), while "system concept" refers to a particular (in some cases notional) implementation of hardware, software, and operational behaviors.

MINE COUNTERMEASURE (MCM)

MCM mission requirements are driven by the Fleet's need to rapidly establish large, safe operating areas, transit routes (Q-routes) and transit lanes. As shown conceptually in Figure 9, these areas are typified by long Sea-Lines of Communication (SLOCs), offshore Fleet Operating Areas (e.g., Carrier Operating Areas (COAs), Amphibious Operating Areas (AOAs)), and Littoral Penetration Areas (LPAs) (e.g., Assault Breach, Port Break-in, and Ship-to-Objective Maneuver (STOM)).

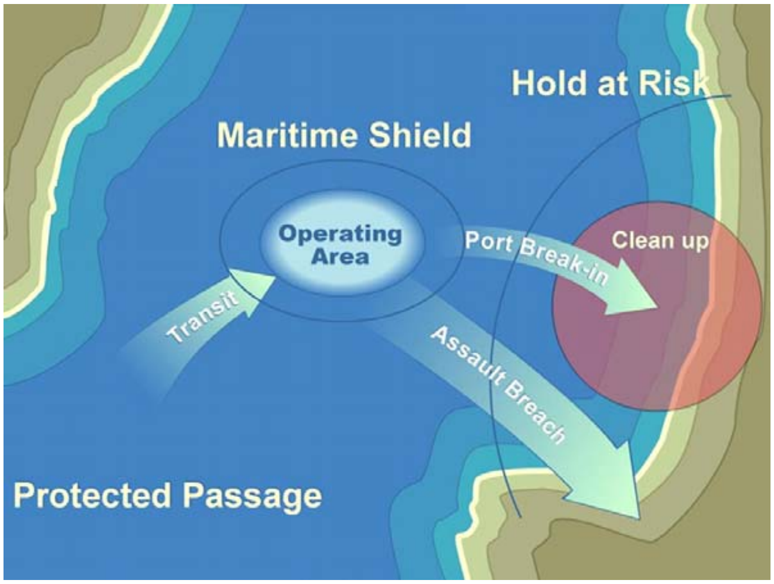

Figure 9 – Fleet Operating Scenarios

These range in size from 100 to 900 nmi^2 or larger, and cover the water column from deep, mineable waters to 'on the beach' in support of Marine Corps operations as depicted in Figure 10.

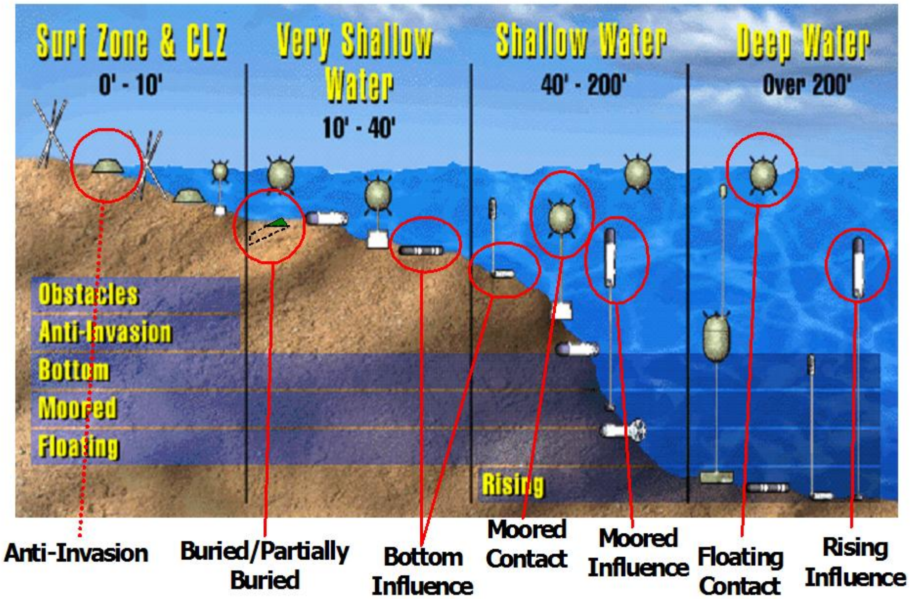

Figure 10 – Littoral Mine Threats

MCM supports all three pillars of Sea Power 21 (Sea Strike, Sea Shield and Sea Base). In doing so, it has to provide a workable and cost-effective solution to a wide range of MCM requirements. In support of Sea Shield and Sea Base, the objective of this MCM capability is to find or create Fleet Operating Areas that are clear of sea mines without requiring manned platforms to enter suspected mined areas, and to shorten MCM timelines. Further, this capability is required to operate within the near-term Navy force structure and to operate independently of other warfighting capabilities. The vision for future MCM operations is to field a common set of unmanned, modular MCM systems operated from a variety of platforms or shore sites that can quickly counter the spectrum of threat mines, assuring access to our Naval Forces with minimum mine risk.

The full range of MCM mission types must be brought to bear to meet these requirements against the myriad mine threat types and operational environments. The lexicon of mine countermeasures includes the following terms and their definitions:

- "Detection": the discovery by any means, of the presence of a mine or mine-like object with potential military significance.
- "Classification": the evaluation of an object to determine if it is non-mine like or mine-like.
- "Localization": establishing the precise position of an underwater object relative to a specific geodetic position.
- "Identification": determination of the exact nature of a mine-like object as a mine. Current doctrine specifies visual identification by a diver or camera, but advances in sonar technology may provide adequate capability in the foreseeable future.
- "Neutralization": rendering (by external means) a mine incapable of firing on a passing target or sweep.

The classic end-to-end response to a mine threat is DCLIN (detect, classify, localize, identify, neutralize). This is more of a technical sequence than an operational one, however, and it is rare that this chronology will take place in anything other than a controlled laboratory or experimental setting. For example, in most practical systems the DCL steps take place independently of the others, which may be foregone entirely if the minefield can be avoided. If the IN steps are necessary, then "relocalization" may also be necessary to start back again at the L step. The following terminology is used to describe actual MCM behaviors as addressed in current doctrine and practiced in the Fleet:

- "Reconnaissance": That phase of the exploratory objective designed to make a rapid assessment of the limits and density of a minefield.
- "Search": the use of sonar or divers to detect and classify mines or mine-like objects.
- "Hunting": the act of searching for mines. Hunting operations can also include marking and neutralization of mines.
- "Breaching": breaking through a minefield, thereby opening a clear path or channel.
- "Clearance" or "clearing objective": removal of detectable mines from an assigned area. Since it is generally impossible to guarantee that all underwater mines have been detected and cleared, a goal is assigned to coincide with a percentage of risk that a potential number of mines remain.

- "Sweeping": the act of towing mine countermeasures gear intended to actuate mines by generating a ship-like signature, or mechanically cutting mooring cables of moored mines.
- "Jamming": overwhelming an influence-activated mine's sensors with external influences, such as noise or a strong magnetic signature, thereby masking a passing ships signature and causing the mine to not detect the passing vessel.
- "Signature": the characteristic pattern of a ship's influence as detected by an influence sea mine (such as magnetic signature, acoustic signature, pressure signature).

USVs, along with UUVs, will have an important role in the conduct of MCM as they are particularly well suited for the ‘dirty - dull – dangerous’ tasks that MCM entails. They provide persistence, which permits significant mine hunting and sweeping coverage at lower cost by multiplying the effectiveness of supporting or dedicated platforms. Additionally, they provide the potential for supporting an MCM capability on platforms not traditionally assigned a mine warfare mission.

The introduction of USV-based MCM systems will provide the Joint Force Commander (JFC) with the capability to conduct persistent organic mine countermeasure operations ranging from intelligence preparation of the battlespace (IPB) to first response MCM, enabling Joint operations to be conducted ahead of power projection forces, at safe stand-off ranges. These MCM operations will open transit lanes for Joint Forcible Entry Operations, clear operating areas for naval forces, and enable protection for amphibious forces, again while keeping manned forces out of harm's way.

In addition to providing safe-standoff, the force multiplication attendant on the use of USVs in MCM can also reduce the timelines associated with providing safe passage through potentially mined waters. Through the application of USV-based MCM systems (e. g., the LCS MCM mission package), the timeline for access to the contested littoral will be reduced and a broader range of options will be available to the JFC. The concept is to gather as much information as possible, as early as possible, in order to minimize the magnitude of follow-on MCM operations required. Knowledge of the environment in the intended operational areas along with intelligence on the adversary’s capabilities focuses efforts on plausible threats and likely threat areas--in the ideal case, mined areas can be avoided entirely. Even minor successes with interdiction or avoidance of the threat before engagement will yield orders of magnitude savings in the operational timeline.

MCM USVs are planned for delivery to the Navy in the near future. These initiatives are considered to be a good beginning toward a future spectrum of USV MCM systems. The development of a completely independent, fully autonomous, long-term USV MCM capability with large area search, autonomous target identification (ID), and fully autonomous neutralization is not considered to be feasible in the immediate future. Even short of this ideal capability, however, there are several MCM capabilities that USVs can provide as significant complements to existing MCM forces, which will only become more useful as the enabling technologies mature. The ultimate goal is a fully-autonomous USV MCM capability to enable the Navy to achieve in-stride or near-in-stride access to any of the world’s littorals, regardless of the mine threat.

The specific sub-missions of MCM selected were MCM Search, MCM Sweep, and MCM Neutralization. A brief discussion of the MCM UUV Delivery mission, which is a potential subset of both MCM Search and MCM Neutralization, is also included.

MINE COUNTERMEASURE (MCM) SEARCH

- "Search": the use of sonar or divers to detect and classify mines or mine-like objects.

MCM SEARCH CONCEPT OF OPERATIONS

When the determination is made that searching is required, it is done in two stages. Initially, a reconnaissance operation is performed to determine the existence and extent of the threat. If a threat is detected and the operational area cannot be moved, then a clearance operation is undertaken to provide a high confidence level that the threat has been mitigated.

In the near term, USVs will contribute to search operations by towing a variable depth sensor that has the ability to detect, classify, and identify mines in the environment. This information derived can be processed in near real-time when the operator is in close proximity, or can be post-mission processed when the system operates at long range.

In the future, USVs may also deploy and retrieve multiple UUVs that will perform the search functions, instead of or in addition to towing sensors. This approach provides for very high area coverage rates through the use of many search assets in parallel, as described in the UUV Master Plan Update 2004, reference (c).

MCM SEARCH SYSTEM CONCEPTS

The near-term system with an MCM search application is the AN/WLD-1 semi-submersible USV that tows the AN/AQS-20 sensor system. The system can vary the tow scope/sensor depth and operating modes to search the water column from near-surface to the bottom for all mineable environments. Sensor imagery and computer-aided classifications (CAC) are provided to an operator for target acquisition.

Future USV systems will deploy UUVs to gain the advantage of higher area coverage rates through multiple, simultaneous operations, without the need for additional operators (reference (c)). While the particular types of USVs and the distribution of search functions across various UUVs will be determined from detailed studies, initial analysis shows that both semi-submersible and planing hull USVs have similar capabilities to manage the UUV payloads. Cost, complexity, and host interface issues will determine the selection.

Figure 11– MCM Search/Delivery

MCM search sub-functions consist of detection, classification and identification. If mines are found during the search, then a neutralization step is undertaken to eliminate the threat. Neutralization is discussed in a separate section below.

The basics of the MCM search/delivery capability are depicted in Figure 11.

MCM SEARCH TECHNOLOGY AND ENGINEERING ISSUES

Future USVs will benefit from the capability to automatically deploy and retrieve UUVs in high sea states at the far reaches of their operating area, without operator intervention.

They will also require autonomous obstacle and threat avoidance capabilities.

The search UUVs require automatic target recognition (ATR) and, ideally, coordinated group behavior capabilities to achieve the very high ACRs necessary to support current and projected Fleet requirements.

Synthetic Aperture Sonar (SAS) is the current leading sensor candidate to best meet the search requirements of the MCM mission. SAS promises to provide both increased resolution and increased area coverage—which can allow (1) a greater area to be searched in a given time, (2) a given area to be searched more rapidly with the same number of vehicles or (3) a given area to be searched with fewer vehicles. The resolution characteristic may be of significance in MCM ATR development.

MINE COUNTERMEASURE (MCM) SWEEPING

- "Sweeping": the act of towing mine countermeasures gear intended to actuate mines by generating a ship-like signature or mechanically cutting mooring cables of moored mines.

For reference, mine sweep performance parameters are contained in the LCS Flight 0 2010 Blue Book , reference (k) for operations with Unmanned Surface Vehicle (USV) Platforms.

MCM SWEEPING CONCEPT OF OPERATIONS

The MCM mantra to date has been: "hunt when you can, sweep when you must". This means that while mine-hunting can be an effective means of clearing mines, external influences such as highly reverberant and high-clutter environments, mine burial, and stealthy mine cases can make minehunting ineffective, so minesweeping may become necessary. In response to the proliferation of threat influence mines, the US Navy has moved away from mechanical sweep systems and toward influence sweep systems. Influence systems generate acoustic and/or magnetic energies sufficient to satisfy the triggering logic of these mines. Regardless, it can be a dangerous mission. Present sweep systems are towed behind MCM ships and helicopters and can pose a significant hazard to those personnel engaged in these operations. Mission analyses conducted for the LCS program and others have shown the possibility of accomplishing this difficult mission through the employment of USV based sweep systems, achieving very significant timeline reductions, while keeping the man out of the minefield.

MCM SWEEPING SYSTEM CONCEPTS

Current mine-sweeping systems rely upon powerful manned platforms to tow the

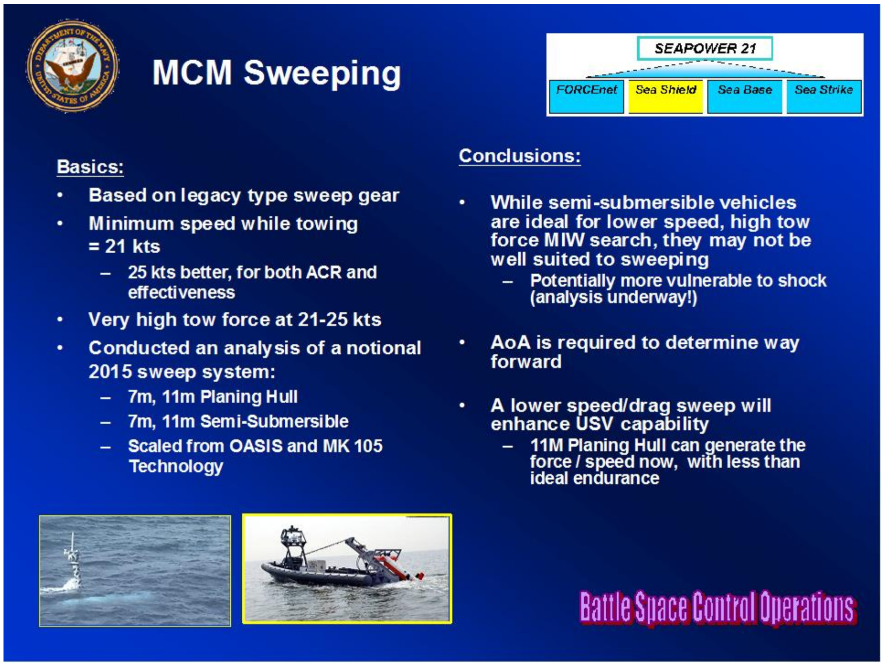

Figure 12 – MCM Sweeping

sweeping devices at sufficient speeds to be effective. The Organic Airborne and Surface Influence Sweep (OASIS), AN/ALQ-220, is one such system now in development for use with the MH-60S helicopter. The OASIS acoustic generator requires a towing speed in excess of 20 knots which is driving performance requirements for the USV Sweep System (US3) now in development by the Office of Naval Research (ONR). To accommodate this requirement, ONR has also developed and demonstrated the Unmanned Sea Surface Vehicle High Thrust variant (USSV-HT) specifically designed to tow an MCM Sweep.

The basics of the MCM Sweeping capability are shown in Figure 12.

MCM SWEEPING TECHNOLOGY AND ENGINEERING ISSUES

Towing payloads places severe demands on the USV by requiring high thrust at relatively moderate speeds. While semi-submersible vehicles are ideal for lower-speed/high-tow-force MCM search, they may not be well suited to sweeping due to their potential greater vulnerability to shock, as compared to a standard surface craft. This is an area where future analysis is required and an Analysis of Alternatives (AoA) should determine the way forward. Ultimately, a lower-speed, lower-drag sweep that does not excessively drive USV design and power requirements would allow for future USV design flexibility, enhancing mission performance with smaller, lower power craft and higher endurance.

MINE COUNTERMEASURE (MCM) NEUTRALIZATION

- "Neutralization": rendering (by external means) a mine incapable of firing on a passing target or sweep.

The proliferation of mine types with various operational positions--resting on or buried under the seabed and throughout the water column--poses a serious challenge to the U. S. Navy’s ability to neutralize them in a timely manner with either manned or unmanned systems or a combination of both.

Nonetheless, neutralization of identified mines is necessary in order to remove the hazard they present to navigation and maneuver. Contributing factors to neutralization planning include: (1) threat mine types may change or U. S. forces may encounter larger numbers of smaller mines, which would stress the number of neutralizers required, and (2), if neutralization can be limited to defined lanes, the problem becomes more tractable.

The ultimate goal is to have a fully automated system which performs all four steps (detection, identification, localization, and neutralization) in a single pass, making reacquisition unnecessary. In the near term, however, it is unlikely that the Maritime Component Commander (MCC) will be able to conduct mine neutralization in stride with detection and classification operations, unless a dedicated MCM vessel is available to perform the entire detect-to-engage sequence. Near-term unmanned systems configured with MCM sub-systems are not expected to have the ability to detect, identify and engage within a single platform and will have to work cooperatively with other manned and unmanned systems equipped for mine neutralization in order to perform neutralization ‘in stride’.

MCM NEUTRALIZATION CONCEPT OF OPERATIONS

For a bottom or moored mine, a neutralization system will be deployed from a loitering USV and will transit to the targeted mine under its own power. The system will relay (1) a sonar picture for precise location of the mine and (2) a visual display to the host vessel's MCM contact evaluator for identification verification prior to neutralization. The purpose of the ID step is to preclude wasting neutralization ordnance on non-mine threats. Once the mine is correctly identified, the Officer in Charge of MCM operations will clear the neutralizer to fire remotely. The neutralization device is an explosive charge effective against both bottom and moored mines. It may be self-mobile (e. g., a mini-torpedo), or a bulk charge which is attached to the mine casing. The charge can either be triggered by acoustic remote control or a timer. All near-term autonomous neutralizers will have to be capable of re-acquiring the target, based on original locations produced during the Search phase.

MCM NEUTRALIZATION SYSTEM CONCEPTS

Three neutralization systems approaches are envisioned within the Neutralization Concept of Operations :

1) A Remotely Operated Vehicle (ROV)-type neutralizer that is automatically deployed by the USV and is self-propelled to the mine. Its camera will provide a positive visual ID prior to it receiving a firing signal, at which point it will launch a neutralizing sub-munition. This system may be based upon present ROV-type airborne neutralizing systems.
2) A stationary explosive charge that is placed by a UUV which has been delivered to the mine danger area and deployed by a USV transporter. The charge is remotely detonated later using an acoustic command or a timing mechanism. The cost of such charges, which already exist in the mine clearance community, would likely be significantly less than the more sophisticated autonomous neutralizers, but somewhat more difficult and risky to place accurately.
3) An autonomous neutralizer in the class of a Man Portable UUV--essentially a small anti-mine torpedo--ferried by the USV to the mine danger area and deployed. This UUV system would self-deploy to the mine. This option could also used be for ‘Q-Route’ lanes or SLOC-clearance missions. The USV ferry method could potentially allow for rapid search and neutralization by a small number of USV’s loaded with autonomous neutralizers.

The number of neutralization sorties is driven by the USV's capacity to carry the neutralization devices. Until robust and reliable Computer-Aided Detection (CAD) and Computer-Aided Classification (CAC) are available, neutralization methods need to provide an operator-in-the-loop function, to put “eyes” on the image of the identified

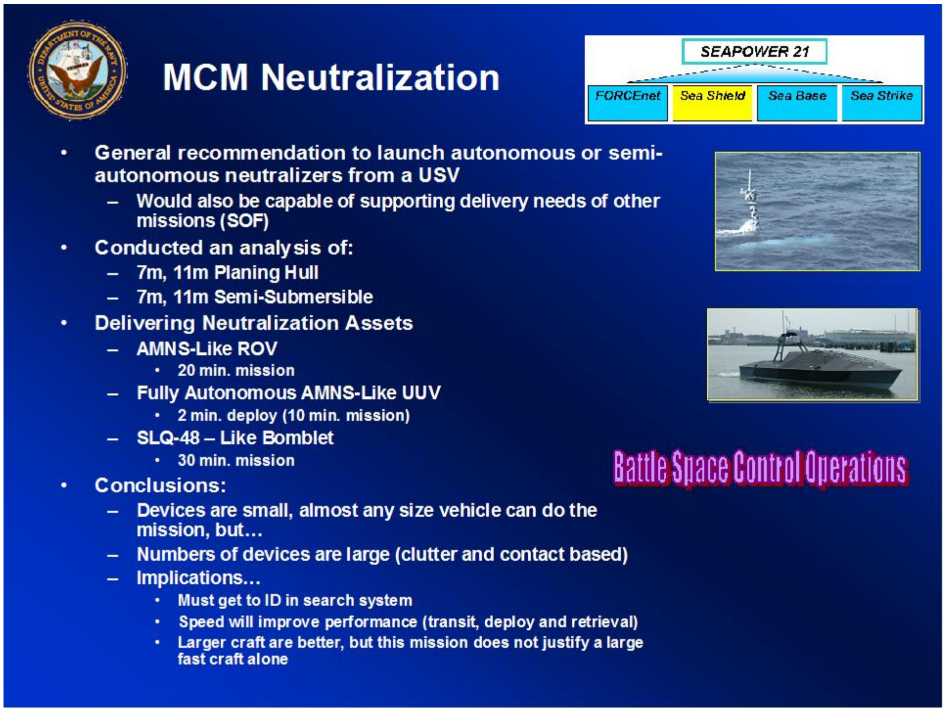

Figure 13 – MCM Neutralization

target prior to neutralization. Neutralization using autonomous neutralizers capable of reacquiring the targets, transported to the Operations Area (OPAREA) by USV, is an attractive option for reducing operational timelines. For example, four 30-knot USVs carrying 135 autonomous neutralizers each could deliver their entire payload in four hours. This is well within the time requirements for the overt clearance of the large mission areas noted at the beginning of the MCM section, or the clandestine LPA.

The basics of the MCM Neutralization capability are shown in Figure 13**.**

MCM NEUTRALIZATION TECHNOLOGY AND ENGINEERING ISSUES

Primary challenges with releasing mine neutralization systems from USVs include the ability to reliably reacquire the mine and achieve proper orientation for effective neutralization. Maintaining communications for man-in-the-loop operations will be a challenge, particularly over the horizon. The prospect of operating manned platforms in a suspected or known minefield, however, should encourage greater development of autonomy for these devices. High sea states may pose problems with USV station-keeping and system deployment. While the above Concepts of Operation and Systems Concepts are not definitive, they clearly indicate that near- to mid-term combined and cooperative USV and UUV technologies can realistically contribute to solving current and emergent MCM requirements. USVs delivering a large number of smaller neutralizers appear to be the best operational approach in providing greater mission flexibility, and facilitating graceful system degradation. With a range of neutralizer systems, shallower waters will become less of a challenge.

While it is desirable to produce one system that will work for all depths, this does not appear feasible in the near- to mid-term. A family of approaches (transport vehicles, sensors, processing, effectors) will most likely be necessary to cover the entire range of potential MCM threats.

CAD/CAC has been demonstrated and it is assumed that Computer-Aided Identification (CAI) is or will become an available technology. This technology is necessary to meet the required mission time, especially for target reacquisition and ID for neutralization purposes. The additional time necessary for the operator to make identification on each classified contact can radically grow the timeline and number of vehicles required. The challenge facing successful integration of CAD / CAC is to get operators sufficiently confident in the algorithm's results so they will actually use this important tool, especially in high contact environments.

Rapid reacquisition and homing on targets with small, low-cost sensors is necessary to produce a cost effective autonomous neutralizer.

Reliable, medium-range acoustic communications (ACOMMS) and autonomous group behavior will also be necessary to meet the timelines. Repeated UUV surfacing and diving to communicate and problem-solve will waste too much valuable mission time. Gateway systems such as Communications/Navigation Network Nodes (CN3) (reference (c)) may be required to facilitate this interaction.

Development of autonomous cooperative behaviors will significantly accelerate MCM operations. Today's fielded autonomous systems consist of individual vehicles that provide data for follow-on decision making (e. g., neutralize, avoid) and have limited ability to work with other vehicles. Simple coordinated behaviors have been demonstrated with dissimilar unmanned systems such as one entity detecting contacts of interest and passing them to a follow-on vehicle with a sensor for identification or further action. Intelligent behaviors between separate vehicles with different sensor classes can result in a rapid acceleration of the MCM timeline. Absent this capability, the only way to shorten the timeline is with brute force (lots of similar systems uniformly searching and sweeping an area).

Unmanned MCM by 2015 is possible, but the envisioned fully independent cooperative autonomy is not likely until further in the future. As noted in many other USV missions areas, this area is ideally suited for a crawl-walk-run approach, where an initial capability with heavy man-in-loop interaction can not only provide immediate value to the Fleet, but can serve as a source for experience and lessons learned in the development of later, more autonomous unmanned MCM systems.

MCM UUV DELIVERY

While not a separate mission, there are two methods of executing the MCM sub-missions discussed above that make use of subordinate UUVs, notably MCM Search and MCM Neutralization. As noted in the MCM Search section, future USV systems may deploy UUVs to gain the advantage of higher area coverage rates through multiple, simultaneous operations, without the need for additional operators. This approach is recommended and discussed in detail in the 2004 UUV Master Plan Update (reference (c)), the graphic for which is shown in Figure 14.

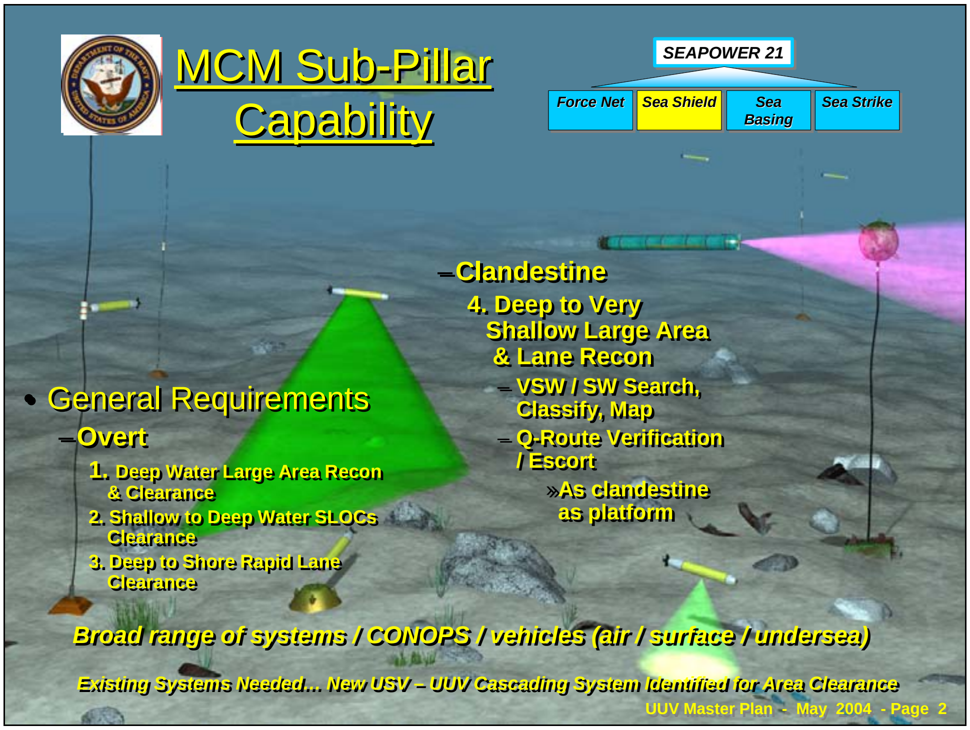

Figure 14 - UUVs in MCM Search

And as discussed in the MCM Neutralization section, UUVs are expected to play a major role in the intermediate to far term in the terminal phases of the MCM Neutralization mission.

In both cases, UUVs will act as payloads or submunition and the USVs will act provide transport, placement, and intermediate communications between the host platform and the USV/UUV combination. As a result, significant USV characteristics will be:

- Payload capability to carry the UUVs
- Payload handling and interface to deploy and retrieve the UUVs
- Communications to the UUV, as well as to the host platform

As noted throughout this Plan, the initial capability for these missions will require significant man-in-loop interaction. As the technologies, especially autonomy, mature and the Fleet gains more confidence in the vehicles's standalone capabilities, the need for reliable, secure, and high-data-rate comms will decrease.

ANTI-SUBMARINE WARFARE (ASW)

It is vitally important that the U.S. Navy be able to achieve and maintain access to all the world's littorals at the times and places of its choosing. In view of the increasing submarine threat from our potential adversaries, it is critical to establish and maintain a highly effective ASW capability. Current ASW techniques are effective in most cases, but there are several factors that point to USV taking on a complementary ASW role in the future:

- Most of the threat submarines which the U. S. Navy will face in the foreseeable future will be conventional (diesel-electric) and designed for local or regional coastal defense. As such, they will have reduced open-ocean transit and magazine (payload) requirements and can be much smaller than U.S. submarines.
- This factor, in combination with local knowledge of near-shore bathymetry, will allow them to operate more easily in shallower waters. It is likely that these submarines will be able to submerge near their homeports and outside the reach of U.S. Forces and make their way to offshore U. S. operating areas.
- The number of submarines that may be 'surge' deployed near-simultaneously by our adversaries mandates a force multiplier to enhance the efforts of existing ASW assets.

Operational concepts for the ASW Mission Capability include monostatic approaches (transmitter and receiver collocated on a single USV), bi-static and multi-static approaches (transmitter(s) and receiver(s) located on different platforms/USVs), and numerous variations on relative location of sensor and shooter in the prosecution phase. USVs will complement and extend existing ASW capabilities, with the specific USV employment scheme based on other available assets and their capabilities.

ASW BACKGROUND

Task Force ASW instituted a reinvigorated focus on and understanding of littoral ASW operations. Among other initiatives, it instituted a standard nomenclature for the three major categories of ASW, as shown in Figure 15:

- "Hold at Risk"– monitoring submarines that exit a port or transit a chokepoint.
- "Maritime Shield"– clearing and maintaining a large Carrier or Expeditionary Strike Group (CSG or ESG) operating area free of threat submarines.
- "Protected Passage"– clearing and maintaining a route for an ESG from one operating area to another free of threat submarines.

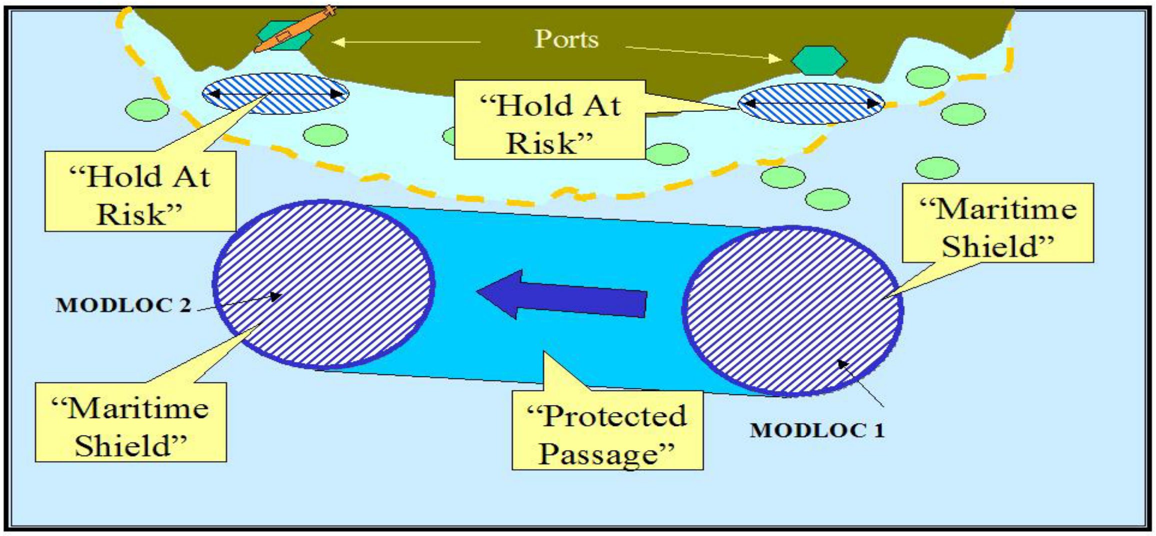

Figure 15 – Task Force ASW Nomenclature

USVs offer significant force multiplication for ASW operations in the Maritime Shield and Protected Passage scenarios, in that they can perform the ASW mission at some level of autonomy. This provides a layer of ASW defense-in-depth for the manned surface group, while freeing the manned combatants for other duties, as well as reducing risk to the manned platforms that would otherwise have been conducting the ASW mission themselves. While offering some advantages in the Hold at Risk scenario, particularly if an overt U. S. presence is desirable, the USV's limited stealth make them generally less ideal candidate vehicles in this category

In all cases, USVs can serve as offboard sensors or sources, extending the range of detection and effect without increasing risk. The manned host platform can serve as the mother ship for a fleet of vehicles, providing the decision-making capabilities while remaining out of harm's way.

In the Maritime Shield scenario, USVs can provide major force multiplication for existing ASW forces. By establishing stand-off submarine surveillance barriers without escalating the level of conflict or placing manned vehicles at risk, USVs in the Maritime Shield scenario can greatly enhance the ability of the Task Force Commander (TFC) to achieve and maintain access, independent of the state of hostilities. In addition to using third-party sensors and cueing assets, or using platform sonars as sources for multi-static prosecution, the USV may also be tasked to plant its own supporting sensor field (e. g., sonobuoys).

USVs can also provide force multiplication for existing ASW forces in the Protected Passage scenario, although the inherent speed of advance inherent in this scenario places greater requirements on the USV. By establishing a submarine-free corridor without placing manned vehicles at risk, USVs in the Protected Passage scenario can greatly enhance the ability of the TFC to move his forces at will, independent of the state of hostilities, while freeing manned assets for other duties (e.g., missile defense for the High Value Units (HVUs)). As in the Maritime Shield case, USVs may use third-party sensors and cueing assets in addition to their own organic sensors.

Variations on the Maritime Shield and Protected Passage missions, depending on the stage of conflict and the implementation of appropriate CONOPs and Rules of Engagement (ROE), include: (a) USV employment of non-lethal weaponry, (b) USV employment of lethal weaponry, (c) USV accumulation of intelligence information on threat submarines, and (d) USV engaging in diversionary maneuvers and behaviors. At a minimum, the USV ASW forces can provide a deterrent or distracting effect against threat submarine aggressors.

ASW OBJECTIVE

This capability focuses on the Task Force ASW "Maritime Shield" and "Protected Passage" scenarios just described, in which a USV provides ASW surveillance services at the boundary of a fixed Aircraft Carrier Battle Group (CVBG) or ESG operating area (Maritime Shield) or in a transit corridor in advance of the movement of a surface group (Protected Passage). The objective of this capability is to use USVs to patrol, detect, track, hand off, or engage adversary submarines using USVs. A further objective is to perform this function under any ROE without taking actions that inadvertently advance the stage of conflict. Given the significant threat that even limited-capability submarines can pose to surface forces, the multiple tasks already assigned to most major surface combatants, and the desire to keep track of submarines regardless of the stage of conflict, USVs are a leading candidate for these tasks.

ASW CONCEPTS OF OPERATIONS

The development of a completely independent, fully autonomous, long-term USV tracking capability with large area search is not considered to be feasible in the immediate future. Even short of this ideal capability, however, there are several ASW capabilities that USVs can provide as significant complements to existing ASW forces. For example, focusing on searching specific areas in which U. S. naval forces will be operating (Maritime Shield) or through which they will pass (Protected Passage) is a simplification in CONOPs objectives which allows relatively simple—compared to manned ASW assets—USVs to create a credible deterrent to threat submarine incursions. USV applications that complement ASW are addressed below, from technically easiest to most difficult to implement, given these simplifying assumptions.

MARITIME SHIELD

The basics of the ASW Maritime Shield capability are shown in Figure 16. The surface group has been assigned an operating area, and it is desired to have USVs maintain an ASW barrier around its perimeter. USVs are deployed in a line around the perimeter and are equipped with sensors. The nature of these sensors is not specified, but will probably be monostatic active (e. g. dipping sonar). A multi-static arrangement with sources aboard either the manned platforms or some of the USVs, with passive receivers on the rest, is another reasonable option. The scenario shown in Figure 16, while not addressing every eventuality, is representative of notional surface operations in terms of scale and relative numbers of units.

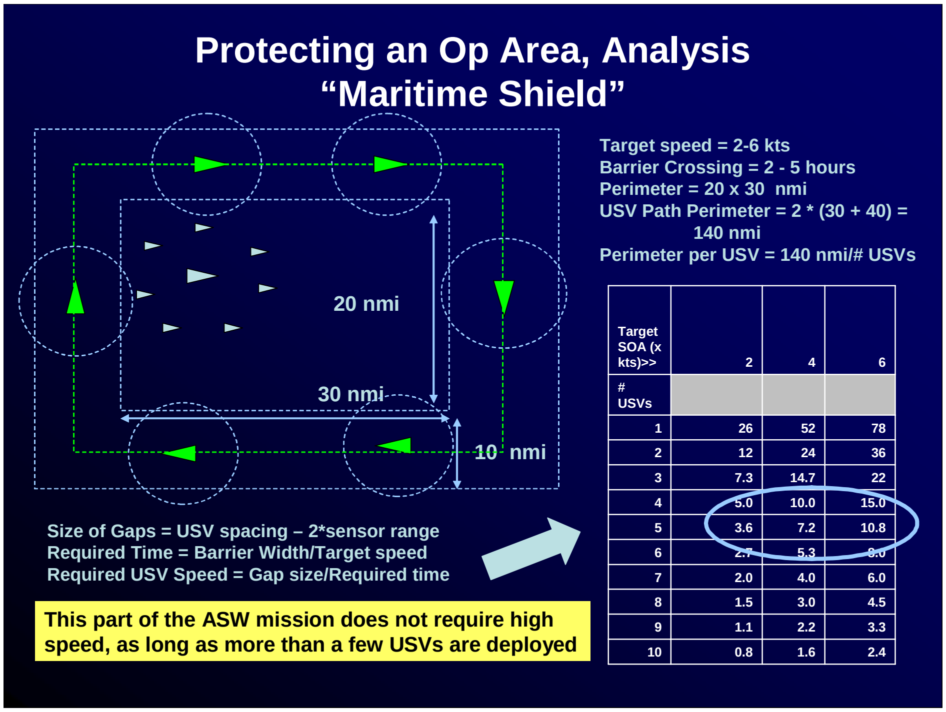

Figure 16 – Schematic Diagram of "Maritime Shield"

The USVs are launched and transit to the barrier area where they form a moving perimeter barrier and monitor that barrier for submarine incursion. The "gaps" in the USV sensor barrier are determined by the distance between the vehicles minus their combined sensor ranges. Patrol speed of the USVs should be such that the gaps are covered in the time it would take an intruder submarine to cross the barrier. USV options at this point, from easiest to hardest technically, include:

- Report contact and respond as directed by the controlling manned platform,
- Autonomously maneuver to optimize and maintain contact, singly or in concert with other USVs, or
- Autonomously maneuver to track and prosecute the target with non-lethal or lethal weaponry.

Additional CONOPs considerations include maintaining the barrier while meeting individual vehicle refueling and maintenance needs, or while one or more of the vehicles is assigned to do an off-barrier track of the target.

In the numerical example shown, a 20 x 30 nmi Operating Area is being guarded from submarine intrusion by six USVs. Each USV has a sensor range (radius) of 5 nmi, and therefore creates a 10 nmi barrier at the perimeter of the Operating Area. Variables were the SOA of the intruder submarine (2 to 6 kts) and numbers of USVs available (1 to 10).

While this is a simple, first-order analysis, there is reasonable conclusion that can be drawn: an effective barrier can be maintained with a relatively small number of USVs traveling at a reasonable rate of speed. As such, this mission capability can provide significant ASW capability to the Task Force Commander with a reasonable investment of unmanned assets.

PROTECTED PASSAGE

The basics of the ASW "Protected Passage" capability are shown in Figure 17. The surface group has been tasked to move from one operating area to another, and it is desired to have USVs maintain a moving ASW barrier in front of the surface group. In the simplest employment scheme, USVs equipped with sensors are deployed in a line abreast such that their sensors overlap or "touch" and in sufficient number to cover the entire transit corridor width. The nature of these sensors is not specified, but will probably be active (e. g. dipping sonar), since multi-static arrangements are not expected to be optimal in a moving-barrier scenario. The scenario shown, while not addressing every eventuality, is representative of surface operations in terms of scale and relative numbers of units.

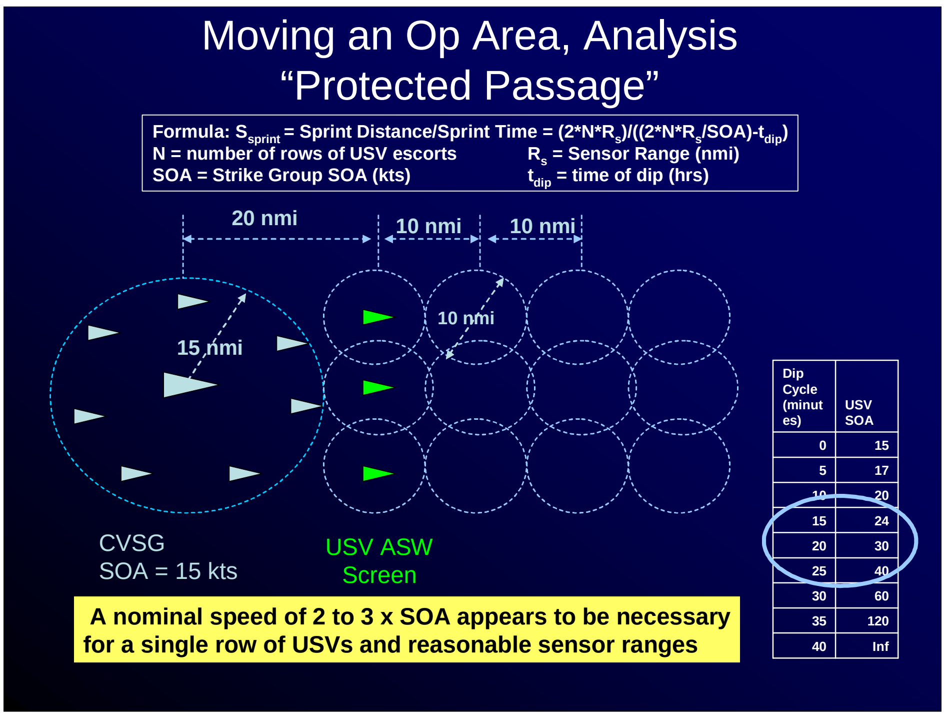

Figure 17 – Schematic Diagram of "Protected Passage"

The USVs are launched and transit to an area in front of the surface group where they "dip" (employ their dipping sonars) to form the first in a series of overlapping ASW barriers and monitor that barrier for submarine incursion. At the end of the dip cycle (lower, operate active sonar, listen and process, retrieve) the USVs sprint ahead to the next dip locus. This process is repeated as necessary until the surface group has reached its new location. The necessary USV Speed of Advance (SOA) is determined by the desired SOA of the surface group, the sensor range, and the dip cycle time.

In the numerical example shown, a surface group with a dispersal radius of 15 nmi desires to transit at 15 knots. USVs with a sensor radius of 5nmi are deployed in a line of three abreast in front of the battle group. Obviously, these USVs must have a net SOA greater than the desired transit speed of the surface group, plus additional speed to reposition while the surface group is advancing. The time for repositioning is reduced by the dip cycle time, when the USVs are assumed to be stationary. The variable in the analysis shown is dip cycle time, which as can be seen, is a key factor in required SOA of the advance USV barrier.

For reasonable ranges of dip cycle time (10 to 20 minutes), a USV speed of 2-3 times the surface group SOA will be necessary. Options for reducing this speed requirement include improving sensor range, reducing or eliminating dip cycle time, and employing more than one row of USVs in a "leapfrog" manner (see comments at end of this section). Options in the event of contact on a threat submarine, from easiest to hardest technically, include:

- Report contact and respond as directed by the controlling manned platform,
- Autonomously maneuver to optimize and maintain contact, singly or in concert with other USVs, or
- Autonomously maneuver to track and prosecute the target with non-lethal or lethal weaponry.

Additional CONOPs considerations include maintaining the barrier while meeting individual vehicle refueling and maintenance needs, or while one or more of the vehicles is assigned to do an off-barrier track of the target.

As can be seen in Figure 17, an effective moving barrier can be provided with a relatively small number of USVs, provided their speeds, sensor ranges, and dip cycle times are adequate for the task. As such, this mission capability can provide significant ASW capability to the Task Force Commander with a reasonable investment of unmanned assets.

The Figure 17 analysis includes only a single row of USVs, since in this example a single row was sufficient to cover the width of the desired transit lane. As a secondary consideration, it was considered potentially problematic to maintain spacing for two rows of USVs both cross-range and down-range, since at least in early implementations there will be significant man-in-loop control of these vehicles. If six vehicles were employed as was the case in the Maritime Shield example--in two rows of three, the required transit speed would decrease significantly to a multiple of 1.4 to 1.7 that of the transiting surface force.

WEAPON EMPLOYMENT CONSIDERATIONS

In the case of lethal or non-lethal attack, a key consideration is time delay between the initial contact and weapon release. Undersea contacts are typically characterized by an Area of Uncertainty (AOU), which is an elliptical area the size and shape of which are determined by target, acoustic propagation, sensor, and processing characteristics. This AOU expands when contact is lost at a rate directly related to: (1) course and speed uncertainty at time of contact loss, and (2) likely target behavior. For example, the AOU for an active target submarine which was poorly characterized initially (ex: solid bearing and range but poor or no derived course and speed) and is assumed to have been 'spooked' by active prosecution will expand much more rapidly than a well-characterized passive sonar target who is unaware of prosecution and maintains patrol routine.

An additional factor in ASW prosecution is the relatively limited space for ASW weaponry and associated launch and command and control (C2) equipment. Typical torpedo options for the USV ASW mission are shown in Figure 18. The most likely options for USV ASW weapon payloads in the near to intermediate future are the Common Very Lightweight (CVLWT) and Lightweight (LWT) torpedoes. These vehicles, particular the CVLWT which is not yet a production program, will have relatively limited search swath widths (transverse search area covered by a torpedo's forward-looking sensor) and total search areas (swath width multiplied by search speed and search time), which is determined by fuel consumption.

Torpedo Payloads

Torpedo Payloads	Diameter (inches)	Weight (lbs)	Warhead (lbs)
CVLWT	6.75	205	50
Mk 54	12.75	550	100
Mk 48 (ADCAP)	21	3900	650

- Significant discriminators are weight, endurance, and detection range (and hence search area / search rate)
- Warhead difference is not as great as one thinks (overpressure at a given range varies with the 1/3 power of explosive weight)
- All will have ASW capability
- Only CVLWT has ATT capability
- Currently only Mk 48 has an ASUW capability; but this will be added to Mk 54

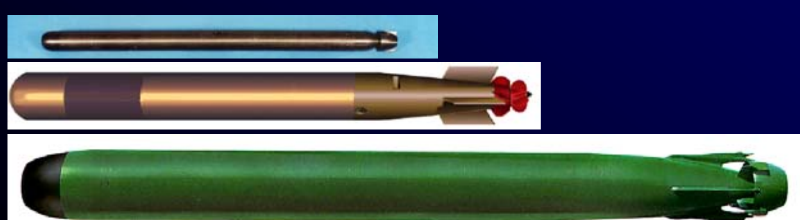

Figure 18 – Example Torpedo Payloads for ASW Mission

The upshots of these two factors - AOU expansion and torpedo search area coverage - are that (1) the response time to get a weapon on a contact is short, even if the target is not alerted by the sensor or the approach of a high-speed "pouncer" and (2) in the absence of long-range standoff ASW weapons such as Vertical Launch ASROC or a ready ASW-armed helicopter, the greatest chance for success results when the sensor and weapon are collocated.

ROE and CONOPs development are required to enable some of the prosecution options, which fall into three basic categories:

- Manual – USV reports contact information, the man in loop evaluates contact and gives specific order to fire. This may include specific weapon presets.

- Semi-autonomous – USV processes contact information and calculates its own best firing options, man in loop has “veto” power or positive control, but is not provided with significant corroborative information from the USV.
- Autonomous – USV makes its own contact and fire decisions, conceptually similar to a mine.

In addition to CONOPs and ROE attention, each increasingly autonomous weapon option would require increased technical and operational assurances to protect friendly forces operating in the vicinity.

As a practical matter, autonomous weapon launch from a USV, be it torpedoes for ASW or other weapons for other missions, will require significant resolution of maritime law issues. A significant body of work has already been done in this field at the Navy Surface Warfare Laboratory, Dahlgren, VA.

SINGLE VS. MULTIPLE VEHICLES

It is recommended that USV-aided ASW Concepts of Operation be executable by single USVs, as opposed to requiring the participation of multiple USVs. While multi-static prosecution can be effective, dependence on a multi-vehicle approach can result in the loss of a single USV precipitating a loss of the entire capability. Additionally, single-USV options allow these capabilities to be executed by Navy ships that only have one USV assigned as part of normal complement.

ASW SYSTEM CONCEPTS

Many of the fundamental technologies required to make the USV ASW mission a reality (sensors, processing, weapon setting and launch) are already in existence, though not necessarily scaled or adapted to the USV applications. Given the Navy’s current interest in armed unmanned vehicles and the ASW mission, it is reasonable to assume that USV-specific developments–analytically, technically, and in Navy focus–will soon make the ASW mission a practical reality. The specific system concepts are pending resolution of vehicle technical and operational issues, as well as engineering and “packaging” issues associated with launch platforms. Work in support of LCS, Undersea Weapons Master Plan (UWMP), and USV programs is beginning to address these issues, while several relevant ONR Future Naval Capability (FNC) studies are progressing. A 7m semi-submersible with appropriate sensor, weapon, and propulsion options is projected to provide acceptable capability in the “Maritime Shield” mission. An 11m USV housing one of several sensor suite options with appropriate propulsion and weapon suites is envisioned to provide acceptable ASW capability for either “Maritime Shield” or “Protected Passage” ASW missions. The sensor suite would likely include an active monostatic sensor, although multi-static concepts using remote sources and USV passive sensors or vice versa are also conceivable. The USV would need extensive communications capabilities, especially for the weapons-release options and probably also for early sensor processing, until ASW automated target recognition software becomes reliable enough to be used autonomously. These communications options would include Line of Sight (LOS) Ultra-High Frequency (UHF) and Satellite Communications (SATCOM), with appropriate cryptographic support and Information Assurance (IA) and Information Security (IS) technology.

ASW TECHNOLOGY AND ENGINEERING ISSUES

Technology issues associated with this capability include: Command, Control, and Communications (C3), automated target Detection, Classification, Localization and Tracking (DCLT), automated target tracking, weapons and weapon control (aiming, presetting, firing), and autonomy. Equally important with the development of specific technologies will be integrating them with each other and with the host USV, and integrating the entire USV-based ASW package with the host platform. Engineering issues associated with weapon storage aboard the vehicle and vehicle stability associated with varying payloads during the launch process also merit careful consideration. Finally, the development of effective ASW weapons with smaller footprints in size and weight (e. g., CVLWT torpedo) would also greatly assist this mission in becoming a reality.

Although the ASW Mission Capability presents various technology challenges—most of which are being worked at ONR and in other technical programs–this capability is high payoff and subsets of this capability would provide immediate force multiplication. The ASW Mission Capability also leads to growth into other future mission areas, such as semi-autonomous or completely autonomous engagement, which will ensure continued dominance.

MARITIME SECURITY

Maritime Security (MS) consists of securing U.S. or allied domestic ports, and protecting ship and maritime infrastructure (piers, docks, anchorages, warehouses) at home and abroad against the spectrum of threats from conventional attack to special warfare to specifically targeted terrorist attacks. MS mission effectivenss stems directly from good situational awareness (SA) and the ability to do something about it. The "MS" mission rubric, therefore, includes persistent Intelligence, Surveillance and Reconnaissance. In the context of this plan, MS also incorporates elements of the Port Security Services (PSS) mission and of the Global War on Terror (GWOT). Maritime Security represents a fundamental USV mission and is essential not only for the traditional purpose of intelligence collection and threat deterrence, but also as a precursor and enabler for essentially all other missions.

The SA subtask of the MS mission encompasses collection and delivery of many types of data: intelligence and information collection of all types, as well as specific target detection, classification, localization and tracking. USVs can be a part of the solution set for information collection in situations where access by manned platforms is problematic, where they can act as a force multiplier in adding additional “eyes and ears” to the Fleet. USVs have the ability to operate at long standoff distances from its host platform, operate in maritime environments characterized by shallow water or other access barriers to manned platforms, operate in areas too militarily hazardous to put manned vehicles of any size at risk, operate autonomously for extended periods of time, and provide a limited level of stealth, certainly beyond that achievable with larger manned platforms.

Possible MS USV missions include:

- Strategic and tactical intelligence collection: Signal, Electronic, Measurement, and Imaging Intelligence (SIGINT, ELINT, MASINT, and IMINT)
- Chemical, Biological, Nuclear, Radiological, and Explosive (CBNRE) detection and localization (both above and below the ocean surface)
- Near-Land and Harbor Monitoring
- Deployment of leave-behind surveillance sensors or sensor arrays
- Specialized mapping and object detection and localization
- Non-lethal and lethal threat deterrence
- "Riverine" operations, such as monitoring civilian boat traffic on inland waterways for threat personnel movements, contraband or threat weaponry smuggling, and similar undesirable activities

It is worth noting that the SA sub-missions are similar to those described in the ISR section of the UUV Master Plan Update (November 2004) (reference (c)). While the UUV option provides stealth beyond that associated with a USV, Semi-Submersible Vehicles (SSVs) can provide a nearly identical stealth profile, given that the ISR mission by definition requires extensive mast or antenna exposure. In some mission areas, additional considerations—including asset availability, re-tasking and persistence—can make the USV (SSV) ISR option attractive.

MARITIME SECURITY OBJECTIVE

The USV Maritime Security missions are: (1) to collect intelligence data above the ocean surface (e. g., electromagnetic, optical, air sampling, weather) and below the ocean surface (e. g., acoustic signals, water sampling, oceanographic or bathymetric info) and (2) deter enemy attacks on established U. S. and allied positions and material, including ships, while (3) keeping manned platforms out of harm's way (Figure 19). Specific Maritime Security USV capabilities would include persistent littoral ISR, harbor or port monitoring, Chemical, Biological, Nuclear, Radiological, Explosives (CBNRE) detection and localization, surveillance sensor emplacement, Battle Damage Assessment, and active target designation. Non-lethal technologies (i.e. paint ball designators, water cannons) can be used to deter or designate threat forces. Lethal systems including guns and/or rockets could be employed to establish a more threatening posture.

These capabilities will provide force multiplication, substantially improved Indications and Warning (I&W), all-source Intelligence Preparation of the Battlespace (IPB), and threat deterrence.

Figure 19 – Maritime Security USV Mission Capability

MARITIME SECURITY BACKGROUND

USVs provide many advantages for the maritime security mission. USVs will have a multi-function capability, operate from a variety of platforms, and will enable the collection of many types of data. USVs could effectively perform these missions in high-risk areas or where hazards to navigation preclude conventional platforms. USVs could be launched from a safe standoff distance, transit to the area of interest, and return with--or transmit subsets of--the data collected, extending the reach of their launch platforms by more than 150 nmi. This greatly reduces the risk to manned platforms, frees them to perform other high priority missions, and is therefore a force multiplier.

The purpose of this mission is to secure domestic and allied ports and infrastructure against adversaries of all descriptions (criminals, terrorists, sovereign nation military and intelligence operatives). A related subset of the ISR mission is support for the Global War on Terror, which focuses remote intelligence gathering specifically on the protection of U. S. maritime assets and infrastructure from specifically terrorist attacks. While these distinctions may seem academic, and may actually be in some aspects of practice, an effective port ISR program backed up by strong intelligence analysis, may actually help to distinguish between the types of perpetrators and their motives and provide for better, more appropriately focused response from U.S. forces.

MARITIME SECURITY CONCEPT OF OPERATIONS

The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches its OPAREA, it performs the mission, collecting information and or deterring aggressive actions over a predetermined period of time. The USV autonomously repositions itself as necessary, both to collect additional information and to avoid or intercept threats and provide a persistent presence in the operating area, perhaps for several weeks. The information collected and actions taken are either transmitted back to a relay station on demand or when "self-cued" (i.e., when the vehicle records a threat change and determines that transmission is necessary). In most cases, the vehicle will be in real-time or near real-time communications with the host platform and can provide information as desired, as well as receive updated instructions from the host platform. This ready availability of communications for Command and Control and Intelligence (C2I) transfer is considered to be one of the major advantages of a USV in this scenario, as opposed to a stealthier UUV. For most USV ISR missions, it is assumed that near real-time communications are available and will be used to support the mission via "reach-back" (i. e., transfer of raw data to a remote processing center for analysis). This approach places much less onus on vehicle information processing and autonomy, and relieves some serious information security issues associated with vehicle-borne intelligence processing. In some cases where a maximum stealth mission (which will necessarily be conducted by a semi-submersible (SS)) is required at the expense of real-time or near real-time transmission, the vehicle will bring the recorded data back to the host platform or to a suitable area remote from the Area of Interest (AOI) for transmission.

Additional options for the MS mission include active response to detected entities. The range of responses ranges from warnings (e. g., a loud-hailer challenge), through marking (e. g., paint ball or radio tag) to actually engagement (e. g., gun, missile, or torpedo). Some of these options overlap with other missions in this plan at this point, such as SUW or MIO.

MARITIME SECURITY SYSTEM CONCEPTS

MS System Concepts are summarized in Figure 20. There are nearly infinite variations, but this capability consists of one or more of these components:

- Sensing
- Signal Processing for DCLT (man in loop, semi-autonomous, or autonomous)
- Decision making (man-in-loop, semi-autonomous, or autonomous)
- Response

Figure 20 – Maritime Security Mission Options

These components will be recognized as mapping to the classic "OODA" (observe, orient, decide, act) loop framework.

Sensing includes the complete spectrum of phenomenology, from visual/IR to electronic, chemical, and others. ISR to some extent forms a part of nearly every conceivable variant of the MS mission. A representative sampling of ISR sensors is shown in Figures 21 and 22.

For both signal processing and decision-making, the degree of autonomy allowed the vehicle will be dependent on the operational situation, its associated ROE, and the state of autonomy development and the confidence the USV's operator's have in it.

Response consists of applying one or more effectors, from warning devices (sounds, flares, recorded or remote-broadcast messages) to non-lethal and lethal effectors as noted previously, including guns, missiles, or torpedoes.

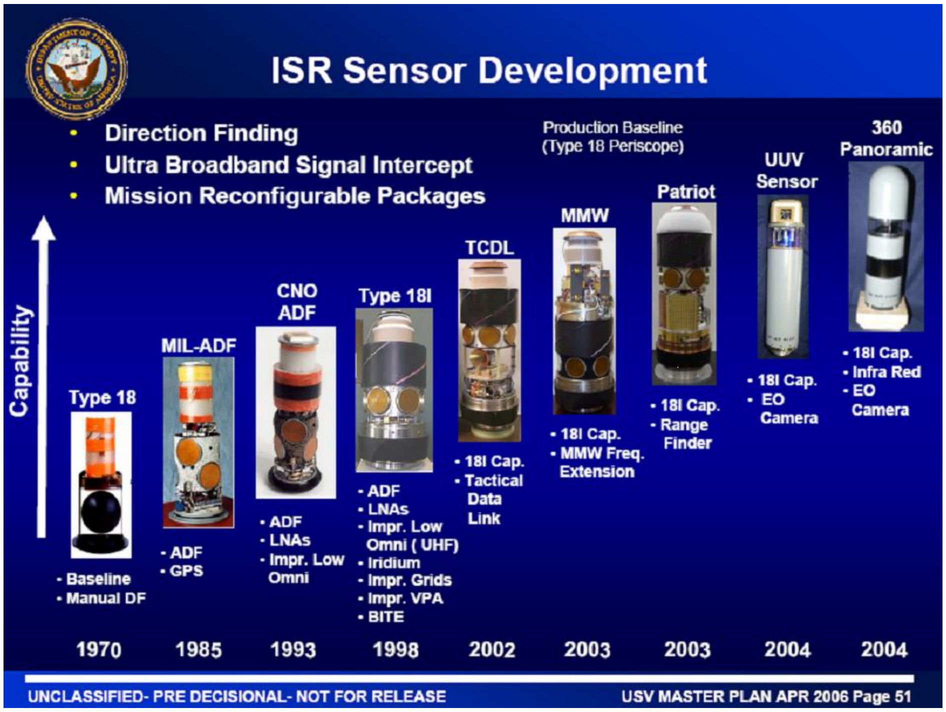

Figure 21 – ISR Sensor Development

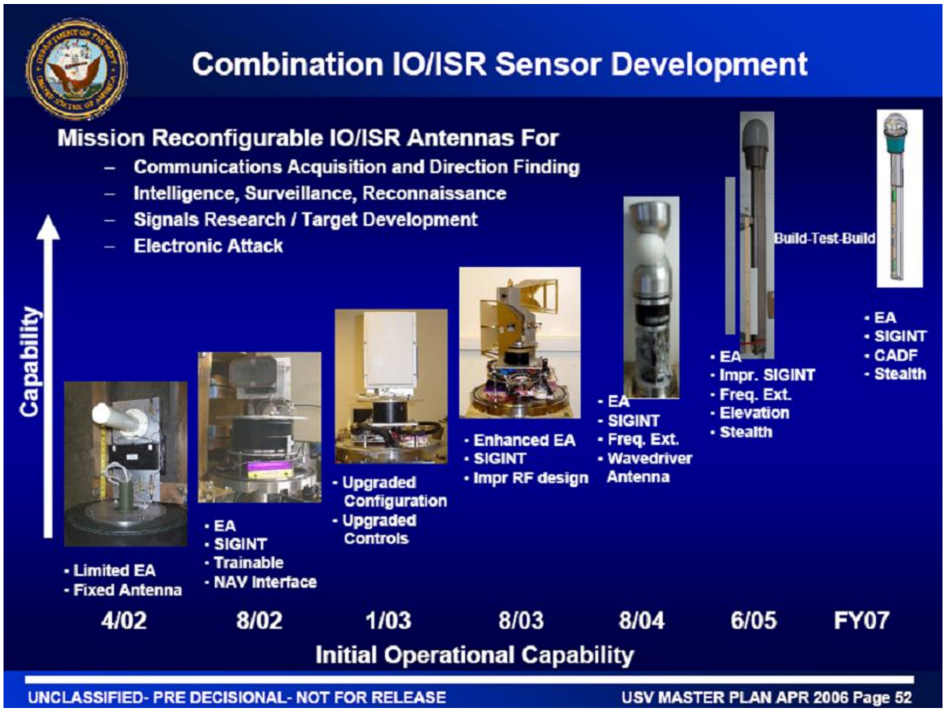

Figure 22 – IO/ISR Sensor Development

A persistent ISR USV capability can be provided via larger vehicles with significant range, endurance, and capacity for a variety of large payloads. However, credible subsets of this capability can be provided in mid-sized vehicles. Some "niche" missions might also be conducted by small custom-built USVs--these smaller vehicles are the exception to the norm. It is expected that the requirements for a particular implementation will vary dramatically from situation to situation. In that vein, it is crucial that MS USV have simple and easy-to-execute payload reconfigurability, and thus be able to accommodate a variety of sensors, processors, communications suites, and effectors.

MARITIME SECURITY TECHNOLOGY AND ENGINEERING ISSUES

Critical technology and engineering issues pertaining to the MS USV mission capability stem from the need to maximize its reliability and autonomy for the higher-end missions. Fail-safe vehicle behaviors, signature reduction, vehicle stability, and extended autonomous operation are some of the major contributors to the baseline MS mission. Reliable long-range communication is also an issue, especially in mission variants where real-time intelligence reach-back is used for intelligence analysis or long stand-off missions. On the other hand, the use of reach-back reduces the vehicle's need for advanced autonomy and on-board processing with associated information security issues. Use of reach-back, however, does place greater emphasis on the aspects of information security associated with communications cryptography.

As USV capability evolves, a major issue to be addressed is the level of autonomy. Ideally, the system will be capable of detecting, recognizing, avoiding and/or engaging threats of a varied and mobile nature. Threat avoidance requires a high degree of autonomy, both in threat recognition and the determination of the best means of avoidance. As capabilities improve and the threat evolves, continual enhancements will be required.

Payload development for the ISR capability is considered to be largely a non-issue in terms of size, weight, and power consumption, given that many ISR sensors are developed for platforms (e. g., Unmanned Aerial Vehicles (UAVs), satellites) with significantly greater limitations in these areas. Even so, minimal size, weight and power for a given capability are desired, even if the USV application doesn't drive the design problem. The USV application may, however, impose unique requirements on sensor integration and packaging and fail safe operations such as:

- Environmental protection against the unusually harsh ocean environment in which they will operate.
- Minimal cross-section (for low detectability) and packaging, especially for mast-mounted sensors and antennas, to optimize vehicle stability in varying sea states.
- Fail safe operations for Non-lethal and lethal technologies.

SURFACE WARFARE (SUW)

The Surface Warfare capability is very similar to some aspects of the MS mission as discussed in the preceding section, but also incorporates the engagement of more difficult threats in relatively open ocean as well as in the littorals. MS mission systems and technologies are heavily relied upon to support surface warfare missions and payload support; providing situational awareness as well as 'friend or foe' identification. The SUW capability will require a larger craft and higher speed (≈30-40 kts) capability. The basic premise of the SUW mission is shown in Figure 23.

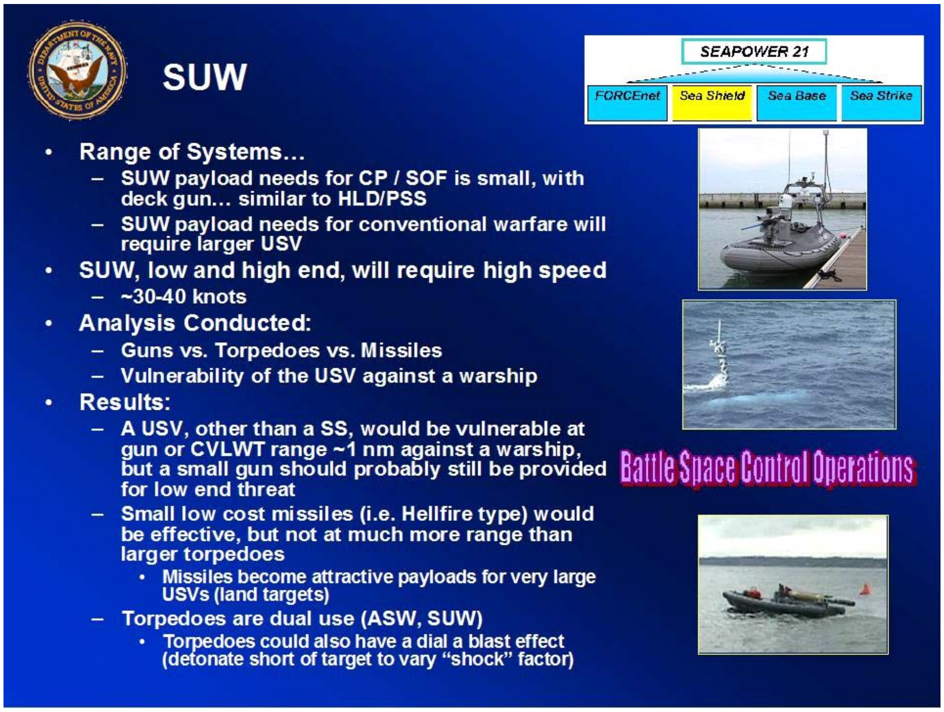

Figure 23 – Surface Warfare

SUW OBJECTIVE

The purpose of performing SUW mission support by a USV is to provide the ability to engage targets through the use of lethal and/or non-lethal weapons while protecting or keeping manned platforms out of harm's way.

SUW USV capabilities will provide force multiplication, all-source Battle Space Awareness (BSA) and act as an integral component to Sea Shield.

SUW BACKGROUND

USVs can provide persistent coverage and effectively provide support for those mission areas of high risk to personnel, which would preclude conventional platforms. Many mission scenarios utilizing small arms as well as other lethal and non-lethal weapons could be effectively performed by USVs.

SUW CONCEPT OF OPERATIONS

The following are summaries of example Concepts of Operations in the SUW mission area. While not exhaustive, this list should provide a feel for the spectrum of SUW-related operations in which USVs can play an important role.

- <u>Coastal Patrol/Homeland Security/Port Security (example)</u> - The USV is launched from its host platform, a surface ship or shore facility and proceeds to the designated patrol area. Once it reaches the area, it performs the mission: patrolling the area, monitoring and addressing or interrogating ‘threats’ as appropriate, repositioning itself as necessary, either with man-in-the-loop direction or autonomously, and providing a persistent presence in the operating area.

- <u>SOF Support (example)</u> - The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches the area, it provides SOF mission support by: performing ISR operations and reporting any penetrations into the area, repositioning itself as necessary, either with man-in-the-loop direction or autonomously, and providing a persistent presence in the operating area. If its area is penetrated, it may have the ability to engage, providing additional opportunity for SOF relocation/extraction.

- <u>SUW Engagement (example)</u> - The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches its area, it patrols the area and monitoring or for ‘threats’ as appropriate, repositioning itself as necessary and provides a persistent presence in the operating area. If its area is penetrated it has the ability to engage. Each of these steps may be under the direct control of a human operator (man-in-loop), semi-autonomous (e. g., human verification and permission to fire on a USV-perceived valid target), or completely autonomous.

SUW SYSTEM CONCEPTS

A persistent SUW mission capability can be provided via larger vehicles with significant range, endurance, and capacity for a variety of large payloads. The SUW USV will have a reconfigurable payload, and thus be able to accommodate a variety of sensors and weapons, both lethal and non-lethal. For the weapon-engagement option, sensors and weapons will need to be collocated on the same USV, with appropriate C4I for the level of operational autonomy.

<u>Mission Payloads Analysis</u>

A brief weapons effectiveness analysis was conducted. In consideration were small arms (guns), torpedoes, and missiles.

- Small Arms – Under consideration within the analysis was: existing fielded assets capable of firing rounds ranging from 7.62mm through 25mm.

Results: A USV, other than a SS, would be vulnerable at gun or CVLWT range (approximately 1 nm) against a warship. Conversely, a USV would only be effective against most threats at less than 1nm.

- Torpedoes - Under consideration within the analysis were: CVLWT, Mk 54 and Mk 48 (ADCAP)

  Results: Torpedoes provide dual-use capability (ASW, SUW). Torpedoes could also conceivably have a "dial-a-blast" effect (detonate short of target to vary "shock" factor), but this option is not under development and is not strictly required for this mission to be effective.

- Missiles – Under consideration within the analysis were: Hellfire, NLOS-LS (NetFires), and Brimstone. Missile system capabilities that would be desired include: inertial navigation system, fixed box launcher (reconfigurable/modular), sealed units (fire-through end cap), network-able, discrimination achieved via multiple sensor sources, maritime environment operations capable ("marinized").

  Results: Small low-cost missiles would be effective, but not at much greater range than larger torpedoes. Though more capable missile systems (e. g., longer standoff ranges, bigger warheads), they are more appropriately installed on and launched from the host ship. For the sizes of missiles reasonable for USV applications, there is little advantage to USV launch.

In summary, the weapons of choice in this scenario appear to be torpedoes, since in the sizes capable of being carried on USVs, they alone have the range to engage the enemy outside the threat's counter-boat weapon range. There is also a much greater chance of the target being unalerted by a torpedo attack than a gun or missile attack.

In any case, in order to execute an autonomous armed mission, significant work will be needed to investigate and generate if necessary the USV rule sets to comply with maritime law and the law of war. Significant work in this area has already been done at the Navy laboratories.

SUW TECHNOLOGY AND ENGINEERING ISSUES

Critical technology and engineering issues pertaining to the SUW USV mission capability stem from the need to maximize its reliability and autonomy for the higher-end missions. Failsafe vehicle behaviors, failsafe weapon behaviors, vehicle stability, and extended autonomous operation are some of the major contributors to the baseline SUW mission. Reliable long-range communication is also an issue, especially in mission variants where real-time situational awareness reach-back is used for engagement actions and decisions analysis. Use of reach-back, however, does place greater emphasis on the aspects of information security associated with communications cryptography.

As capability evolves, a major issue to be addressed is the level of autonomy. Ideally, the system will be capable of detecting, recognizing, reporting and avoiding or engaging threats of a varied and mobile nature. Threat avoidance requires a high degree of autonomy, both in threat recognition and the determination of the best means of avoidance, autonomous threat engagement even more so. As capabilities improve and the threat evolves, continual enhancements will be required.

USV weapons applications are not currently driving payload development for SUW missions. Primary drivers for weapons that would be used are: withstanding the maritime environment (stabilization, seawater exposure), automation of weapon operation and loading, and addressing weapon faults and fail-safes.

SPECIAL OPERATIONS FORCES (SOF) SUPPORT

USVs supporting SOF missions will require unique capabilities in addition to those being addressed in support of the more conventional mission areas addressed in this Plan; e. g., MS, and SUW. This section will discuss unique capabilities.

SOF units require support for conducting missions involving unconventional warfare, counter-terrorism, reconnaissance, direct action and foreign internal defense, among others. SOF roles are typically those in which the aim is to achieve disruption by "hit and run" and sabotage, rather than more traditional "force on force" combat. Other significant roles lie in providing essential intelligence from close to or among the enemy, and increasing roles in combating terrorists, their infrastructure and activities.

Due to the variety of missions and related environments that SOF can be called upon to operate in, SOF-Support USVs will also be required to cover operational environments from coastal to riverine. Each environment presents unique challenges to effective and reliable operation.

SOF SUPPORT OBJECTIVE

The two primary purposes of using USVs to support SOF missions are: (1) ISR (standard and non-standard sensors), and (2) transportation and material support. (Figure 24).

Figure 24 – Special Operations Forces (SOF) Support

SOF SUPPORT BACKGROUND

In the ISR role, USVs can provide persistent coverage and effective support for SOF mission areas that would preclude conventional platforms, providing early warning and maintaining a perimeter in areas of high risk to personnel. Many mission scenarios utilizing small arms as well as other lethal and non-lethal weapons could be effectively performed by USVs. In this sense, this mission area bears a lot in common with the MS mission.

USVs can also effectively provide mission support in high-risk areas or where hazards to navigation or personnel preclude conventional CONOPS. USVs could be launched from a safe standoff distance, transit to the area of interest, and return with or transmit subsets of the data collected. Other options include planting stand-alone sensor packages, dropping off advance or real-time resupply packages (ammo, food, fresh water, batteries), and providing maritime diversion, distraction, or deception in support of the SOF mission.

SOF SUPPORT CONCEPT OF OPERATIONS

Riverine ISR

Due to the size and likely clandestine nature of the operations, small, low-observable (LO) USVs will be required. Although perfect stealth in a physical, floating, and mobile object is not realistic, there are technologies and techniques available to minimize vehicle observables. SOF personnel aboard a larger manned riverine craft launch a man-portable USV when entering an area of contention. The USV proceeds covertly to the area to be investigated in support of the mission and reports that data back to the operators in real time. Alternately, due to mission restrictions, it can collect the data and returns to the manned platform. Operating in this manner, the USV is essentially serving as a round-the-bend ISR platform.

Insertion/Extraction of SOF Personnel and/or Equipment

Serving as a logistical support asset, larger USVs could provide SOF with an alternative to utilizing manned platforms for these purposes. USVs could be pre-positioned and lie in waiting for the appropriate time to provide support.

Other Missions

U.S. SOF are legendarily innovative in adapting the systems and equipment at hand to fit emergent mission needs and environment. The modularity inherent in USVs can be a great asset in support mission innovation.

SOF SUPPORT TECHNOLOGY AND ENGINEERING ISSUES

In the near term, the technology and engineering issues relating to USVs providing SOF support are the need to minimize the vehicle's size and observability while maximizing power density and reliability. As with all USVs, suitable and reliable communication is an issue, especially in mission variants where real-time intelligence reach-back is used for intelligence analysis.

SOF USV applications will impose unique requirements on sensor integration and packaging due to size constraints:

- Environmental protection against the unusually harsh ocean environment in which they will operate
- Minimal observable cross-section (low detectability): visual, IR, radar, acoustic, other
- Packaging, especially for mast-mounted sensors and antennas
- Modularity for mission innovation

ELECTRONIC WARFARE (EW)

USVs have broad application to Joint and Naval Warfighting requirements supporting Conventional Warfare, Irregular Warfare and Homeland Defense through strategic use of EW and Information Operations (IO). This capability is synergistic with the Maritime Security Mission.

EW OBJECTIVE

The objective of this capability is to use USVs to provide a means of deception, jamming, and warning of electronic attack. USVs can provide a persistent and effective capability with significant range, endurance, and capacity for large payloads and power generation (Figure 25).

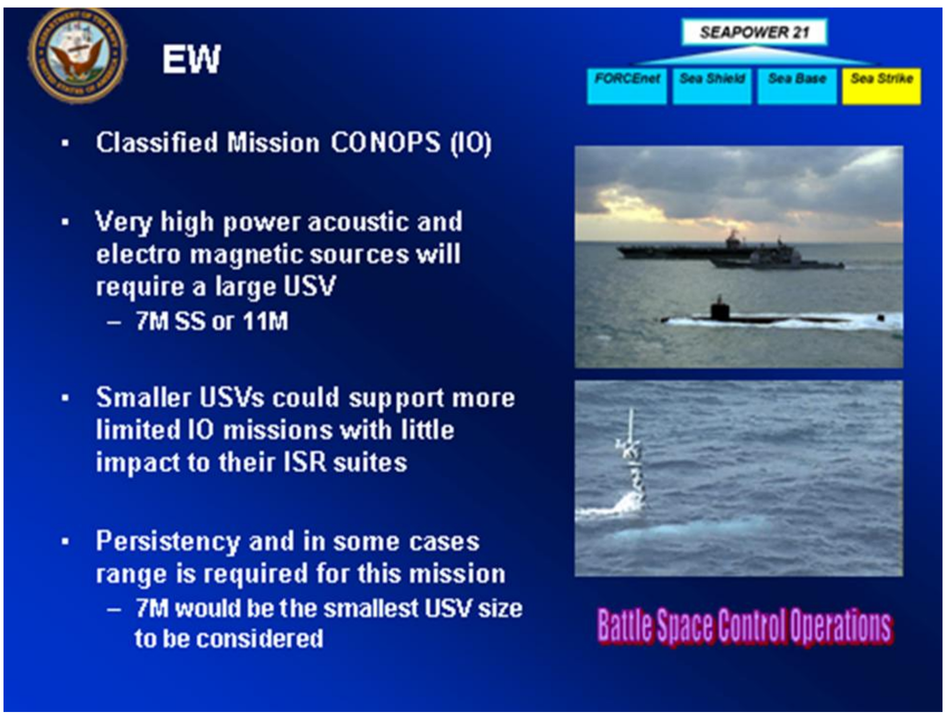

Figure 25 – Electronic Warfare

EW CONCEPT OF OPERATIONS

The specifics of the Electronic Warfare mission are classified; it is a subset of IO and closely related to Intelligence, Surveillance and Reconnaissance (ISR). Many technologies exist to enable this mission area. For example, it could be possible for a USV to generate false targets for deception in support of anti-ship missile defense, initiate a denial of service, or instigate spoofing, local area network jamming, and other disruptive IO missions. For example: In support of a CSG, ESG or Surface Strike Group

(SSG), a USV could be equipped with a False Target Generator (FTG) and be used in a counter-targeting or Military Deception (MILDEC) role.

In a related application in the same scenario, the USV is used as a picket ship for that same Strike Group. The USV is equipped with an Electro Optics/Infrared (EO/IR) sensor on a retractable/extendable mast with receiver(s) in the body of the vehicle capable of conducting passive spectrum detection and threat warning for the battle group. That same USV, given the appropriate repeater and/or transponder device, could be used within the CSG/ESG/SSG to aid in force Anti-Ship Missile Defense (ASMD). An economic advantage of using the USV in this role is that the repeater and/or transponder are reusable assets whereas some of the other options are not. An added benefit of using the USV in an ASMD role is that it can be used as an automated remote platform to augment the LCS Platform in a hostile environment, allowing the LCS to perform its primary missions.

Additionally, a USV can provide an extended jamming capability. Size and power of the jammer vs. capabilities of the USV will determine the overall mission capabilities and limitations. For example, a high-power jammer mounted on a large USV could be used in an expeditionary role to provide electronic screening, masking, or deception prior to a beachhead being penetrated by Special Operations Forces (SOF). Concurrently, that same USV mounted with an EO/IR/Laser capability could provide a tactical advantage when used in a Target (ship or aircraft) Illumination or Anti-Terrorism/Force Protection (AT/FP) role. Smaller jammers with directional high-gain antennas could be used in a relatively covert manner near hostile shores, airfields or chokepoints. Roles include communications jamming or deception, a Global Positioning System (GPS) jamming or in a Maritime Improvised Explosive Device (MIED) defeat role. Another application for the SSV would be the USW application of an underwater generator that generates false screw rates or similar ship sounds, to simulate false surface ships or submarines or mask real ones.

EW TECHNOLOGY AND ENGINEERING ISSUES

Any size USV can contribute to this mission; however, size will directly influence the extent of the USV's contribution. USV size-related issues including Antenna and Sonar apertures, height, weight, and power consumption--in addition to the normal USV considerations of environmental resistance and stability--directly impact the effective range of the mission payload. Enabling technologies should be sought to improve mission payload power efficiency, allowing the technology to be used on smaller USVs and for longer times. Conversely, USV technologies and capabilities should be pursued to provide stability in higher sea states, improved power generation and mission endurance, and the ability to maintain speed in a variety of operating conditions.

MARITIME INTERDICTION OPERATIONS (MIO) SUPPORT

MIO SUPPORT OBJECTIVE

MIO is traditionally defined as activities by naval forces to divert, disrupt, delay, or destroy the enemy's military potential before it can be used effectively against friendly forces. Preemptive protective measures can protect not only maritime assets, but also ground forces by disruption of sea-based lines of supply to the enemy. For MIO in this context, emphasis is on vessel boarding, search, and seizure capabilities.

Commander Naval Surface Force (CNSF) has communicated a strong requirement to the Chief of Naval Operations (CNO) for MIO on the LCS reference (l). Due to the increased threats associated with the GWOT, plans have been formulated to conduct sustained MIO with the augmentation of personnel on the LCS. MIO is by definition a manned mission. The MIO role of USVs is to enhance situational awareness in support of the manned mission. In general, this MIO effort would require a small USV system that would support a boarding party by investigating the threat vessel at the waterline and below. Potential support payloads for this role include ISR, EO/IR, CBRNE, Weapons of Mass Destruction (WMD) detectors, ROVs, UUVs, and UAVs (Figure 26).

Figure 26 – Maritime Interdiction Operations (MIO) Support

MIO SUPPORT CONCEPT OF OPERATIONS

The following example scenario should provide a flavor of USV MIO support missions. It is not intended to be prescriptive or limiting, since each MIO situation is likely to have its own unique characteristics and requirements.

The USV will provide ISR support to the manned 11m RIB performing MIO. The USV will support the MIO mission by providing a capability to detect a threat through a variety of devices and sensors to enhance situation awareness. Examples:

- USV approaches a potentially hostile ship ahead of the manned RIB to help gage reaction ("draw fire")
- USV approaches and monitors the far side of an interdicted vessel from the manned MIO boat, to check for cargo jettisoning, fleeing personnel, etc.
- The USV uses sensors (ROV/UUV) to check for below-waterline oddities such as trapdoors, moon pools, or hidden cargo compartments and "drop tanks".
- USV uses special sensors to search for unusual phenomena (e. g., CBNRE traces, large numbers of personnel in "cargo" holds).

In these ways using a USV may reduces the need for manning in support of MIO, and should improve the operation's effectiveness. In conjunction with the USV, launching and recovering an UAV could provide additional monitoring of suspicious objects or behaviors during the MIO mission, similar to that noted above, except from an aerial perspective.

MIO SUPPORT SYSTEM CONCEPTS

The MIO USV should be small to facilitate handling and carrying from the "mother" MIO RIB. The size of the current demonstration MIO USV is approximately 5m. A 3m USV to support the MIO mission would be sufficient. The sea state limitations of a 5m craft compared to a 3m are insignificant, while the advantages of the 3m in ease of handling from a manned MIO craft (likely an 11m RIB) are considerable. Fuel load and endurance are not issues for this mission, as the USV will be operated in relatively close proximity to the mother craft, and for relatively short periods of time.

The MIO USV will be equipped with the basic ISR suite including camera and radio. In addition, the USV should be able to accommodate a variety of sensors including CBNRE and WMD sensors. In this case, payload modularity will greatly facility this mission becoming not just a reality, but an effective and useful one.

MIO SUPPORT TECHNOLOGY AND ENGINEERING ISSUES

Critical technology and engineering issues pertaining to the MIO USV mission capability stem from the requirements for vehicle stability and failsafe vehicle behaviors. At least initially, the requirement for long time on station and significant autonomy is considered to be minimal, since the MIO Support mission will be operated in close proximity to a manned MIO craft. This situation may change as mission experience is gained and autonomy technologies advance. Reliable communications capability is required, even in the initial implementations, to ensure that the MIO crew is able to make effective use of its USV "assistant", as well as learning of its activities and their results in real time.

The challenge for the MIO support USV will be the “height of eye” issue for both observation and communication. An enhanced surveillance and communications relay capability may be achieved by working in conjunction with an UAV, and normally inaccessible underwater observations may be facilitated by the use of an ROV or UUV.

Launch and retrieval issues of a 3m from an 11m RIB may include mechanical interactions between launch/retrieve system and vehicle and fluid interaction between launch/retrieve system and vehicle.

Autonomy issues need to be addressed. Threat recognition and determining the means for object avoidance must be considered. Continued enhancements will be required as the threat evolves.

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CHAPTER 3 - INTEGRATING THE CAPABILITIES INTO A FAMILY OF SYSTEMS

At this point in the Master Plan process, the desired capabilities and concepts were fairly mature. It remained to integrate these capabilities into a larger Navy family of USVs, to provide the postulated capabilities as cost-effectively as possible. It became obvious early on, however, that given the breadth and depth of the mission spectrum to which USVs can contribute, no single combination of vehicle, payload, and host vehicle would suffice. Instead, it was decided to develop a family of systems that could effectively accomplish the desired missions without a proliferation of customized "one-off" USV packages for every situation.

The Joint acquisition instruction, CJCSI 3170.01E, (reference (m)) offers these two definitions:

Family of Systems (FoS) - A set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects. For instance, the warfighter may need the capability to track moving targets. The FoS that provides this capability could include unmanned or manned aerial vehicles with appropriate sensors, a space-based sensor platform or a special operations capability. Each can provide the ability to track moving targets, but with differing characteristics of persistence, accuracy, timeliness, etc.

System of systems (SoS) - A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any part of the system will significantly degrade the performance or capabilities of the whole. The development of a SoS solution will involve trade space between the systems as well as within an individual system performance. An example of a SoS would be a combat aircraft. While the aircraft may be developed as a single system, it could incorporate subsystems developed for other aircraft. For example, the radar from an existing aircraft may be incorporated into the one being developed rather than developing a new radar. The SoS in this case would be the airframe, engines, radar, avionics, etc. that make up the entire combat aircraft capability.

In this framework, it can be clearly seen that individual mission package solutions comprised of a specific host platform, USV, and payload comprise a "system of systems", while the solution set for all USV missions comprises a "family of systems". In fact, the ultimate aim of the Navy's USV programs will be to produce a "family of systems of systems" that are interrelated and synergistic to address the Navy's USV mission needs at minimal cost.

With this approach and goal in mind the Master Plan Team: (1) reviewed USV craft types and their associated characteristics, (2) analyzed the key attributes associated with each USV mission and (3) compared the vehicle attributes against the mission needs. This comparison also included the USV-related capabilities and limitation of the ships on which they would be transported. This process is discussed in much greater detail in Appendix D. As a result of this analysis, the Team recognized that the desired mission set could be accomplished in a limited set (four) of USV craft types. As a final check on its efforts, the Team compared the USV mission set, as executable in four USV classes, with both Sea Power 21 and Joint Capability Area (JCA) guidelines, to ensure that the recommended family of USV systems met Navy and Joint needs.

USV CRAFT TYPES

There were several considerations that shaped the Team's review of potential USV hull types. As defined in Chapter 1, USVs are tactical systems capable of air or sea transport. As a result, the types and sizes of vehicles considered in this plan were limited to those that could be transported by standard Navy ships, including those sizes and hull shapes already in use in the Navy. As also noted in Chapter 1, a USV is a vehicle that operates at or near the sea surface. Hence, a major design driver for USVs is the interface of the vehicle with the sea surface. By definition, a USV will have no vehicle operators on board, although it may have the capability of being manned for testing, troubleshooting or when required for a manned mission. Purely training vehicles, such as target drones, were excluded from this Plan, as they are covered under separate programs. Operating at or near the sea surface gives USVs the ability to continuously communicate with suitably-equipped surface, air and underwater assets. Mission requirements and currently available technologies result in USVs having varying levels of autonomy. With these considerations in mind, the following craft types were considered for this Plan.

SEMI-SUBMERSIBLE (SS) CRAFT

Operating with most of its volume below the surface, the semi-submersible design exhibits lower drag and platform motion than conventional hull designs. When wave-making drag is eliminated, the total craft drag is significantly reduced, thus allowing for a larger percentage of the craft’s power to be available for other purposes, such as towing or powering payloads. Power required for propulsion, in general, is a function of speed cubed. Due to the relationship of form drag to power required, speeds are limited to around 25 knots for a 7m SS. Being speed limited, the semi-submersible can be fitted with highly efficient (low speed, large diameter) propulsion systems, making them competitive with other craft designs. Nominally a 7m SS is comparable to an 11m planing hull in terms of towing capability. Figure 27 summarizes the characteristics of the SS craft.

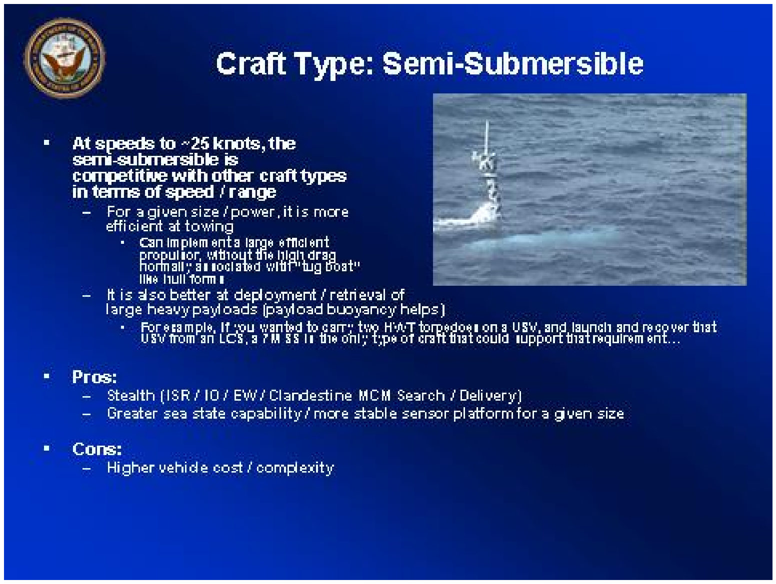


Figure 27 – Semi-Submersible Hull Type

Operating below the surface, the SS is less effected by sea state, giving it a larger operational weather window. Sea-state related motions are reduced which is useful for sensor and payload stabilization, such as MCM high-resolution sonars and directional antennas. This hull form is also more conducive to deployment and retrieval of a variety of payloads. With payloads carried on conventional hulls, the difficulty arises in raising the payload off the USV deck, over the side and through the air/sea interface. None of the above needs to occur when a SS carries its payload beneath the interface to begin with.

With the majority of the hull under water the SS has reduced radar and visual signatures and is therefore more conducive to missions requiring stealth.

The SS is somewhat more costly than conventional hull designs due to the increased complexity of its systems and its uniqueness.

CONVENTIONAL PLANING HULL CRAFT

Conventional planing hulls come in a variety of shapes, the most common types being the V-Hull, Modified V, and M-Hulls. The familiar RIB is a subset of the V-Hull hull type. The V-hull provides an excellent blend of performance with a broad speed range including a top speed exceeding 20 knots, depending on craft shape and loading. This hull is very competitive with other hull types in terms of transport efficiency (speed, payload, and range). While this hull type is very capable of towing, the hull drag is sensitive to load distribution (longitudinal center of gravity (LCG)), tow point and trim angle. As a result, it may be less efficient than other craft types in this size range, especially at speeds less than 25 knots. These craft offer high payload fraction (i.e., percentage of payload weight to loaded craft weight) and can be of low complexity. Figure 28 provides a summary of this craft's characteristics.

Figure 28 – Conventional Planing Hull Type

At low speeds these craft may be less stable in a seaway and tend to roll when at rest, while at high speeds they may pound (slam) and are somewhat inefficient at transitional speeds. At normal operating speeds, they are likely to exhibit more motion than other hull types.

These conventional planning hull types tend to be lower in cost as a result of commonality with commercial craft and the resulting manufacturing economies of scale.

SEMI-PLANING HULL CRAFT

The Semi-Planing hull provides lower drag and higher sea-state capability than the conventional V-Hull and its variants when operated at moderate speeds. It also exhibits lower sea state sensitivity and provides a more stable sensor platform for a given size at approximately the same cost. This hull type is capable of speeds up to 30 knots, can be highly efficient across a broad range of speeds, and can also perform towing.

This hull form typically has a lower payload fraction than conventional planing hulls for a given waterline length and tends to be more slender with higher length-to-beam ratios. Figure 29 provides a summary of this craft's characteristics.

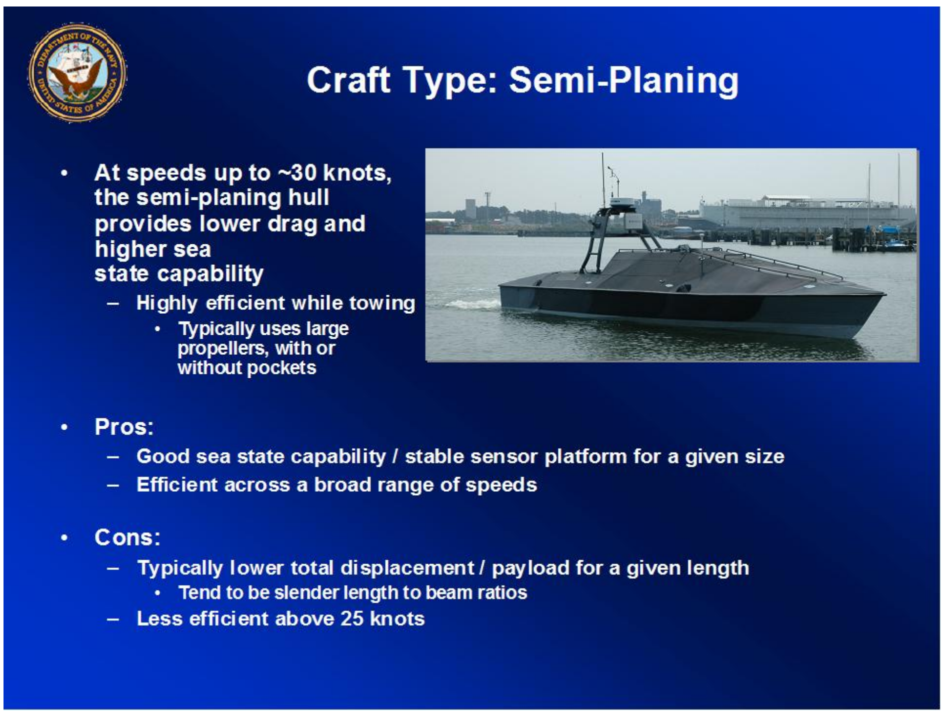


Figure 29 – Semi-Planing Hull Type

HYDROFOIL CRAFT

The hydrofoil craft provides the lowest drag and best sea-keeping of all hull forms and provides a very stable platform at speed in moderate sea states. It is capable of speeds well in excess of 40 knots. Generally, it is not suited to towing due to the conflict of optimizing the propulsor to achieve high-speed operation versus the low-speed/high-thrust operations required for efficient towing.

Due to the complexity of design, this hull type is more costly that the planing hull craft. The necessity of retracting or folding the foils for launch and recovery can be problematic.

Figure 30 is a summary of this craft's characteristics.

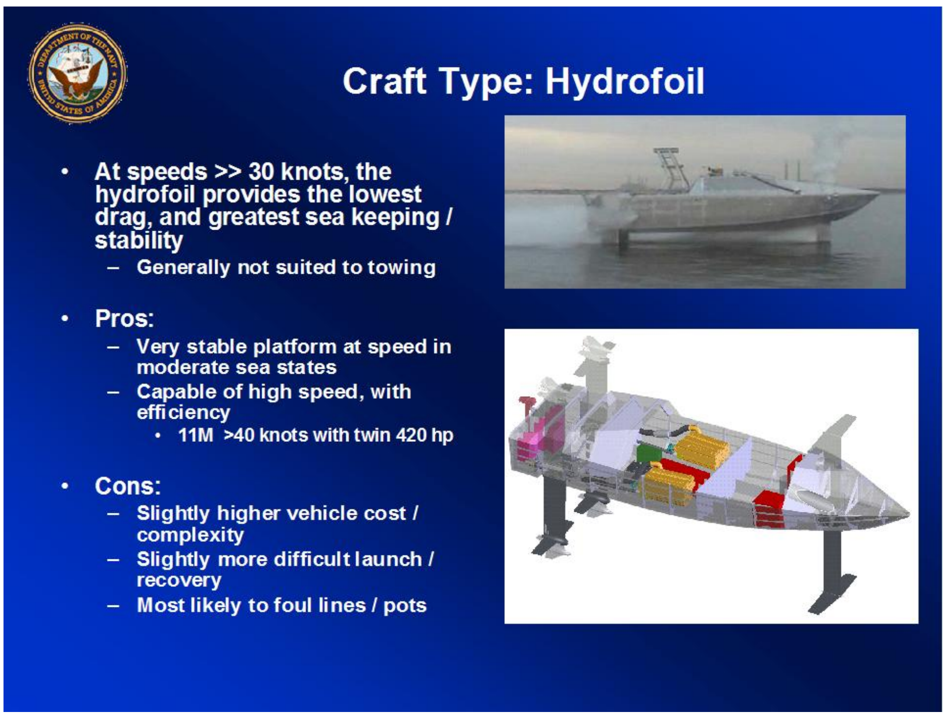


Figure 30 – Hydrofoil Hull Type

OTHER

There is a myriad of other conventional and non-conventional craft types not addressed by this Plan. They include; sailboats, pure displacement, other lifting bodies, Small Waterplane Area Twin Hull (SWATH), wave piercing, and multi-hulls. In general, these craft type are well suited to particular niche requirements and are not of general-purpose design, with costs that can vary between the vehicle being expendable and its being a capital asset. Aside from the pure displacement craft, they tend to have lower accommodation of large weight-fraction changes in either payload or fuel load, which makes them unsuited to extended operations or deployment of heavy sensors. It is for these reasons that these craft types were not considered candidates for standard, common USV needs. Some examples are discussed in Figure 31.

Figure 31 – "Other" Hull Types

ESTABLISH USV CLASSES

An additional major finding from the 2006 USV Master Plan Workshop effort (Appendix C), was that restricting USV sizes and types to a limited number of "classes" would have benefits that would resonate throughout the Fleet and USV acquisition programs, specifically in areas of:

- Fleet compatibility,
- leveraging commercial development,
- Common Control,
- Standards,
- Commonality,
- Modularity, and
- Human Systems Integration.

During the review of USV boat types and the Key Attributes (KAs) associated with the selected USV missions, it became obvious that many of the mission KAs mapped directly to the characteristics of various sizes and hull types of potential USVs. Toward this end, the USV Master Plan Core Team conducted an analysis considering the requirements of the USV missions (Chapter 2), and a variety of Naval Architecture characteristics (e. g., stability, payload fraction, tow power, maximum and sustained operating speeds, endurance) associated with different types and sizes of vehicles. The single most heavily-weighted consideration in all this analysis was the entering requirement to be "transported by Navy ships". A collateral requirement was to minimize modifications necessary to existing Navy ships to accommodate USVs. As a result, common Navy hull forms and sizes were preferred options, all other factors being equal.

These considerations, the process, and its conclusions are described in much greater detail in Appendix D. Descriptions of the vehicle types and sizes as derived from the analysis are provided below.

X-Class: cheap, expendable, probably special-purpose and purpose-built, details not important from a Master Plan perspective.

Harbor Class (7m) – Maritime Security is an all-Navy concern, and this is the size of boat carried on most or all Navy vessels.

Snorkeler Class (semi-submersible) – MCM Search requires: (1) the ability to pull a tow body, (2) stability in sea states, up to and including (and possibly beyond) Sea State 3, and (3) mission endurance.

Fleet Class (11m) – Required to provide (1) adequate power and payload for ASW, (2) power and tow force for MCM Sweep, and (3) endurance for these and other missions.

These four classes are described below and their application to Navy and Joint missions is discussed at the end of the Chapter.

DESCRIPTIONS OF FOUR CLASSES

X-CLASS (SMALL)

The X-Class is unique in that these small, special purpose craft should be purpose-built and not standardized for modularity. Modularity standardization would not be cost-effective or efficient, due the small size of the craft and the overhead associated with modular construction. The other three classes all benefit from modular construction and all four classes should utilize a common command and control system. The X-Class USVs are 3 meters in length or smaller and built to support the needs of SOF Support and MIO Support, as shown in Figure 32. They have limited endurance, payload, and sea-keeping ability.

Figure 32 – X- Class USVs

HARBOR CLASS (7M)

The Harbor Class USVs use a 7 meter RIB with moderate endurance as the basis for its missions. The requirements for the Harbor Class are driven by the need to be hosted by the majority of warships to perform ISR and MS missions. The ISR payload will be arch-mounted such that it can remain in place for manned operation of the craft. Figure 33 summarizes the Harbor Class USV.

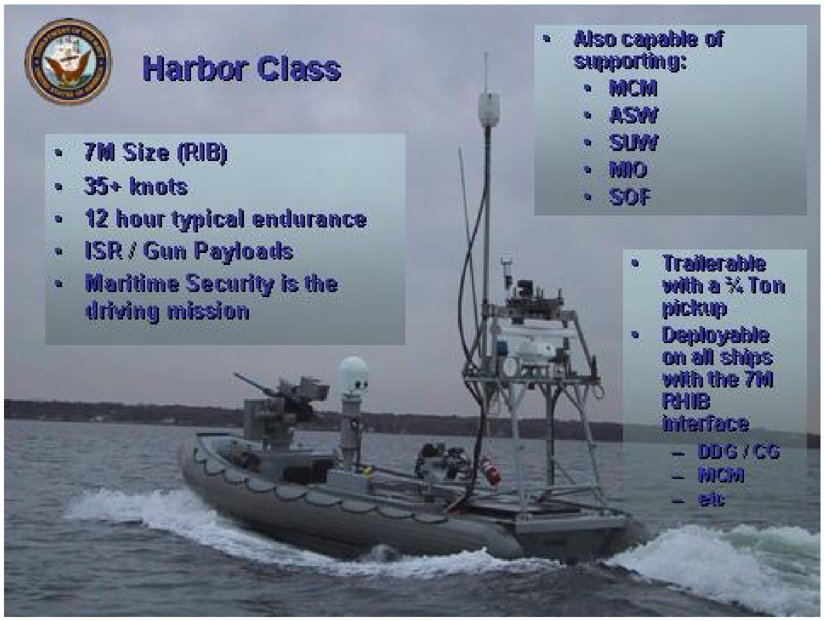


Figure 33 – Harbor Class USV

SNORKELER CLASS (7M SS)

The Snorkeler Class USV is a 7 meter semi-submersible craft. During operation it is submerged with only its snorkel above the surface. This mode of operation provides a much more stable platform in high sea states than other surface hull types. The need for this class is driven by the MCM Search/ Neutralization and ASW missions, as shown in Figure 34.

Figure 34 – Snorkeler Class USV

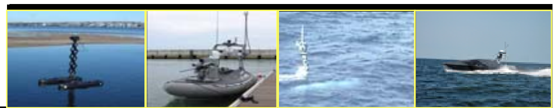
FLEET CLASS (11M)

The Fleet Class USVs are 11 meter planing or semi-planing hull craft. They provide moderate speed/endurance while towing MCM sweep gear or high speed and very long endurance to support ASW, SUW, or EW missions. They also support manned operation through the ability to remove and replace their mission systems in less than 24 hours. Figure 35 summarizes their capabilities.

Figure 35 - Fleet Class USV

MEETING MISSION REQUIREMENTS WITH FOUR CLASSES OF USVs

These four recommended classes of USVs can meet all of the UUV missions, as shown in Figure 36.



USV MP Priority	Joint Capability Area (JCA)	Seapower Pillar	USV Mission	X-Class (small)	Harbor Class (7M)	Snorkeler Class (7M SS)	Fleet Class (11M)
1	Battle Space Awareness (BSA) / Access/ Littoral Control	Sea Shield	Mine Countermeasures (MCM)		MCM Delivery, Search / Neutralization	MCM Search, Towed, Delivery, Neutralization	MCM Sweep, Delivery, Neutralization
2	BSA / Access/ Littoral Control	Sea Shield	Anti-Submarine Warfare (ASW)			Maritime Shield	Protected Passage and Maritime Shield
3	BSA, HLD, Non-Trad Ops, 7 Others	FORCEnet	Maritime Security		ISR/ Gun Payloads		7M Payloads
4	BSA / Access/ Littoral Control	Sea Shield	Surface Warfare (SUW)		SUW, Gun	SUW (Torpedo), Option	SUW, Gun & Torpedo
5	BSA / Access/ Littoral Control/ Non-Trad Ops	Sea Strike	Special Operation Forces (SOF) Support	SOF Support	SOF Support		Other Delivery Missions (SOF)
6	BSA, C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control	Sea Strike	Electronic Warfare		Other IO	High Power EW	High Power EW
7	BSA, Stability, Non-Trad Ops, Littoral Control	Sea Shield	Maritime Interdiction Operations (MIO) Support	MIO USV for 11M L&R	ISR/ Gun Payloads		

Primary Missions supported by

X-Class	Harbor Class	Snorkeler Class	Fleet Class
Secondary Missions of each class that are possible			

Figure 36 – Four USV Classes

USV MISSION SET: RELATION TO SEA POWER 21 AND JOINT CAPABILITY AREAS (JCAs)

After creating the USV mission set, the Study Team then double-checked the validity of its findings by comparing the missions and their projected ultility with stated goals and objectives of Sea Power 21, and with Joint Capability Areas (JCAs) (reference (n)). The specific JCAs cited are:

- Joint Battlespace Awareness*
- Joint Command and Control*
- Joint Network Operations*
- Joint Interagency Cooperation*
- Joint Public Affairs Operations
- Joint Information Operations*
- Joint Protection*
- Joint Logistics*
- Joint Force Generation
- Joint Force Management
- Joint Homeland Defense*
- Joint Strategic Deterrence
- Joint Shaping and Security Coooperation*
- Joint Stability Operations*

- Joint Civil Support*
- Joint Non-Traditional Operations*
- Joint Access and Access Denial Operations*
- Joint Land Control Operations*
- Joint Maritime/Littoral Control Operations*
- Joint Air Control Operations
- Joint Space Control Operations

* The seven postulated USV missions are projected to provide contributions to at least 14 of the 12 JCAs (Figure 37). In addition the mission definitions and boundaries for both USV missions and the JCAs are not absolute, so the possibility exists that USVs will contribute in even more areas than projected here, and in ways that will only be discovered after Fleet introduction and experimentation.

In the Navy context, Sea Power 21 specifies the use of unmanned vehicles as force multipliers and risk reduction agents for the Navy of the future and postulates a host of specific missions (reference (o)).

USVs support the majority of Sea Power 21 (SP21) pillars, with the largest number supporting Sea Shield, particularly with the Homeland Defense, Sea/Littoral Superiority and Force Enabling capabilities required for sea-based theater and strategic defense.

The mapping of the USV mission set to Sea Power 21 and Joint Capability Areas is depicted in Figure 37.

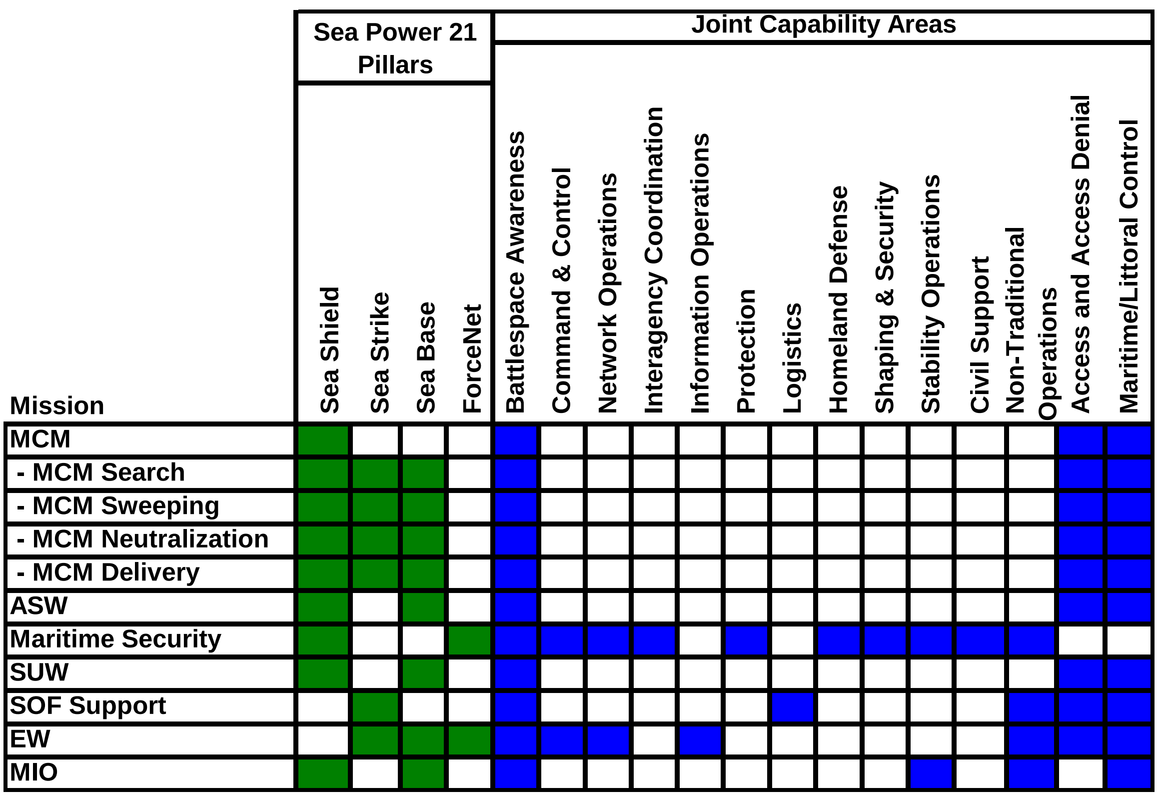


Figure 37 – Mapping of Missions to SP21 and JCAs

Up to this point, the focus of discussion has been on operational issues, boat types, payloads, and technology issues focused on specific USV mission areas in support of Navy and Joint operational requirements. The next sections focus on technology and programmatic implementations in a broader sense, to ensure that USV programs are constituted to maximize USV performance characteristics while retaining cost-effectiveness.

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CHAPTER 4 - OVERARCHING USV TECHNOLOGY AND ENGINEERING ISSUES

TECHNOLOGY AND ENGINEERING ISSUES

The next step after selecting and validating the mission set and determining the feasibility of accomplishing these missions in a limited number of USV classes was to examine the engineering and technology issues that crossed USV missions, classes, and programs. The notional USV mission packages, Concepts of Operations (CONOPs), and technology challenges for individual USV missions are covered in detail in Chapter 2. There are other technology issues, however, that were not only those associated with operating the vehicles themselves within their mission profile, but also the broader issues associated with transport to the operating area, launch and recovery from the host platform, delivery and recovery of the vehicle's own mission sub-packages and a host of similar issues. They fell into two categories: (1) those areas where the technology itself was inadequate to fully support the desired mission set and (2) those areas where the technology in itself was probably adequately mature, but implementation was weak or immature.

Technologies that fell into the first category (technical development needed) were:

- Autonomy
- Obstacle and Collision Avoidance
- Threat Avoidance
- Automatic Target Recognition (ATR)
- Autonomous Deployment and Retrieval of USV Sub-Payloads

Technologies that were felt to be adequately technically mature, but needed more implementation and concept work were:

- Common Control
- Weapon Release
- Vehicle Launch and Recovery from Host Platform

TECHNOLOGY ASSESSMENT

Conceptual systems for each of the mission capabilities identified by the Master Plan Core Team were assessed from a technology readiness perspective using Technology Readiness Levels (TRLs) (Figure 38).

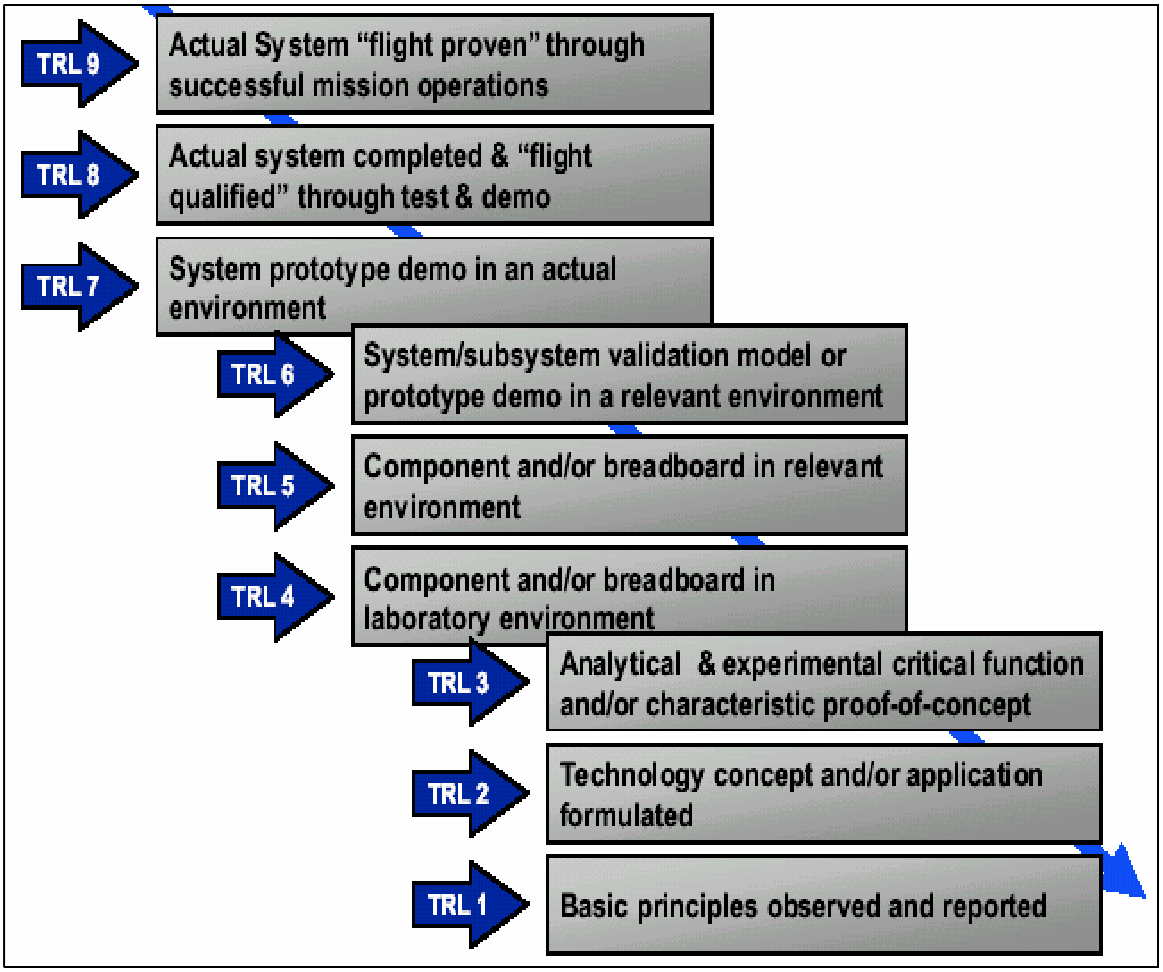

Figure 38 - TRL Definitions

The concepts were then each evaluated across several areas of technology, using a modified Delphi Process with TRLs as metrics, to determine (1) the maturity level of the concepts, (2) the technology areas that require investment, (3) the optimal sequencing of system developments, and (4) the overall schedule that may be achieved.

A summary with average scores for this TRL assessment is shown in Figure 39.

Vehicle System	Average
Hull	**8.3**
Ballast	**9.0**
Energy	**9.0**
Navigation, Guidance, & Control	
Autonomy	**6.6**
Threat Avoidance	**4.5**
Group Behavior	**5.0**
Autonomous Obstacle Avoidance Surface & Submersible	**5.3**
Common Control	**7.5**
Autonomous Obstacle Avoidance at Interface	**3.5**
Navigation System	**8.6**
Communications	
Line-of-Site	**8.5**
Over-the Horizon	**7.5**
Networked (Multi-Vehicle Control)	**5.0**
Propulsion	**8.3**
Masts	**8.7**
Auto Launch & Recovery	**7.0**

Figure 39 - Consolidated TRLs for USV Classes

TECHNOLOGY ISSUES

There are several issues that pertain to overall USV technology development. The importance of each of these areas will vary based on the specific payload, hull type, and operational mission profile, but all will factor in to some degree.

The development of a completely independent, fully autonomous, long-term USV capability in many of the Chapter 2 mission areas is not considered to be feasible in the immediate future. Even short of this ideal, however, there are several capabilities that USVs can provide immediately as significant complements to existing forces, and several more are technically mature enough to deliver in the near future. It is also worth noting that in nearly every one of these areas, especially in the autonomy and C4I categories, the communications profile of a USV lends itself to a "crawl-walk-run" development process:

- Crawl = Manual: USV in continuous communication, man-in-loop, control and decision-making on host platform
- Walk = Semi-automatic: USV in periodic communication, many autonomous functions (piloting, collision avoidance), human permission required for major decisions (e. g. target pursuit, weapon release)
- Run = Automatic: USV in communications only as necessary to execute its mission profile. Completely independent, fully autonomous, independent USV operations.

Using this approach, even the 'crawl' capability can provide near-term value to the Fleet while producing valuable training, experience, and lessons learned to the technical and acquisition communities for incorporation into the development process.

AUTONOMY

The area of autonomy and control is a major research area for all UVs, whether military, commercial, or academic in origin. Autonomy offers the benefit of minimizing manning and bandwidth requirements while extending the tactical range of operations beyond the line of sight. Accordingly, adaptive functionality to various degrees is a key element for most of the USV missions. For example, the need for long-term independent operation is essential for the MS, ASW, and MCM missions where the requirement exists to transit long distances, detect, assess, and avoid potential threats and collect information independent of direct human operators. Another aspect of autonomy is the cooperative or collaborative coordination among multiple vehicles. This is viewed as an important enabling capability for large-scale ASW and MCM where required object sensing and intervention and ocean surveillance may occur simultaneously with other operations.

While USVs have the luxury to operate using Radio-Frequency (RF) communication links to an operator’s control station that can be long-range with encrypted high data rates, trade-offs and performance limitations exist (e. g., communications link allocation during real-world operations). The USV community must wean itself from the telecommunication bandwidth. It is not reasonable or perhaps even possible to “tele-operate” USVs through the Global Information Grid (GIG) and even local network loading for USV operations should be minimized. Autonomy will be fundamental in accomplishing this goal.

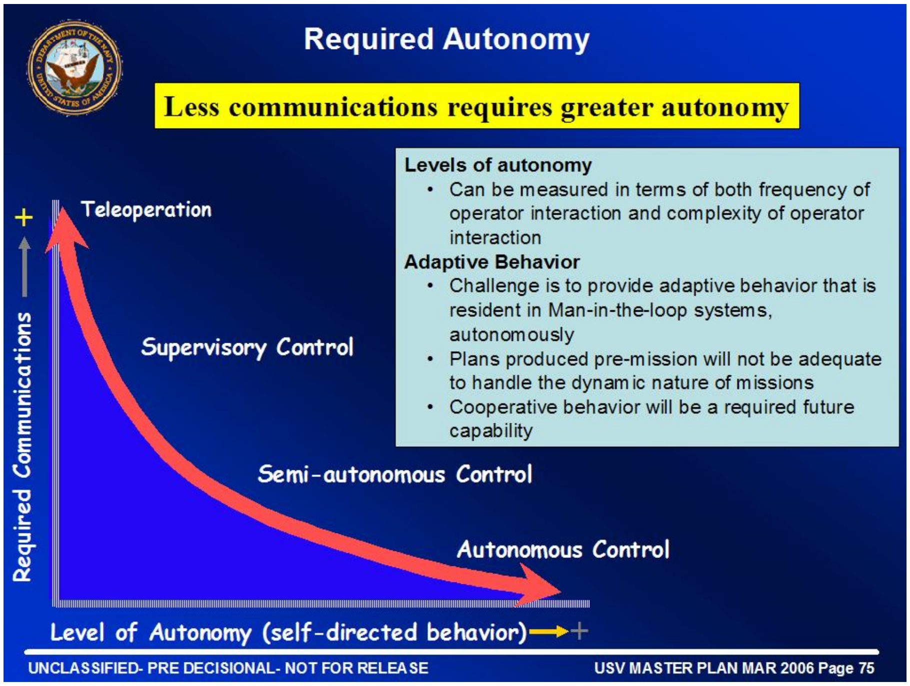

Figure 40 – Communications Bandwidth vs. USV Autonomy

In order to reduce communications, increased autonomy is required to push signal processing and decision-making to the lowest level at which it can be successfully accomplished. Levels of autonomy can be measured in terms of both frequency of operator interaction and complexity of operator interaction as seen in the chart, Figure 40, above.

Areas requiring additional development in order to meet JCA mission requirements cover the spectrum of USV operations. Data from USV sensors must be collected, evaluated and sorted for importance, both as a mission product and as it may impact vehicle operation for the remainder of the sortie. The USV must autonomously recognize data representing a threat or calling for a change in its initial sortie plan and then respond appropriately. Unanticipated events or data may require that the vehicle report its findings immediately, abort a mission, or alter its sortie priorities. As already noted, the requirement for sophisticated autonomy in support of successful USV missions is potentially less than for other types of unmanned systems, at least for the delivery of an initial capability, due to the potential for maintaining a communication link between human controllers and the vehicle. Autonomy remains a goal in almost every area, however, to reduce bandwidth and communications requirements as well as operator manning and work-loading.

The autonomous use of weapons with unmanned systems of all types is an issue being investigated by the Army, Navy and Air Force laboratories and the Joint Ground Robotics Enterprise (JGRE) under OSD. Legal issues will continue to drive the general rules of engagement for weaponized USVs in most cases. Certainly for the near term, human-in-the-loop control will be required for most weapon applications, to ensure that the target is properly identified. In the case of armed USVs, for example, an ASW "kill box" or MIW "mine danger area" could be designated allowing for automatic modes to be used with greater confidence.

For mine neutralizer systems, there are several unique weapon release issues. Target localization accuracy is important and the neutralizer must locate and reacquire the target with inexpensive short range sensors. Until dependable automatic target recognition (ATR) algorithms are developed and proven, a robust, high-bandwidth C3 will be needed to support man-in-the loop control. Battle damage assessment following neutralization attempts will be required to verify that the target was neutralized.

In summary, capabilities are needed that can adapt to changes in environment and mission profiles. Pre-deployment programming of vehicle mission plans will not be sufficient to handle the dynamic nature of some missions. The challenge is to provide auto-adaptive behaviors that are currently resident in human-in-the-loop systems. Multi-system autonomous, cooperative behaviors will be a required future capability.

OBSTACLE & COLLISION AVOIDANCE

All USVs except the smallest special purpose vehicle must have the ability to autonomously avoid obstacles. These include:

- Land masses
- Watercraft
- Low-hanging obstacles such as, bridges and tree limbs for inshore operations
- Submerged shallow obstacles such as hulks, reefs, and sandbars
- Interface obstacles, such as, swimmers, buoys, and floating debris
- Submerged obstacles for USVs that tow systems.

THREAT AVOIDANCE

Most of the JCA missions require the autonomous avoidance of threat systems. This includes ships, boats, aircraft, active sensor systems (e. g., radar), and to the extent possible, passive detection systems. The tradeoff here is between vehicle vulnerability to interdiction or destruction and the complexity and sophistication (and hence, cost) of its self-protection suite.

AUTOMATED TARGET RECOGNITION (ATR)

ATR is required to facilitate both Obstacle and Threat Avoidance in all mission areas, and is needed for primary mission accomplishment in MCM, MS, ASW, and SUW missions.

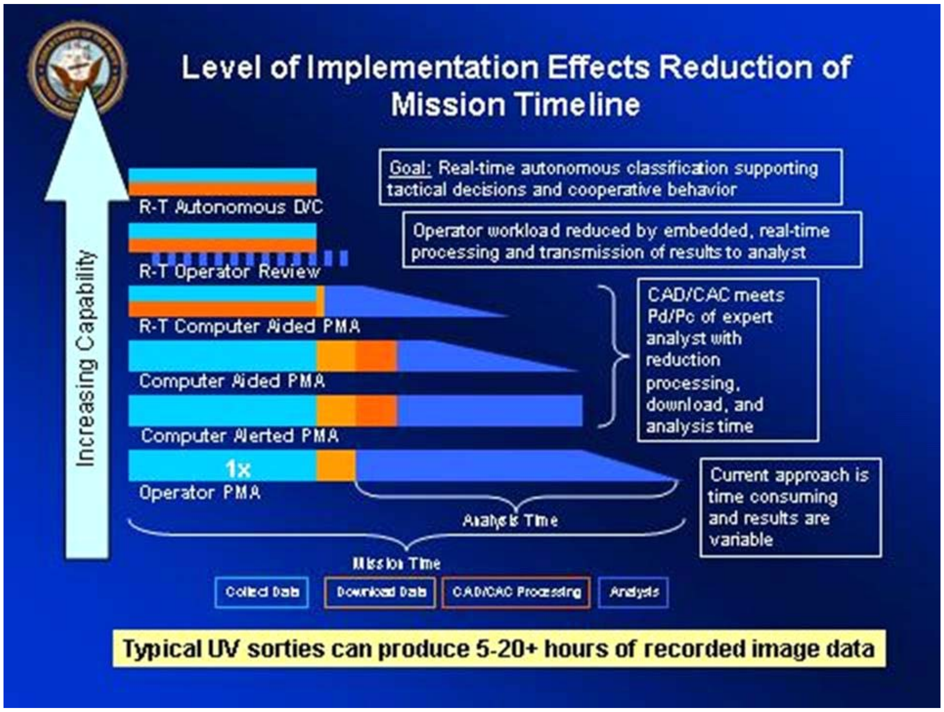

Figure 41 – Level of Implementation vs. Timeline Reduction

As shown in Figure 41, the benefits of ATR are realized as huge reductions in overall mission times and the ability of the systems to act on findings in real-time, while still in the field. This capability is key to allowing these systems to execute multiple steps without returning to the host platform or communicating with an operator.

All of the missions require some degree of obstacle and collision avoidance. Craft control algorithms are sufficiently mature; however, sensor processing is lacking for autonomous operations. Some combination of sonar, radar, optical, and infrared sensors will likely be required and image processing algorithms, especially for the latter two, are in their infancy. The community would benefit greatly from increased developments in this area.

While sensing is generally a well-developed field, there are some areas that are of ongoing concern to USV operations, particularly for in the MCM, ASW, and SUW missions. Development is needed in increasing area coverage rate (ACR), improved classification and identification capabilities, non-traditional tracking techniques, and multi-threat chemical, biological, nuclear, radiological, and explosive sensors.

Synthetic Aperture Sonar (SAS) is the current leading candidate to best meet the requirements of the MCM mission. SAS promises to provide both increased area coverage—which can allow (1) a greater area to swept in a given time with the same number of vehicles, (2) a given area to be swept more rapidly with the same number of vehicles or (3) a given area to be swept with fewer vehicles. SAS also promises to provide increased target resolution. This latter characteristic may be of significance in ATR development for MCM. Broadband acoustic techniques also hold great potential to provide extended-range mine identification capabilities.

Sensor processing and the automated decision making associated with the processing remains a developmental area for both MCM and ASW. For MCM, the principal risk will be the autonomous processing of sonar and optical images to classify mine-like objects and identify mines. The community is working on the development of the second generation of autonomous sonar processing and is currently able to do this autonomously in some environments. However, optical processing for mine and above-water objects is only now beginning to be developed. For ASW, the biggest challenges are associated with autonomous processing, target recognition, countermeasure rejection, Target Motion Analysis (TMA), and tactics.

AUTONOMOUS DEPLOYMENT & RETRIEVAL OF UNTETHERED SYSTEMS

Autonomous payload deployment and retrieval from a USV is an area that has not been developed. Figure 42 shows the deployment and retrieval requirements for the USV Missions.

USV Missions	Deployment or Retrieval Required			
	UUV/ ROV	USV	Missile	Torpedo
MCM	D&R			
ASW				D
MS	D&R			
SUW			D	D
SOF Support				
EW				
MIO Support	D&R	D&R		

Figure 42 – Deployment/ Retrieval Requirements

This is an area that is probably far in the future in terms of full implementation. On the other hand, this area can certainly benefit from:

- The fact that operator-assisted launch and recovery technologies exist, at least in rudimentary form. Torpedo and missile launch, for example are very well understood and implemented on a variety of platforms.
- The ability to deliver initial implementations with man-in-loop control, eventually maturing to partial and then full autonomy, as discussed at the start of this chapter.

USV ENGINEERING & CONCEPT OF OPERATIONS ISSUES

The assessment process uncovered two areas that have sufficient technological basis, yet require further engineering or operational development: common control and weapons release.

COMMON CONTROL

The effective operation of the USV capabilities envisioned by the Master Plan will result in the simultaneous operation of many dissimilar unmanned systems. A common control approach is necessary to minimize proliferation of unique hardware and software, manning and training requirements, and communications systems,.

Common control for all unmanned vehicles (UxVs)—air, surface, undersea, and ground—is the ultimate goal in the unmanned vehicle community for many reasons:

- To allow ready transfer of control of an unmanned vehicle from one operator to another (commonality of technical control system from location to location),
- To allow control of multiple types of vehicles from a single control station (commonality of graphical user interface and human-machine interface),
- To minimize training across host platforms, operators, and vehicle types by standardizing UV controls, and
- To minimize logistics requirements by providing common hardware, spare parts, and maintenance practices across the community.

While these goals are still far from reality, significant work has been done in "commonizing" unmanned vehicle command, control and autonomy. In addition to the OSD Sponsored Joint Unmanned Systems Common Control (JUSC2) ACTD, discussed below, significant work has been done in several related areas:

- Autonomous navigation and obstacle avoidance
- Spartan USV ACTD and USV initiatives
- ONR Platform Initiatives
- Remote mine-hunting (AN/WLD-1), USV Test Beds, and Independent Laboratory Innovative Research (ILIR) initiatives
- Autonomous payload and sensor control and,
- USV Weaponization

The Navy end-state vision for unmanned systems common control is depicted in Figure 43. Development of the joint interoperability standards has not been done with representation from all the services including the OSD.

The Navy and OSD have taken the first step towards UV common control with the JUSC2 ACTD. This ACTD ties together a number of UV C2 systems on LCS Flight 0 and adds joint standards (JAUS & STANAG 4586). However, JUSC2 is just the first step toward replacing all the separate stovepiped UV C2 systems with one common control station that minimizes number of operators required. Currently, there is no program of record to transition from JUSC2 to a unified common control station that completely replaces the separate C2 systems that come with each UV. However, there are efforts ongoing to provide such a program to fully develop, integrate, deploy, and sustain a unified common UV control station for LCS spirals and other Naval platforms, surface and submarine.

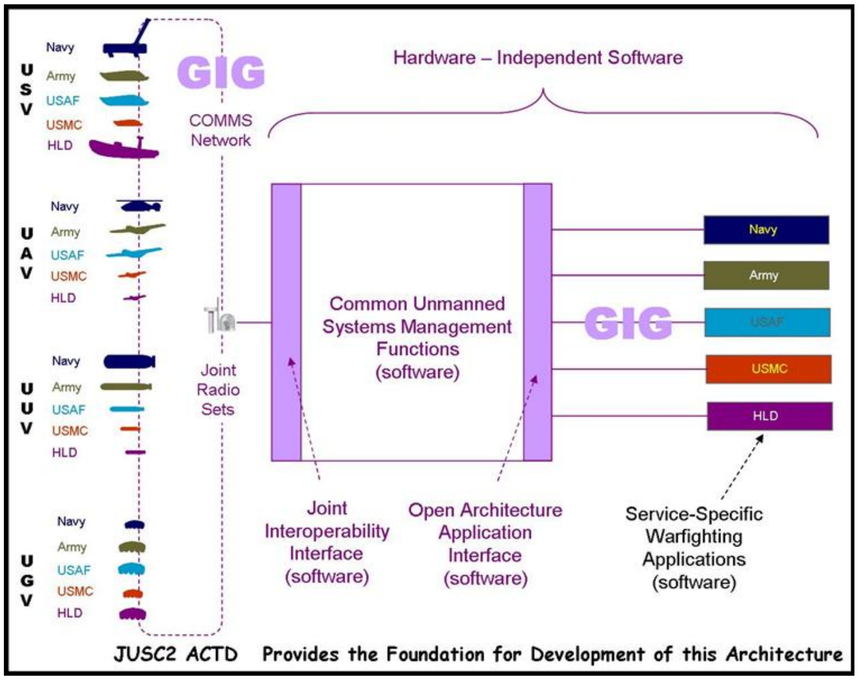

Figure 43 – Navy End-state Vision for Unmanned Systems Common Control

Part of the key to accomplishing the ultimate vision is in establishing standards for interoperability, communications, Hull, Mechanical, & Electrical (HM&E) and payload modularity, and Command, Control, Communications, and Computers (C4) architecture. This specific factor is discussed in greater detail in the section entitled "Standards and Modularity".

WEAPON RELEASE

The MCM Neutralization, ASW, and SUW missions require carrying and releasing weapons. As noted in the Autonomy section, legal issues drive much of the technical and operational problem associated with weapon release, autonomous or man-in-loop. Numerous legal and procedural guidelines, such as friendly-fire prevention procedures, ROE, law of the sea, and International Regulations for Preventing Collisions at Sea (COLREGs), must be taken into account, together with technical development, in realizing these capabilities.

The general concept for autonomous use of weapons is depicted in Figure 44**.**

Primary technical challenges for weapon release from USVs include the ability to reliably target the right objective and achieve proper tracking in all sea states where the system is likely to be employed. High sea states may pose problems with USV station keeping, aiming (guns, missiles, non-lethal projectiles) and system deployment (torpedoes, UUVs sensors). Maintaining communications for man-in-the-loop operations will be a challenge, particularly over the horizon (OTH). Reliable medium-range acoustic communications and autonomous group behavior will also be necessary to meet operational requirements. Gateway systems such as the Communications/Navigation

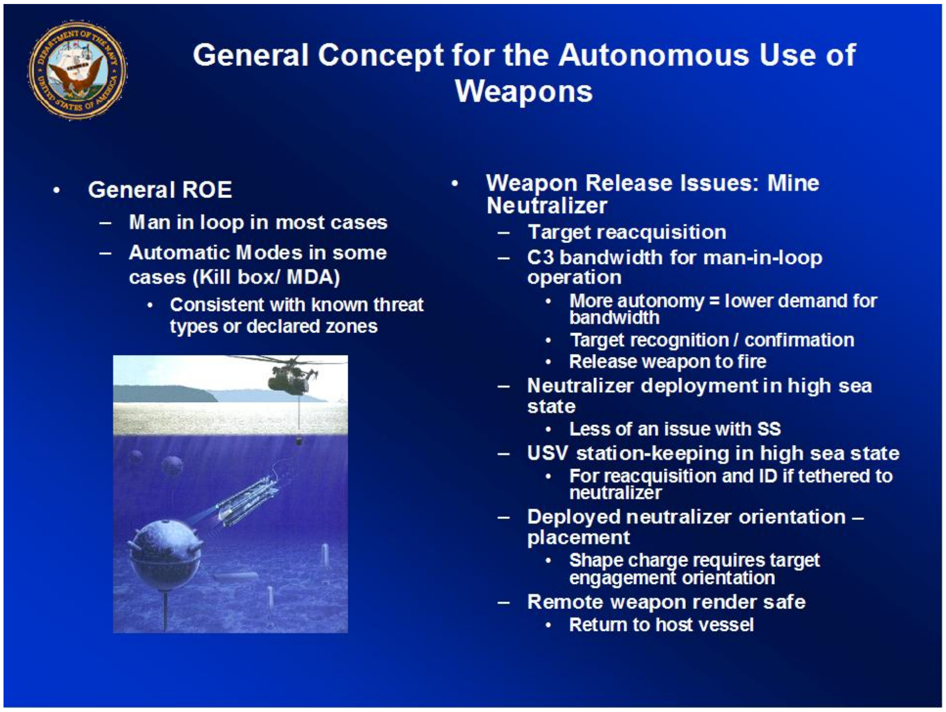

Figure 44 – General Concept for the Autonomous Use of Weapons

Network Nodes (CN3) for USV/UUV interactions, or intermediary UAVs for OTH communications, may be required to facilitate this interaction. Computer-Aided Detection and Computer-Aided Classification and has been demonstrated and it is assumed that Computer-Aided Identification is or will become an available technology. This technology is necessary to meet the required mission time, especially for target acquisition/reacquisition with a high degree of reliability. As noted in the ATR section, the automation of the DCLI process—and the removal of the man from the decision loop—can dramatically reduce sense-to-response timelines.

For the MCM Neutralization sub-mission, neutralizer deployment and USV control for tethered mine neutralizers, will be difficult in high sea states. This, however, will be less of an issue with a semi-submersible USV than it will be for other craft designs. Finally, the neutralizer most have the ability to "render safe" in order for it to re return to back to the host vessel.

Additional weapon release issues are identified in Figure 45.

Weaponizing unmanned systems is a highly controversial issue that will require a patient 'crawl-walk-run' approach as each application's reliability and performance is proved. This will require starting with the vehicle itself to ensure its performance adheres to appropriate operational regulations. Initial applications of weaponizing any unmanned systems will require man-in-loop control (e.g. Predator UAV) to ensure positive control of the vehicle and its weapon. For weaponized USV operations during war or other categories of hostile action, ROE will likely follow the precedent from other weapon release doctrine. For example, the likelihood of hazarding non-combatants during ASW missions may be sufficiently low to allow autonomous weapon release under certain conditions. Patrol areas or ‘kill boxes’ could be announced and demarcated (e.g. present

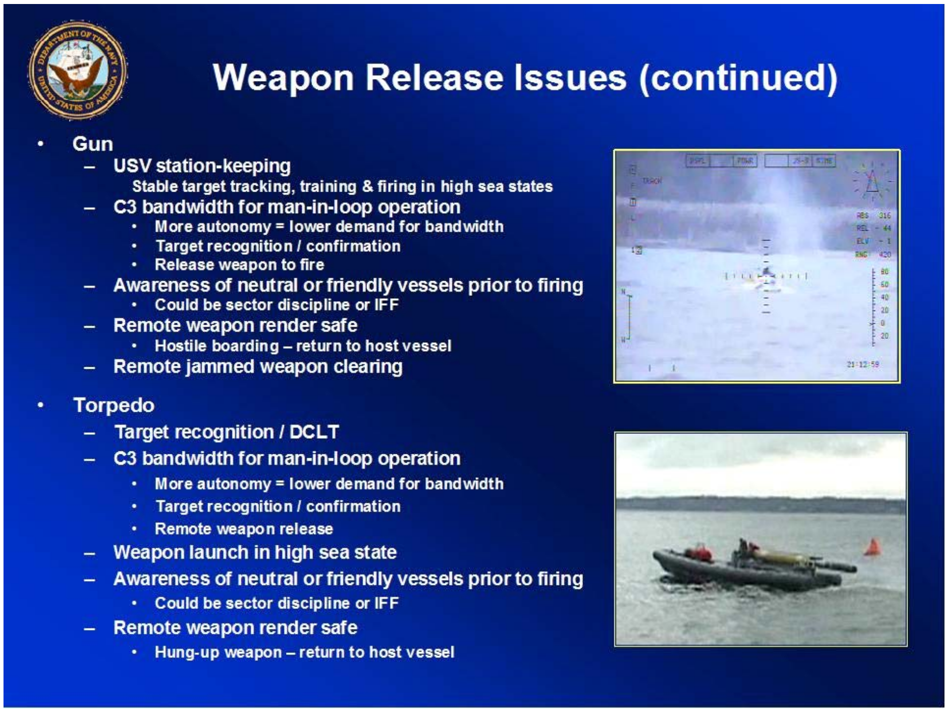

Figure 45 – Additional Weapons Release Issues

minefield doctrine and law) for the purpose of keeping innocents from passing through. Guns, missiles, torpedoes and non-lethal projectiles can ‘hang fire’, creating potentially dangerous conditions for USV recovery personnel and other vessels within the operating area. The challenge will be the ability to remotely render USV weapon systems safe (with verification) or face the choice of having to scuttle the USV. In these areas, precedent in retrieving armed aircraft which have been unable to drop their payloads (e. g., wing-mounted bombs) may be of value. Scuttling may also become necessary if there is a chance that the USV could be taken by hostile forces. In this case, the ability to remotely destroy the weapon and/or the USV will be useful. As confidence in system reliability, function and targeting algorithms grow, more autonomous operations with weapons may be considered. Legal opinion, ruling and precedent will be set as each application is fielded and used during operations. This will drive the ROE for all armed unmanned system operations.

VEHICLE LAUNCH AND RECOVERY (L&R)

The successful operation of USVs is dependent on the capability of delivering and recovering the USVs from the operational area. As shown in Figure 46, there is a variety of challenges to be addressed, including:

- Safety and operability throughout all L&R operations and conditions
- Adapting the L&R system to accommodate USV variants
- Host platform interfaces and potential conflicts including:
    - Proximity to main propulsors

- Mechanical and fluid interactions between the USV and L&R system
- Commonality and portability of the USV L&R system interfaces while:
  - Not inherently precluding use on other surface vehicles
  - Not substantially impacting the overall host platform arrangements
  - Minimizing restrictions on host platform speed and CONOPS in general
- Development of a simple system that minimizes manpower, maintenance and the number of operations required.

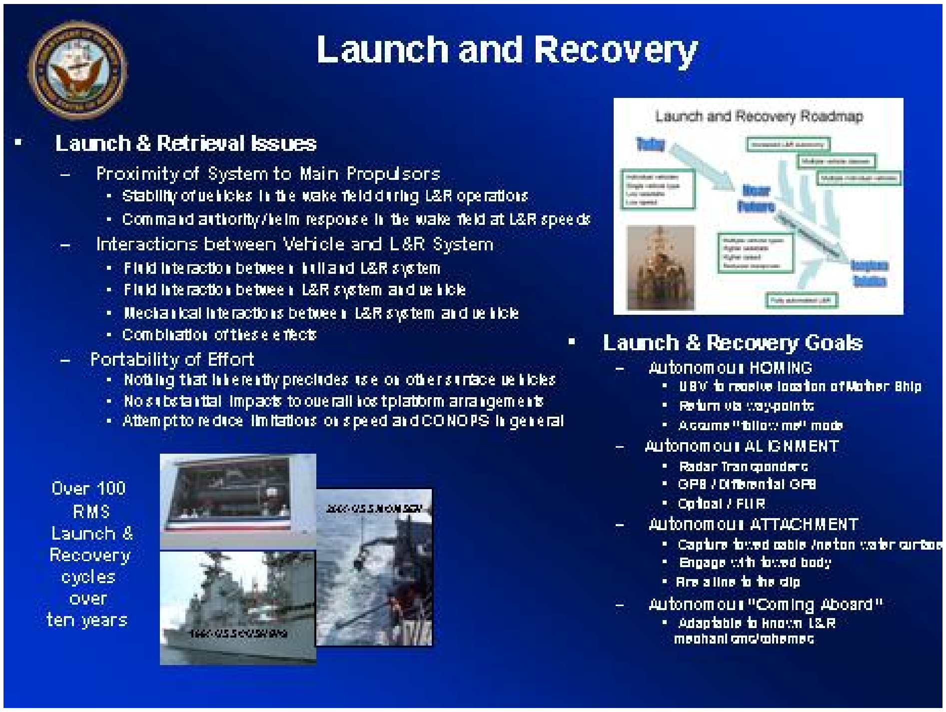

Figure 46 – Launch and Recovery

In the case of ships such as LCS, which will deploy and depend on the utility of multiple USVs, satisfying these issues, as well as automating portions of the process, will provide enhanced operational capability. As an example of specific USV L&R impact to overall operations, USV L&R can only be conducted at low ship speeds and in relatively low sea states. Developmental goals for USV L&R should include operations at higher speeds and higher sea states.

Automating the L&R process, from the USV perspective, can be broken down into the following components: autonomous homing, alignment, attachment and "coming aboard". Technology development supporting these components should be pursued. Challenges include:

- The development of common command and control aboard the USV to deal with operational vehicle performance in the face of command authority issues at the low speed associated with L&R
- The development of passive sensors and control system integration that provide the information necessary to address automated L&R requirements

- The development of robust grappling/attachment mechanisms that provide adequate "coming aboard" control while minimizing the impact to the USV and shipboard systems

While these goals have not been fully realized, significant work has been conducted to address a number of the USV launch and retrieval issues. Figure 47 illustrates the current state of the art for automated USV L&R.

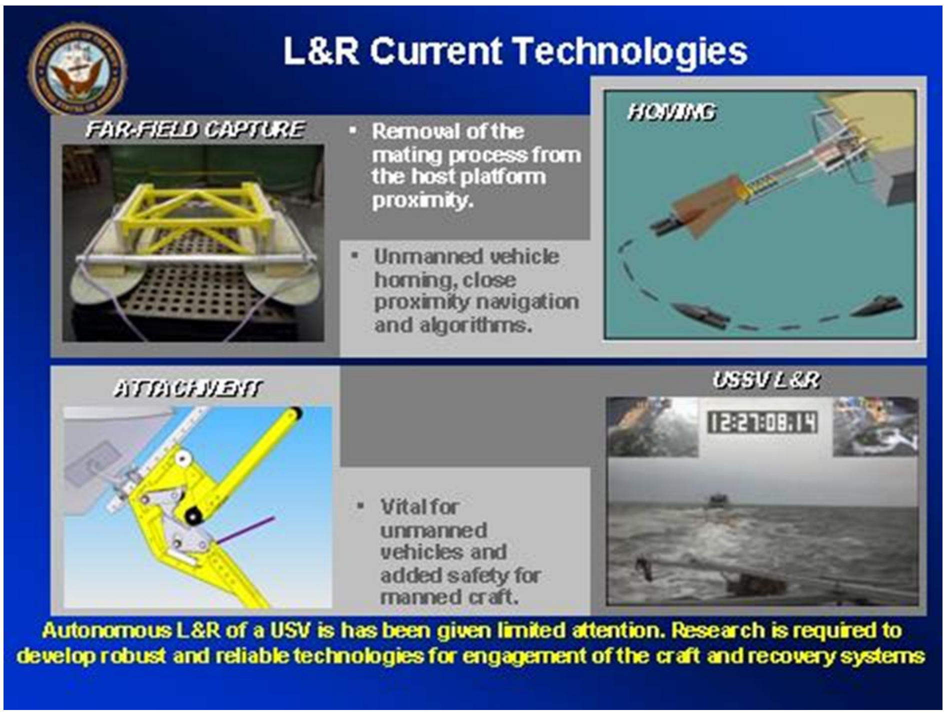

Figure 47 – L&R Current Technologies

This concluded the analysis and synthesis efforts of the Master Plan Team. The results of this work were consolidated into a series of Recommendations and a Summary, which are presented in the next two chapters.

CHAPTER 5 - RECOMMENDATIONS AND CONCLUSIONS

Technical recommendations in pursuit of individual mission requirements are contained in the preceding Chapters and summarized in a series of roadmaps, by vehicle class, immediately below. In addition, this plan forwards a number of higher-level programmatic recommendations for areas where the Navy can greatly facilitate its implementation of a coherent and sustainable long-term USV program.

MEET MISSION REQUIREMENTS WITH FOUR CLASSES OF USVs

The four recommended classes of USVs can meet all of the desired USV missions, which in turn provide significant benefit to both Sea Power 21 (Navy) and Joint Capability Area (JCA) (DoD) mission needs. The process by which this conclusion was derived is discussed in detail in Chapter 3.

USV CLASSES: SUMMARY DESCRIPTIONS AND TECHNOLOGY ROADMAPS

The section below provides summary description of the vehicle classes described in greater detail in Chapter 3, along with their associated technology roadmaps. These roadmaps identify the desired technologies and developmental thrust areas along with the estimated technology insertion timeframes. Within the roadmaps, technology thrusts are color coded in accordance with Figure 48 below and arrows exist in the correct colors to indicate the nominal time when the transition is required. The technology plan to follow shows the roadmap for technology development over time for each vehicle class, culminating in an overall USV combined roadmap. On the more complex roadmaps, letters follow the technology thrust bars to indicate which specific mission that technology supports within that class. The letters carry over to the summary roadmap at the end of the chapter.

TECHNOLOGY ROADMAP KEY		
Technology Thrust Area	**Desired Technologies/Developmental Thrusts**	**Recommended Timeframe for Technology Insertion**
Autonomy		
Hull, Mechanical & Electrical		
Launch and Recovery		
Weapon/Payload		

Figure 48 -Technology Roadmap Color Key

The four classes of USVs recommended by this plan are shown in Figure 49. A summary of each class is provided, followed by its roadmap (Figures 50-53). The summary roadmap is shown in Figure 54.

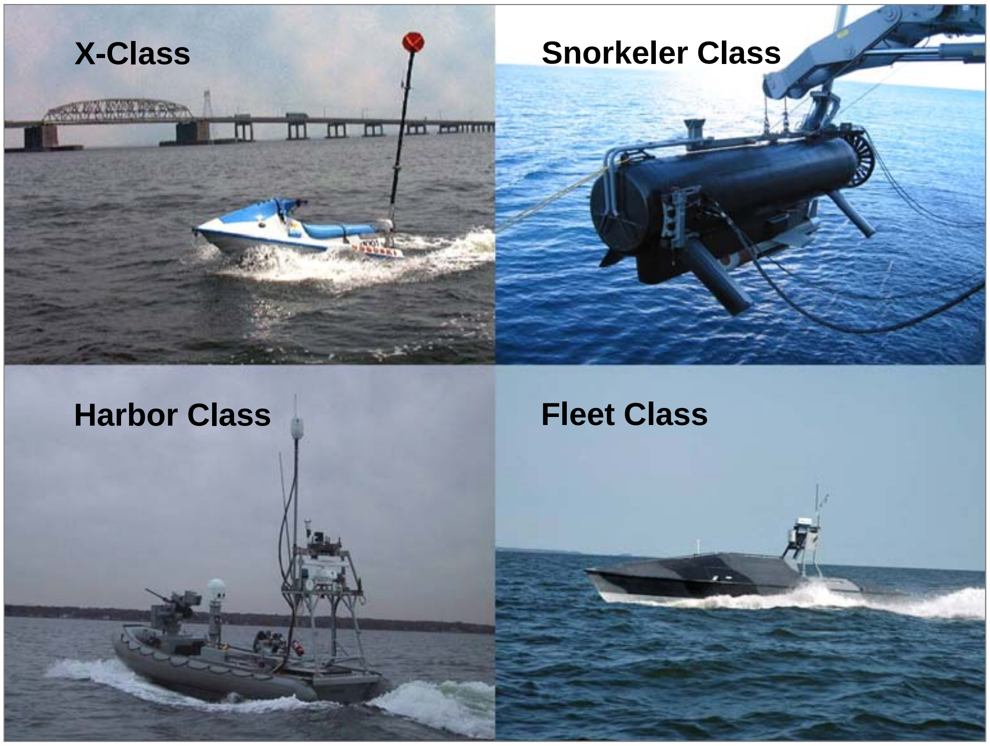

Figure 49 - Four USV Classes

X-CLASS (SMALL)

The X-Class is unique in that these small, special purpose craft should be purpose-built and not standardized for modularity. To do so would not be cost-effective or efficient, due the small size of the craft and the overhead associated with modular construction. The other three classes all benefit from modular construction and all four classes should utilize a common command and control system. The X-Class USVs are 3 meters in length or smaller and built to support the needs of SOF Support and MIO Support. They have limited endurance, payload, and sea-keeping ability. The roadmap for the X-Class is shown in Figure 51.

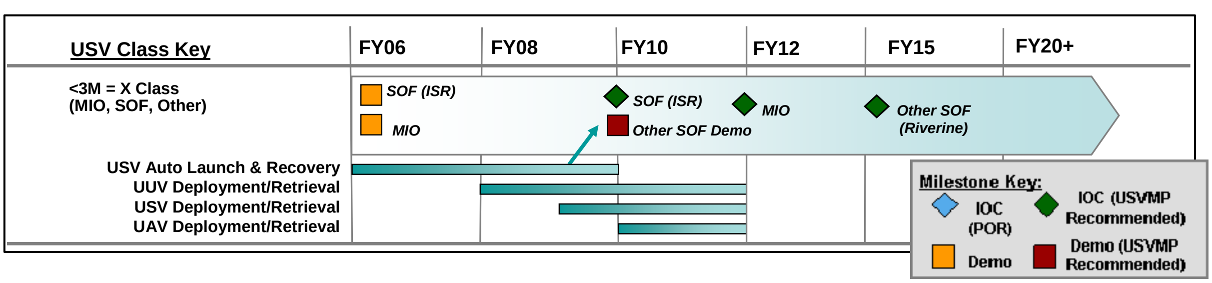

Figure 50 – X-Class Roadmap

Although there have been recent demonstrations conducted using this vehicle class, further investments in USV auto launch and recovery technologies will be necessary to achieve an effective MIO and SOF mission capability beginning in the FY2010 timeframe.

HARBOR CLASS (7M)

The Harbor Class USVs use a 7 meter RIB as the sea-frame. The requirements for the Harbor Class are driven by the need to be hosted by the majority of warships to perform ISR and Maritime Security missions. The ISR payload will be arch-mounted such that it can remain in place for manned operation of the craft. The roadmap for the Harbor Class is shown in Figure 51.

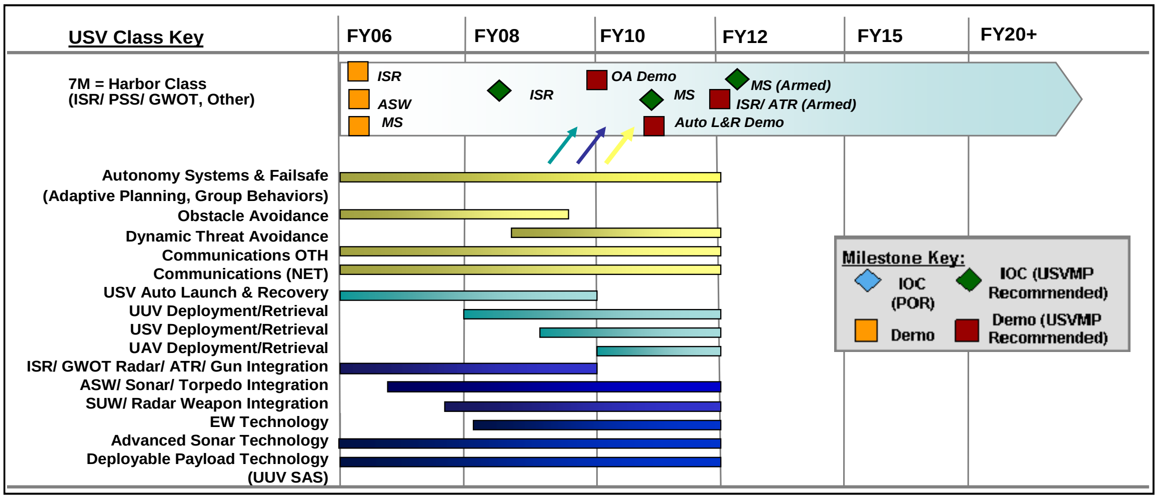

Figure 51 – Harbor Class Roadmap

Mature autonomy, launch and recovery, and weapons/payloads technologies will be required beginning in the FY2009-FY2010 timeframe. In order to achieve the autonomy capability that the harbor class requires to perform MS missions, investments in areas such as adaptive planning/group behaviors, obstacle avoidance, and communications will be required. Technology investments to achieve necessary weapon/payload capability should include technologies that will enable radar/ATR/gun integration, sonar/torpedo integration, and radar/weapon integration with technology insertions beginning in FY2009. Robust electronic warfare, advanced sonar, and deployable payload technologies are also needed to support this class.

SNORKELER CLASS (7M SS)

The Snorkeler Class USV is a 7 meter semi-submersible craft. During operation it is submerged with only its snorkel above the surface. This mode of operation provides a much more stable platform in high sea states than other surface hull types. The need for for this class is driven by the MCM Search/ Neutralization and ASW missions.

The roadmap for the Snorkeler Class is shown in Figure 52.

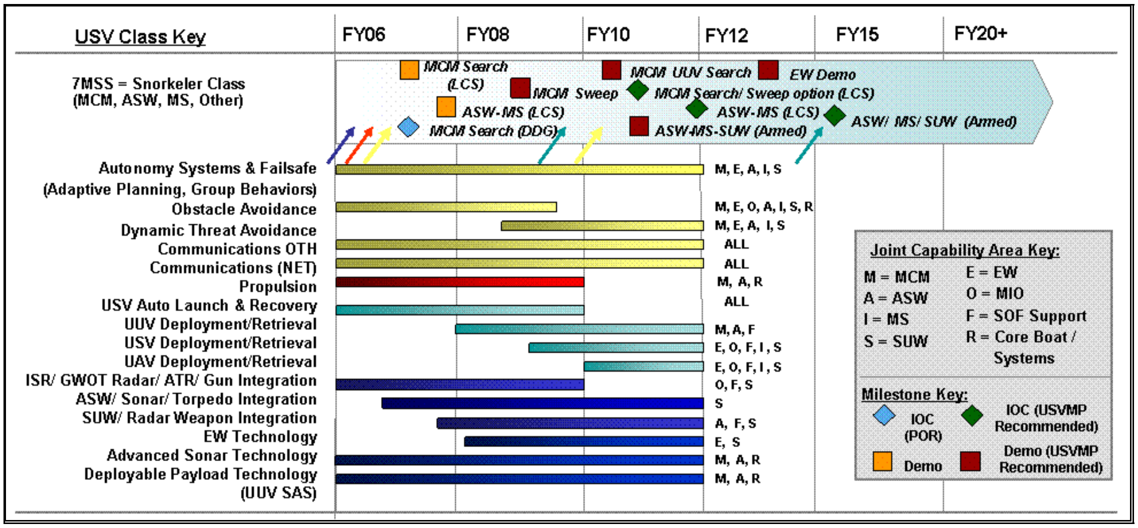

Figure 52 – Snorkeler Class Roadmap

The Snorkeler class of USVs requires investment in propulsion technologies to support HM&E requirements, launch and recovery to achieve weapon/payload capabilities, and some autonomy, particularly in the area of adaptive planning/group behaviors to support the MCM (M), EW (E), ASW (A), MS (I), and SUW (S) Joint Capability Area USV Missions.

FLEET CLASS (11M)

The Fleet Class USVs are 11 meter planing or semi-planing hull craft. They provide moderate speed/endurance while towing MCM sweep gear or high speed and very long endurance to support ASW, SUW, or EW missions.

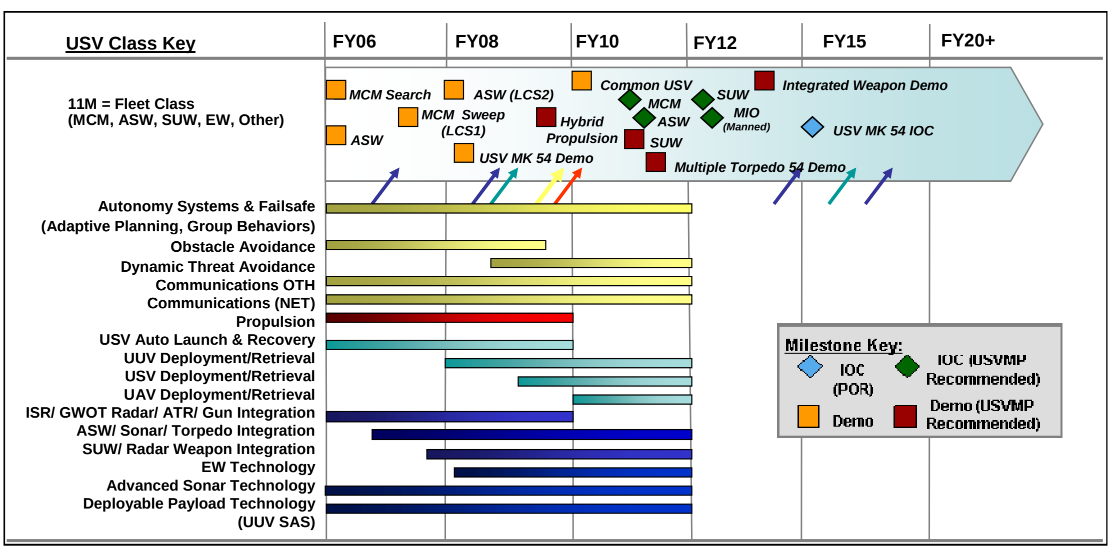

Figure 53 – Fleet Class Roadmap

This option is provided by a modular propulsion system. They also support manned operation through the ability to remove and replace their mission systems in less than 24 hours. The roadmap for the Fleet Class is shown in Figure 53.

The integrated roadmap (Figure 55) summarizes the technology thrusts and program deliverables for all four classes. The synergy between the technology thrusts needed by the various classes highlight the need for coordinated technology investments as well as commonality and modularity.

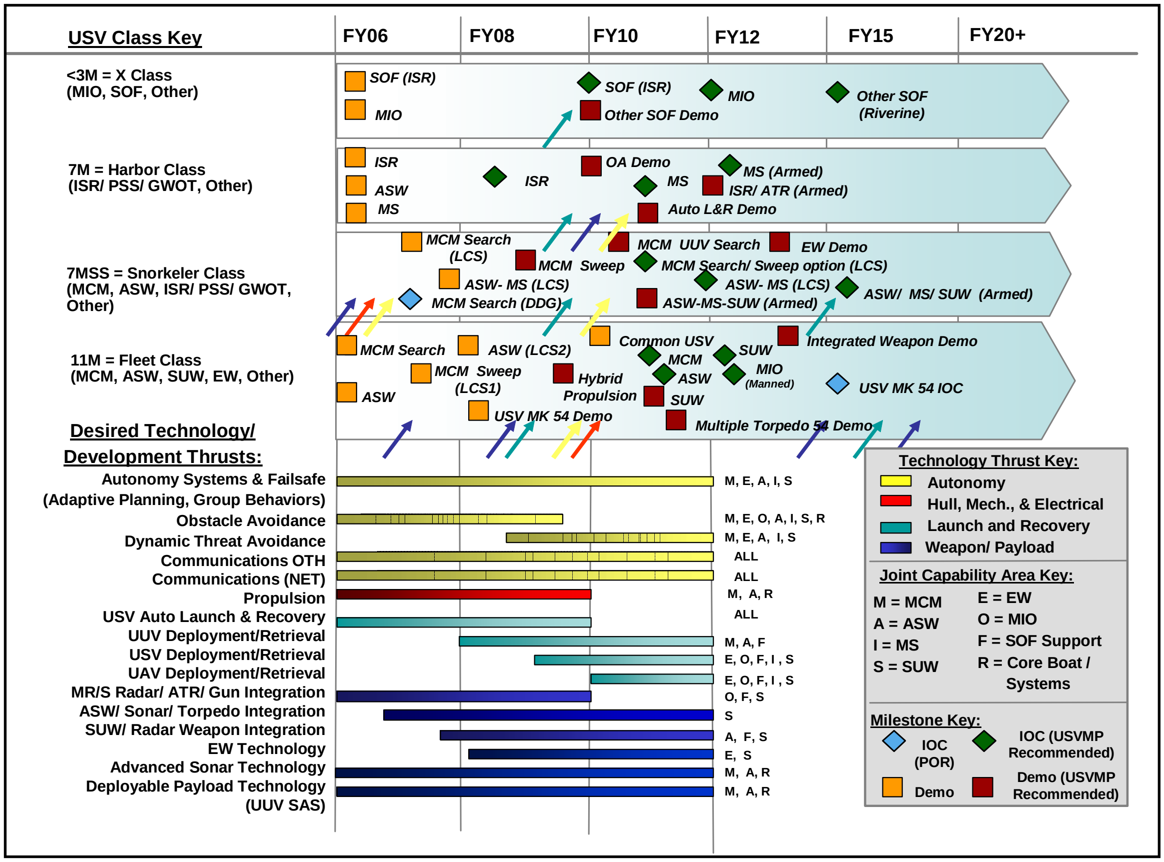

Figure 54 – Master Plan Consolidated Roadmap

MANNING UNMANNED SURFACE VEHICLES

Many of the U. S. Navy's surface forces have existing ship's boats in the form of standard 7m RIBs, together with the appropriate launching and retrieval hardware and crew skills. While this seems like an ideal situation for the introduction of similarly-sized USVs, there may be conflicts between potential USV operations and the normal uses of the ship's boat.

The limited size and payload space of the Harbor class vehicles and their mission set speak against the requirement to conduct major vehicle reconfiguration from manned to unmanned operation. As a result, it is recommended that the Harbor class USVs be developed with a baseline dual manned/unmanned capability. The mission set proposed for this class of vehicle should allow this conversion with minimal hardware reconfiguration. For example, the ISR suite and human operator console would remain aboard in both configurations. Conversion to an unmanned armed picket mission would entail installing a gun and setting the control system for automatic operation. This approach will allow the ships with only one boat position to take advantage of USV missions, while retaining a necessary baseline manned boat capability (Figure 55).

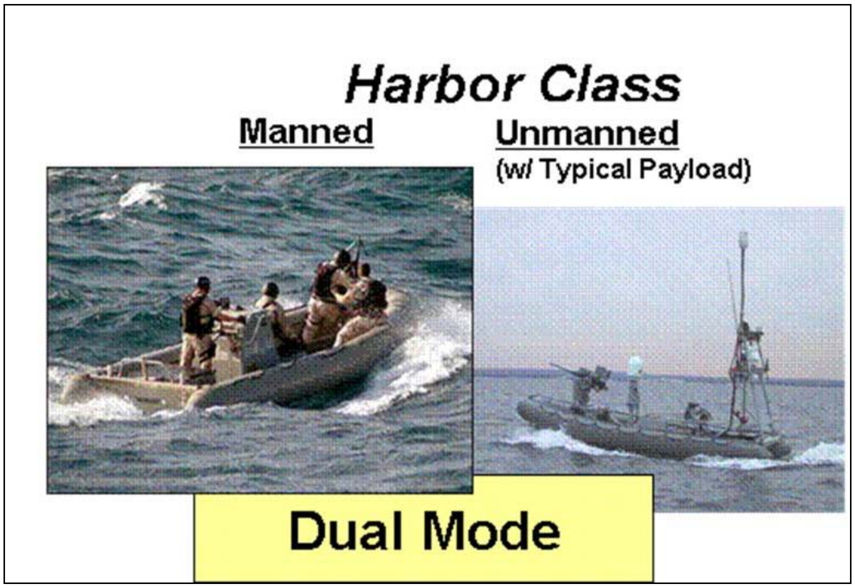

Figure 55 – Harbor Class

There is no projected utility in having a manned provision for the X-Class USV or the Snorkeler Class SSV. The Fleet Class USV will be employed by LCS as part of appropriate mission packages and by other ships with the ability to handle large boats (e. g., amphibious ships). The size of this vehicle will enable it to carry significant personnel, hardware and consumable payloads, and will also facilitate a modular approach to reconfiguring the vehicle. It is recommended that the Fleet Class be designed to be operated either manned or unmanned with reconfiguration being conducted in a reasonable amount of time (nominally less than 24 hours) (Figure 56).

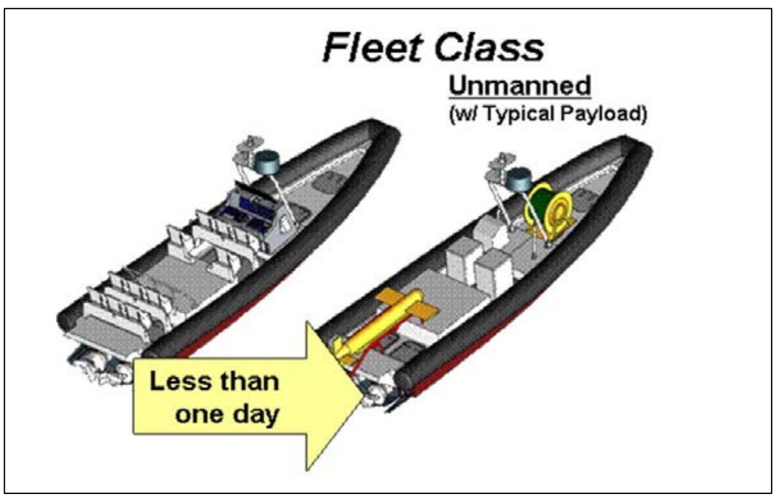

Figure 56 – Manned vs. Unmanned USVs

STANDARDS, COMMONALITY, AND MODULARITY

STANDARDS

One of the keys to accomplishing the ultimate vision of UV common control is the establishment of standards for the major factors affecting vehicle design, configuration, and operation. The following standards have been or will need to be established for unmanned systems common control, interoperability, and modularity:

- Unmanned Systems C2 / Interoperability Standards
  - Common control systems
  - Open interface (API) standards (XML), and
  - JAUS & STANAG 4586 joint/coalition interoperability standards.
- Unmanned Systems C4I Communications Standards
  - Coordinated with Navy C4I Roadmap
  - Address FORCEnet/GIG Compliance, including Undersea FORCEnet
  - Pursue common radios and antennas and IP-based networking
  - Coordinate efforts with PEO(C4I)
- Unmanned Vehicles Size/HM&E/Payload Modularity Standards
  - Start with UUVs – leverage past progress by UUV Program Office (PMS 403)
  - Include addressing potential standards for autonomy
  - Open Architecture Standards
  - Address open architecture interfaces to combat systems
  - Computing environment and functional architecture standardization focus
  - Coordinate efforts with PEO(IWS)

Use of Commercial off the Shelf (COTS) equipment may help drive acceptance of current commercial practice and standards. Use of Navy and DoD standards such as FORCEnet-based architecture will ensure USV interoperability with other systems.

COMMONALITY

As can be seen throughout this Plan, one of the strengths of USVs is the wide variety of USV missions that can be conducted in a limited number of vehicle types/sizes (classes). Given the multi-mission nature of modern surface ship tasking and the historical tendency for the Fleet to develop new uses for its hardware in situ, an active effort should be made throughout the USV development process to achieve commonality insofar as possible. As noted in the Common Control section of Chapter 4, the use of common components, hardware, software and interfaces will, ideally:

- Allow ready transfer of control of an unmanned vehicle from one operator to another (commonality of technical control system from location to location)

- Allow control of multiple types of vehicles from a single control station (commonality of graphical user interface (GUI) and human-machine interface (HMI))
- Minimize training across host platforms, operators, and vehicle types by standardizing UV controls across the community, and
- Minimize logistics requirements by providing common hardware, spare parts, and maintenance practices across the community.

By developing and following up-to-date standard interfaces and USV payload standards, the need for custom interfaces and payloads is mitigated or eliminated. Standardization between modules for a given vehicle class will ease payload module transfer between vehicles or vehicle transfer between host platforms. Common vehicle functions should be considered for leverage among the different classes. The development and institution of standards as noted in the preceding paragraph will help in this pursuit, but it is also incumbent on the acquisition community to ensure that these standards are followed, to preclude proliferation of incompatible hardware, logistics trains, and crew training programs.

MODULARITY

USV utility will be much enhanced by designing the vehicle, payload packages, and interfaces such that a mission payload package change can be executed in a modular "plug and play" manner. For example, as noted in the Manning Unmanned Vehicles section, it is desired to be able to convert the Harbor Class RIB from manned to unmanned configuration with a minimum of custom attachments or interfaces.

The development of USV guidance and standards in support of HM&E and Command and Control as noted in the Standards section will ease the interchange of mission payload modules on the vehicle itself and a similar standardized modular approach should also ease interface issues with the host platforms for: (1) same-class vehicles with different payloads and (2) USVs of different classes, for those host platforms that can handle more than one class.

MAINTAIN A BALANCED USV TECHNOLOGY PROGRAM

A balanced technology program is required for both USV payloads and vehicles to support the seven capabilities described in this document. Specific technology recommendations and roadmaps are described later in this chapter. Figure 57 summarizes current vehicle costs. However, the vehicle costs are typically a small fraction of the overall Research, Development, Test, and Evaluation (RDT&E) costs.

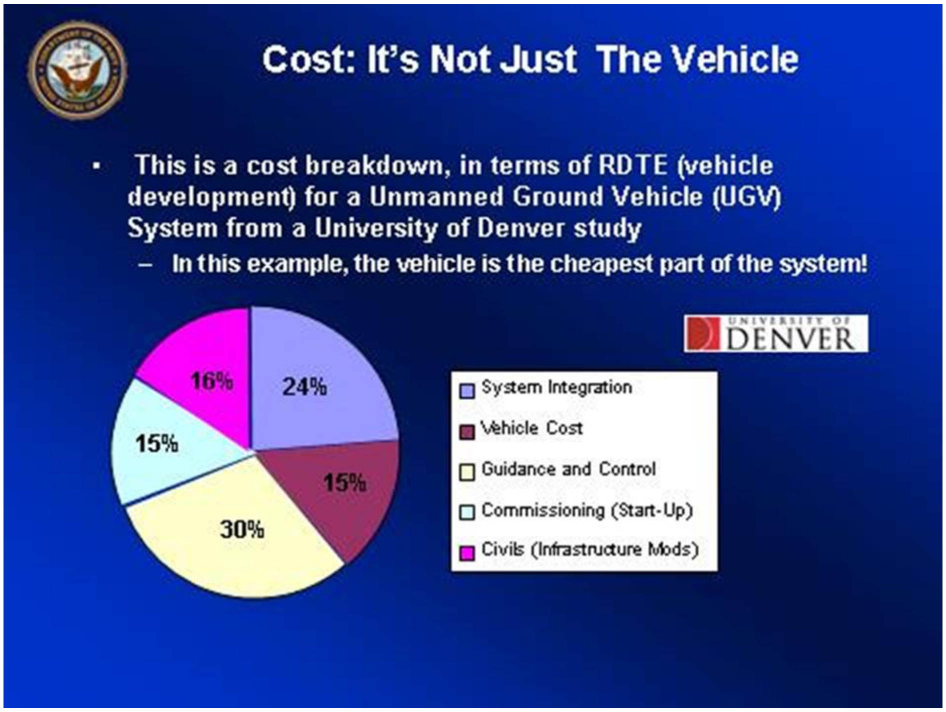

Figure 57 – Life Cycle Breakdown for Typical Unmanned Vehicle

It is clear then, that USVs must be developed from the start as systems rather than as individual components, not only in pursuit of good engineering and operational practice, but as a practical aid to predicting and managing life-cycle costs. Developing mature government vehicle prototypes (Advanced Design Model (ADM)) and other system-level experimentation (e. g., ACTDs) are therefore critical to successfully transitioning technology to industry and supporting Fleet experimentation.

INCREASE EXPERIMENTATION IN USV TECHNOLOGY

Experimentation with systems should be expanded to provide risk reduction for technology and operations. It is essential to involve Navy operators throughout the development process, through outreach to operational, doctrine, and training commands, to expand and refine employment concepts. Innovation must be pursued with test and evaluation programs using USV technologies from government, academia, and industry. Legal review of autonomous USV operations and weaponization must occur, as missions become better defined and closer to fleet introduction.

COORDINATE WITH OTHER UNMANNED VEHICLE PROGRAMS

Various programs are ongoing throughout DoD with UUVs, UAVs, and UGVs. The Navy has the responsibility to coordinate these and other programs for shipboard integration into Naval platforms. Work is ongoing by Navy-wide laboratory teams in developing an unmanned system integrated roadmap and plan. The continuation of government/ industry standards teams with the ASTM International Standards Organization and the Association for Unmanned Vehicle Systems International (AUVSI) is recommended, to facilitate the incorporation of Joint Interoperability Standards, so that unmanned systems can be shared across services.

It is critical that investment be made to support a unified common control station that replaces today's stovepipe efforts for UV stations, to better support LCS future development and the integration of UVs on other Navy platforms.

FIELD SYSTEMS IN THE FLEET

Continued introduction of functional USVs into the fleet is critical. Fleet operators have enthusiastically received a variety of small vehicles ($\leq$7m) for a variety of operational applications. While no Fleet-fielded 'program' systems exist as such, operational demonstration vehicles such as the multi-purpose Spartan-Scout USV and the Sea Fox small ISR USV provide a critical pool of Fleet USV experience and form a critical link in the evolution of future generations of USVs. Execution of larger vehicle programs needs to pursue a “spiral development” philosophy. Some capabilities, even if they are interim, need to be provided to the fleet for experimentation and feedback as soon as possible. As noted several other places in this Plan, USVs are uniquely situated for implementing a crawl-walk-run 'spiral' capability, with an initial rudimentary man-in-loop approach providing immediate Fleet value. This approach also provides for valuable feedback for the development of more sophisticated, autonomous versions of the same mission, or new missions suggested by Fleet users. ***A partial technical solution in use in the Fleet much more valuable than perfection in the laboratory.***

MODELING, SIMULATION, AND HUMAN SYSTEMS INTEGRATION (HSI)

The Mission Payload/USV/host platform combination can clearly be viewed as a closely-linked system of systems, where changes at one level of the hierarchy resonate up and down the system. For example, changes in armament for one of the armed USV missions may lead to changes in weapon storage and handling aboard the host platform and the USV, changes in host platform C3 requirements for launching the new weapon, changes in required USV-board target motion analysis processing, weapon presetting and weapon launch criteria, and so on. Due to the complexity of these interrelationships, the technical risk to the overall system will be high, especially in the introductory phases of significantly new mission packages and associated CONOPs.

A cost-effective way of reducing risk in complex technical systems is by means of modeling and simulation (M&S). Figure 58 shows an example of conceptual hierarchy of M&S systems representative of that necessary for USV system evaluation. The layers in the pyramid correspond to actual levels of modeling, each with distinct characteristics, chief among which are technical detail and fidelity. Some well-known and commonly-used naval warfare models may cover more than one level. The lowest level is “Engineering”, aka “physics level”, where the level of technical fidelity is quite high, but where the output metrics will have little meaning to typical Naval operators, commanders, or acquisition professionals.

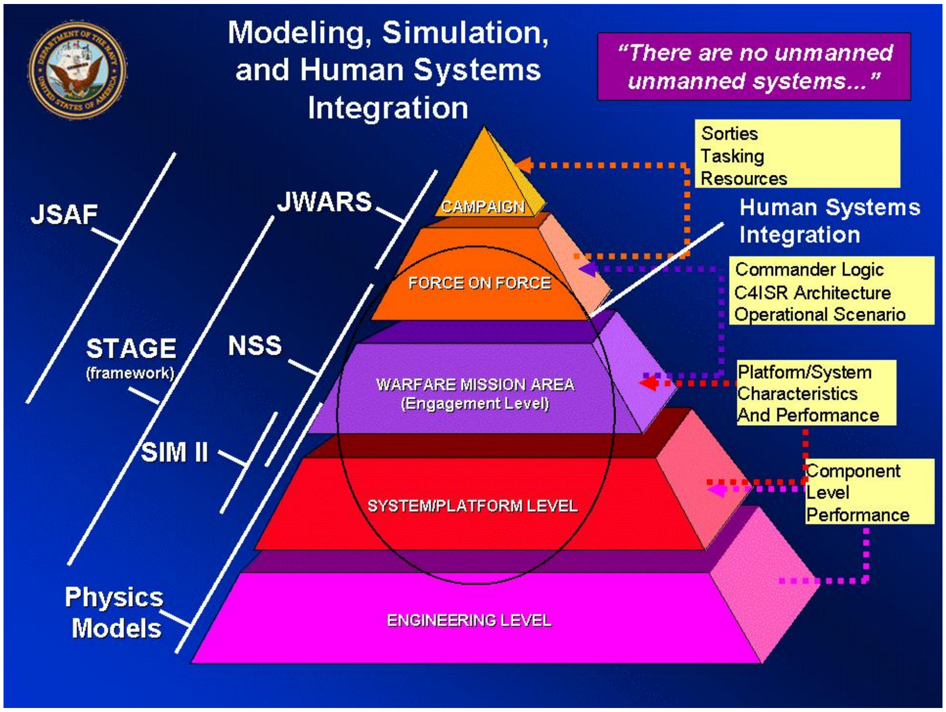

Figure 58 – M&S Hierarchy with HSI Focus Levels

The successive levels up the pyramid are characterized by broader scope, lower fidelity, and more generally meaningful (for the non-specialist end user) metrics. At the top of the pyramid is campaign M&S, which in its broadest sense encompasses the entire war, including the land battle, air war, and C4I. The most familiar and useful parts of this pyramid to Navy developers and operators are those between the "Force-on-Force" layer and the "System/Platform" layer, inclusive. While they are clearly linked to the lowest levels by USV/payload technical performance and limitations and to the highest levels by effect on the overall war, these are the levels at which development, acquisition, and employment typically focus.

Not coincidentally, these are also the levels at which HSI play the greatest role. As noted in the NAVSEA HSI Instruction, reference (p), HSI in NAVSEA systems applies to "all aspects of acquisition, including product design, development, production, test and evaluation, and service introduction", the aim of which is to "focus on sailor performance and ... improve total system performance and reduce life cycle costs. Total system elements include hardware, software and human operators, maintainers and support personnel."

As noted on the figure, "there are no unmanned 'unmanned' systems'", and human beings will interface with current and future USVs throughout their lifecycles and in every phase of their operations. HSI issues throughout a USV lifecycle include:

- Manufacture to ready-for-issue (RFI): ease of manufacture, storage, handling and transport
- Issue to employment: shipboard loading and handling, environment, space, weight, and accessibility for maintenance

- Employment: launch and recovery (L&R), refueling and replenishing (including armament), operator control and display (C&D), and C4I reliability to support valid remote situational awareness (SA)
- End of deployment: offload and cleanup
- End of life: demilitarization, detoxification, and special environmental or security handling of components.

While HSI concerns for an operational system tend to cluster on the middle three areas, all are worthy of consideration in meeting HSI goals. In reaching these goals, it is imperative that HSI be considered early and throughout the design process for "hardware, software and human operators, maintainers and support personnel". M&S, if properly integrated and executed throughout a USV program, can play a major role in achieving HSI goals, while simultaneously minimizing technical risk by simulating environments, situations, and circumstances that are prohibitively expensive or impossible to execute in an at-sea setting. This is particularly useful for systems that are not yet built, or for operations that are planned for areas that are normally inaccessible for testing purposes. For example, a recent successful UUV project noted that it spent approximately 100 hours of simulated in-water testing for every hour of in-water testing, with corresponding savings, not only on in-water test costs (high), but also in discovering potential in-water problems before they ever had a chance to actually occur.

In summary, well-executed M&S and HSI programs can have major positive effect on USV programs and should be built in from the beginning and used throughout any planned program.

CONCLUSIONS

The USV Master Plan Study Team was chartered by the Program Executive Officer for Littoral and Mine Warfare (PEO(LMW)). The Team's tasking was to develop the Department of the Navy's Unmanned Surface Vehicles (USV) Master Plan, to guide USV development in effectively meeting the Navy's present and future needs in support of Sea Power 21 and Fleet requirements.

In executing this guidance, the Team followed a detailed and rigorous process, which included developing a USV Vision and subordinate objectives; evaluating Navy and DoD guidance and the Study Team chartering documentation; gaining an understanding of the present state of USV development, and of the types of boat hulls that might be of use in current and future USV applications; gaining an understanding of Fleet operational priorities, technical requirements, and practical limitations relative to USV operations, current and future; reviewing the current and likely future state of technologies available to assist in crafting reasonable, notional USV capability packages, conducting technical and operational analysis to the extent needed to evaluate practicability and potential military utility of notional USV capability packages; and considering the full spectrum of DOTMLPF issues associated with vehicle ownership and operation throughout its life cycle.

As a result of this process, the following recommendations are forwarded to the technical development and acquisition communities to assist in making the desired USV capabilities a reality in the Fleet.

OVERALL FINDINGS AND RECOMMENDATIONS

Promulgate and execute Navy USV planning with four classes of vehicles: X-Class, Harbor Class, Snorkeler Class semi-submersible, and Fleet Class. This recommendation has positive ramifications on the execution of all of the other recommendations.

- Align acquisition strategies/ approaches to the 4 classes of vehicles, with common core systems and interfaces to the greatest degree possible.
- Wean from the bandwidth. Greater autonomy must be developed to reduce data requirements sent “to” the USV, and more advanced automated target recognition must be developed to reduce the data requirements “from” the USV.
- Invest in a balanced USV technology program, which includes five technical imperatives:
    - autonomy and automated target recognition;
    - obstacle / collision avoidance;
    - coupled payloads / weapons;
    - launch and recovery for host platform/vehicle and vehicle/payloads; and
    - advanced hulls, mechanical, and electrical, systems.
- Continue to deploy modules (non-standard) to Littoral Combat Ship and other Fleet platforms to meet critical milestones and provide early operator feedback.
- Field systems in the Fleet with Sea Trials, before or in parallel with acquisition efforts.
- Make use of the USV's ability to deliver capability in "crawl-walk-run" sequence. Deliver initial man-in-loop capabilities now, and use that experience to guide development of future semi-autonomous and fully autonomous upgrades.
- Conduct risk reduction for technology and operations.
- For the weaponized USV options, investigate or develop the necessary rules of maritime law and law of war associated with operating autonomous armed vehicles. Apply these rules early and throughout the design and development process.
- Develop USVs consistent with Navy and DoD guidance, including compliance with Joint Architecture for Unmanned Systems (JAUS).
- Comply with the PEO-LMW-chartered and industry-led unmanned systems standards being developed. Standardize the vehicle interface to the host as well as within the vehicle, with standards for each class and common vehicle functions leveraged among different classes.

- Continue the outreach to Navy operational, doctrine, and training commands to expand and refine employment concepts for USVs, to ensure they are integrated with the concepts of Navy transformation.

The Navy is in the process of a tremendous transformation, as dramatic and far-reaching as the development of the aircraft carrier at the beginning of the 20th century. Unmanned systems, and in particular Unmanned Surface Vehicles, will provide much-needed force multiplication while lowering risk to manned vessels and personnel. These factors will enable a smaller Navy to address the entire spectrum of Navy requirements--from conventional campaigns and smaller regional conflicts to the broad Global War On Terror--and maintain its critical support of our nation's Defense requirements and its national strategic aims.

APPENDICES

APPENDIX A: LIST OF ACRONYMS AND ABBREVIATIONS

ACOMMS	Acoustic Communications
ACR	Area Coverage Rate
ACTD	Advanced Capability Technology Demonstration
ADM	Advanced Development Model
AOA	Amphibious Operating Area
AOI	Area of Interest
AOU	Area of Uncertainty
API	Application Programming Interface
ASMD	Anti-Ship Missile Defense
ASMD	Anti-Ship Missile Defense
ASROC	Anti-Submarine Rocket
ASTM	American Society for Testing and Materials
ASW	Anti-Submarine Warfare
AT/FP	Anti-Terrorism/Force Protection
ATR	Automated Target Recovery
AUVSI	Association for Unmanned Vehicle Systems International
BDA	Battle Damage Assessment
BSA	Battle Space Awareness
C&D	Control & Display
C2	Command and Control
C2I	Command and Control and Intelligence
C3	Command, Control, Communications
C4	Command, Control, Communications, Computers
C4I	Command, Control, Communications, Computers, Intelligence
CAC	Computer-Aided Classification
CAD	Computer- Aided Detection
CAI	Computer-Aided Identification
CBNRE	Chemical, Biological, Nuclear, Radiological, and Explosive
CLF	Combat Logistics Force
CN3	Communication/Navigation Network Nodes
CNO	Chief of Naval Operations
CNSF	Commander Naval Surface Force
COA	Carrier Operating Area
COLREGs	International Regulations for Preventing Collisions at Sea
CONOPS	Concept of Operations
COTS	Commercial-Off-the-Shelf
CRRC	Combat Rubber Raiding Craft
CSG	Carrier Strike Group
CVBG	Aircraft Carrier Battle Group
CVLWT	Common Very Lightweight
DARPA	Defense Advanced Research Programs Agency
DCLIN	Detect, Classify, Localize, Identify, Neutralize
DCLT	Detection, classification, localization and tracking

DDG	Guided Missile Destroyer
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Material, Logistics, Personnel and Facilities
ELINT	Electronics Intelligence
EMP	Electromagnetic Pulse
EO/ IR	Electro Optics/ Infrared
ESG	Expeditionary Strike Group
EW	Electronic Warfare
FNC	Future Naval Capability
FoS	Family of Systems
FTG	False Target Generator
GIG	Global Information Grid
GPS	Global Positioning System
GUI	Graphical User Interface
GWOT	Global War on Terror
HME	Hull, Mechanical & Electrical
HMI	Human-Machine Interface
HSI	Human Systems Integration
HVU	High Value Unit
HWT	Heavyweight
I&W	Indications & Warnings
IA	Information Assurance
ID	Identification
IED	Improvised Explosive Device
ILIR	In-House Laboratory Independent Research
IMINT	Imagery Intelligence
IN	Identify, Neutralize
IO	Information Operations
IPB	Intelligence Preparation of the Battlespace
IR	Infrared
IS	Information Security
ISR	Intelligence, Surveillance and Reconnaissance
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Areas
JFC	Joint Forces Command
JFCOM	Joint Forces Command
JGRE	Joint Ground Robotics Enterprise
JUSC2	Joint Unmanned Systems Common Control
KA	Key Attributes
L&R	Launch & Recovery
LCG	Longitudinal Center of Gravity
LCS	Littoral Combat Ship
LO	Low-Observable
LOS	Line of Sight
LPA	Littoral Penetration Areas

LWT	Lightweight
M&S	Modeling & Simulation
MASINT	Measurement Intelligence
MCC	Maritime Component Commander
MCM	Mine Countermeasures
MDA	Mine Danger Area
MIED	Maritime Improvised Explosive Device
MILDEC	Military Deception
MIO	Maritime Interdiction Operations
MIW	Mine Warfare
MS	Maritime Security
NLOS-LS	Non Line Of Sight – Launcher System (Missile system)
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
NWDC	Navy Warfare Development Group; Navy Warfare Doctrine Command
OASIS	Organic Airborne and Surface Influence Sweep
ONR	Office of Naval Research
OODA	Observe, Orient, Decide, Act
OPAREA	Operations Area
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
OTH	Other the Horizon
PEO	Program Executive Officer
PEO IWS	Program Executive Office for Integrated Warfare Systems
PEO LMW	Program Executive Officer for Littoral and Mine Warfare
PSS	Port Security Services
QDR	Quadrennial Defense Review
RDT&E	Research, Development, Test and Evaluation
RF	Radio Frequency
RFI	Ready-for-Issue
RIB	Rigid Inflatable Boat
RMOP	Remote Minehunting Operational Prototype
ROE	Rules of Engagement
ROV	Remotely Operated Vehicle
SA	Situational Awareness
SAS	Synthetic Aperture Sonar
SATCOM	Satellite Communication
SIGINT	Signal Intelligence
SLOC	Sea-Line of Communication
SOA	Speed of Advance
SOCOM	Special Operations Command
SOF	Special Operation Forces
SoS	System of Systems
SP21	Sea Power 21
SS	Semi-Submersible
SSG	Surface Strike Group

SSN	Attack Submarine
SSV	Semi-Submersible Vehicle
STANAG	Standard NATO Agreement
STOM	Ship-to-Objective Maneuver
SUW	Surface Warfare
SWATH	Small Waterplane Area Twin Hull
T&E	Test & Evaluation
TFC	Task Force Commander
TMA	Target Motion Analysis
TRL	Technology Readiness Level
UARCs	University Affiliated Resource Centers
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UHF	Ultra High Frequency
US3	USV Sweep System
USSV-HT	Unmanned Sea Surface Vehicle- High Tow
USV	Unmanned Surface Vehicle
USV MP	Unmanned Surface Vehicle Master Plan
UUV	Unmanned Undersea Vehicle
UV	Unmanned Vehicle
UWMP	Undersea Weapons Master Plan
WMD	Weapons of Mass Destruction
XML	Extensible Markup Language

APPENDIX B: REFERENCES

(a) Program Executive Officer Littoral and Mine Warfare Memorandum 4200, Ser 420/001, dtd 06 Jan 2006, Subj: Charter for the Unmanned Surface Vehicle (USV) Master Plan

(b) Able & Baker, July-Aug 1946.

(c) Unmanned Undersea Vehicles Master Plan, 2004

(d) Navy News Stand, Enterprise Carrier Strike Group Deploys Unmanned Surface Vehicle, Story Number: NNS031217-04, 12/17/2003

(e) Enterprise Carrier Strike Group/USS GETTYSBURG Deployment Persian Gulf, (PACOM, C3F, C2F, C5F: Oct 03 to Feb 2004)

(f) Distributed Autonomous System for Maritime Domain Awareness, Douglas Horner, Naval Postgraduate School, Monterey, CA

(g) RhumbLines, February 3, 2006.

(h) The National Defense Strategy of The United States of America, March 2005

(i) Draft-Pre-decisional Report to Congress on Annual Long-Range Plan for the Construction of Naval Vessels for FY 2007

(j) "US Navy USV Master Plan Workshop" Kickoff Brief, Paul Dunn, Study Director, February 8-9, 2006, San Diego CA

(k) Littoral Combat Ship (LCS) Baseline Flight 0 Seaframe and Spiral A Mission Package Systems (U) "Blue Book", Draft, 26 January 2006.

(l) Director, Surface Warfare (N76) ltr to Program Manager, LCS Mission Modules (PMS420), Ser N76/U843509 dtd 27 Feb 06

(m) Chairman of the Joint Chiefs of Staff Instruction CJCSI 3170.01E, 11 May 2005, "Joint Capabilities Inegrations and Development System"

(n) Secretary of Defense (SecDef) Memorandum dtd 6 May 2005, Subject: Operational Availability (OA)-05 / Joint Capability Areas

(o) Sea Power 21, Admiral Vern Clark, U.S. Navy. Naval Institute "Proceedings", October 2002

(p) NAVSEAINST 3900.8A dtd 20 May 2005

The following documents, while not cited specifically in this Plan, were used in the formulation of its content:

- "J-8 Development of Joint Capabilities Areas " Mar 2005 (http://www.dtic.mil/futurejointwarfare/strategic/jca_jcstank7march.ppt
- ASW Way Ahead Study, March 2006
- CNO N3/N5 Strategy / Implications, Adapted from VADM Morgan Brief, NDIA 2005
- *CNO Remarks at International Seapower Symposium*, Naval War College, 21 Sep 05

- Congressional Budget Office Report, The Long-Term Implications of Current Defense Plans and Alternatives: Summary Update for Fiscal year 2006, October 2005
- Department of the Navy, Highlights of the Department of the Navy's FY2006/FY2007 President's Budget
- Draft-Pre-decisional Report to Congress on Annual Long-Range Plan for the Construction of Naval Vessels for FY 2007
- Integrated Priority Lists (i.e: JFCOM, SOCOM)
- National Defense Strategy (March 2005)
- National Plan to Achieve Maritime Domain Awareness (Oct 2005)
- National Strategy for Maritime Security (Sept 2005)
- Navy 3/1 Strategy
- Navy Strategic Plan, June 2006
- Quadrennial Defense Review: 6 February 2006
- Ref: Navy Warfare Publication (NWP) 3-19 DRAFT, March 2002
- "Sea Power 21", *Proceedings*, October 2002
- Statement of Ronald O'Rourke before the SASC Seapower Subcommittee on 12 April 2005

APPENDIX C: USV MASTER PLAN APPROACH AND RESULTS OF ANALYSIS

The overall process for creating this Plan is described in Chapter 1 of the main text. This Appendix focuses on the Workshop process and its results.

PEO-LMW tasked the Naval Sea Systems Command, Naval Undersea Warfare Center, USW Weapons and Vehicle Systems Product Area, with the development of the Department of the Navy's USV Master Plan, reference (m). Two teams were established to execute this task – the USV Master Plan Study Team and the USV Master Plan Core Team.

The USV Master Plan Study Team included representation from all major USV stakeholders, including Fleet commands, OPNAV sponsors, program offices and subject matter experts from Navy laboratories and academia. Team members had extensive experience in a wide variety of current and potential USV applications, as well as technical and acquisition perspectives associated with making USV capabilities a reality. The Team's overall task was to identify areas of opportunity in operational USV applications and recommend USV-specific programs, technologies and resources to facilitate the in achieving the future vision for USVs.

The USV Master Plan Core Team, an executive subset of the USV Master Plan Study Team, was also established to: (1) conduct engineering and operational analyses of the inputs received and (2) develop a cohesive, actionable USV Master Plan for the Navy. The USV Master Plan Core Team was composed of the Study Director, Littoral Mine Warfare Chief engineer, USV Technical Authority Warrant Holder, Coastal Systems Station Chief Engineer and an Operational Aspects Expert, USW WV Product Area USV Customer Advocate, Lead Naval Combatant Craft Architect, and an Executive Officer.

The team used the generic structured master planning process depicted in Figure C-1.

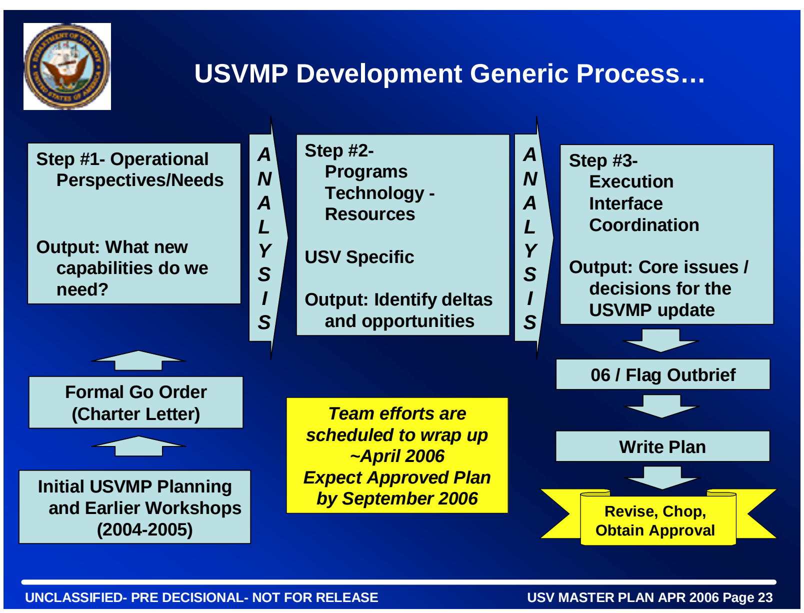

Figure C-1 - USV Master Plan High-Level Process

Plan development was built around the results from two Workshops conducted at the Naval War College in late 2004 and at the Fleet ASW Training Center in early 2006. Aspects of Steps 1-3 in Figure C-1 were accomplished at these Workshops, with additional analysis being conducted as necessary. Each workshops included the Study Team and a broad spectrum of representatives from industry, the Fleet, academia, Naval Warfare Centers, University Affiliated Resource Centers (UARCs), the Chief of Naval Operations (CNO) staff (OPNAV), Program Executive Office (PEO) staff, the Office of Naval Research (ONR), and the Defense Advanced Research Programs Agency (DARPA). Each Workshop consisted of one or more days of formal presentations by subject-matter experts in operational, technical, and acquisition areas germane to military USV applications.

Decision-support software technology was used to maximize the efficiency of information gathering and group decision-making. This information technology consists of a collection of laptop computers connected by common software. This system allowed for electronic text chat simultaneous with formal presentations, provided decision support tools (e. g., rank order voting), and retained a permanent record of individual contributions.

Follow-on analyses were conducted by the Core Team at the conclusion of each of the Workshops. The results were used to identify core issues and decisions.

The Study Team, represented by the Study Director, had frequent interactions with the Council of Captains and Flag Oversight Board, as well as providing briefings to major stakeholders. These briefings occurred throughout the process to ensure the Plan's alignment with the Navy vision and to obtain concurrence on the way ahead. All were major contributors to the success of this effort.

2004 USV Master Plan Workshop

The initial USV Workshop was held on 28 July 2004 at Naval Weapons Development Center (NWDC), Newport RI. In attendance were 49 representatives from 22 organizations and 13 different commands. A complete listing of commands and personnel involved in the 2004 Workshop is contained in Attachment 1.

The objectives of this workshop were to identify and prioritize Naval warfare mission capabilities where USVs can contribute. Only Naval Warfighters voted in mission prioritization. Mission capabilities were aligned to Sea Power 21 pillars. As depicted in Figure C-2 below, five (5) missions accounted for over 90% of the votes. In order of priority, they are:

- Mine Warfare (MIW)
- Force Protection (FP)
- Anti-Submarine Warfare (ASW)
- Intelligence, Surveillance & Reconnaissance (ISR)
- Surface Warfare (SUW)

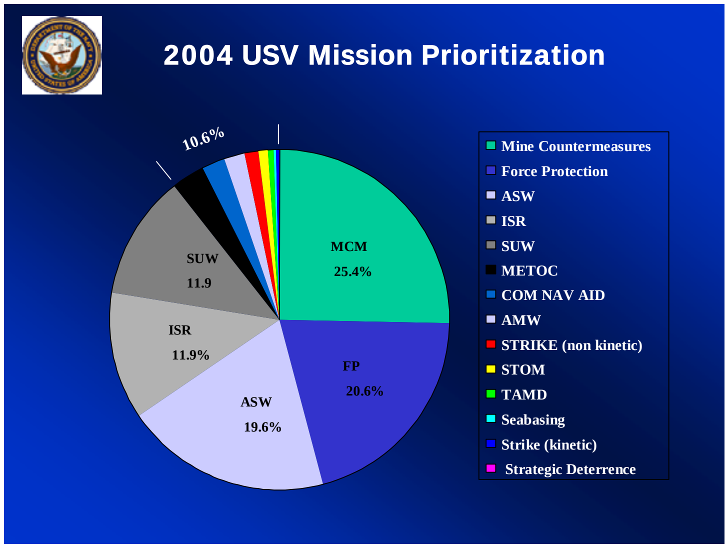

Figure C-2 – 2004 USV Mission Prioritization

Additionally, the participants determined notional performance characteristics of USVs required to fulfill the Mission Capabilities. The characteristics are shown in Figure C-3 below.

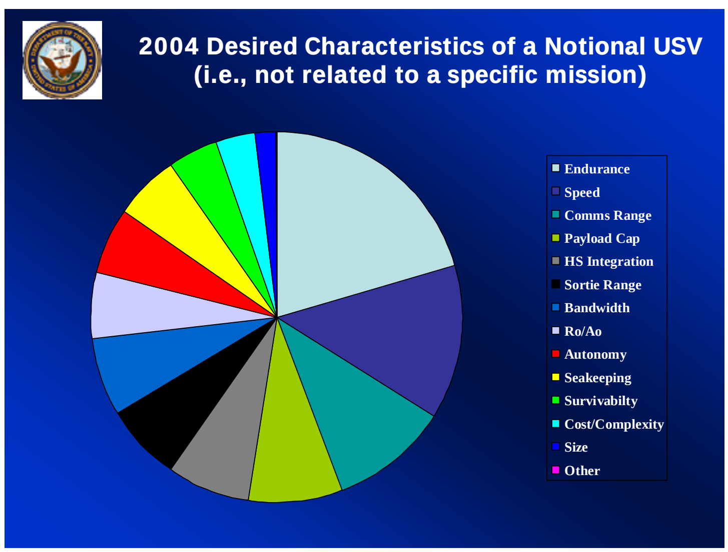

Figure C-3 – 2004 Desired Characteristics of a Notional USV

2006 USV Master Plan Workshop

The 2006 USV Master Plan workshop was conducted at the Fleet ASW Command in San Diego, CA, on 8-9 February 2006. The purpose of this workshop was to assess joint and Naval warfighting needs, current programs, current technology, and integration/execution requirements, to ensure that the conclusions from the 2004 Workshop were still valid.

An environmental scan was conducted in which all relevant Navy and DoD plans were thoroughly reviewed. In addition, attention was given to priorities identified in recent

Navy strategic guidance, in addition to other areas such as resources, technology readiness and insertion, and next-generation platform capabilities. Missions, approaches, and technical and programmatic recommendations from the 2004 Workshop were either validated or updated. Fifty (50) representatives from 38 organizations--including industry, the Fleet, Academia, Warfare Centers, University Affiliated Resource Centers (UARCs), OPNAV, PEO, and ONR/DARPA--attended the 2006 Workshop. A listing of 2006 Workshop Expert Panels and Workshop Attendees is included as Attachment 2.

As was the case at the 2004 Workshop, mission prioritization voting was conducted. As depicted in Figure C-4, more than 60 missions were reviewed, grouped, prioritized, and assessed to determine the suitability of USVs in meeting the Joint, Navy, and Homeland Defense requirements. The results 2006 voting were:

Mission	Raw Score
MCM	**29**
- MCM Search	
- MCM Sweeping	
- MCM Neutralization	
- MCM Delivery	
HLD / Port Security / Services	**24**
ASW	**21**
ISR	**15**
SUW	**14**
EW	**14**
MIO	**13**
SOF Support	**9**
Enablers/ Logistics	**8**
Oceanography	**3**
Search & Rescue	**0**

Figure C-4 – 2006 Voting Results: "Mission" Roll-Up

Analyses included assessing the range of vehicle requirements (i.e. speed, round-trip transit requirements, endurance, towing, payload, complexity, and hotel power), as well as evaluating potential USV payloads for mission utility.

The 2006 missions in order of priority are:

- Mine Countermeasures (MCM)
- Anti-Submarine Warfare (ASW)
- Maritime Security (MS)
- Surface Warfare (SUW)
- Special Operations Forces (SOF) Support

- Electronic Warfare (EW)
- Maritime Interdiction Operations (MIO) Support

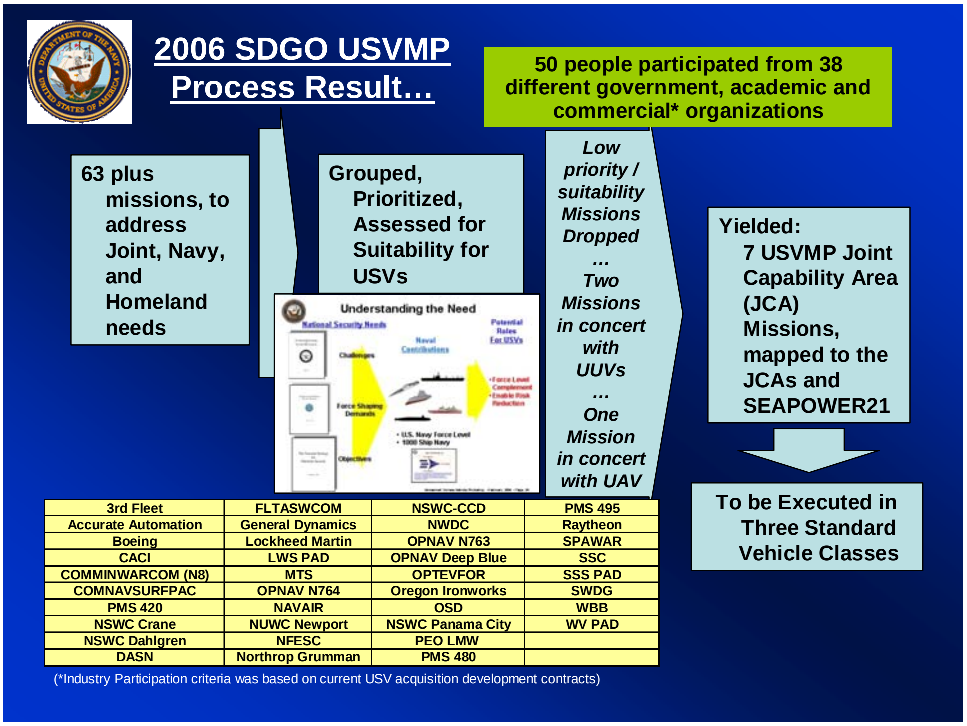

Figure C-5 – 2006 SDGO USVMP Process Result

The mission prioritization results of both workshops were consistent. Although there was a different cross section of attendees and focus between the 2004 and 2006 workshops (2004 Workshop – Mine Warfare; 2006 Workshop – ASW), the top five priority mission results were identical - MCM, FP, ASW, ISR, and SUW. What were in 2004 referred to "Force Protection" and "Intelligence, Surveillance & Reconnaissance" are now incorporated under the heading of "Maritime Security". Not surprisingly, changes in the operational environment since 2004 have increased the importance of EW, MIO, and SOF support. Although oceanography has decreased in importance, all USVs do this to some degree while conducting MCM search and Intelligence Preparation of the Battlespace (IPB).

One additional major finding emerged from the 2006 Workshop and related efforts. At the conclusion of detailed analysis of results of both workshops, the Study Team determined that a range of USV systems will be required, not one single class, and that some missions can and will be performed by more than one “class”. The end result was that USVs have a significant role in seven Joint Capability Area missions and should be executed in three (3) standard USV classes (Harbor, Snorkeler, and Fleet) and one (1) non-standard class (X-Class). The derivation of this result is discussed in greater detail in Chapter 3 of the main text and Appendix D.

A well-defined process, participation by key stakeholders, continuous communication with Navy leadership, and a robust technology tool to facilitate the process were key enablers in the development of this USV Master Plan.

Appendix C, Attachment 1

2004 USV Master Plan Expert Panels

Core Study Team for the 2004 USV Master Plan:

Guy Santora, NSWC Panama City	Dr. Harry Zervas, NUWC Newport
Lisa Tubridy, NSWC Panama City	Vic Ricci, NUWC Newport
Cecil Whitfield, PMS 420	John Canning, NSWC Dahlgren
Bob Brizzolara, NAVSEA Carderock	John Ebken, SPAWAR Systems Center- San Diego
John Dolan, NSWC Philadelphia	

2004 Workshop Attendees:

LCDR Dave Polatty	Dr. Harry Zervas	John Barkley
Linda Wazlavek	Arthur Hommel	David Place
LCDR Russell Gottfried	LCDR Steve Martin	CDR Greg Goolishian
CDR Paul Judice	Robert Fondren	Julia Gazagnaire
Jack Smith	CDR John Neagley	John A. Dolan
LCDR Dale Maxey	CAPT Jim Stewart	CDR Thomas Dearborn
David DeMartino	LT Brendan Piccolo	RADM (ret) John Pearsen
Will Sokol	LT Lucy Erickson	John Ebken
CDR Mike Incze	John Webster	Paul Hagan
David Jardot	Mark Wasilewski SPARTAN USV	
Tracy Frost	Dr. Harvey M. Spivack	
Frank Hamilton	John Pearson	

Organizations Attending 2004 Workshop:

NWC	PMS403 CHENG	CNA
OPNAV N763	OPNAV N752	NPG
NWDC	NSWC Dahlgren	US CFFC
OPNAV N701	SSC – SD	COMSURFPAC
NSWC CD (Norfolk)	COMNAVSURFPAC (N8)	COMSURFLANT (N82)
NMORA 0966	ONI	NSWC CD (PHL)
COMOPTEVFOR	PMS420 CHENG	COMSURFLANT
ONR	NSWC PC	PEO LMW CHENG
USSOCOM	NUWC NPT	

Appendix C, Attachment 2

2006 USV Master Plan Expert Panels

Core Study Team for 2006 USV Master Plan:

- Cecil Whitfield, PEO (LMW), Chief Engineer, PMS 420
- Guy Santora, NSWC Panama City (USVMP Deputy), USV Technical Warrant Holder
- Dave DeMartino, NSWC Panama City, Chief Engineer, Panama City
- CDR (ret.) Ron Swart, NSWC Panama City, Operational Aspects
- Chris Hillenbrand, NUWC Newport, USV Customer Advocate, USW Weapons and Vehicle Systems
- Will Sokol, NSWC Norfolk, Naval Architect, NSWC Carderock Combatant Craft Division
- Laura Neveu, USW WV Support, USVMP Executive Officer

Flag Oversight Board:

- Jim Thomsen, Program Executive Officer, Littoral & Mine Warfare (PEO LMW)
- RADM Raymond M. Klein, Deputy Director, Submarine Warfare (OPNAV N87)
- RADM Bernard J. McCullough III, Director, Surface Warfare (OPNAV N86)
- RADM Mark H. Buzby, Deputy Director, Surface Warfare (OPNAV N86)

2006 Workshop Attendees:

Brad Beeson	Charles Eckhart	David Purdy
Ron Bosch	Joe Gillis	Vic Ricci
Todd Bowden	Sam Hester	Guy Santora
Jim Broughton	Joseph Hewlett	Pat Savage
Larry Brown	Chris Hillenbrand	Gregory Settelmayer
Michael Bruch	Larry Howard	Randy Short
Steve Busch	Terry Kasey	Scott Small
Daniel Busch	Rich Kimmel	Will Sokol
John Canning	David Lesko	Ron Swart
Steven Castelin	Ian McClintock	Kevin Sweeney
Jonathan Cutone	Daniel McLeod	Tony Tillmon
Larry Datko	Frederick McMullen	MK Tribbie
Hellman Dave	Abdi Nazari	Elwood Webster
Jerome DeJaco	Laura Neveu	John Webster
Dave Demartino	Steven Olson	Steven Wells
Paul Dunn	Bob Pap	Cecil Whitfield
John Ebken	Jason Pike	Mack Whitford

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APPENDIX D: DERIVATION OF STANDARD USV CLASSES

An additional major finding from the 2006 USV Master Plan Workshop effort (Appendix C), was that restricting USV sizes and types to a limited number of "classes" could have benefits that would resonate throughout the Fleet and USV acquisition programs, specifically in areas of Fleet compatibility, leveraging commercial development, Common Control, Standards, Commonality, Modularity, and Human Systems Integration. The upshot of this effort was to craft a multiplicity of missions, payloads, host platforms, and USVs boat types into a bounded "family of systems of systems".

Toward this end, the USV Master Plan Core Team conducted an analysis considering the requirements of the USV missions (Chapter 2), and a variety of Naval Architecture characteristics associated with different types and sizes of vehicles (Chapter 3). The major steps in this analysis were:

1) Listing the relevant characteristics necessary to meet the USV missions
2) Evaluating USV boat types against this list
3) Evaluating USV boat types against five additional criteria: Ship Class Compatiblity, Scaleability to 7m, 11m, or "X" (unspecified small) size, and In-Inventory/Production
4) Down-selecting to a limited number of classes based on the previous three steps
5) Evaluating each mission vs. the characteristic list and the USV Class, to (1) evaluate each mission to determine which USV characteristics predominated, (2) evaluate the chosen four classes against each mission to determine which class(es) would be most appropriate for mission execution and (3) ensure that all the USV missions could be accomplished in the postulated four classes.

Operational capability for a given vehicle can be defined in multiple ways and from a variety of perspectives, depending on the operational profile. The characteristics chosen for this analysis were:

- Endurance (time)
- Speed (kt)
- Payload Capacity
- Range
- Fuel Utilization and Capacity
- Tow capacity
- Seakeeping at speed
- Seakeeping at rest/dead in water (DIW)
- Size
- USV available interfaces
- Cost
- Communication
- EO/IR Sensing
- Autonomy

- Signature
- Common Payload Services
- Transportability

As can be readily seen, some of these 17 characteristics are related to the USV alone, some to features of the USV/host platform interface, some almost exclusively to USV payload, and some to more than one or all of these issues. Some of these characteristics are relatively straightforward to analyze in a quantitative way. An example analysis for the Payload feature is contained in Attachment 1. This type of quantitative analysis was used where possible in the evaluation process for each step, as well as in rolling up the individual category evaluations into an overall family of systems across multiple missions. In other areas, there were necessarily varying degrees of technical rigor, simplifying assumptions, and educated estimations based on the operational and technical experience of the Core Team members. As a result, the specific numbers in any given block are arguable. Nonetheless, the overall trends are consistent and clear.

The results of the first step, the evaluation of USV boat type evaluation vs. mission needs and "other" characteristics are shown in Figure D-1.

Equivalent Size & Displacement Craft	Semi-Submersible	Planing	Semi-Planing	Hydrofoil	Displacement	Sail	Lifting Body	SWATH	Wave Piercing	Multi-Hull	Notes and Comments
Characteristic											
Endurance (hr)	5	5	4	5	3	5	5	5	4	4	Longer is positive
Speed (kt)	3	5	4	5	3	1	4	4	4	4	Faster is positive
Payload Capacity	1	2	2	1	3	1	1	2	2	2	More is positive
Range	5	5	4	5	3	5	4	5	4	4	Farther is positive
Fuel Utilization & Capacity	5	5	4	5	3	5	4	5	3	4	More fuel & efficiency is positive
Tow capacity	4	2	3	1	3	1	2	3	3	3	Larger Bollard pull is Positive
Seakeeping at speed	5	4	4	5	3	3	4	4	4	4	More tow fish stability is positive
Seakeeping at rest	5	2	3	2	3	4	2	4	3	4	Operation in higher sea state is positive
Size	3	3	3	3	3	3	3	3	3	3	Smaller is positive
USV Available Interfaces	3	3	3	3	3	3	3	3	3	3	More capability is positive
Cost	1	5	3	2	3	5	2	2	3	2	Lower cost is positive
Communication	3	3	3	3	3	3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing	3	3	3	3	3	3	3	3	3	3	Greater resolution and range is positive
Autonomy	4	3	3	3	3	1	3	3	3	3	Greater independence is positive
Signature	2	3	3	3	3	1	3	3	3	3	Lower signature is positive
Common Payload Services	3	3	3	3	3	2	3	3	3	3	Requiring the mission payload to bring less is positive
Transportability	1	3	3	1	3	1	1	2	3	2	Ease of transport is positive
Ship Class Compatibility	2	3	3	2	3	1	2	2	3	2	Availability for multiple ship classes is positive
11 meter	1	5	5	4	3	1	4	4	4	4	Applicability to this scale is positive
7 meter	5	5	5	1	3	1	3	3	3	3	Applicability to this scale is positive
x-Class	1	4	4	1	3	1	1	1	1	4	Applicability to this scale is positive
In inventory/Production/program?	5	5	4	4	3	1	2	2	3	1	Numbers of vehicles in inventory is positive

"Crawl" Vehicles
7 meter SS
7 & 11 Meter RIBs
11 Meter Semi-Planing
11 Meter Planning Hull
X-Class

Displacement hull form is Benchmark

	Relative Scale					
Less Capable	1	2	3	4	5	More Capable

Figure D-1 - Evaluation of Potential USV Characteristics

Notes on Figure D-1: "3" was considered the median standard, in this case a displacement hull craft. Lower numbers were considered less capable (2 = less capable, 1 = significantly less capable) and higher numbers more capable (4 = more capable, 5 = significantly more capable). Each characteristic evaluated has an explanation (far right-hand box) as to whether more or less in that category is considered desirable. The boat types were evaluated for equivalent sizes/displacements.

The section of Figure D-1 below the break was an evaluation of readily available and ship-compatible boat types and sizes in the Navy. Ship compatibility was a driving consideration in this process, since USVs as defined in this plan are "tactical systems capable of air or sea transport", and most of the missions are designed as adjuncts to Fleet capabilities. A rough summary of Fleet availability of existing boats is shown in Figure D-2. It should also be noted that the ~7m semi-submersible is also already available to the Fleet in the Remote Minehunting System (RMS) system.

Standard Navy RIB Complements		
Ship Class	**7m RIB**	**11m RIB**
FFG	1	
CG	2	
DDG	2	
CV/CVN	2	
LPD 17	2	1
Other Amphibs	Varies	Varies
Navy Totals*	269	44
*Exclusive of shore-based assets		

Figure D-2 - Fleet Availability of Standard Navy RIBs

Another driving factor was the desire to perform each USV mission with the smallest appropriate vehicle. This factor is another aspect of Navy ship compatibility which also impacts areas of shipboard handling, storage, maintenance, fueling, and overall resource allocation.

The obvious conclusion from Figure D-2 is that in terms of ready availability and compability with the existing Navy, the 7 and 11m RIBs and the 7m SSV stand out. These were chosen as tentative classes and labeled as follows:

7m – "Harbor"
7m SSV – "Snorkeler"
11m – "Fleet"

There is also a class of unspecified size and configuration, the "X-Class", which contains small vehicles that are in production or in use by the Fleet, but will not constitute a large enough or consistent enough group to be specified. Vehicles in this class will include those used as special-purpose research vehicles (e. g., oceanography vehicles) or those designed to be expendable (e. g., some SOF applications).

Note: Class sizes above are intended to be approximate, as opposed to prescriptive. For example the "7m" and "11m" numbers were chosen because of their current existence in the Navy, the actual class could be on the order of $\pm$10-20% from this value, the primary criterion being compatible with existing Navy boat infrastructure.

The next phase of the analysis was to determine which USV characteristics were the most important on a mission-by-mission basis. This was accomplished by using the same set of characteristics, and evaluating the four tentative USV classes against each mission. As previously noted, the purpose of this exercise was three-fold: (1) to evaluate each mission to determine which USV characteristics predominated, (2) to evaluate the chosen four classes against each mission to determine which class(es) would be most appropriate for mission execution and (3) to ensure that all the USV missions could be accomplished in the postulated four classes. This was done by means of a modified version of the top section of Figure D-1. Instead of all possible boat types across the horizontal axis, this matrix only addresses the four designated classes. An example "blank" of this mission evaluation form is shown in Figure D-3.

Mission Name	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
Description of Mission	<5 Meters	7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	Notes/Comments
Characteristic							
Endurance (hr)	1	2	4	5	5	3	Longer is positive
Speed (kt)	1	2	2	2	3	3	Faster is positive
Payload Capacity	1	2	2	4	5	3	More is positive
Range	1	2	4	5	5	3	Farther is positive
Fuel Utilization & Capacity	1	3	4	3	3	3	More fuel & efficiency is positive
Tow capacity	1	2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability	1	2	5	4	4	3	More tow fish stability is positive
Seakeeping	1	2	5	3	3	3	Operation in higher sea state is positive
Size	5	4	4	3	3	3	Smaller is positive
USV Available Interfaces	1	3	3	3	4	3	More capability is positive
Cost	5	4	1	3	3	3	Lower cost is positive
Communication	1	3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing	2	3	3	3	3	3	Greater resolution and range is positive
Autonomy	1	3	4	3	3	3	Greater independence is positive
Signature	4	3	5	3	3	3	Lower signature is positive
Common Payload Services	1	3	5	3	4	3	Requiring the mission payload to bring less is positive
Transportability	5	5	5	3	3	3	Ease of transport is positive
Ship Class Compatibility	5	5	2	2	2	3	Availability for multiple ship classes is positive

Less Capable				More capable
Relative Scale				
1	2	3	4	5

(red)	Not Seen as a mission for class
(yellow)	Secondary Mission for class
(green)	Primary Mission for class

Figure D-3 - "Blank" Mission Evaluation Sheet

Notes on Figure D-3. In this case, an 11m RIB is considered the baseline case, and the 17 characteristics are evaluated for each of the other classes, including two other hull-type variants for the llm size.

These characteristic numbers do not vary from mission to mission (Figures D-4 through D-13) . What does change is that the Core Team subject matter expert (SME) for each mission was asked to gray over the characteristics that were of lesser importance in that mission. This provided the mechanism for making sure that the most important characteristics of each mission were in fact covered by one or more USV classes. The rationale for the vehicle characteristics chosen should be evident from the mission discussions contained in the main text and are not repeated here.

The Team then made decisions about which class(es) to recommend for each mission, based on the following:

- Shipboard availability of the vehicle
- Matching vehicle characteristics with mission needs
- Accomplishing the mission in the smallest appropriate vehicle

As a result, the vehicle type boxes for each mission are colored in with the final recommendation. (red= not a mission for this class, yellow = secondary mission for this class, green = primary mission for this class). Although not shown on the Figure D-4 example, the individual mission analyses include any significant additional information pertinent to the case (e. g., this class of vehicle is already in use for this mission).

The following diagrams are a mission-by-mission presentation of the results of this analysis.

Mission: MCM Search		X-Class	Harbor Class	Snorkeler Class	Fleet Class			
The use of sonar or divers to detect and classify mines or mine-like shapes			7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	Notes/Comments
Characteristic								
Endurance (hr)			2	2	5	5	3	Longer is positive
Range			2	2	5	5	3	Farther is positive
Tow capacity			2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability			2	5	4	4	3	More tow fish stability is positive
Seakeeping			2	5	3	3	3	Operation in higher sea state is positive
Communication			3	3	3	3	3	Higher BW capacity is positive
Autonomy			3	3	3	3	3	Greater independence is positive
Signature			3	4	3	3	3	Lower signature is positive
		Not Viable		This class is currently designed and used for this mission				

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Legend
Not Seen as a mission for class
Secondary Mission for class
Primary Mission for class

Figure D-4 - Mission Evaluation for MCM Search

Mission: MCM Sweep	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
The act of towing mine countermeasures gear intended to actuate mines by generating a ship-like signature.			7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)			2	5	5	3	Longer is positive
Speed (kt)			2	2	3	3	Faster is positive
Payload Capacity			2	4	5	3	More is positive
Range			2	5	5	3	Farther is positive
Tow capacity			4	5	4	3	Larger Bollard pull is Positive
Seakeeping			5	3	3	3	Operation in higher sea state is positive
Size			4	3	3	3	Smaller is positive
Cost			1	3	3	3	Lower cost is positive
Autonomy			3	3	3	3	Greater independence is positive
Transportability			2	3	3	3	Ease of transport is positive
Ship Class Compatibility			2	2	2	3	Availability for multiple ship classes is positive
	Not Viable	Not Viable		This class is currently designed and used for this mission			

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Legend	
Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-5 - MCM Sweep Mission Evaluation

Mission: MCM Neutralization	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
Rendering (by external means) a mine incapable of firing on a passing target or sweep.		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Speed (kt)		2	2	2	3	3	Faster is positive
Payload Capacity		2	2	4	5	3	More is positive
Range		2	2	5	5	3	Farther is positive
Fuel Utilization & Capacity		3	3	3	3	3	More fuel & efficiency is positive
Tow capacity		2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability		2	5	4	4	3	More tow fish stability is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
Size		4	4	3	3	3	Smaller is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
Autonomy		3	3	3	3	3	Greater independence is positive
Transportability		5	2	3	3	3	Ease of transport is positive
Ship Class Compatibility		5	2	2	2	3	Availability for multiple ship classes is positive
	Not Viable - Too Small						

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Legend	
Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-6 - MCM Neutralization Mission Evaluation

Mission: MCM UUV Delivery	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
Capacity to deliver smaller unmanned systems.		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Speed (kt)		2	2	2	3	3	Faster is positive
Payload Capacity		2	2	4	5	3	More is positive
Range		2	2	5	5	3	Farther is positive
Tow capacity		2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability		2	5	4	4	3	More tow fish stability is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
Size		4	4	3	3	3	Smaller is positive
USV Available Interfaces		3	3	3	4	3	More capability is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing		3	3	3	3	3	Greater resolution and range is positive
Autonomy		3	3	3	3	3	Greater independence is positive
Signature		3	4	3	3	3	Lower signature is positive
Common Payload Services		3	2	3	4	3	Requiring the mission payload to bring less is positive
Transportability		5	2	3	3	3	Ease of transport is positive
	Not Viable - Too Small						

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-7 - MCM UUV Delivery Mission Evaluation

Mission: ASW	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
"Maritime Shield" and "Protected Passage" USV provides ASW surveillance services at the boundary of an operating area or in a transit corridor.		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Speed (kt)		2	2	2	3	3	Faster is positive
Payload Capacity		2	2	4	5	3	More is positive
Range		2	2	5	5	3	Farther is positive
Fuel Utilization & Capacity		3	3	3	3	3	More fuel & efficiency is positive
Tow capacity		2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability		2	5	4	4	3	More tow fish stability is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
Size		4	4	3	3	3	Smaller is positive
USV Available Interfaces		3	3	3	4	3	More capability is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing		3	3	3	3	3	Greater resolution and range is positive
Autonomy		3	3	3	3	3	Greater independence is positive
Common Payload Services		3	2	3	4	3	Requiring the mission payload to bring less is positive
Transportability		5	2	3	3	3	Ease of transport is positive
Ship Class Compatibility		5	2	2	2	3	Availability for multiple ship classes is positive
	Not Viable - Not enough endurance				This class is currently designed and used for this mission		

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-8 - ASW Maritime Shield Mission Evaluation

Mission: ASW	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
"Maritime Shield" and "Protected Passage" USV provides ASW surveillance services at the boundary of an operating area or in a transit corridor.		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Speed (kt)		2	2	2	3	3	Faster is positive
Payload Capacity		2	2	4	5	3	More is positive
Range		2	2	5	5	3	Farther is positive
Fuel Utilization & Capacity		3	3	3	3	3	More fuel & efficiency is positive
Tow capacity		2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability		2	5	4	4	3	More tow fish stability is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
Size		4	4	3	3	3	Smaller is positive
USV Available Interfaces		3	3	3	4	3	More capability is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing		3	3	3	3	3	Greater resolution and range is positive
Autonomy		3	3	3	3	3	Greater independence is positive
Common Payload Services		3	2	3	4	3	Requiring the mission payload to bring less is positive
Transportability		5	2	3	3	3	Ease of transport is positive
Ship Class Compatibility		5	2	2	2	3	Availability for multiple ship classes is positive
	Not Viable - Not enough endurance				This class is currently designed and used for this mission		

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-9 - ASW Protected Passage Mission Evaluation

Mission: Maritime Security	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
Collect Intel data, deter enemy attack, keep manned platforms out of harms way, harbor and port monitoring, CBRNE Detection, BDA, and target designation.		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Payload Capacity		2	2	4	5	3	More is positive
Fuel Utilization & Capacity		3	3	3	3	3	More fuel & efficiency is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
Size		4	4	3	3	3	Smaller is positive
USV Available Interfaces		3	3	3	4	3	More capability is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing		3	3	3	3	3	Greater resolution and range is positive
Common Payload Services		3	2	3	4	3	Requiring the mission payload to bring less is positive
Transportability		5	2	3	3	3	Ease of transport is positive
Ship Class Compatibility		5	2	2	2	3	Availability for multiple ship classes is positive
	Not Viable - not enough payload						

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-10 - Maritime Security Mission Evaluation

Mission: SOF Support	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
ISR (Standard and Non-standard); transportation and materiel support.	<5 Meters	7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Size	5	4	4	3	3	3	Smaller is positive
Cost	5	4	1	3	3	3	Lower cost is positive
Communication	1	3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing	2	3	3	3	3	3	Greater resolution and range is positive
Signature	4	3	4	3	3	3	Lower signature is positive
Transportability	5	5	2	3	3	3	Ease of transport is positive
Ship Class Compatibility	5	5	2	2	2	3	Availability for multiple ship classes is positive

Less Capable — More capable

Relative Scale				
1	2	3	4	5

- Not Seen as a mission for class
- Secondary Mission for class
- Primary Mission for class

Figure D-11 - SOF Support Mission Evaluation

Mission: Electronic Warfare	X-Class	Harbor Class	Snorkeler Class	Fleet Class			
Deception , jamming and warnings of attack		7 Meter RIB	7 Meter SS	11 Meter Semi-Planing	11 Meter Planning Hull	11 Meter RIB	11 m RIB is Benchmark Notes/Comments
Characteristic							
Endurance (hr)		2	2	5	5	3	Longer is positive
Speed (kt)		2	2	2	3	3	Faster is positive
Payload Capacity		2	2	4	5	3	More is positive
Range		2	2	5	5	3	Farther is positive
Fuel Utilization & Capacity		3	3	3	3	3	More fuel & efficiency is positive
Tow capacity		2	4	5	4	3	Larger Bollard pull is Positive
Tow Stability		2	5	4	4	3	More tow fish stability is positive
Seakeeping		2	5	3	3	3	Operation in higher sea state is positive
USV Available Interfaces		3	3	3	4	3	More capability is positive
Cost		4	1	3	3	3	Lower cost is positive
Communication		3	3	3	3	3	Higher BW capacity is positive
EO/IR Sensing		3	3	3	3	3	Greater resolution and range is positive
Autonomy		3	3	3	3	3	Greater independence is positive
Common Payload Services		3	2	3	4	3	Requiring the mission payload to bring less is positive
Transportability		5	2	3	3	3	Ease of transport is positive
	Not Viable Lacks payload capacity						

Less Capable — More capable

Relative Scale				
1	2	3	4	5

- Not Seen as a mission for class
- Secondary Mission for class
- Primary Mission for class

Figure D-12 - Electronic Warfare Mission Evaluation

Mission: MIO Support	X-Class	Harbor Class	Snorkeler Class	Fleet Class	
ISR (Standard and Non-standard); transportation and materiel support.	<5 Meters	7 Meter RIB			11 m RIB is Benchmark Notes/Comments
Characteristic					
Speed (kt)	1	2			Faster is positive
Seakeeping	1	2			Operation in higher sea state is positive
Size	5	4			Smaller is positive
Cost	5	4			Lower cost is positive
EO/IR Sensing	2	3			Greater resolution and range is positive
Transportability	5	5			Ease of transport is positive
Ship Class Compatibility	5	5			Availability for multiple ship classes is positive
			Not Viable - not deployable from 11meter RIB		

Less Capable — More capable

Relative Scale				
1	2	3	4	5

Red	Not Seen as a mission for class
Yellow	Secondary Mission for class
Green	Primary Mission for class

Figure D-13 - Maritime Interdiction Operations Mission Evaluation

Again, while some of the details of the above evaluations are debatable, the trends are consistent and clear. The summary conclusion from this effort was that the Navy can accomplish its USV missions in four classes of vehicles, and that it needs all four classes to accomplish the missions. The constraints and requirements of these vehicles may be summarized as follows, across the mission set:

<u>X-Class</u>: cheap, expendable, probably special-purpose and purpose-built, details not important from a Master Plan perspective.
<u>Harbor Class (7m)</u> – Maritime Security is an all-Navy concern, and this is the size of boat carried on most or all Navy vessels.
<u>Snorkeler Class (semi-submersible)</u> – MCM Search requires: (1) the ability to pull a tow body, (2) stability in sea states, up to and including (and possibly beyond) Sea State 3, and (3) mission endurance.
<u>Fleet Class (11m)</u> – Required to provide (1) adequate power and payload for ASW, (2) power and tow force for MCM Sweep, and (3) endurance for these and other missions.

An overall summary of this evaluation and decision process is shown in Figure D-15. This Figure cross-correlates the desired USV missions with their associated JCAs and shows that all seven USV missions can be accomplished by one or more of just four classes of USV.

USV MP Priority	Joint Capability Area (JCA)	Seapower Pillar	USV Mission	X-Class (small)	Harbor Class (7M)	Snorkeler Class (7M SS)	Fleet Class (11M)
1	Battle Space Awareness (BSA) / Access/ Littoral Control	Sea Shield	Mine Countermeasures (MCM)		MCM Delivery, Search / Neutralization	MCM Search, Towed, Delivery, Neutralization	MCM Sweep, Delivery, Neutralization
2	BSA / Access/ Littoral Control	Sea Shield	Anti-Submarine Warfare (ASW)			Maritime Shield	Protected Passage and Maritime Shield
3	BSA, HLD, Non-Trad Ops, 7 Others	FORCEnet	Maritime Security		ISR/ Gun Payloads		7M Payloads
4	BSA / Access/ Littoral Control	Sea Shield	Surface Warfare (SUW)		SUW, Gun	SUW (Torpedo), Option	SUW, Gun & Torpedo
5	BSA / Access/ Littoral Control/ Non-Trad Ops	Sea Strike	Special Operation Forces (SOF) Support	SOF Support	SOF Support		Other Delivery Missions (SOF)
6	BSA, C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control	Sea Strike	Electronic Warfare		Other IO	High Power EW	High Power EW
7	BSA, Stability, Non-Trad Ops, Littoral Control	Sea Shield	Maritime Interdiction Operations (MIO) Support	MIO USV for 11M L&R	ISR/ Gun Payloads		

	Not Seen as a mission for class
	Secondary Mission for class
	Primary Mission for class

Figure D-14 - Accomplishing the USV Mission Set in Four Classes

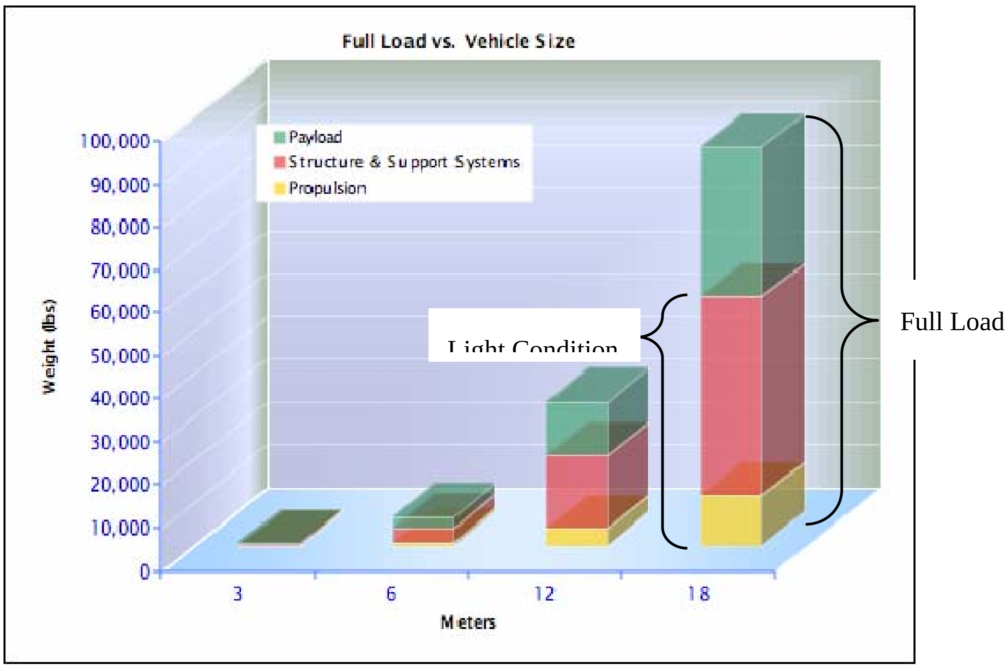
The end result was that the selected USV mission set can be executed in three (3) standard USV classes (Harbor, Snorkeler, and Fleet) and one (1) non-standard class (X-Class).

Attachment 1 to Appendix D
Example Payload Analysis for USV Class Evaluation

Payload was one of the 17 characteristics evaluated in determining the feasibility of accomplishing all the USV missions in a bounded number of USV classes. Even this relatively straightforward category requires several simplifying assumptions.

For illustrative purposes, the following bar chart outlines the association between Vehicle Size, Full Load Condition, Light Condition, and Payload.

The relationship of the (2) primary weight components of the vehicle's Light Condition and their relationship to available payload are illustrated. <u>Note</u>: Only moderate operational speeds are assumed in this example.



Definitions

<u>Light Condition</u>: Craft complete, ready for service in every respect, including weight reservations for Pre-Planned Product Improvement (P3I), liquids in machinery at operating levels, without mission payload or any items of variable load. (Includes seawater in waterjets, if installed)

<u>Full Load Condition</u>: This condition is determined by adding the following variable loads (payload) to Light Condition:

- Mission System/Payload
- Full Fuel

- Ammunition (as applicable)

Payload Fraction: Common term used to characterize the efficiency of a particular design. Payload fraction is calculated by dividing the weight of the payload by the weight of the otherwise empty craft when fully fueled. Fuel represents a considerable amount of the overall mission-ready weight, and for shorter missions it is quite common to load less fuel in order to carry a heavier load. For this reason the useful load fraction calculates a similar number, but based on the combined weight of the payload and fuel together.

The takeaway observations in this category are:

(1) that larger vehicles can carry more payload and
(2) payload fraction is also greater; that is, a greater percentage of the USV/payload system is payload, as opposed to infrastructure,

so for missions that require larger payloads (e. g., ASW), larger vehicles will be required.

Similar analyses were done, quantiatively or qualitatively, across the board for the boat types, missions, and USV classes discussed in this Plan.