The Navy Unmanned Undersea Vehicle (UUV) Master Plan

April 20, 2000

Approved for Public Release 27 March 2001. Distribution is unlimited

Administrative Note

This report was prepared under funding received from PEO (USW), PMS403. The study was conducted during the period 1 April 1999 – 31 December 1999. Study participants included representatives from the Naval Undersea Warfare Center Division Newport; Space and Naval Warfare Systems Center San Diego; Naval Oceanographic Office; Naval Surface Warfare Center, Dahlgren Division, Coastal Systems Station; and the Johns Hopkins University / Applied Physics Laboratory.

ASN/RDA chaired an Oversight Board providing executive leadership and guidance. The board included: N84, N85B, N86B, N87, N873, N096, N81, CNR, DNI, CNMOC, SEA93, NUWC-TD, PEO-USW, DASN/MUW, and USD A&T.

This document consists of an Executive Summary, followed by five chapters addressing the UUV Vision, Missions, Signature Capabilities, Technology Issues & Risks and closes with an overall development plan and detailed recommendations. Amplifying details and references are provided in separate Appendices.

Record of Changes

Revision	Change Pages	Date
Initial Release (unsigned)	N/A	28 December 1999
Approved Version (signed)	Changed text on pages ES-1; 2-4; 3-6- 4-6, 4-7; 5-3, 5-4; Added Appendices A-D. Repaginated as required.	20 April 2000
Approved for Public Release	Cover Page modified to reflect Distribution Statement A	27 March 2001

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Navy UUV Master Plan

Executive Summary

Unmanned Undersea Vehicles (UUVs) are on the threshold of playing key roles in the battlespace. Critical missions including Intelligence, Surveillance, Reconnaissance, Mine Countermeasures, Tactical Oceanography, Communications, Navigation, and Anti-Submarine Warfare can be effectively addressed with UUVs. The technology and industrial capacity are ready to proceed, yet the fleet has little UUV based capability today.

Worldwide, there are hundreds of UUVs under development or commercially available, providing capabilities to our adversaries in excess of those available to our own fleet. With careful decisions and investments today, UUVs can be positioned to become significant contributors to the Navy's capabilities tomorrow, and be ready for the unexpected future. This comprehensive Navy UUV Master Plan, developed via an ASN/RDA chartered study team, incorporates near-term acquisition efforts, and at the same time establishes the direction for long-term development and technology investments.

Before continuing, it is important to consider UUVs in the broader context of unmanned systems in general. Unmanned air vehicles are now commonplace in many military operations as both weapons (cruise missiles) and reconnaissance platforms (Predator UAV). Unmanned ground vehicles are being developed for high-risk operations such as mine field operations and bomb disposal, as well as surveillance. In the ocean environment a variety of unmanned systems have been developed including: towed systems; hard-tethered devices such as remotely operated vehicles (ROVs); systems not capable of fully submerging such as unmanned surface vehicles or semi-submersible vehicles; and bottom crawlers. Many of these systems or vehicles have been in use for years (ROVs for deep-water search and salvage), or are in the late stages of development (the Navy's Remote Minehunting System --RMS).

Fully cognizant of the full spectrum of these rapidly developing unmanned capabilities the study team began work. In order to sharpen the focus on undersea systems more finely, the following definition for UUVs was employed:

> An unmanned undersea vehicle is defined as a self-propelled submersible whose operation is either fully autonomous (pre-programmed or real-time adaptive mission control) or under minimal supervisory control and is untethered except for data links such as a fiber optic cable.

The Vision for UUVs and the Objective of the UUV Master Plan

The study team was challenged by ASN/RDA to establish a long-term vision for UUVs with the ultimate question:

What do we want to be able to do using UUVs 50 years from now?

Based upon the current pace of technology and the progress over the last 50 years, the study team developed a Vision including elements of: undersea work; information collection and transfer; and engagement. That vision is achievable.

Using the vision (Figure ES-1) to "begin with the end in mind", the objective of the UUV Master Plan is to establish priorities for near-term acquisition programs and technology investment that will fulfill current and projected U.S. naval requirements, while at the same time laying the foundation for long-term applications that are difficult to imagine.

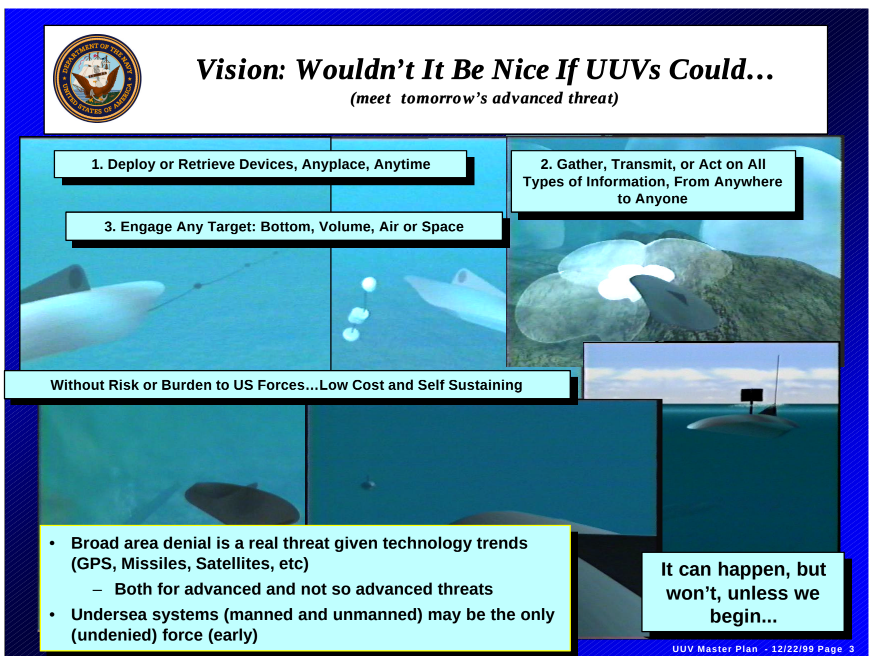

Figure ES-1: UUV Master Plan Vision

Background

This document is consistent with and amplifies upon the challenges of the 1994 UUV Program Plan which established the following four priorities:

- Priority 1: Near-term stopgap mine reconnaissance capability
- Priority 2: Greatly improved, higher-performance mine reconnaissance capability
- Priority 3: Surveillance, intelligence collection, and tactical oceanography capability
- Priority 4: Research and development of enabling technologies for future UUV missions

Significant portions of that plan are now well on the way to completion. The first priority evolved into the Near-Term Mine Reconnaissance System (NMRS), which completed testing in May 1999 and is now available for contingency operations. The second priority resulted in the Long-Term Mine Reconnaissance System (LMRS) program for which a four-year development contract was awarded in October 1999 leading to IOC in 2003.

Some elements of the third priority have begun and others are programmed to begin as LMRS reaches IOC. Specifically, CNO N87 has programmed funding, primarily to pursue surveillance and intelligence collection from submarines. CNO N096, via the Naval Oceanographic Office, has also initiated synergistic efforts that address elements of tactical oceanography. The Office of Naval Research and others continue to pursue the fourth priority at an investment level of approximately $25 million per year.

This UUV Master Plan builds on the original UUV Program Plan, examining the details of Priority 3 capabilities, and taking into account new missions now projected to be possible given the continued government research in Priority 4 UUV enabling technologies along with commercial developments.

Approach

The first stage in developing the Master Plan was to generate a comprehensive pool of emerging UUV missions. The team considered near-term needs (10 years) as well as how those needs would evolve in the mid- to far-term (50 years). To do this, several techniques were employed including field surveys, expert panels, and analysis. During this stage, the goal was to develop a wide-ranging innovative list of applications without regard to technical feasibility, political acceptability, or affordability. The missions were then analyzed and prioritized in accordance with fleet and national needs. The areas where further expansion of UUV employment can be realized beyond those capabilities already started via the UUV Program Plan are:

- Intelligence/Surveillance/Reconnaissance
- Mine Countermeasures
- Oceanography
- Communication/Navigation
- Anti-Submarine Warfare

- Weapons Platform
- Logistics Supply and Support

Signature Capabilities

Based on these high priority missions, the following four Signature Capabilities, listed in priority order, were defined:

- Maritime Reconnaissance
- Undersea Search and Survey
- Communication/Navigation Aids
- Submarine Track and Trail

These broad ranging capabilities group together those missions with similar operational and technological requirements. These Signature Capabilities, which are recommended for near-term Navy UUV development, incorporate both existing and new start efforts and address near and mid-term objectives while providing the technological and operational foundation for long-term goals.

Maritime Reconnaissance (Figure ES-2) will complement and expand existing Intelligence/Surveillance/Reconnaissance (ISR) capabilities, extending the reach into denied areas, and enabling missions in water too shallow for conventional platforms. This capability will include multi-function systems, operating from a variety of platforms, enabling the collection of critical electromagnetic and electro-optic data.

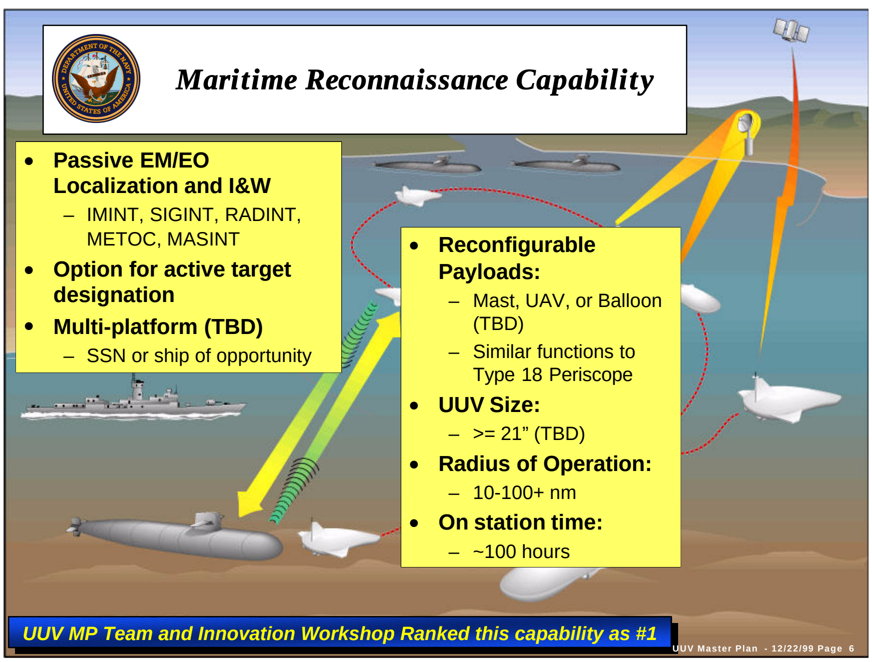

Figure ES-2: Maritime Reconnaissance Capability

Undersea Search and Survey (USS) (Figure ES-3) is an extensive capability area encompassing all aspects of the environment from Object Sensing and Intervention (OSI) to Ocean Survey (hydrographic and oceanographic environmental characterization). A range of UUV systems will be required and some are already fielded or in development which address the following needs: clandestine reconnaissance and battle space preparation; in-stride mine reconnaissance and clearance; and hydrographic and oceanographic environmental characterization. This range of UUV systems will support these needs in the applicable environments, from the surf zone to the deep ocean.

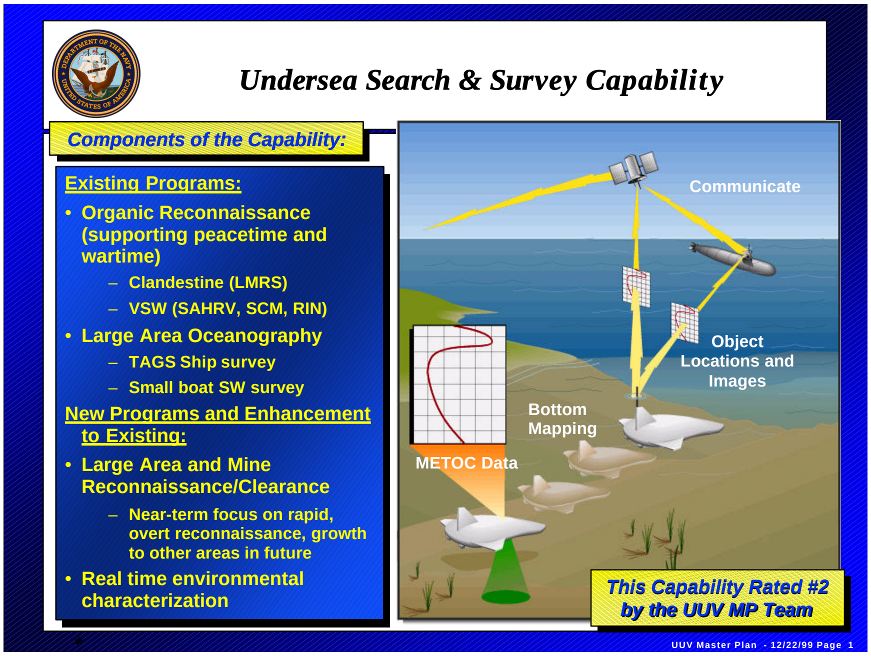

Figure ES-3: Undersea Search and Survey Capability

Communication/Navigation Aids (Figure ES-4) will be the enabling undersea nodes of the Net-centric Warfare Sensor Grid. They will provide connectivity across multiple platforms, both manned and unmanned, as well as the ability to provide navigation assistance on demand. Communication and Navigation modules developed as part of this capability will transition into other UUV systems, reducing the overall developmental burden and risk.

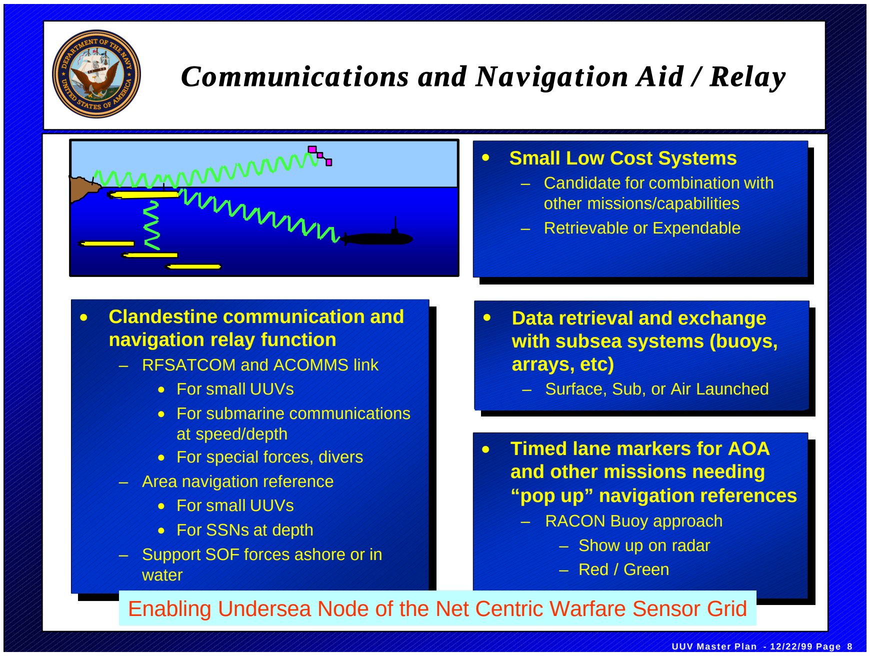

Figure ES-4: Communication/Navigation Aid Capability

Submarine Track and Trail (Figure ES-5) will complement and extend existing anti-submarine warfare capabilities. The vision is to provide a full detection, tracking, and handoff capability using UUVs, ultimately leading to engagement. While full realization of this vision will require long-term investment, there remain near- to mid-term ASW needs that can be well served by precursor systems.

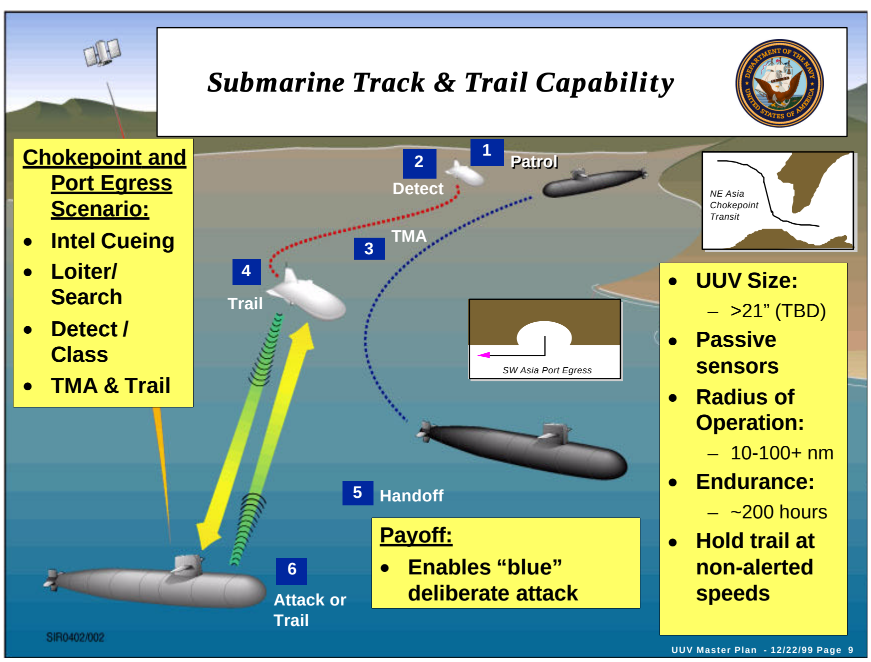

Figure ES-5: Submarine Track and Trail Capability

Path to the Vision (Figure ES-6): While these four Signature Capabilities cannot encompass all UUV missions, the vision can be achieved by commencing work in these areas. **Maritime Reconnaissance**, which starts as an ISR periscope type of mission, could lead to target designation, launch and coordination of UAVs for battle damage assessment and intelligence collection purposes, and ultimately to engagement via missiles. **Undersea Search and Survey**, which starts with the existing programs augmented by a "swarm" of small reconnaissance UUVs, could lead to rapid clearance, and ultimately to undersea work. **Communication/Navigation Aids**, which starts as a simple communication/navigation relay, could lead to autonomous undersea communication/navigation networks that could augment GPS and communication satellite functions, e.g. in the event of local jamming or other adverse action. Finally, **Submarine Track and Trail**, which starts as a mobile cueing function, could lead to increasing levels of engagement, perhaps first against unmanned systems and eventually, with substantial permissive action links, against manned systems. In the far term a fully autonomous capability could be realized.

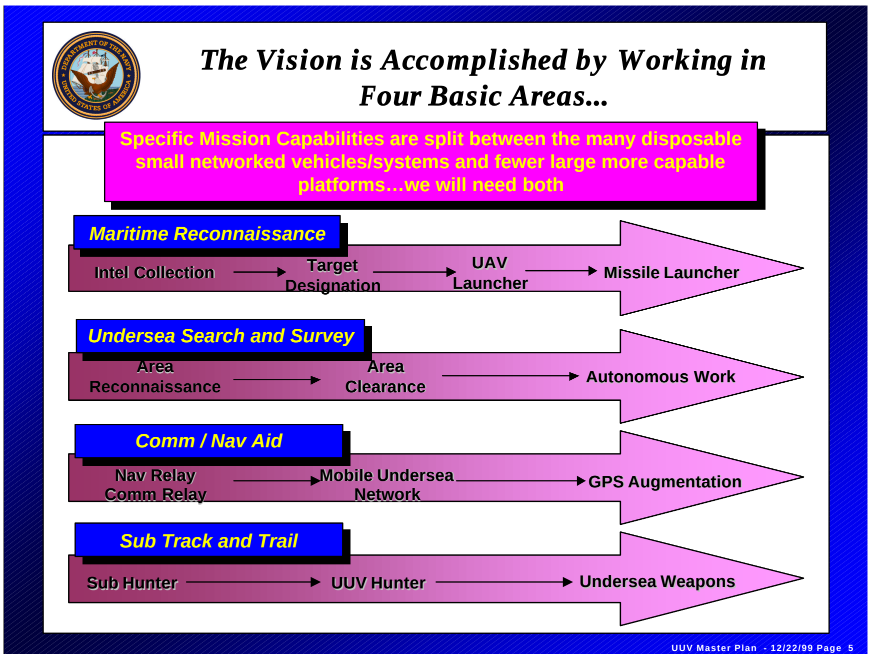

Figure ES-6: Path to the Vision

Technology Issues and Acquisition Risks

Each of the Signature Capabilities has some associated technology issue(s), resulting in varying degrees of acquisition risk. Nevertheless, it is possible to begin acquisitions immediately with acceptable risk. This can be achieved by either aiming for a partial Initial Operational Capability or, in some cases, by initially accepting a vehicle larger in size and/or with lower performance. These technology risk issues, associated with the ability to support near-term acquisitions (POM-02 start), are summarized in Figure ES-7.

Risk vs. Technology vs. Capability

	Maritime Reconnaissance		Undersea Search & Survey								Navigation/ Communication Aid			Submarine Track and Trail				
			Object Sensing & Intervention					Oceanography										
	Pass.	Active	Detect (SLS)	Class (SAS)	ID	Neut	Interv.	Bottom Char	Bathy	Volume Meas.	Comm.	Nav.	Data Ex.	Detect	Class	TMA	Trail	Hand-off
Communications	Yellow	Green	Green	Green	Green	Green	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
Navigation	Green	Green	Y-G	Y-G	Y-G	Y-G	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green
Energy	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Red	Green
Propulsion	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Green
Mission Equip.	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Sensors	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green
Data Processing	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Autonomy	Yellow	Yellow	Green	Green	Yellow	Green	Red	Green	Green	Green	Green	Green	Yellow	Yellow	Red	Yellow	Red	Yellow

- **Definitions:**
  - Mission Equipment: Specific HW items associated with the Mission, not on-board sensors, but includes deployed equipment
  - Sensors: UUV Installed Sensors Specific to accomplish the mission function
  - Data Processing: Data processing and management specific to the mission requirements
  - Autonomy: Software / artificial intelligence and decision making associated with performing the mission without human guidance
- **Ratings for near term Acquisition (assuming minimal risk mitigation):**
  - Green: Low Risk ; Y-G Risk Low-Moderate dependent on size
  - Yellow: Moderate Risk
  - Red: Significant Risk

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Figure ES-7: Technology Risk for Near-Term Acquisition Program

Although the exact coloring of some risk areas in the figure can be debated, the overall trend and accuracy of the table supports the conclusions described within this plan. For example, communications for any single UUV is for the most part not a major risk area. History has shown that greater bandwidth will be consumed at the same rate it is produced, but sufficient bandwidth already exists to perform missions associated with the Signature Capabilities. Risks will be associated with multiple vehicles operating together, for example, the architecture associated with a network of 100 UUVs. Enemy intercept of UUV communications for missions where such intercept would generate a tactical risk may also be an issue.

Accurate navigation is not a risk area unless the system is constrained by size and/or the Concept of Operations (CONOPS) prohibits or constrains the frequency of Global Positioning System (GPS) fixes. When those restrictions exist, navigational problems can be addressed via use of an active communications/navigation aid, such as a transponder field or UUV, or by passive means such as terrain matching.

Propulsion and energy are never the raison d'être, and as a result, there will always be a desire to minimize the size, cost, and signature of energy and propulsion systems. The risks associated with implementation of any of the Signature Capabilities from a propulsion and energy standpoint are for the most part low. The full Maritime Reconnaissance capability will either require a larger UUV or advanced energy source as will the Submarine Track and Trail capability.

Overall, sensor risk is low for all capabilities except Submarine Track and Trail. However, sensor processing and the automation/decision making associated with the processing are higher risk. For Undersea Search and Survey, augmentation via the implementation of synthetic aperture sonar for increased area coverage will have added benefit, but autonomous processing of sonar and optical images to classify mine-like objects and identify mines remains a risk. For Submarine Track and Trail, there is some risk associated with the miniaturization of sensors, but the more significant risks are associated with sustained speed and endurance, autonomous processing, target recognition, countermeasure rejection, Target Motion Analysis (TMA), and tactics.

Development Plan

The UUV Master Plan was created with one basic goal to be achieved via several underlying philosophies:

Goal:

Deliver End Items…And Begin Using Them!

Deliver robust UUV capabilities to the fleet as soon as possible at minimum cost. There are several parallel UUV developments underway with valid missions. There are also existing capabilities that must be rapidly expanded. UUVs can enhance the effectiveness of U.S. forces while reducing risk at a fraction of the cost of manned systems.

Philosophy:

Minimize Cost, Maximize Synergy, But One Size Does Not Fit All!

In the near-term, UUVs will continue to vary in size and shape to suit the interfaces of the launch and recovery platform, as well as the intended mission. Therefore, synergy will be a challenge as one size does not fit all. A secondary objective is to minimize UUV rework and associated costs required to maintain or to enhance the Signature Capabilities as new platforms come into service.

Roadmap

UUV functional elements are common across the majority of systems. In particular, hull, mechanical, electrical, and hotel functions are very similar in many UUV systems. If partitions and interfaces can be standardized for these elements, savings in costs and time and improvements in performance can be achieved through economies of scale. A summary version of the programmatic roadmap developed within this plan is provided in Figure ES-8. Key components include the continuation of current programs, the development of UUVs and UUV payload technologies, and the delivery of “end items”--mission reconfigurable UUVs based on standardized modules.

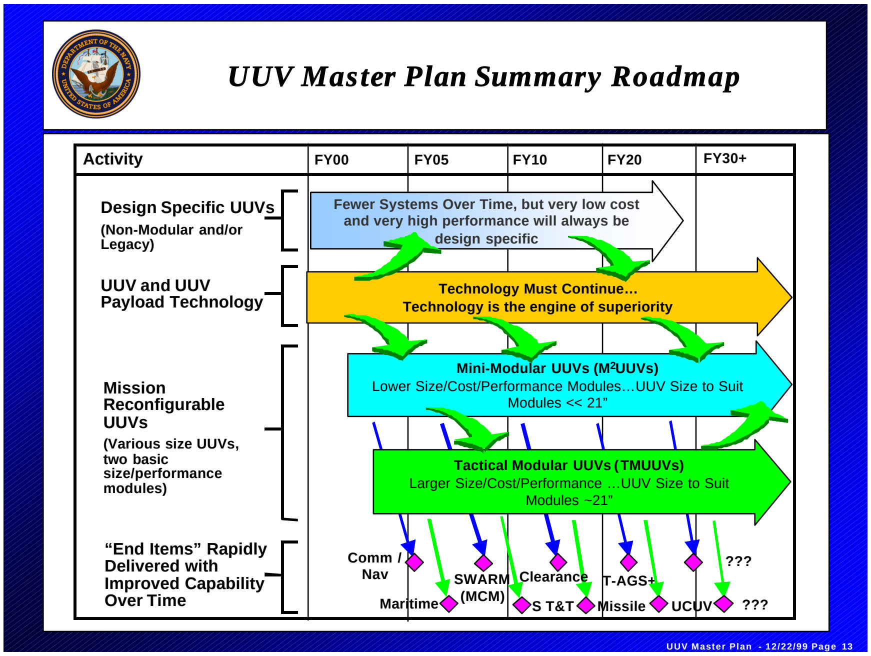

Figure ES-8: UUV Master Plan Summary Roadmap

Recommendations

Specific recommendations made within this plan include:

- Complete current UUV development and integration programs and planned upgrades. These systems address high priority needs and the technology, experience, and components of these programs will help form the foundation for future efforts.

- Continue to execute a balanced technology program for both UUV Payloads and UUV Technology that supports the vision and the four Signature Capabilities. Ensure technologies are advanced that support the needs and reduce the risk of both small modular networked systems and larger high performance modular systems.

- Develop standards for future UUV module sizes and interfaces. It is expected that with two different module sizes the majority of future UUV needs can be cost effectively accomplished. The savings associated with standardization of modules (cost sharing in development, operations, and support) and the emergence of capabilities that could otherwise not be afforded will be lasting.

- Begin execution of an integrated program to achieve the four Signature Capabilities and begin using UUVs for the benefit of the fleet. Increase coordination between the various UUV developers/users and program managers rather than attempting to combine all UUV programs into one site/location/program.

- Begin outreach to Navy operational, doctrine and training commands to expand and refine employment concepts for UUVs. Address logistical and mission impact of installing and operating UUV systems on combatants early in the ship and UUV acquisition cycle. Continue innovative thinking and review and update this plan periodically.

- Prior to initiation of any new UUV effort and at major decision points within existing UUV programs, conduct cost-effectiveness trades to determine whether small modules, large modules, or design specific approaches are required.

Conclusion

The Navy is strategically positioned to rapidly move forward to achieve the UUV vision. The only barriers are funding, some of which is in place, and coordination. Technology and industrial capacity are ready to proceed. Despite the fact that there are literally hundreds of UUVs under development or in operational use worldwide, which have logged thousands of dive hours, the fleet has little UUV-based capability today. With careful decisions and investments today, UUVs can become significant contributors to the Navy's capabilities tomorrow, and be ready for the unexpected future. The alternative is to fall behind the technical capability of adversaries that decide to exploit existing commercial systems. Now is the time to build on this plan.

Deliver End Items…And Begin Using Them.

1 The Vision

The UUV Master Plan study team was encouraged by the Assistant Secretary of the Navy (Research, Development, & Acquisition) to consider a long-term vision for UUVs without initial consideration of technical, operational, or fiscal constraints. Today U.S. naval forces enjoy maritime superiority around the world and find themselves at a strategic inflection point during which future capabilities must be pondered with creativity and innovation. Change must be embraced and made an ally in order to take advantage of emerging technologies, concepts, and doctrine and thereby preserve the nation's global leadership. The innovation principle applies to *what* we buy as well as *how* we buy and operate it - all the while competing with other shifting national investment interests.

The resultant UUV vision (Figure 1-1) is to have the capability to do everything, everywhere, anytime using UUVs. One can conceive of scenarios where UUVs sense, track, identify, target, and destroy an enemy - all autonomously. Admittedly this vision is futuristic, perhaps 50 years distant. Even though today's planners, operators, and technologists cannot accurately forecast the key application for UUVs in the year 2050, this plan provides a roadmap to move toward that vision. There is every reason to believe that pursuit of this plan's recommendations beginning in the year 2000 will soon place large numbers of UUVs in the hands of naval users. There the UUVs can begin addressing near-term needs while increasing understanding of mid- to far-term possibilities. Even the most futuristic applications can evolve in a confident, cost effective manner. This confidence is based on several factors: the signature capabilities solve a broad range of user needs; critical technologies are identified that will enable tomorrow's more complex applications; and key principles and best practices are recommended that provide for a logical, flexible, and affordable development effort into the future.

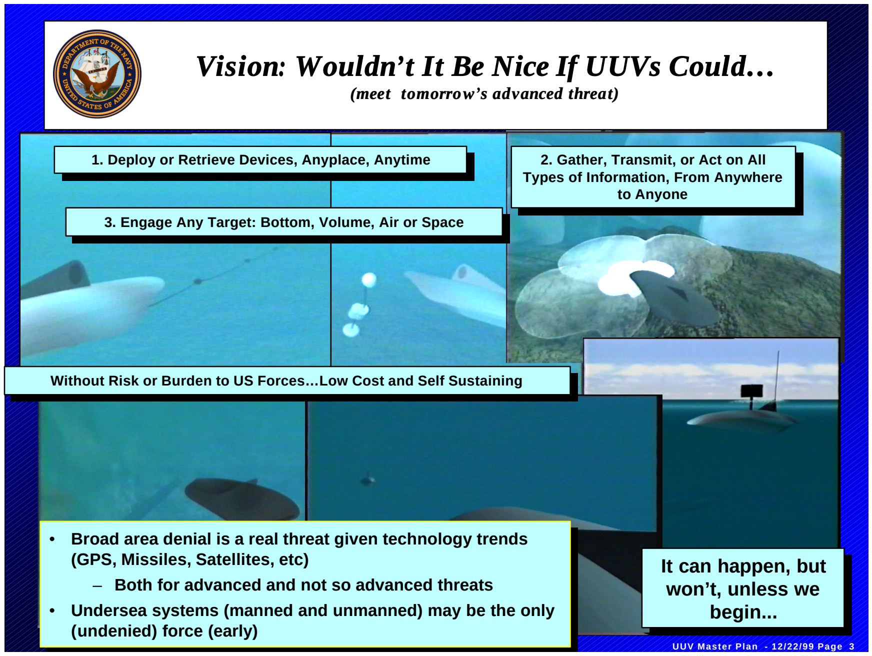

Figure 1-1: UUV Master Plan Vision

1.1 Navy Needs

The needs of naval forces as they are understood today (references are listed in Appendix A) are briefly reviewed here before next discussing how UUVs can support those needs. Bear in mind that the intent of this plan is to prioritize near-term UUV investments that can also support future yet-to-be determined needs which will be explored by the Naval Warfare Development Command's Maritime Battle Center, the Marine Corps Warfighting Laboratory, and other organizations.

The Navy needs stealthy and/or unmanned systems to gather information and engage targets in areas denied to traditional maritime forces. Area denial will increase in both likelihood and extent through the adversary's strategy of asymmetric warfare, i.e., the use of easily acquired weapons to exploit U.S. weaknesses rather than competing head-to-head or symmetrically with the world's superpower. Asymmetric weapons include quiet submarines, mines, tactical ballistic missiles, cruise missiles, weapons of mass destruction, and information warfare. Space-based surveillance systems, long-range precision strike weapons, and robust command and control networks may also be used by adversaries to further threaten a U.S. Navy whose doctrine and force structure require operation in the littorals in order to enable power projection ashore. In addition to direct threats, diplomatic constraints or rules of engagement may preclude the early entry of overt maritime forces. For example, coalition aircraft and ships remained south of a specified latitude during Operation Desert Shield in order to prevent touching off a ground war. Tools are needed that avoid counterdetection by the enemy or are invulnerable to attack thereby allowing penetration of denied areas for sustained independent operations. In this way military commanders can keep other forces out of harm's way during the initial phases of a conflict while still employing the necessary tools to prepare and shape the battlespace, ensuring ultimate defeat of the area denial threat.

Noncombatant naval activities in support of the warfighter, such as collection of meteorological and oceanographic data, also need to consider offboard unmanned systems to improve performance and reduce costs.

1.2 UUV Possibilities

It is time for creative thought and planning about the future of UUVs and their naval applications. An unmanned undersea vehicle is defined as a self-propelled submersible whose operation is either fully autonomous (pre-programmed or real-time adaptive mission control) or under minimal supervisory control and is untethered except for data links such as a fiber optic cable. This document does not address towed systems, hard-tethered devices such as remotely operated vehicles, systems not capable of fully submerging such as unmanned surface vehicles or semi-submersible vehicles, or bottom crawlers. UUVs should be used in applications where they increase performance, lower cost, or reduce the risk to manned systems. The characteristics of UUVs that make these application principles possible are their ability to put sensors in an optimal position in both the vertical and horizontal dimensions, autonomy, endurance, low-observability, and standoff or reach from the launch platform.

Naval Doctrine Publication 1 (NDP 1) discusses the characteristics of expeditionary naval forces; they are ready, flexible, self-sustaining, and mobile. UUVs possess these characteristics in varying degrees. For example, today’s UUVs are sustained by human intervention at frequent intervals but tomorrow's UUVs will have longer endurance between replenishment and will be serviced by autonomous undersea networks. The critical operational capabilities naval expeditionary forces can provide include:

- Command, Control, and Surveillance which encompasses the gathering, processing, and distribution of information vital to the conduct of military planning and operations.
- Battlespace Dominance. The battlespace in which naval forces operate is neither fixed in size nor stationary. It can be visualized as zones of superiority, surrounding one or more units or even the entire force, that are shifted as the situation requires in maneuver warfare rather than attrition warfare.
- Power Projection. The ability to take the fight to the enemy is a strength enjoyed by naval forces and has always been one of the nation's primary objectives in war.
- Force Sustainment which starts with combat-ready forces that are provided with effective, reliable and maintainable weapon systems, trained operators and maintenance personnel, and the necessary consumable supplies, spare parts, and facilities to be operationally self-sufficient.

Forward From The Sea … Navy Operational Concept of March 1997 further examines how naval forces operate across the three components of the 1995 National Military Strategy: peacetime engagement, deterrence and conflict prevention, and fight and win. UUVs can offer capabilities in each of these areas, particularly in preparation of the battlespace in the face of area denial threats that may present undue risks to manned systems. The many possibilities for UUVs to contribute to naval needs derive from their operational advantages, which include:

- Autonomy. The ability to operate independently for extended periods creates a force multiplier that allows manned systems to extend their reach and focus on more complex tasks. Costs are reduced when sensors or weapons are operated from the smaller infrastructure of a UUV rather than entirely from manned platforms.
- Risk reduction. The unmanned nature lowers or eliminates risk to personnel whether it is a risk of the environment, the unforgiving sea, or an enemy in combat.
- Low Observability. UUVs operate fully submerged with low acoustic and magnetic signatures. They maintain a low profile when surfaced to extend antennae. The possible intent for follow-on manned operations in a route or area is not revealed and the element of surprise is preserved. Unlike towed or hard-tethered systems (ROVs), they have less risk of entanglement with underwater or floating obstructions.
- Deployability. By virtue of their limited size, UUVs provide a capability organic to the mobile battle group. They can also be designed as flyaway packages or be pre-positioned in forward areas. Their launch can be adapted to a variety of platforms including ships, submarines, aircraft, and shore facilities. The UUV recovery craft need not be the same as the launch craft. Recovery may be delayed or dismissed entirely for low cost expendable systems. Multiple UUVs can be deployed simultaneously from one platform.
- Environmental Adaptability. UUVs can operate from deep to very shallow water, in foul weather and seas, under tropical or arctic conditions, and around the clock.

1.3 Linkage to Other UUV Plans and Studies

This document is consistent with and amplifies the challenges of the 1994 UUV Program Plan which established the following four priorities:

- Priority 1: Near-term stopgap mine reconnaissance capability
- Priority 2: Greatly improved, higher-performance mine reconnaissance capability
- Priority 3: Surveillance, intelligence collection, and tactical oceanography capability
- Priority 4: Research and development of enabling technologies for future UUV missions

Significant portions of the 1994 plan are now well on the way to completion. The first priority evolved into the Near-Term Mine Reconnaissance System (NMRS) which completed testing in May 1999 and is now available for contingency operations. The second priority resulted in the Long-Term Mine Reconnaissance System (LMRS) program for which a four-year development contract was awarded in October 1999 leading to IOC in 2003.

Some elements of the third priority have begun and others are programmed to begin as LMRS reaches IOC. Specifically, funding has been programmed by CNO N87 to pursue surveillance and intelligence collection. CNO N096, via Commander, Naval Meteorological and Oceanographic Command and the Naval Oceanographic Office, has also initiated synergistic efforts in oceanography. The Office of Naval Research and others continue to pursue the fourth priority at an investment level of approximately $25 million per year.

Since 1994, additional studies have been performed which provide guidance. This guidance included assessments not only of the role of UUVs, but of the evolution of warfighting concepts and means. Those plans and studies include the *Integrated ASW Master Plan* (1998), *Undersea Vehicles and National Needs* (1996), and the Defense Science Board *Future Submarine Study* (1998). A complete listing of documents referenced is provided in Appendix A. This UUV Master Plan builds on the original UUV Program Plan, examining the details of Priority 3 capabilities, and taking into account new missions now projected to be possible given the continued government research in Priority 4 UUV enabling technologies along with commercial developments.

2 Missions

In the future, UUVs will perform a myriad of missions supporting fleet objectives both in wartime and peacetime. The first stage in developing the Master Plan was to generate a comprehensive pool of potential UUV missions. To do this, several techniques were employed including field surveys, expert panels, and analysis. During this stage the goal was to develop a wide-ranging innovative list of applications without regard to technical feasibility, political acceptability, or affordability. The missions generated were then analyzed and prioritized in accordance with fleet and national needs.

2.1 Mission Generation Methodology

A wide variety of mission sources were sought, looking for a broad range of current and potential UUV users. This was accomplished by field surveys, expert panel discussions, examination of the literature, and analysis by the UUV Master Plan study team.

2.1.1 Field Surveys

Interviews were performed with a large number of potential users in the fleet, industry, science and academia, and other federal agencies. The emphasis was placed on potential users of UUVs as opposed to those solely involved with technology development. A broad cross section of interviewers and interviewees provided a full range of UUV applications. Appendix B contains a list of those contacted and their principal UUV interests.

The users surveyed expressed both unique and overlapping UUV mission needs. From the Navy perspective, a great deal of interest was exhibited in various aspects of mine countermeasures, both in realizing those missions outlined in the 1994 plan and as a continuing expansion of the current work. Other high priority missions from the naval perspective included intelligence/surveillance/reconnaissance (ISR), anti-submarine warfare (ASW), undersea search and survey, and oceanography. Industry is pursuing UUV applications for long range cable and pipelaying surveys and for subsea intervention and operations. Scientific applications include detailed bathymetric mapping, deep-water sampling, and long term observations. Other government agencies have also evidenced a need for UUVs in hazardous waste operations, fisheries research, drug interdiction, and bathymetric mapping.

2.1.2 Expert Panels

Three groups of UUV experts contributed to the development of the plan. The Core Team developing the plan was a group of UUV experts from a full range of Navy laboratories and academia. Team members have extensive experience in UUV applications for mine countermeasures, anti-submarine warfare and training, search and salvage, deep ocean object recovery, tactical oceanography, surveillance, inspection, and undersea work. The Oversight Board was chaired by the Assistant Secretary of the Navy (Research, Development and Acquisition) and represented the stakeholders in UUV development. The third element was a group of visionary experts in the underwater field brought together for an Innovation Workshop to brainstorm ideas and innovative concepts for UUV application and development. The make-up of the three panels is also provided in Appendix B.

2.1.3 Related Studies

In addition to the field studies and panel discussions, existing literature on UUV applications and technologies was also reviewed. In the time since the 1994 UUV Program Plan a number of studies have been performed examining the various roles and status of UUV systems and technologies. Key among these were the 1996 National Research Council Report *Undersea Vehicles and National Needs* and the 1999 Marine Technology Society CD-ROM *Operational Effectiveness of Unmanned Underwater Systems*. Relevant conference proceedings, including the *IEEE/ MTS OCEANS*, *ADC/MTS Underwater Intervention*, and *Unmanned Undersea Submersible Technology* were surveyed to ascertain the state of the art in academic and commercial UUV development. All information gathered was incorporated in the mission generation and analysis for the plan.

2.1.4 Core Team Analysis

Once the list of missions was generated, the core team analyzed the data, looking for the common and high priority mission characteristics. Key evaluation criteria included mission type, degree of innovation, uniqueness of the UUV ability, technology development required, multiple applications, and overall importance to the Navy. This analysis resulted in the generation of key mission categories and the prioritization of missions to be pursued as discussed in Sections 2.2 and 2.3 below.

2.2 Mission Categories

Based on mission analysis, UUV missions fell into several general categories: intelligence/surveillance/reconnaissance, mine countermeasures, oceanography, communication/navigation, antisubmarine warfare, engagement, and logistics supply and support. Each of these categories addresses key Navy needs and has its own set of mission characteristics and requirements. All of the missions generated, from the simplistic to the far-fetched, are discussed below as they relate to the overall realm of possibility.

2.2.1 Intelligence/Surveillance/Reconnaissance (ISR)

The ISR mission area encompasses collection and delivery of many types of data: intelligence collection of all types, target detection, and mapping data. UUVs are uniquely suited for information collection due to their ability to operate at long standoff distances, remain on station for long periods of time, operate independently and provide a level of clandestine capability not available with other systems. There are many applications, particularly of a military nature, whereby UUVs are the only effective means of gathering desired information. UUVs can provide a capability to access previously denied areas, and provide an information conduit without undue risk to personnel or high value assets. Possible missions include:

Intelligence collection: SIGINT, ELINT, MASINT, etc.
Battle damage assessment
Bio-chemical or nuclear detection and defense
Ship escort: extended "eyes and ears"
Search and recovery to full ocean depth
Deployment of leave-behind sensors or sensor arrays
Underwater security: divers, mines, etc.

2.2.2 Mine Countermeasures (MCM)

Development of current Navy UUVs has been driven by the need for clandestine mine detection and mapping capabilities. The Near-Term Mine Reconnaissance System (NMRS) and the Long-Term Mine Reconnaissance System (LMRS) were developed in accordance with the 1994 UUV Program Plan as previously described. As these systems become part of the fleet, additional MCM functions are desired to expand on the mapping capabilities present now or planned in the vehicles. These include higher fidelity mapping and classification, automated identification, operation in the littoral zone, and wide area neutralization. Many of these functions may be best served by using smaller expendable UUVs in conjunction with or instead of the large dedicated systems now employed. MCM operations that are or will be performed by UUVs include:

<u>Reconnaissance</u>	Detection
	Classification
	Localization
	Identification
<u>Clearance</u>	Neutralization
	Sweeping
<u>Protection</u>	Spoofing
	Jamming

2.2.3 Meteorology and Oceanography

Collection of oceanographic data is of key importance both for strategic and tactical operations. A complete and up to the moment knowledge of the ocean bottom, its characteristics and environmental conditions is a vital asset for mission planning. Long-term observation of water column characteristics will provide for improved communication and operational capabilities. UUVs are well suited for many oceanographic tasks as they can independently collect information for later delivery or transmission. Conventional oceanographic data collection is largely dependent on hull mounted or towed systems that require extensive surface ship support and suffer speed limitations imposed by the tow cable. UUVs will permit collection of significantly greater quantities of data at less cost by multiplying the effectiveness of existing platforms. UUV technology provides the opportunity to acquire affordable, near real time data at required temporal and spatial sampling densities. Analysts will integrate these UUV gathered data with remotely sensed and conventional survey data and models to provide maritime warfighters with critical knowledge of areas such as bathymetry, tides, waves, currents, winds, mines, wrecks and obstructions, and acoustic and EM/EO propagation. Envisioned missions of this type include:

Bathymetry and bottom imagery
Thermal and acoustic properties
Ocean currents and tides
Chemical, nuclear, and biological sampling
Bottom structure and composition
Meteorological data
Long term observation stations

2.2.4 Communication/Navigation Aid

UUVs can serve as critical communication and navigation links between various platforms; at sea, on shore, even into the air and space realm. As with the ISR missions, they can be operated from a variety of platforms, at long standoff distances, for extended periods of time. A small vehicle can function as an information conduit between a subsea platform and an array, or it can covertly come to the surface and provide a discrete antenna. As an aid to navigation, UUVs can serve as stand-by buoys, positioning themselves at designated locations and popping to the surface to provide visual or other references for military maneuvers or other operations. UUVs can also provide the link between subsurface platforms and GPS or other navigation tools without exposing the platform to unnecessary risk. Pre-positioned beacons could be placed to provide navigational references in circumstances where conventional means are not available or desirable for use. This makes them attractive for a variety of communication and navigation functions including the following:

<u>Communication</u>:	Cable laying and repairs
	"Phone booths": underwater network nodes for data transmission
	Underwater connectors (e.g., "Flying Plug")
	Low aspect deployed antennas (SATCOM, GPS)
<u>Navigation</u>:	Deployment of transponders or mobile transponders
	Inverted GPS capability (antenna to surface)
	On demand channel lane markers
	Harbor pilot

2.2.5 Anti-Submarine Warfare (ASW)

A UUV offers significant force multiplication for ASW operations. It can serve as an offboard sensor and/or source, extending the range of detection without increasing risk. The host can serve as the mother ship for a fleet of vehicles providing the decision-making capabilities while remaining out of harm's way. UUVs are currently used as training targets; an application that may be extended to the battlefield in the form of decoys deployed at safe standoff ranges from the platform.

<u>Fire Control Aid</u>:	Vessel sensing/tagging
	Submarine track and trail

	Target illumination
<u>Auxiliary</u>:	Exercise targets
	Decoys
	Patrol vehicle for security

2.2.6 Autonomous Weapons Platform

The autonomous weapon option is controversial, but inevitable, although many years away. Several current systems set the precedent, including Tomahawk, which is an armed unmanned aerial vehicle (UAV); the ADCAP torpedo; the Improved Submarine Launched Mobile Mine (ISLMM), and the CAPTOR mine. Speed, covertness, and long standoff allows a UUV to be an effective weapon or weapon platform. Launching a weapon from a UUV allows a launch point closer to the target and moves the "flaming datum" away from high value platforms so that their positions are not exposed. In addition, a UUV could be used to not only deliver weapons, but could also act as a weapons adjunct: illuminating targets, serving as decoy, and providing additional sensor and targeting information. Some of the potential UUV engagement applications include:

<u>Weapon</u>:	Autonomous mine
	Delivery and attachment of mines or other weapon
	Remote Torpedo Launcher
	Remote Missile Launcher
	Directed energy UUVs
	Counter UUV weapon
	Expendable mine neutralization device

2.2.7 Logistics Supply and Support

One of the most critical portions of any military operation is logistical supply and support. UUVs can facilitate these operations by providing covert re-supply to troops without exposing high value platforms. On a large scale, it would be possible to send a large UUV tanker out and refuel a surface ship in a relatively undetectable manner. On a smaller scale UUVs could provide valuable just-in-time supplies to advance forces providing them with additional supplies and armament. UUVs can also provide a means of performing work tasks that currently require divers or other personnel intensive means. Concepts for using UUVs for supply and support include:

<u>Supply</u>:	Covert freighter or tanker
	Submarine "trailer" carrying additional supplies
	Weapons courier supporting Special Forces
	Undersea base station: a remotely deployable habitat
	Cache of supplies with recall on demand
<u>Support</u>:	Undersea installation and repairs
	Diver replacement
	Ship hull inspection
	Infrastructure inspection

2.3 Mission Prioritization

Once the list of potential missions was compiled, each mission was analyzed for technical feasibility, political acceptability, and operational desirability. The missions were prioritized based on input from operational personnel and experts in the field, and on data obtained from existing studies and documentation. Table 2-1 summarizes the results of the prioritization. Overall, there was a general consensus on the top mission areas of Intelligence/Surveillance/Reconnaissance, Mine Countermeasures, Oceanography, Communication/Navigation, and Anti-Submarine Warfare. These high priority missions formed the basis for the four Signature Capabilities of the UUV Master Plan. The Weapons platform mission was seen as too politically sensitive for near-term implementation prior to the development and proving of other autonomous capabilities. The Logistics Supply and Support mission, while potentially useful in some scenarios, was seen as more effectively performed by more conventional means for the immediate future. Some of these missions may be ideally suited to Unmanned Surface Vehicles (USVs).

Table 2-1: Mission Prioritization Summary

Missions	**Signature Capability**
Intelligence/Surveillance/Reconnaissance	Maritime Reconnaissance
Mine Countermeasures	Undersea Search and Survey
Oceanography	
Communication/Navigation Aids	Communication/Navigation Aids
Anti-Submarine Warfare	Submarine Track & Trail
Weapons Platform	
Logistics Supply and Support	

These broad ranging Signature Capabilities incorporate the high priority missions, grouping together those with similar operational and technological requirements. These are the areas recommended for near-term Navy development. Incorporating both existing and new start efforts, they are intended to address near- and mid-term objectives while providing the technological and operational foundation for the long-term goals.

Maritime Reconnaissance addresses the ISR missions, encompassing intelligence collection from all arenas. Undersea Search and Survey provides a capability for large area reconnaissance, key to both tactical oceanography and MCM goals. The Communication/Navigation Aid can function as both a key operational capability in its own right, and also as a component to other, more complex systems. Finally, the Submarine Track and Trail addresses some of the key ASW needs that will be well served with UUV technology.

Each of these signature capabilities is discussed in detail in the following chapter. Objectives, background, preliminary concept of operations and notional system concepts are presented, as well as the related technical and engineering issues that must be addressed for success.

3 Signature Capabilities

Four Signature Capabilities have been defined. These capabilities not only meet near-term needs, but also are expected to evolve to support mid- and long-term goals as shown in Figure 3-1. **Maritime Reconnaissance**, which starts as an ISR periscope type of mission, could lead to target designation, launch and coordination of UAVs for battle damage assessment and intelligence collection purposes, and ultimately to engagement via missiles. **Undersea Search and Survey**, which starts with the existing programs augmented by a "swarm" of small reconnaissance UUVs, could lead to rapid clearance, and ultimately to undersea work. **Communication/Navigation Aids**, which starts as a simple communication/navigation relay, could lead to autonomous undersea communication/navigation networks that could augment GPS and communication satellite functions, e.g. in the event of local jamming or other adverse action. Finally, **Submarine Track and Trail**, which starts as a mobile cueing function, could lead to increasing levels of engagement, perhaps first against unmanned systems and eventually, with substantial permissive action links, against manned systems. In the far term a fully autonomous capability could be realized.

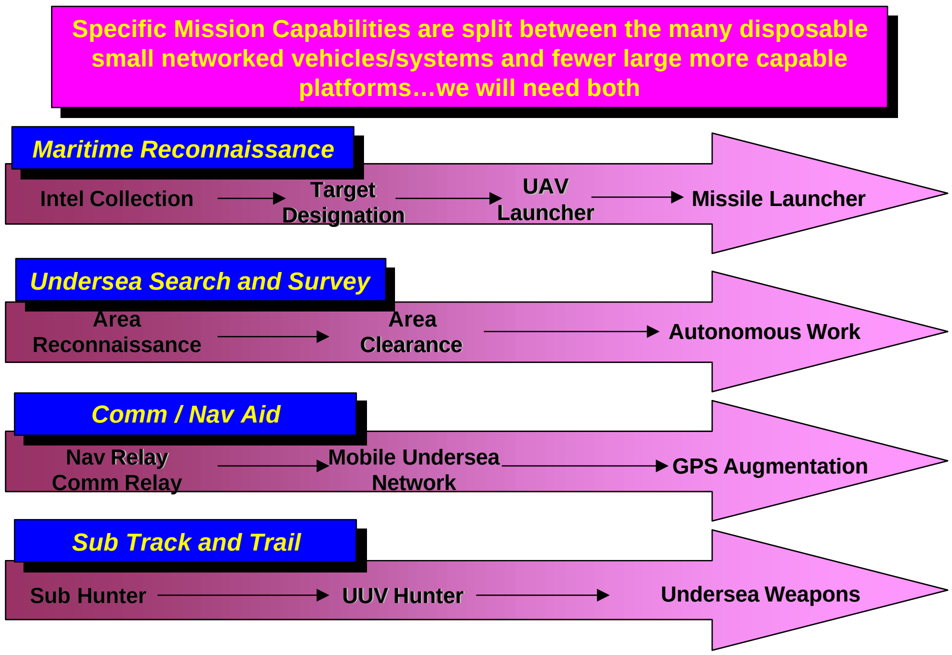

Figure 3-1: Signature Capabilities From the Present to the Future

Each of these Signature Capabilities is discussed in detail in the sections following. Objectives, background, preliminary concept of operations and notional system concepts are presented, as well as the related technical and engineering issues that must be addressed for success.

3.1 Maritime Reconnaissance Capability

The Maritime Reconnaissance Signature Capability answers the number one priority mission of Intelligence/Surveillance/Reconnaissance (ISR). It will extend the ISR reach into waters that are inaccessible to platforms. It will be a multi-function system, operating from a variety of platforms, enabling the collection of all types of data.

Advantages are provided by the use of a UUV for the ISR mission. UUVs can effectively perform these missions in high-risk areas or wherever water is too shallow for conventional platforms. A long-range vehicle could penetrate such areas, extending the platform's reach more than 200 NM. A UUV can be launched from a safe standoff distance, transit to the area of interest, and return with or transmit the data collected. This would greatly reduce the risk to manned platforms while freeing them to perform other high priority missions.

3.1.1 Objective

The objective of the Maritime Reconnaissance signature capability is to collect multi-disciplinary intelligence data across the entire electromagnetic spectrum while remaining undetected by the enemy. Other types of sensors could also be deployed, to collect additional data. The net result would be substantially improved indications and warning. Follow-on enhancements to basic ISR UUV capabilities could include active target designation (laser), battle damage assessment and launch and coordination of UAVs.

3.1.2 Background

ISR collection is the number one priority UUV mission, and is expected to be asset intensive. UUVs can offset reductions in the overall size of the fleet while increasing area coverage rate and tactical reach. They provide acceptable risk in the face of dynamic threats, while simultaneously providing force multiplication.

3.1.3 Preliminary Concept of Operations

The general ISR concept of operations is shown in Figure 3-2. The vehicle is launched from a platform of opportunity, submarine, surface ship, or even an aircraft or shore facility. It then proceeds to the designated observation area. Once it reaches the location, it performs the mission, collecting the information over a predetermined period of time. It autonomously repositions itself as necessary, both to collect additional information and to avoid threats. The information collected is 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 some cases where absolute detection avoidance is required at the expense of real-time or semi-real-time transmission, the vehicle may simply carry the recorded information back to the host platform or to a more appropriate area for transmission.

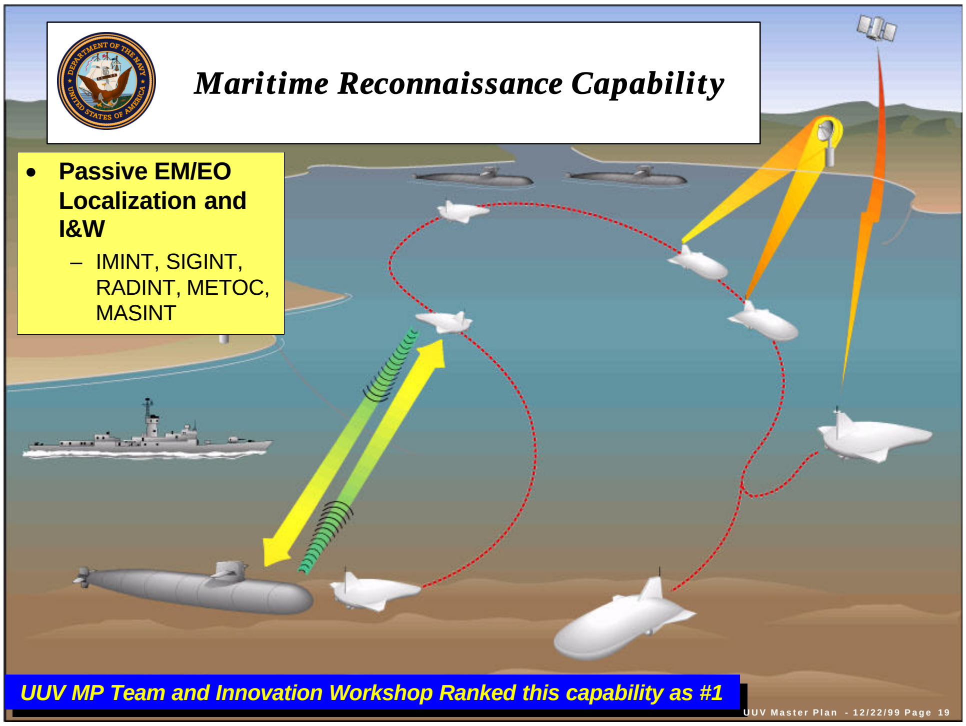

Figure 3-2: Maritime Reconnaissance Preliminary Concept of Operations

3.1.4 System Concept

The ultimate Maritime Reconnaissance capability can be provided via a relatively large vehicle with significant range and endurance that can carry a variety of large payloads. However, credible subsets of the capability can be provided in UUVs as small as 21” in diameter, or even smaller vehicles for limited missions.

The Maritime Reconnaissance capability will have a reconfigurable payload, able to accommodate a variety of sensors. Table 3-1 summarizes possible operational characteristics for both a limited capability (near-term) and full capability (long-term) Maritime Reconnaissance vehicle concept.

Table 3-1: Maritime Reconnaissance Notional Capability

	Limited Capability	Full Capability
Radius of Operation (NM)	50-75	75-150+
On station time (hours)	<100	200+
Speed (knots)	~4	~ 5
Nominal Displacement (pounds)	< 2800	5,000 -20,000
Payload (pounds)	< 100	>> 100

3.1.5 Technology and Engineering Issues

Critical technology and engineering issues pertaining to the Maritime Reconnaissance capability stem from the need for secrecy, signature reduction, failsafe vehicle behavior, and extended autonomous operation. Long range communication, though not always required, is an issue. While means of communication currently exist, work needs to be done to expand capabilities in this area. In particular, there is a strong desire to increase the bandwidth of communications links while reducing probability of intercept.

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

Payload development for the Maritime Reconnaissance capability should largely be concentrated in the effective packaging and integration of sensors. With the large number of sensors desired, it is vitally important that they be packaged with a minimal cross section. Improvements in individual sensor performance will also be key to the overall mission operation.

3.2 Undersea Search and Survey Capability

The Undersea Search and Survey (USS) Signature Capability (Figure 3-3) is an access enabler and force multiplier for the fleet, preparing the littoral undersea battlespace for entry and occupation. This capability addresses all aspects of the environment through Object Sensing and Intervention (OSI) and Ocean Survey.

OSI includes finding mines, shipwrecks, lost objects, pipelines, cables, and other objects of interest in all ocean environments. It also includes possible intervention in the environment. Some examples are, mine neutralization, object recovery, and connection to in-situ equipment. Ocean Survey is the collection of hydrographic and oceanographic data, again in all ocean environments. While it is true that the oceanographic function is described herein as a dedicated set of capabilities, these will be augmented with oceanographic data gathered from most UUV types and provided as near to real time as possible.

USS supports preparation of the battlespace in operations planning, selection of operating areas, enabling operations in denied areas, and locating and recovering lost objects.

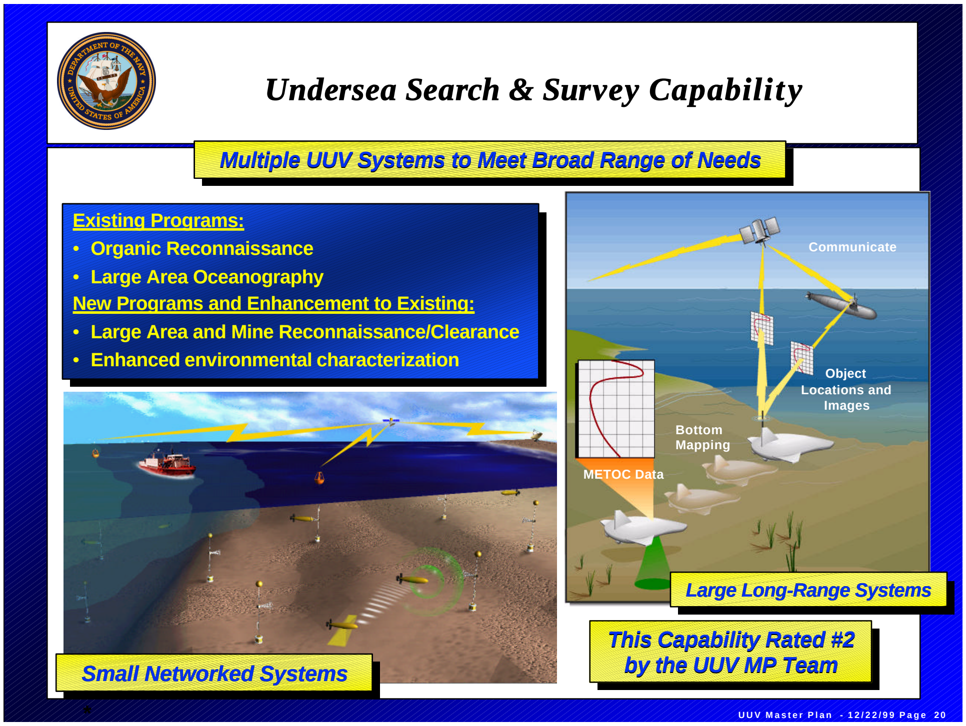

Figure 3-3: Undersea Search and Survey Signature Capability

3.2.1 Objective

The objectives of USS range from reconnaissance of large littoral undersea areas to detailed characterization of specific battlespace areas. The ability is required to perform these missions in areas were battlespace dominance has not been achieved. The focus is on the littoral but a deep-water survey capability is also required for bottom characterization to accomplish cable route pre-installation and inspection and detection, localization, identification, and recovery of man-made objects from the seafloor in all water depths.

An objective of USS is collection of high-quality accurately positioned data. UUV technology is a force multiplier to manned platforms and is essential to meet critical ocean survey and OSI requirements. Applicable USS requirements documents are listed in the references. Ocean survey data types will include physical, geological, chemical, biological, and oceanographic measurements. OSI data includes detection, classification, localization, and identification, with spatial accuracy, of mines, mine-like objects, and hazards to navigation. OSI also includes rapidly and responsively eliminating mine threats from designated areas of the battlespace.

The predominate driver for adopting UUV technology for USS is to increase the timeliness and cost effectiveness with which the fleet can acquire affordable, near real time data at required temporal and spatial sampling densities. Used in conjunction with remote sensors, other ocean data and models, UUV-acquired data will provide warfighters with critically required foreknowledge of environmental parameters such as bathymetry, tides, waves, currents, winds, and acoustic propagation, and accurate locations of mines, hazards to navigation, and other objects of interest.

3.2.2 Background

Currently, Undersea Search and Survey capabilities are represented in several developing systems. The Long-Term Mine Reconnaissance Systems (LMRS) is a submarine hosted UUV that is specifically designed to address the fleet's needs for clandestine mine reconnaissance. LMRS is designed to perform best in waters 40 to 300 feet deep but also provides a capability in shallower water and in depths to 1500 feet. The Semi-Autonomous Hydrographic Reconnaissance Vehicle (SAHRV) will perform reconnaissance in shallower water to support amphibious landings, hydrographic mapping, and MCM operations. The SAHRV is also a candidate for adaptation to collection of ocean survey data when used from Hydrographic Survey Launches. A number of small vehicle programs are in development that will address advanced MCM capabilities in the Very Shallow Water/Surf Zone (VSW/SZ) Program. These include the VSW MCM Search-Classify-Map (SCM) UUV program, which will be followed by the VSW MCM Reacquire, Identify and Neutralize (RIN) vehicles. When mature and transitioned to acquisition these capabilities will improve naval MCM resources in the VSW/SZ region. The Columbus class vehicles will address expansion of the T-AGS ocean survey capabilities. Smaller vehicles of limited endurance are available to execute shallow water hydrographic and coastal oceanographic surveys. Concepts for ocean survey profilers that operate over great ranges by extracting energy directly from the ocean are in development. Wide area search to depths of 20,000 feet is possible by UUVs such as the Advanced Unmanned Search System (AUSS). These capabilities tend to focus on the ends of the spectrum between sensing the environment and objects in the environment, as indicated in Figure 3-4.

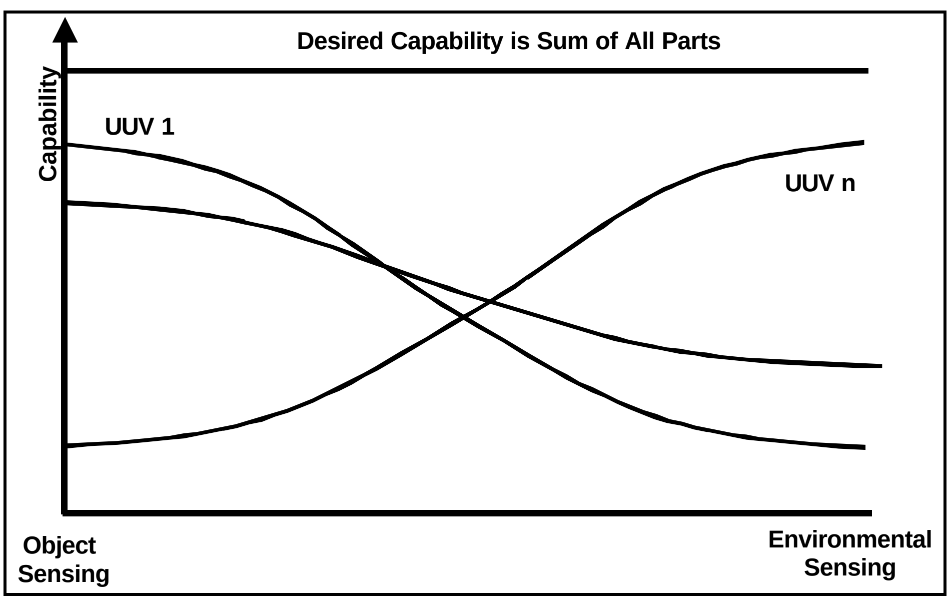

Figure 3-4. Desired Capability

USS must address this entire spectrum. New concepts and upgrades to developing capabilities will provide systems that span a greater range between the environment and object sensing. Appendix C summarizes an array of UUVs and related technologies developed over the past two decades. Much of this body of work has proven the technologies required for the new USS concepts. Examples of applicable technology are: control and fault diagnostic techniques from the Large Scale Vehicle (LSV); sensor integration, navigation, and communications technology from LMRS; packaging and manufacturing approaches from EMATT; and sensor technology from the Advanced Sensors Program.

3.2.3 Concept of Operations

It is clear that no single system can meet all of the USS requirements. A family of systems and UUVs that provide a coordinated approach will make a significant contribution to meeting USS needs. These systems will be deployed worldwide, at all levels of conflict, from a variety of host platforms.

During peacetime, ocean survey operations occur worldwide. These operations are augmented by large UUVs operating from T-AGS platforms. These UUVs are optimized for long endurance with little intervention to gather multidisciplinary ocean survey data. Smaller, midrange UUVs are also employed for use from Hydrographic Survey Launches, other small craft, and aircraft. These UUVs operate in specific areas. Other small dedicated UUVs will drift with the currents or glide using energy extracted from the oceans while profiling to gather ocean survey data over very large areas. This concept includes the Profiling Autonomous Lagrangian Circulation Explorer (PALACE). These systems support documented oceanographic requirements, which are listed in the references.

OSI capabilities are designed for conflict or deterrence operations. However, they can be used during peacetime, for lost object location operations, and for their primary mission of battlespace preparation. Mid-sized UUVs operating clandestinely from submarines focus on critical operating areas. In particular, these systems are well suited for forward operations in denied areas to determine the status of the undersea battlespace. Near real time transmission of this information facilitates the selection of fleet operating areas and the necessity for other follow-on battlespace preparation operations, such as MCM.

Small UUVs will be used for OSI missions in specific areas to augment manned platform operations. These UUVs will be delivered to the very shallow water and surf zone by small manned boats to survey assault lanes. Other small UUVs will be air dropped into the areas of interest and operate cooperatively to search large areas. This technique will provide very high total area coverage rates to support the fleet’s desired operating timelines, presently unachievable in many critical areas.

Table 3-2 summarizes typical examples of UUVs, their employment, hosts, and capability focus, showing the wide range of needs that must be met. Since it is impossible for any one system cover the entire range of requirements, several different sizes and capability systems are needed. An approach that leverages commonality to the maximum extent can allow the multiple system approach to be cost and operationally effective.

Table 3-2: USS Concept Employment.

Vehicle Size	Typical Concept	Primary Host	Primary Mission	Mission Employment	Primary Focus
Large	Columbus	T-AGS	Ocean Survey	Peacetime	Long Endurance
	AUSS	Craft of Opportunity	Search	Peacetime	Deep Ocean
Medium	LMRS	Submarine	OSI	Clandestine	Denied Areas
Small	SWARM	Aircraft	OSI	Overt/Low Observable	High Area Coverage Rate
	PALACE	Aircraft	Ocean Survey	Peacetime	Broad Area Profiling
	SAHRV	Small Boat	OSI/Ocean Survey	Low Observable	Very Shallow Water/Surf Zone

While the primary mission may be OSI or Ocean Survey, all UUVs will provide at least some data in both areas. OSI vehicles will gather as much ocean survey data as possible. Ocean Survey vehicles will gather as much bottom object information as their sensors allow. Common data elements and archives will allow for rapid access to all information that may exist for the areas of interest.

3.2.4 System Concepts

Meeting the USS challenge in the future will require near continual upgrades to developing capabilities and new concepts because of the continually evolving threat as well as the difference between current and desired capability. Systems such as LMRS should be upgraded over time to yield bathymetric products for battlespace preparation and to provide high area coverage rates in more severe clutter environments. All future OSI systems should provide as much ocean survey data as is reasonable. Massively parallel approaches should be explored to attain in-stride OSI capabilities over large areas.

A mix of vehicle sizes and capabilities will be required to satisfy all of the USS requirements. Figure 3-5 shows some of the variation in size among vehicles in use or under development today. Large vehicles operating from surface ships will allow long range missions that are well suited for wider spatial sampling needs such as ocean survey. Mid-sized vehicles operating from submarines or surface combatants that can trade stand-off range and endurance for clandestine insertion that are well suited for USS sampling or small operating areas.

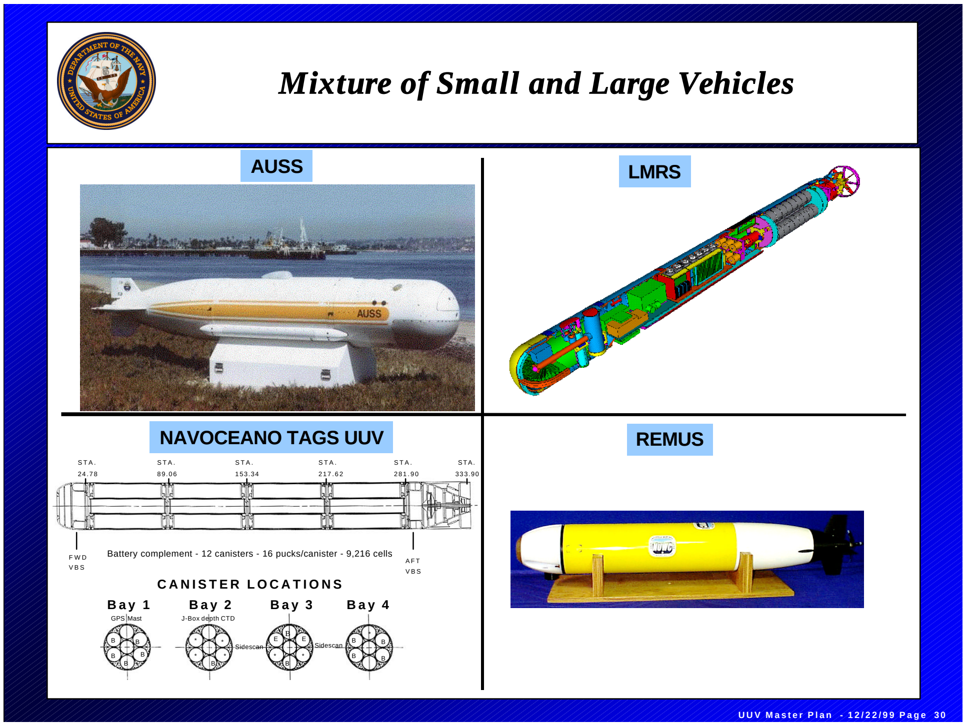

Figure 3-5: Sample Vehicle Sizes

Small vehicles with limited range and mission time require insertion directly into the area of interest. Their small volume and lack of transit range are compensated by the ability of a host to carry many systems. This concept is called the Shallow Water Autonomous Reconnaissance Modules (SWARM). The SWARM concept requires many UUVs to operate cooperatively. This approach is substantially different from current UUV operations and is discussed in more detail in Appendix D. The SWARM concept provides a cost effective and flexible approach to attaining very high area coverage rates for those cases when the systems can be inserted directly into the operating area. Figure 3-6 describes the trade-off between vehicle size, numbers, total system weight, and cost. The small vehicles (approximately 75 vehicles of 500 pounds displacement) represent a good trade between individual vehicle capability, potential host platform delivery capability, and typical large operations areas, for example a CVBG operation area.

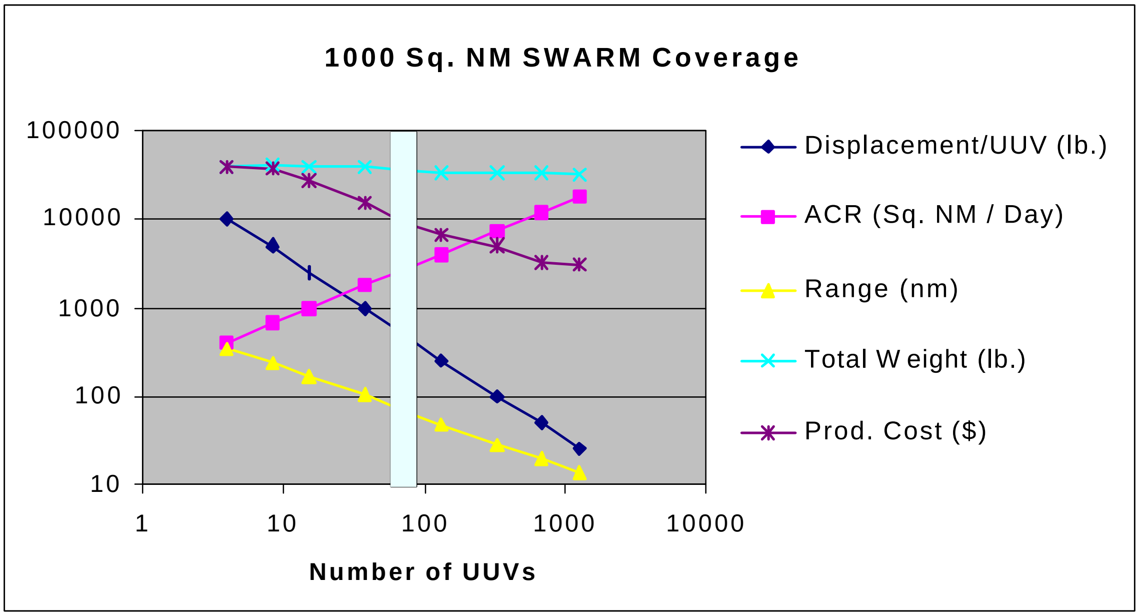

Figure 3-6: Plot of Numbers vs. size, cost, weight, and ACR

3.2.5 Technology and Engineering Issues

The USS program is executable with existing technology. However, to achieve the full benefits of UUVs, advances in technology are necessary.

In the longer term, survey of denied areas will require reliable high-bandwidth communications over several hundred miles. Some long-range UUV missions will require a significant increase in navigational accuracy without surfacing the vehicle. Several technologies have the potential to provide this communication link, including moored or mobile acoustic transponder networks or onboard comparison of terrain with archives of bottom features from acoustic imagery.

Operational requirements mandate significant increases both in mission range and endurance. Higher-density energy storage and improved means for extracting energy from the ocean environment are essential. Undersea docking stations for recharging batteries and extracting data should be viewed as long-term necessities.

Launch and recovery systems for large ocean survey UUVs are complex and dangerous. The Vehicle in Cocoon (VIC) technique mitigates some of those issues; however, simpler launch and recovery procedures are highly desirable.

Operational use of UUVs requires a simulator for mission planning, mission reconstruction, and data-acquisition systems testing. Simulation is also required for vehicle design, performance analysis, and operator training. Improved visual interfaces, improved vehicle hydrodynamic models, four-dimensional oceanographic models and sensor models are required.

Technology to support SWARM is mature and most aspects have been proven in the field. Cooperative behavior of many autonomous vehicles will require engineering development. Sensor technologies that can achieve the needed levels of performance to make the SWARM concept feasible have been proven. Engineering for this application is low risk.

3.3 Communication/Navigation Aids

The Communication/Navigation Aid (Comm/Nav Aid) will be the enabling undersea node of the Net-centric Warfare Sensor Grid. It will provide connectivity across multiple platforms and the ability to provide navigation aids on demand. Navigation and communication components developed for this capability will become integral parts of or support other UUV systems fielded in the future.

3.3.1 Objectives

The objective of the Comm/Nav Aid Signature Capability is to provide a clandestine communication and navigation relay function for a wide variety of platforms. As a communications relay, the primary focus is on providing a high-speed, high-bandwidth data link for underwater use. Link would be established with underwater stations, other platforms, and SATCOM capabilities as shown in Figure 3-7. The advantages offered by using a UUV include the ability for extended standoff distances, greater accessibility, and high bandwidth and data rate communications. Potential users would include other UUVs, submarines operating at speed and depth, Special Forces units, and any other application where covert communication is desirable.

As a navigation aid, the Comm/Nav Aid is envisioned as an on-site on-demand reference point for subsea or surface operations. Pre-positioned, either just prior or long in advance of planned operations, the vehicles could provide reference beacons (visual, radar, or acoustic) for other UUVs, submarines, special forces, or surface operations. These could take the form of lane designators, undersea mileposts, or even a network supplementing or replacing conventional navigation means. In critical situations, the Comm/Nav aid could provide an above or below water navigation capability equivalent to GPS accuracy without the need for direct satellite communication. Comm/Nav aid UUVs might also aid less capable UUV systems, providing a mobile reference system.

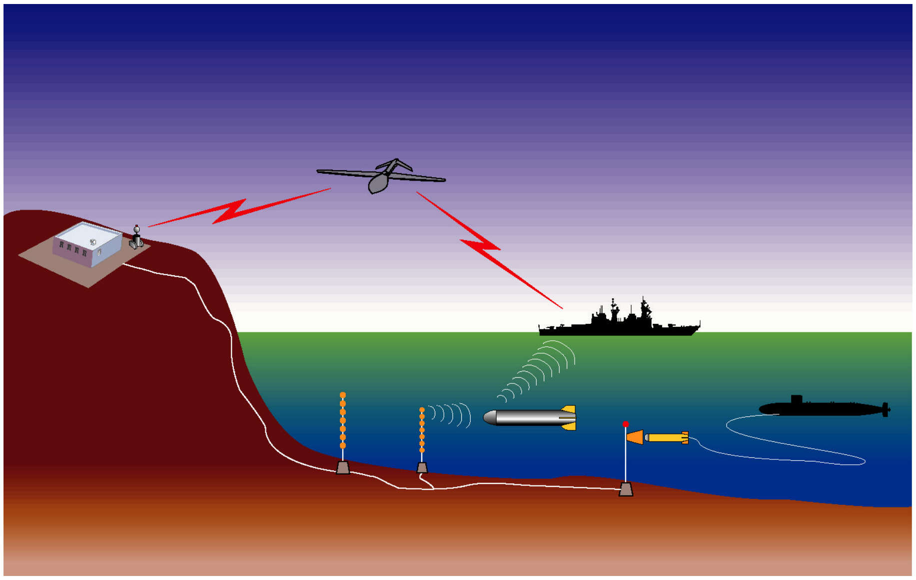

Figure 3-7: UUVs for Underwater Connectivity

3.3.2 Background

There have been a number of programs addressing various aspects of the component Communication/Navigation Aid Signature Capability. These provide key enabling technologies that will be incorporated into the Comm/Nav Aid systems. Several relevant programs are described below as a sampling of the development status for some of the critical technologies.

Docking: A key technology for the Comm/Nav aid is the ability for an autonomous vehicle to dock with a docking station for the exchange of data or possible recharging. This capability has been demonstrated by a number of existing systems including NMRS, MIT Sea Grant Odyssey, SPAWARSYSCEN Flying Plug, and WHOI REMUS vehicles.

GPS Operations: There have been a number of approaches to using GPS navigation for underwater vehicles. Periodic surfacing and deployment of small antennas to the surface have both been effectively demonstrated as means of accessing the GPS network. Hybrid navigation systems, combining both acoustic and GPS navigation are currently being developed. The vehicle navigates acoustically relative to buoys, whose position is determined via GPS. Essentially, this provides an inverted GPS grid for use underwater. Taking this one step further, the use of pre-deployed bottom reference units is a logical progression of this technique.

Communications: Depending on the need for the specific mission combinations of communications capabilities would be employed including RF, FLTSATCOM, acoustic, laser or fiber. Fiber optic is the current choice for high bandwidth, high data rate communications. It has been demonstrated over long distances and using small diameter fibers. However, it has a limited lifespan, requires a hard connection and is costly. Acoustic communications is very appealing for vehicle operation as it does not require a hard connection with the vehicle and may be accomplished over significant distances. A great deal of work has been performed in this area over the past decade, resulting in development of acoustic modems and other data communication techniques. UUV communications to a submarine has also been demonstrated using lasers, as well as the use of a sub-launched UAV. Small RF systems and towed SATCOM systems have been demonstrated as well.

3.3.3 Preliminary Concept of Operations

The general concept of operations is to provide on the spot connectivity and navigation capability for a variety of platforms. This is envisioned as both a stand-alone capability and also as a component to other Signature Capabilities. The modules developed for the Comm Nav Aid would also support the navigation requirements of the Undersea Search and Survey and the communication needs of the Maritime Reconnaissance. Table 3-3 below summarizes notional capabilities.

Table 3-3: Communications/Navigation Notional Capability

Radius of Operation (NM)	1-10
On station time (hours)	~100
Endurance (operational) (hours)	12
Speed (knots)	2-5
Nominal Displacement (pounds)	500

For use as a communications relay, the vehicle would be outfitted with the desired mode(s) of communication: optical fiber spool and connector, acoustic modem, laser communication, or SATCOM antenna. The vehicle is deployed from the platform and makes the desired connection, be it with a subsea fixture, other platform, or the surface for SATCOM transmissions. The data exchange would take place- either one-way or two-way – with minimal impact to the host platform operation. Once the communication was concluded, the vehicle could either be scuttled or recovered, depending on the operational circumstances. While this function is most obviously an asset to submarine platforms, it could also be used effectively by special forces, other UUVs, or even surface platforms requiring connectivity to a subsea installation. Even Unmanned Aerial Vehicles (UAVs) could be used as relays, either launched from UUVs as a link in the transmit chain or from another platform as a remote receiver link.

On-demand navigation references could be a useful tool to platforms of all types. The vehicles would be programmed to transit to desired marker locations. Deployment of the vehicles could be performed by a variety of platforms (including airdrops) well in advance of the intended need. The vehicles would then proceed to the designated locations, navigating by means of inertial and/or GPS. They would sit quiescent until the time of operation. This could be set as a time span after launch, an absolute time, or upon a specified signal, such as an acoustic pulse. Once activated, the vehicles would deploy the navigation beacons, be it pop up buoys, acoustic transponders, or other means of indicating position. Once the operation is complete, the vehicles would have the options of scuttling or returning to a home base for recharging and reuse.

3.3.4 System Concepts

Many basic system features are common to both the communication and navigation functions of the Comm/Nav Aid. The basic vehicle configuration is seen as a small, low-cost system, potentially expendable under certain operational conditions. Ideally the system will be adaptable to a variety of platforms, requiring a minimum of support equipment for launch. Beyond the vehicle system itself, many of the subsystems (communication and navigation modules) developed for this Signature Capability will become integral parts of the other systems discussed.

The communications portion of the Comm/Nav Aid is seen as a versatile communications link, able to provide connectivity through a selection of modes. Conceivably, such a vehicle could contain an optical fiber pack and connector, much as has been demonstrated on the Flying Plug. It could contain an acoustic modem, relaying communications from a subsea network. A vehicle could carry a SATCOM antenna, providing a safe standoff capability from the host platform, while allowing a full range of contact with conventional communication channels. Laser communications have also been demonstrated on UUVs- this too could be incorporated as yet another means of communication. Ideally, the stand-alone Communications aid system could be easily configurable with a variety of communications modes, readily adaptable to the operational needs.

The navigation system component is seen as relatively straight forward, requiring mainly the ability and endurance to navigate to a desired location. This would most likely entail the use of GPS navigation, whereby a relatively small UUV can maintain a low enough profile on the surface to avoid detection. Auxiliary forms of navigation, such as an inertial unit, would supplement and enhance the operating capabilities. The vehicle payload would be the navigation beacon, be it an underwater acoustic source or a pop-up buoy. The buoy would include both visual and radar targets, enabling its use under a wide variety of conditions. Sizing of this system would be largely dependent on the buoy requirements and the desirability of being able to transit significant distances. It is conceivable that a network of these vehicles could be placed on a semi-permanent basis, acting as a supplement or replacement to GPS for underwater systems.

For both the communication and navigation functions, whole networks can be envisioned, whereby UUVs provide one of many types of linkages. Network nodes can serve as homing and docking stations for UUVs, providing data communication and energy replenishment.

3.3.5 Technology and Engineering Issues

Of all the Signature Capabilities discussed, the Comm/Nav Aid is the most technologically ready for development. There are no critical path developments preventing the construction and deployment of systems similar to those described. All of the key abilities have been demonstrated as feasible by individual autonomous systems. Enhancements to the integral technologies, however, will permit the systems to achieve a wider range of operational capabilities. System complexity, long term deployment, and other factors will be key in the development of cost effect systems.

Much work is currently ongoing on undersea communication modes. Particularly in the area of acoustic communications, advancements are desirable in bandwidth, data rates, range, and reliability. There are a variety of optical fibers available for use, but improvements in reliability, life span, and costs will all contribute to the viability of use. The key engineering issue for the employment of these systems is largely one of the infrastructure required. In one rendition, these vehicles are seen as the means of connecting to the undersea communications grid, but such a grid must first exist before they can be of use. There must be docking stations available that are readily compatible with the vehicles and reliable over long periods of time. Issues such as long term immersion and biofouling must be considered for long term use. Both the vehicles and all supporting infrastructure must be designed to operate in a rugged and reliable manner for long duration deployments.

3.4 Submarine Track and Trail Capability

The Submarine Track and Trail Capability is illustrated in Figure 3-8. It will complement and extend existing anti-submarine warfare capabilities.

3.4.1 Objective

The objective of this capability to patrol, detect, track, trail, and handoff adversary submarines to U.S. Forces using UUVs. A further objective is to perform this function under any rules of engagement and without taking actions that could inadvertently advance the stage of conflict. Given the restriction of access due to bathymetry, the fact that undersea forces may be the only forces early, and the desire to track and trail submarines regardless of the stage of conflict, the UUV is a logical candidate for the task.

3.4.2 Background

It is vitally important that the Sea Lines of Communication remain open. In order to do this, it is necessary to establish and maintain a highly effective Anti-Submarine Warfare (ASW) capability. This is done now, but there are several factors that point to Unmanned Undersea Vehicles (UUVs) taking on an ASW role in the future:

- Due to the lack of an ocean transit or large magazine (payload) requirement, adversary submarines can be much smaller than U.S. submarines, and can therefore submerge in shallower waters. Due to the bathymetry and local knowledge, it is possible, and likely, that these submarines can and will submerge near homeports and outside the reach of U.S. Forces.
- Further in the future, due to proliferation of other technology, air superiority cannot be assured at all stages of conflict. Without local air superiority, undersea vehicles (manned and unmanned) may be the only undenied forces early in the conflict. However, those manned platforms may be insufficient in number, without force multiplication from unmanned systems, to accomplish the battle space preparation required in a timely manner and with reasonable risk.
- In ASW, especially in submarine vs. submarine engagements, it is best to be in the position of first to act. Dominance is not possible in reactive submarine warfare.

3.4.3 Preliminary Concept of Operations

Baseline Situation: It is assumed that some type of cueing exists (satellite or other) on the home port and nominal readiness of adversary submarines, but it would be unlikely to have knowledge of sailing dates or times. The precise course of departure from the port to the 12 NM limit and the location of the dive point are also variables. Due to the possibility of adversary (local) air superiority and the limitations of the bathymetry around ports of interest, candidate UUV launch platforms may have a closest point of approach which is still a substantial distances away from the dive point.

Baseline CONOPS: It is therefore anticipated that the UUV would launch from a substantial distance and transit into the search area, most likely prior to the adversary submarine leaving the pier. Based on chokepoints or known patterns, the UUV would, potentially with the assistance of smaller UUVs or deployed devices, establish a barrier patrol and sustain this patrol for several days. The UUV would maneuver as necessary to classify detected targets and upon valid detection begin a trailing operation. It would be necessary during this trailing operation to both avoid counter-detection and to communicate to U.S. Forces that a trail had been initiated and to provide periodic updates. The UUV would break trail and transit to a rendezvous location based on the initial sortie plan or as updated via the communication intervals. Later, perhaps after a significant loiter period, the UUV would be recovered or replenished to enable another mission. Figure 3-8 following illustrates the concept.

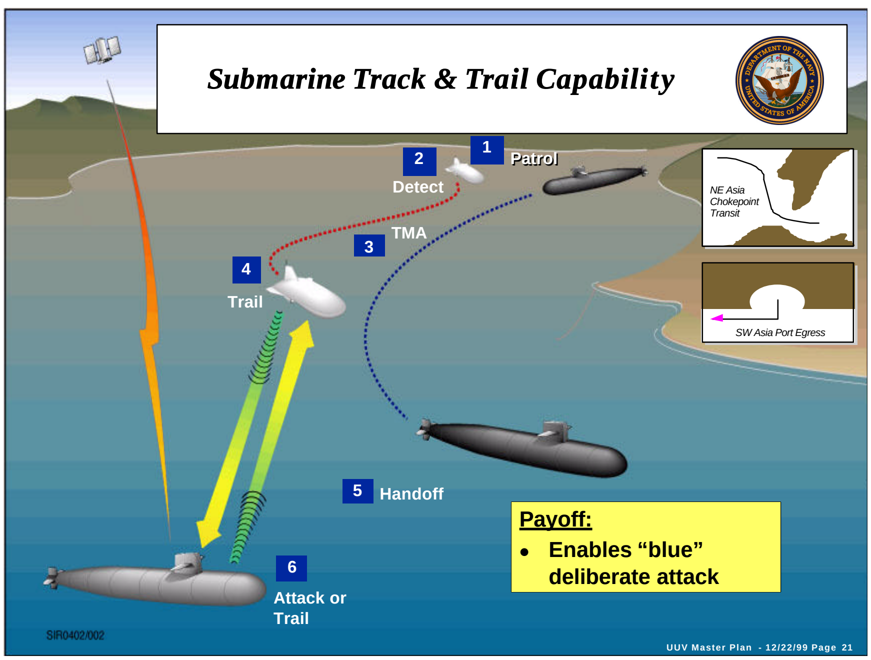

Figure 3-8: Submarine Track & Trail Concept

Alternative Situations and CONOPS: The situation and associated CONOPS above are demanding, but will occur from time to time. Situations with better cueing, or situations with different Rules of Engagements (ROE), can significantly reduce the technical challenge for the UUV, and may be the only situations for which a capability can be fielded in the near-term. Examples of situations with better cueing would be the submarine track and trail missions performed with the UUV in combination with Advanced Deployable Systems (ADS) or Deployable Autonomous Distributed System (DADS). An example of an ROE change is one permitting tagging, eliminating the requirement to trail, or in a situation with air superiority, immediate handoff to air ASW assets. Any of the above, or combinations of the above, reduce the endurance requirements on the UUV substantially by either reducing loiter time or eliminating the requirement to maintain trail on the target submarine for a significant time. These changes would also reduce the complexity associated with UUV Autonomy. Initial variants of Submarine Track and Trail UUVs may also be used for consort operations, providing a mobile source or a sensor working coordination with conventional manned ASW assets.

3.4.4 System Concept

The submarine track and trail capability is the least well defined of any in the UUV Master Plan. The specific system concept is pending the resolution of the technical issues, decisions on launch platforms (submarine, surface ship, or both) and resolution of engineering issues associated with those platforms. Work in DD21 and the DARPA Future Submarine Payload study may begin to address those engineering issues. The expected system parameters identified by the UUV Master Plan are listed in Table 3-4.

Table 3-4: Notional Capabilities, Submarine Track & Trail

Radius of operation (NM)	10-100+
Endurance (hours)	>200
Patrol Area –Choke Point (NM)	5-20
Speed Range (knots)	3-12
Displacement (tons)	~10

The ultimate Submarine Track and Trail capability is envisioned to be provided by a large UUV housing several sensor suites with an advanced energy and propulsion capability. The sensor suite would likely include: a passive acoustics suite, either conformal or towed; a non-acoustic suite, which is used for the initial detection and as an aid in maintaining trail; and a short range very high frequency, low probability of intercept sonar for obstacle avoidance and close tracking. The UUV would have extensive communications capabilities; these would include ACOMMS and SATCOM and may include others. Use of a "floating wire" type SATCOM system is likely, as this would enable transmission of quarry parameters without breaking trail.

3.4.5 Technology and Engineering Issues

Technology issues associated with this capability include communications, energy/propulsion, sensors, and autonomy. Specific issues associated with these technology areas are addressed in more detail in the following chapter. Engineering issues obviously exist with the launch and recovery (assumed) of a fairly large UUV, and associated with those engineering issues are some CONOPS details. Those details include the decision on whether or not to recover to the same platform to which handoff occurs, and if so, when/how to recover without losing the trail or alerting the tracked submarine.

Launch and recovery of large vehicles on the submarine may actually be simpler than with 21” vehicles since clearances and alignment can be designed to not be as difficult as it is with 21” x 240” vehicles and 21” diameter tubes. Although the engineering implications may be simplified, there will be a significant cost associated with submarine platform modifications of this scale. Submarine compatible larger vehicles in the near-term must be either wet docked, towed, or compatible with existing interfaces (missile tubes, dry deck shelters).

Launch and recovery of a large (potentially 10 ton) vehicle from surface craft is a significant engineering challenge. Operation in high sea states with or without divers would be difficult, but not insurmountable. Cruiser/Destroyer type platforms are the least capable of taking on such a task, but have the advantage of usually operating forward and possess relatively low freeboard. Large deck ships (carriers, amphibs, auxiliaries) are either not suited to the task, have no room in the well deck (amphibs) or are not always operating forward (auxiliaries). As a result, surface launched and recovered UUVs will have to be engineered to meet the needs of smaller combatants, which means that size must be minimized, and 10 ton vehicles are likely to be found unacceptable. Although the ultimate capability presents some technology challenges, this capability is very high payoff, and subsets of this capability would provide immediate force multiplication. The Submarine Track and Trail capability also leads to growth into other mission areas, such as engagement, which will ensure continued dominance.

4 UUV Technology and Engineering Issues

Effective use of UUVs requires both appropriate technology development and sound engineering. To achieve the four Signature Capabilities, efforts must be made in both areas. Technologies to be developed include autonomy, communications, and sensors. Engineering efforts are required to modularize vehicle systems, reducing the overall costs while increasing capabilities and interchangeability.

4.1 Technology Area Risk Assessment

There are a number of technologies common to all UUV missions. These include the overall vehicle architecture, communications, navigation, energy, mission critical sensors, data processing and overall autonomy. Each of the Signature Capabilities was examined in light of the technological capability required and assessed as to the risk involved. Figure 4-1 below summarizes the technology risk for accomplishing each of the missions as described in the plan. Green indicates a mature capability, with current technologies able to perform the task with little or no development required. Yellow indicates that some refinement and enhancement is required to fully realize the mission as described. Red indicates that a significant development effort will be required before the full mission can be reliably performed. Many of these are matters of degree, whereby the mission may be performed at a lower level with less development required. The most critical technologies are discussed in more detail in the following sections.

Risk vs. Technology vs. Capability

	Maritime Reconnaissance		Undersea Search & Survey								Navigation/ Communication Aid			Submarine Track and Trail				
			Object Sensing & Intervention					Oceanography										
	Pass.	Active	Detect (SLS)	Class (SAS)	ID	Neut	Interv.	Bottom Char	Bathy	Volume Meas.	Comm.	Nav.	Data Ex.	Detect	Class	TMA	Trail	Hand-off
Communications	Yellow	Green	Green	Green	Green	Green	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
Navigation	Green	Green	Y-G	Y-G	Y-G	Y-G	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green
Energy	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Red	Green
Propulsion	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Green
Mission Equip.	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Sensors	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green
Data Processing	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Autonomy	Yellow	Yellow	Green	Green	Yellow	Green	Red	Green	Green	Green	Green	Green	Yellow	Yellow	Red	Yellow	Red	Yellow

- **Definitions:**
  - Mission Equipment: Specific HW items associated with the Mission, not on-board sensors, but includes deployed equipment
  - Sensors: UUV Installed Sensors Specific to accomplish the mission function
  - Data Processing: Data processing and management specific to the mission requirements
  - Autonomy: Software / artificial intelligence and decision making associated with performing the mission without human guidance
- **Ratings for near term Acquisition (assuming minimal risk mitigation):**
  - Green: Low Risk ; Y-G Risk Low-Moderate dependent on size
  - Yellow: Moderate Risk
  - Red: Significant Risk

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Figure 4-1: Technology, Risk, and Capability

4.1.1 Energy

Energy has long been a major consideration due to its affect on the ultimate performance of extended vehicle missions. When one moves away from surface supplied power, the energy source becomes a major factor in the design and efficiency of a vehicle system. Energy is not the driving force for any of the Signature Capabilities; however, for all operations there is a desired to minimize the size, cost, and signature of the energy and propulsion system.

The risks associated with implementation of any of the Signature Capabilities from a propulsion and energy standpoint are for the most part low, and the larger the vehicle the lower the risk. For Submarine Track and Trail, regardless of the UUV size, trailing, with the need to communicate periodically, may require the UUV to operate at a higher average speed and to vary speed (drop back to communicate, and sprint up to hold trail). An energy dense power source with the ability to operate over a wide range of power densities combined with the requirement for a very quiet propulsion train is a technology concern.

4.1.2 Communication

Communication is required between the vehicle and surface platform for both the transmission of commands to the vehicle and transmission of data from the vehicle to the support platform. Primary issues to be considered when evaluating a mode of communication for a UUV task include available bandwidth, range between source and receiver, covertness, and the infrastructure required. These are of particular concern for the Maritime Reconnaissance and the Submarine Track and Trail Missions, when communication is desirable without exposing the sender or receiver to possible hostile interception.

Communications is for the most part not a major risk area. History has shown that greater bandwidth will be consumed at the same rate it is produced, but sufficient bandwidth exists to perform missions associated with the Signature Capabilities. Nonetheless, an expansion of bandwidth capability is desirable in those methods allowing more covert communication, such as acoustic communications.

Risks are also associated with multiple vehicles operating together, such as is proposed for the Undersea Search and Survey Capability. Methods of effective communication between vehicles working in a network must be established and proven. This is presently being addressed by various research efforts, mostly under ONR sponsorship.

4.1.3 Sensors

All of the missions described depend on the effective use of sensors, most particularly the Undersea Search and Survey and the Submarine Track and Trail capabilities. Development in the sensor arena needs to be concentrated in increasing area coverage rate (ACR), use of passive non-acoustic sensors, and sensor processing.

In order best to meet the requirements of the USS capability, Synthetic Aperture Sonar (SAS) implementation on UUVs is desired. This is not far from being achieved since the technology has been demonstrated on towed bodies, both at high resolution and at long range, but not yet both. SAS would provide both increased area coverage rate, or reduced numbers of UUVs and increased resolution. A SWARM system with SAS would likely require only half the UUVs while delivering a superior product. An LMRS with SAS would have a three- to five- fold improvement in classification area coverage rate, at roughly three times better resolution.

Passive ASW sensors clearly exist and the performance of these sensors at apertures possible from a medium sized UUVs is suitable for this mission. However, the real breakthrough ASW sensor for UUV applications may be non-acoustics since this technology is not as strongly aperture dependent and can therefore be exploited in smaller systems. Regardless of the sensor choice (passive acoustics, non-acoustics, or electro-magnetic) sensor algorithm processing must be automated so that the sensor can be used in a "trail, but do not be counter-detected" role. Some of the passive homing technology can be lifted from torpedoes, but implementation of the "track, but avoid" tactic will require work.

Sensor processing and the automation/decision making associated with the processing remains a developmental area for both USS and STT. For Undersea Search and Survey the principle risk will be the autonomous processing of sonar and optical images to classify mine like objects and identify mines. For Submarine Track and Trail, the risk is associated with autonomous processing, target recognition, counter measure rejection, Target Motion Analysis (TMA), and tactics.

All of the missions require a degree of precision navigation, from the long-distance transits of the Maritime Reconnaissance System to full area coverage of the Undersea Search and Survey Systems. Accurate navigation is not a risk area unless the system's size, CONOPS, or intended use prohibit or constrain the frequency of use of the Global Positioning System (GPS). When those restrictions exist, navigational problems can be addressed via use of an active communications/navigation aid such as a transponder field or UUV, or by passive means such as terrain matching.

4.1.4 Autonomy

Autonomy issues are key to all the Signature Capabilities. The need for long-term independent operation is the basis for both the Maritime Reconnaissance and Submarine Track and Trail missions. Both of these require the ability to transit long distances, detect, assess, and avoid potential threats, and collect information independent of direct human operation. Another aspect of the autonomy question is the operation and coordination of multiple vehicles. This is key to accomplishing large scale Undersea Search and Survey tasks, both for Object Sensing and Intervention and Ocean Survey applications.

The area of autonomy and control is a major research area for all UUVs, whether military, commercial, or academic in origin. Areas requiring development cover the spectrum of UUV operations. Sensor data must be collected and combined to create a meaningful information base for decision making. The system must be able to take the information and use it for planning, while maintaining mission priorities in light of the data collected. The system must be able to react to rapidly changing data, allowing the vehicle to avoid threats and maintain proper operation. Finally, the system must know when to communicate the data, while avoiding hostile interception. These areas all require continuing work to develop the robust capacity required by the Signature Capabilities.

4.2 Engineering Implementation

As important as the technology involved is the engineering implementation of that technology. Engineering considerations are often driven by the size of sensors, energy sources, and payloads, as well as logistic concerns. However, the size and number of vehicles to be used, the overall system costs, and the interchangeability of modules all need to be considered as a critical part in developing the needed capabilities.

4.2.1 Vehicle Size and Number

Whereas vehicle size is rarely a critical component of the mission, it is generally advantageous to have as small a package as possible to facilitate storage, handling, and general logistics. In most cases, the size is driven by the energy and payload requirements needed for a given mission. For example, Figure 4-2 shows some general size and number tradeoffs for UUV coverage of a 1000 sq. NM area. Either a few large vehicles can be used or many smaller ones. Depending on the specific mission requirements, any part of this range may be appropriate. For instance, the long range requirements of the Maritime Reconnaissance and Submarine Track and Trail missions point to the use of a large single vehicle, while the area coverage requirements of the Undersea Search and Survey point to multiple smaller systems.

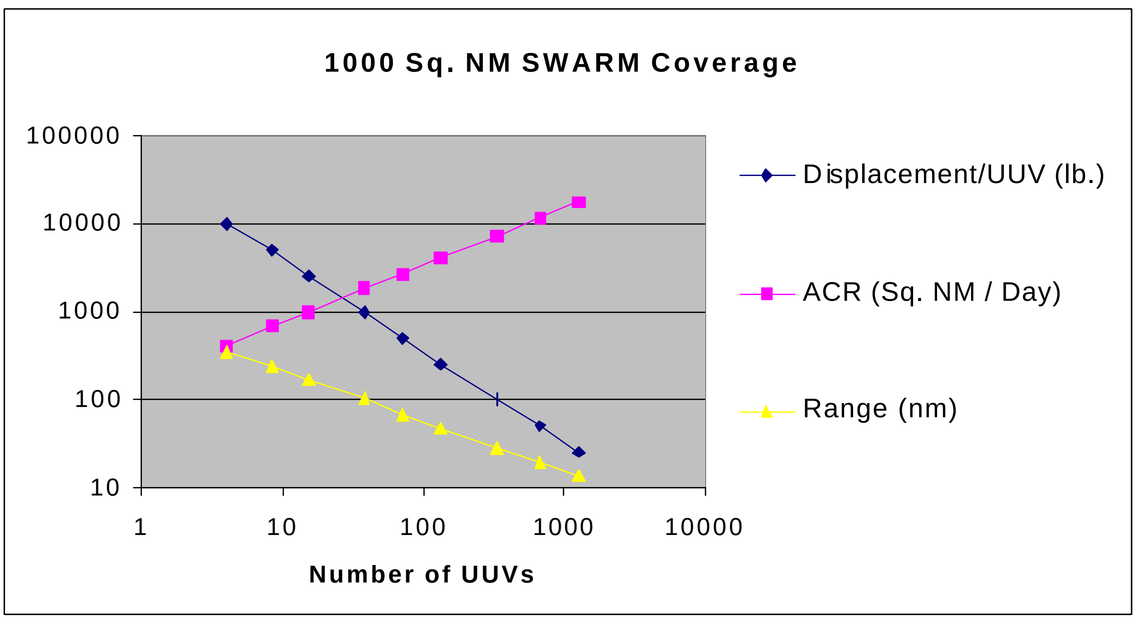

Figure 4-2: Trade-Offs Among Vehicle Size and Numbers

4.2.2 Cost vs. Quantity

An additional challenge for the UUV Master Plan is delivering the cost savings of high production rates, not only for the few UUVs that are produced in quantity, but also for all UUVs. Figure 4-3 summarizes the range of normalized production cost for UUVs or

UUV like devices (torpedoes) covering sizes from 25 lbs. to 20,000 lbs. As shown in Figure 4-3, at low or prototype production rates, typical cost is $1,000 per pound for UUVs. At higher production rates, there is less data, but the trends indicate that costs approach $100 per pound.

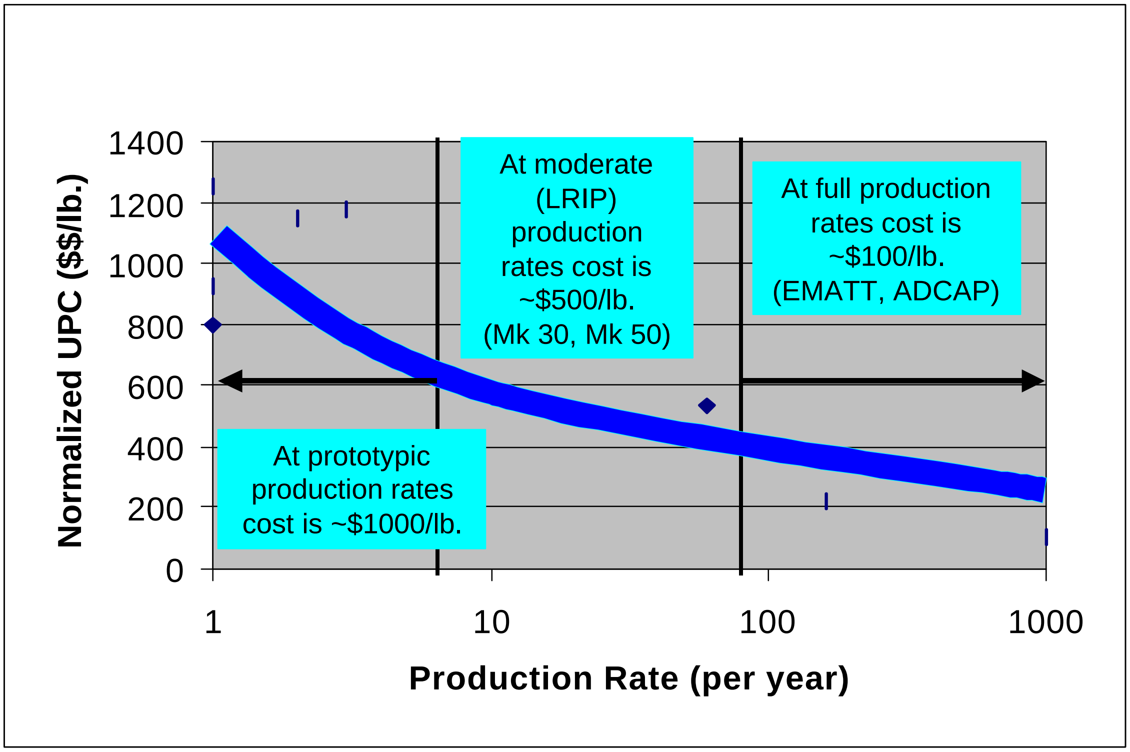

Figure 4-3: UUV Cost as a Function of Production Rate

4.2.3 Benefit of Modularity

To achieve the cost benefits of mass production in larger, low production rate systems, a modular approach is recommended. Development of standardized vehicle modules will provide the basis for all the Signature Capabilities, while maximizing the compatibility and transition of components across systems. NUWC-Newport, NAVOCEANO, and Florida Atlantic University are demonstrating this concept in construction of their respective UUVs as shown in Figure 4-4.

The cost benefit and ability to reuse hardware from previous UUV configurations should outweigh any performance penalty for this type of packaging. If modules are common across different UUV capabilities, a “common parts bin” results which significantly reduces overall cost. Use of common hardware modules as well as common software modules will enable more effective transition from legacy systems as needs evolve.

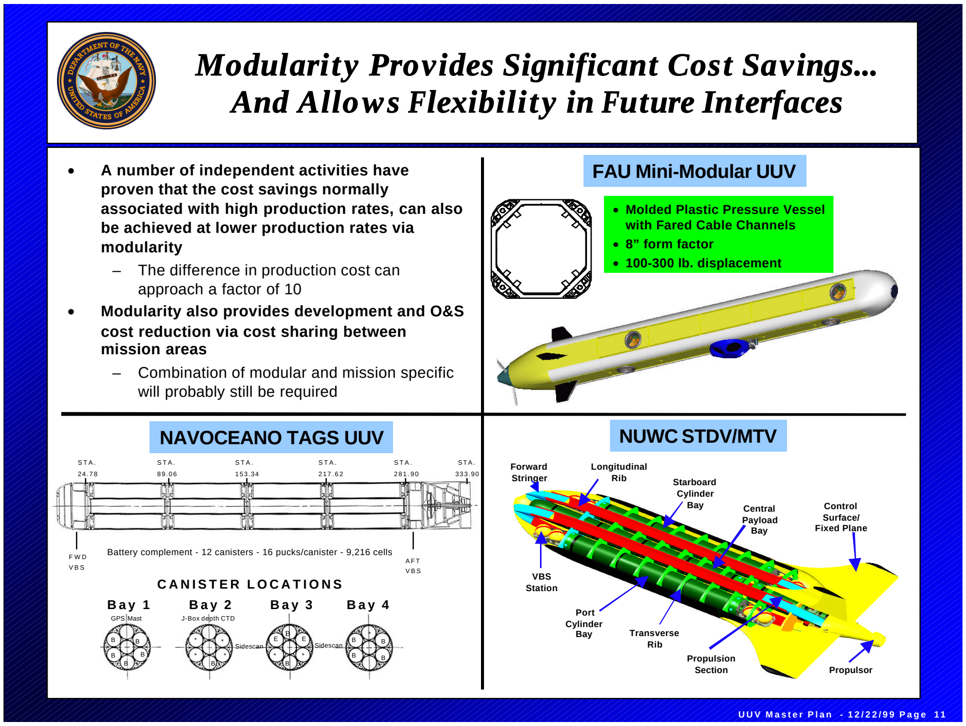

Figure 4-4: Benefits of Modularity

4.2.4 Size of Modules / Vehicles

To be prepared for a full range of potential needs, both known and unknown, UUVs should be sized to allow maximum flexibility. This includes consideration of launch and recovery platforms, specific mission requirements and anticipated payload considerations. Regardless of how these evolve, standardized vehicle modules will maintain future flexibility and accommodate transition from existing efforts.

This plan will not define the standard, but will charge the UUV acquisition community with the development of such a standard. It is believed that as few as two module sizes will be required. High performance modules supporting robust processing capability and high performance UUV components need not be larger than 21" diameter. This size is compatible with ATR boxes, 6U VME cards, and high performance Inertial Navigation Units while leaving sufficient room for quieting, cooling, and maintenance considerations. It should not be necessary for the largest standard modules to be significantly different than 21" diameter. This will also enable transition of components/technologies from existing UUVs or UUV acquisitions (NMRS, LMRS, and Mk 30 Mod 2) to reduce risk.

Smaller low cost modules can be employed when the mission does not require the navigation or processing power associated with the larger modules. The smaller size is more difficult of a choice with multiple platform infrastructures (6 ¼" tube, 12 ¾" tube, and various airframe interfaces), COTS formats (PC104, 3U VME), and standard tubing/pipe sizes competing to define an optimum. Some compromise will be required. It is expected that reasonable choices in the 6" to 12" size can be made. Although there may be a need for three sizes, the selection of the exact module sizes is being left to future studies. The greatest savings will occur if there are only two module sizes. The balance of this document is based on that assumption.

Vehicle size will not necessarily be a function of module size. Module size will be selected based on the component performance required, and vehicle size will suit the mission and platform interface needs. Figure 4-5 indicates the range of vehicle sizes possible with a small module size, notionally 9" diameter.

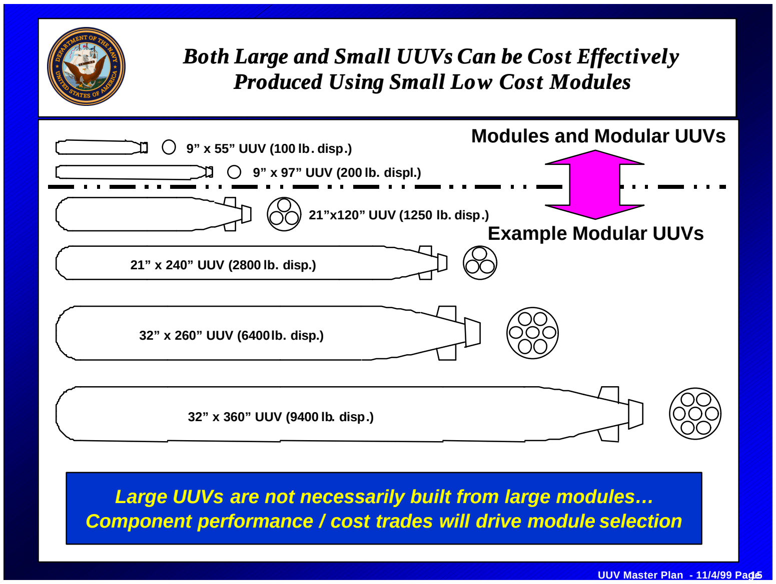

Figure 4-5: Small Low Cost Modules Support Multiple Vehicle Sizes

Similarly, Figure 4-6 below indicates the range of possibilities for the larger, nominal 21" modules.

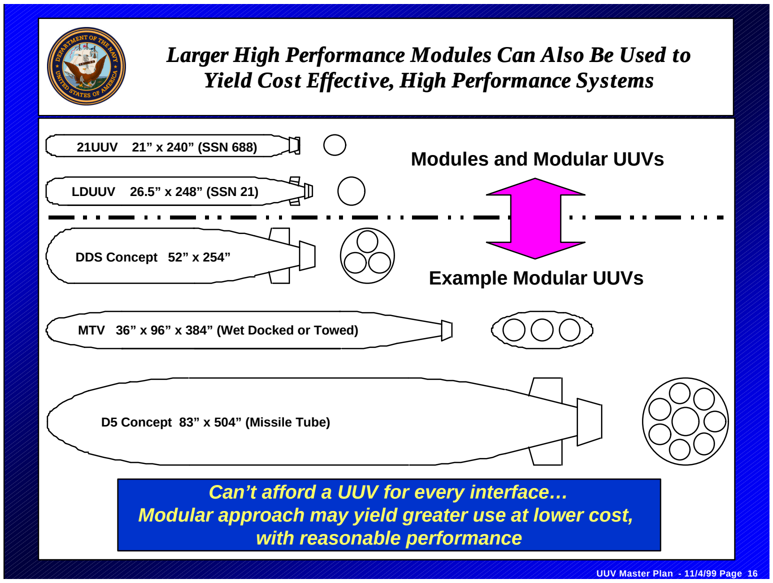

Figure 4-6: Large High Performance Modules Support Multiple Vehicle Sizes

5 Development Plan

5.1 Key Considerations / Underlying Philosophies

The UUV Master Plan was created with one basic goal to be achieved via several underlying philosophies:

Goal:

Deliver End Items … And Begin Using Them!

Deliver robust UUV capabilities to the Fleet as soon as possible at minimum cost. The UUV Master Plan recognizes that there are several parallel UUV developments underway at this time, each with a valid mission, and these should be continued. There are also a few existing capabilities, and those capabilities must be rapidly expanded. UUVs can provide a revolutionary increase in undersea capability, enhancing the effectiveness of our forces while reducing risk. Furthermore, UUVs can provide this force multiplication at a very small fraction of manned systems cost.

Philosophy:

Minimize Cost, Maximize Synergy, But One Size Does Not Fit All!

The philosophy of minimizing cost and maximizing synergy is easy to derive and accept, but existing UUVs already span an impressive range of sizes: from as little as 25 lbs. to as great as 32,000 lbs displacement. UUVs will continue to vary in size and shape to suit the interfaces of the launch platforms as well as the intended mission. Therefore, synergy is a significant challenge since one size does not fit all. In addition, it is a secondary objective to minimize UUV rework and associated costs required to maintain or enhance the signature capabilities as new platforms come into service.

5.2 Programmatic Roadmap

Realization of the four Signature Capabilities will involve both the continuation of present UUV efforts and the initiation of new programs. A programmatic roadmap, summarized in Figure 5-1, was created that outlines the connection between existing Navy programs and recommended development efforts. As shown in the figure, two new development thrusts are proposed:

- Mini-Modular UUVs (in various sizes)
- Tactical Modular UUVs (in various sizes)

These new thrusts leverage the benefits of current UUV, or legacy, programs while exploiting ongoing and future payload technology developments. Within these major thrust areas, components will be developed in a modular fashion to address long-term needs and cross-vehicle compatibility. With standardization, and synergistic oversight, the rapid development of new capabilities will be realized.

As is indicated in Figure 5-1, the Master Plan has four basic building blocks, working synergistically to deliver capabilities. These four parts are design specific UUVs (today's legacy), UUV/UUV Payload technology, mini-modular UUVs in various sizes from small undersea modules and Tactical Modular UUVs in various sizes from larger undersea modules. Key elements of the plan are expanded in the following sections.

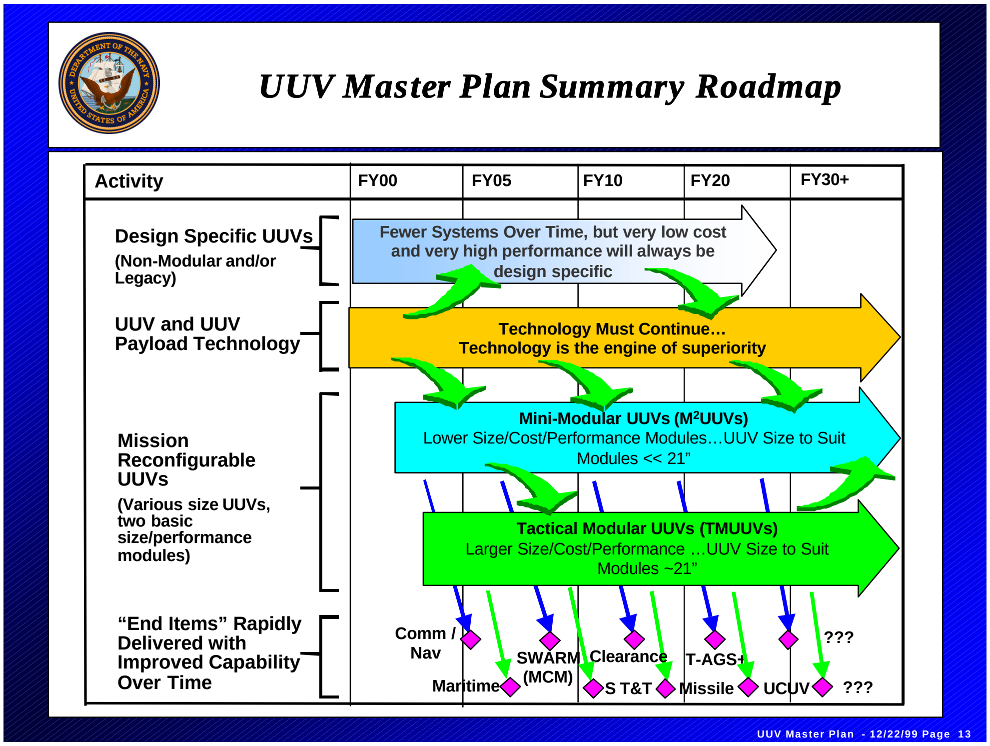

Figure 5-1: UUV Master Plan Summary Roadmap

5.2.1 Dedicated and Legacy Systems

Current UUV programs will contribute to the development of the Signature Capabilities while fulfilling near term requirements. Figure 5-2 shows a more detailed view of the roadmap, relating current programs, Master Plan recommendations and end-item deliverables. Oceanographic systems such as the Columbus Class UUVs and systems derived from REMUS type vehicles will provide the baseline for Undersea Search and Survey oceanographic missions. Small vehicles based on existing platforms will also be evaluated by the Search, Classify, Map (SCM) and Reacquire, Identify, and Neutralize (RIN) efforts under the VSW MCM Detachment. UUVs such as AN/BLQ-11A (LMRS), with its IOC in FY03, and the existing Mk 30 Mod 2 training target, will transition components to a Tactical Modular UUV infrastructure. Mission dedicated, high production items, such as the EMATT targets and oceanographic profilers will be required to fill their appropriate niches. Special purpose and one-of-a-kind vehicles will be necessary to conduct unique missions, e.g. full ocean depth. The Master Plan and roadmap provide a methodology to exploit the best attributes of the previous systems in a manner that will focus future technological developments and efficiently apply resources toward meeting the objectives of the Signature Capabilities.

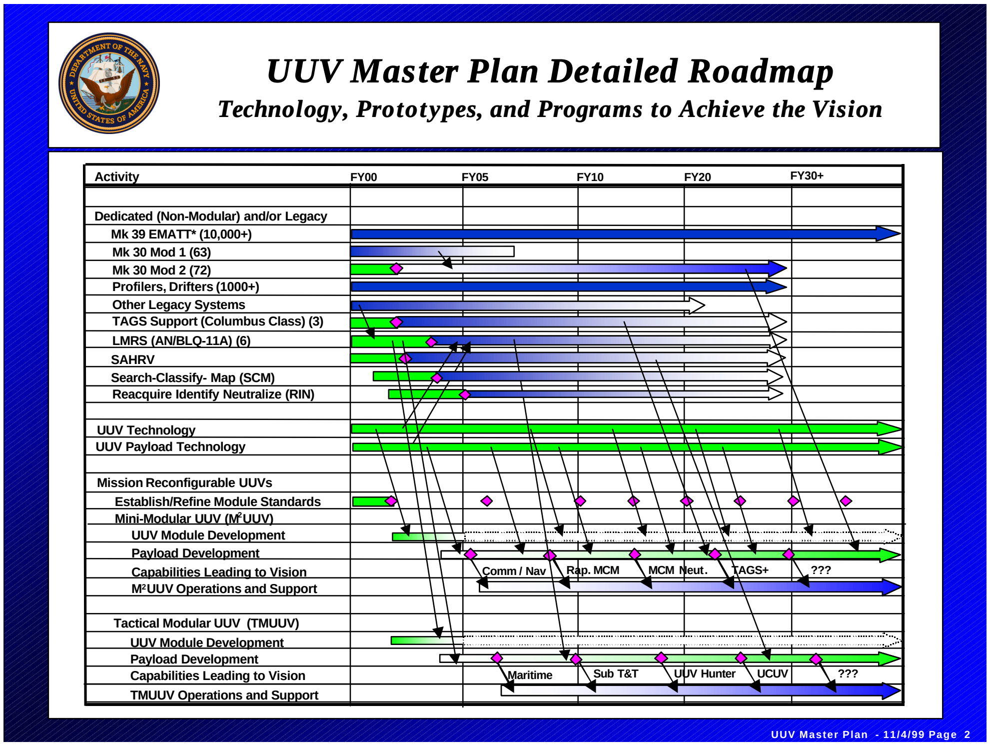

Figure 5-2: Detailed Roadmap

5.2.2 UUV and UUV Payload Technologies

As discussed in Chapter 1, the U.S. has advocated a military philosophy of dominance. The U.S. will achieve dominance via a combination of superior warfighting systems, and superior infrastructure, leadership and training; resulting in a joint, coordinated presence that is difficult to counter. In order to support this philosophy, the U.S. must also lead in unmanned systems, not just manned systems. Although is has been pointed out herein that the technology is ready to proceed on this plan, continued strong investment in technology will be required to create and sustain unmanned undersea dominance.

Technology Is The Engine Of Superiority

5.2.3 Mission Reconfigurable UUVs

The core of the Master Plan is the development of modular UUV systems that can be readily configured to a variety of missions. With common functional modules and standardized internal interfaces, great flexibility and transition between systems can be achieved. As described in Section 4.2.4, standardization of module sizes is recommended: small 6-12” diameter modules and larger, nominally 21” diameter modules. These standards will form the foundation for a variety of UUV sizes and capabilities as outlined in the following paragraphs.

5.2.3.1 Mini Modular UUVs (M^2UUVs)

The Mini-Modular UUV will be fielded in various sizes based on the small undersea modules. These modular UUVs would provide the Comm/Nav Aid capability and augment our current USS capability. The first step in developing the M^2UUVs would be standardization of the module size and contents, with special attention paid to those capabilities needed by the vehicle system as a whole. As these standard modules are developed, payload modules will be developed on a parallel path, thus insuring system compatibility. These payload modules will include specific packages such as oceanographic sensors, communications links, and navigation systems. In turn, they can provide the building blocks for larger systems. Following the initial module development, UUVs that meet the requirements of the Comm/Nav Aid mission can be fielded, possibly as early as FY2005. Later M^2UUVs will form the core of the SWARM concept providing a rapid mine reconnaissance capability by FY08 with a clearance capability to follow. As required, oceanographic and other missions enabled by the M^2UUVs would follow.

5.2.3.2 Tactical Modular UUVs (TMUUVs)

The Tactical Modular UUV would address the needs of the Maritime Reconnaissance and the Submarine Track and Trail capabilities. As with the M^2UUVs, the first step is the standardization of module size and contents, with special attention paid to those capabilities needed by the vehicle system as a whole. As these modules are developed, the payload modules will be developed on a parallel path, insuring system compatibility. Modules developed under the M^2UUV program will also be considered for incorporation in the system. This approach can lead to an initial Maritime Reconnaissance Capability by FY07. The Submarine Track and Trail capability is obviously more difficult to achieve, however, if the technology is pushed, an effective UUV capability can be fielded. Initial variants of the Submarine Track and Trail capability may be less autonomous, require closer coordination to US Forces (both surface ship and submarine) and may be smaller than the systems of the Vision. As dedicated modules become established, and UUV mission capabilities grow, more complex missions can be pursued. Eventually, the full Maritime Reconnaissance and Submarine Track and Trail Capability can be achieved, and perhaps, tactical engagement with missiles and/or weapons launched by UUVs can be explored.

5.2.4 Synergy

The goal of the Master Plan is to rapidly deliver new UUV capabilities to the Fleet, with a strategy for upgrading those capabilities with minimal time and expense. This plan effectively synergizes the efforts under legacy, developmental, and technology programs. The coordination of these efforts will yield rapid results. Development of the Mini- and Tactical Modular UUVs, in coordination with existing efforts will provide both new and future capabilities with a firm foundation for continued expansion. Development and fielding of advanced technologies will provide growth and dominance. The establishment of standards as previously discussed will be critical to the success of future systems, for without them the required modularity will not be achieved. In addition, without oversight at an appropriate level within the Navy, eventual fragmentation of the plan will likely be realized. Cooperative programs between government, academia, and Navy centers of excellence in UUV technology and systems, with proper guidance, will achieve the vision of this Master Plan. The effective implementation of UUVs in the future will result in the control of the world's oceans by the U.S. Navy. The alternative is all too obvious.

5.3 Recommendations

The previous sections detail the necessary steps to meet the visions of this Master Plan. The specific recommendations that follow provide a summary of those key points. Although prioritization of these recommendations is not an easy task because of their critical interrelationships, they are listed in their general order of importance:

- Complete current UUV development and integration programs and planned upgrades. These systems address high priority needs and the technology, experience, and components of these programs will help form the foundation for future efforts.

- Continue to execute a balanced technology program for both UUV Payloads and UUV Technology that supports the vision and the four signature capabilities. Ensure technologies are advanced that support the needs and reduce the risk of both small modular networked systems and larger high performance modular systems are advanced.

- Develop standards for future UUV module sizes and interfaces. It is expected that with two different module sizes the majority of future UUV needs can be cost effectively accomplished. The savings associated with standardization of modules (cost sharing in development, operations, and support) and the emergence of capabilities that could otherwise not be afforded will be lasting.

- Begin execution of an integrated program to achieve the four Signature Capabilities and begin using UUVs for the benefit of the Fleet. Increase coordination between the various UUV developers/users and program managers rather than attempting to combine all UUV programs into one site/location/program.

- Begin outreach to Navy operational, doctrine and training commands to expand and refine employment concepts for UUVs. Address logistical and mission impact of installing and operating UUV systems on combatants early in the ship and UUV acquisition cycle. Continue innovative thinking and review and update this plan periodically.

- Prior to initiation of any new UUV effort and at major decision points within existing UUV programs, conduct cost-effectiveness trades to determine whether small modules, large modules, or design specific approaches are required.

5.4 Conclusion

The Navy is strategically positioned to rapidly move forward to achieve the vision for UUVs. The only barriers are funding, some of which is in place, and coordination. Technology and industrial capacity are ready to proceed. Despite the fact that there are literally hundreds of UUVs under development or in operational use worldwide, which have logged thousands of dive hours, the fleet has little UUV-based capability today. With careful decisions and investments today, UUVs can become significant contributors to the Navy's capabilities tomorrow, and be ready for the unexpected future. The alternative is to fall behind the technical capability of adversaries that decide to exploit existing commercial systems. Now is the time to build on this plan.

Deliver End Items…And Begin Using Them.

ACRONYMS

Acoustic Communications	ACOMMS
Acoustic Doppler Current Profiler	ADCP
Advanced Deployable System	ADS
Advanced Unmanned Search System	AUSS
Amphibious Warfare Ship	AMPHIB
Analyses of Alternatives	AOA
Anti-Submarine Warfare	ASW
Anti-Surface Warfare	ASUW
Area Coverage Rate	ACR
Assistant Secretary of the Navy, Research, Development and Acquisition	ASN/RDA
Autonomous Underwater Vehicle	AUV
Coastal Systems Station	CSS
Commander Naval Meteorology and Oceanography Command	COMNAVMETOCCOM (CNMOC)
Commercial Off the Shelf	COTS
Concept of Operations	CONOPS
Conductivity, Temperature, Depth	CTD
Deployable Autonomous Distributed Systems	DADS
Electro-Magnetic/Electro-Optical	EM/EO
Electronics Intelligence	ELINT
Feet Seawater	FSW
Fleet Satellite Communications	FLTSATCOM
Global Positioning System	GPS
Imagery Intelligence	IMINT
Inertial Navigation System	INS
Initial Operational Capability	IOC
Intelligence, Surveillance and Reconnaissance	ISR
Landing Craft, Air Cushion	LCAC
Long-Term Mine Reconnaissance System	LMRS
Measurement and Signature Intelligence	MASINT

Mine Counter Measures	MCM
Mine Warfare	MIW
Mini-Modular UUVs	M^2UUV
Naval Surface Warfare Center	NSWC
Naval Undersea Warfare Center	NUWC
Naval Oceanographic Office	NAVOCEANO
Naval Special Warfare	NSW
Near-Term Mine Reconnaissance System	NMRS
Object Sensing and Intervention	OSI
Oceanographic Survey Ship Class	T-AGS
Office of Naval Research	ONR
Operating Area	OPAREA
Operational Requirements Document	ORD
Operations Other Than War	OOTW
Over the Horizon Targeting	OTHT
Pre-Planned Product Improvements	P^3I
Profiling Autonomous Lagrangian Circulation Explorers	PALACE
Radar Intelligence	RADINT
Reacquire, Identify, Map	RIN
Remotely Operated Vehicle	ROV
Rules of Engagement	ROE
Search, Classify, Map	SCN
Semi-Autonomous Hydrographic Reconnaissance Vehicle	SAHRV
Shallow Water Autonomous Reconnaissance Modules	SWARM
Side-Looking Sonar	SLS
Signal Intelligence	SIGINT
Space and Naval Warfare Systems Center	SSC, SPAWARSYSCEN
Synthetic Aperture Sonar	SAS
Tactical Mission Reconfigurable UUV	TMUUV
Target Motion Analysis	TMA
TOMAHAWK Land Attack Missile	TLAM

Undersea Search and Survey	USS
Under Sea Warfare	USW
Unmanned Aerial Vehicle	UAV
Unmanned Surface Vehicle	USV
Unmanned Undersea Vehicle	UUV
Variable Ballast System	VBS
Vehicle in Cocoon	VIC
Very Shallow Water / Surf Zone	VSW/SZ

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APPENDIX B-1: Field Study Results

Interviews were performed with a large number of potential users in the Fleet, Industry, Science and Academia, and other Federal Agencies. The emphasis was placed on potential users of UUVs, as opposed to those solely involved with the technology development. While some potential users were not interviewed due to time and scheduling constraints, the broad cross section of interviewers and interviewees provided a full range of UUV applications.

<u>Navy and Marine Corps Applications</u>
From the fleet perspective, a great deal of interest was expressed in various aspects of mine countermeasures, both in realizing those missions outlined in the 1994 plan and as a continuing expansion of the work currently being performed. Other high priority missions from the Naval perspective included intelligence / surveillance / reconnaissance (ISR), anti-submarine warfare (ASW), undersea search and survey, and tactical oceanography.

Table B-1: Navy and Marine Corps Potential Users and Associated Applications

Source	Primary UUV Interests
CNO N84T: ASW Division	ISR, Tactical Ocean., Offense and Defense
CNO N852: Mine Warfare Branch, Expeditionary Warfare Division	MCM for AOA
CNO N863B: Maritime Warfare Branch, Surface Warfare Division	ASW, MCM, Tactical Oceanography
CNO N873B: Deep Submergence Branch, Submarine Warfare Division	MCM, Surveillance, Tactical Ocean.
CNO N875: Science and Technology Branch, Submarine Warfare Division	ISR, ASW
CNO N88: Air Warfare Division	Surveillance, MIW, Battlespace Dominance
CINCLANT: Commander in Chief, Atlantic	MCM—All depths
COMINEWARCOM: Mine Warfare Command	MCM—All depths
NAVOCEANO: Naval Oceanographic Office	Tactical Oceanography
PEO-MIW-EOD: Mine Warfare – Explosive Ordnance Disposal	VSW-SW MCM
SUBDEVRON5: Submarine Development Squadron	Search and recovery
SWDG Surface Warfare Development Group	MCM including beach zone
USACOM US Atlantic Command (note: become US Joint Forces Command 7 Oct 99)	ISR, Comms, Tactical Ocean., Target ID
USCENTCOM US Central Command	Reconnaissance, Bathymetry, MCM
USSOCOM US Special Operations Command	VSW MCM

Commercial Applications

UUVs are becoming more widely accepted in industry, as the technology matures and systems become a cost-effective alternative to conventional methods. This is particularly true in the offshore oil and gas domain, where the need to operate in deeper water requires the use of advanced technologies. This includes long range surveys for cable and pipelaying and subsea intervention and operations. Other commercial areas where vehicles are playing a greater role include automated ship hull inspection, infrastructure inspection, and operations in hazardous environments. UUVs have become commercially viable and accepted, as evidenced by the Norwegian HUGIN vehicle, the Danish Martin, and the English Autosub, all currently in regular operation.

Table B-2: Commercial Potential Users and Associated Applications

Source	Primary UUV Interests
American Bureau of Shipping	Ship hull inspection
C&C Technologies	Bathymetric survey
Cybernetix	Subsea oil and gas intervention
Deep Ocean Engineering	Infrastructure and nuclear Inspection, subsea intervention
Imetrix	Ship hull inspection, infrastructure inspection, aquaculture
International Submarine Engineering	Bathymetric survey, cable laying, mine countermeasures
Norwesco	Infrastructure inspection
Oceaneering	Subsea oil and gas intervention
Shell	Subsea oil and gas intervention
Simrad	Bathymetric survey

Science and Academic Applications

Much of the UUV development has occurred in academic circles, both for scientific and military applications. In many of these cases, the scientific needs have driven the development of the technologies required to perform the mission. These include bathymetric mapping and deep water sampling. In other cases, the technologies are only now beginning to reach a point whereby the missions can be realized, especially where long term operation is required.

Table B-3: Science and Academic Potential Users and Associated Applications

Source	Primary UUV Interests
Naval Postgraduate School	Mine countermeasures, advanced control applications
Naval Research Laboratory: Mapping Charting & Geodesy Branch	Bathymetric charting
Scripps Institute of Oceanography	Long term bottom monitoring, biological sampling, water sampling, current mapping
Texas A&M University	Geophysical Survey
University of Rhode Island	Rapid Environmental Assessment, Focused Environmental Assessment
University of South Florida	Micro data following
University of Washington: Applied Physics Laboratory	Long term, long range oceanographic monitoring
Woods Hole Oceanographic Institution	Integrated autonomous systems

Other Government Users

Other government agencies have also evidenced a need for UUV type operations. These include a full range of applications from hazardous waste operations for the Department of Energy, to fisheries research for NOAA, to drug interdiction by the Coast Guard to bathymetric mapping for the USGS. Recent events off the coast of New England also point to an occasional need for object search and recovery by the National Transportation Safety Board and Federal Aviation Agency.

Table B-4: Other Government Potential Users and Associated Applications

Source	**Primary UUV Interests**
Defense Special Weapons Agency	Underwater security
Department of Energy	Hazardous material handling
National Oceanographic & Atmospheric Administration	Fisheries research
Office of Naval Research	Synoptic Ocean Observation, MCM
US Coast Guard	Damage assessment, drug interdiction
US Geologic Survey	Bathymetric mapping

APPENDIX B-2: Expert Panels

Core Team:
The Core Team developing the plan was a group of UUV experts from a range of Navy laboratories and academia. Team members have extensive experience in UUV applications for mine countermeasures, anti-submarine warfare and training, search and salvage, tactical oceanography, surveillance, inspection, and undersea work.

<u>Paul Dunn, Study Technical Director, Naval Undersea Warfare Center, Newport</u>

Mr. Dunn has been an employee of the Naval Undersea Warfare Center Division Newport, RI since 1982. He has worked extensively on propulsion, and later in his career on undersea vehicle acquisition. Currently, Mr. Dunn is the Division Head for Unmanned Undersea Vehicles (UUVs). His Division supports the current UUV and Target Acquisition and In-Service programs for PMS403, works on UUV technology, mostly for the Office of Naval Research, and maintains a number of UUV testbeds ranging in size from 60 to 32,000 lb. displacement. Mr. Dunn earned Bachelor and Masters degrees in Mechanical Engineering and has been granted seven patents for work related to UUV energy and propulsion technology.

<u>Dave DeMartino, Naval Surface Warfare Center, Panama City</u>

Mr. DeMartino joined CSS, in 1975 as a design engineer for manned and unmanned undersea navigation, control, and sensor systems. He progressed into systems engineering and project management for autonomous and manned undersea vehicles, ultimately heading the Special Warfare Systems and Special Vehicles Branches. In 1994, he was appointed as the Deputy Director of the CSS Modeling and Simulation Office with the responsibility to develop a modern, integrated modeling and simulation tool-set for use in Littoral Warfare analysis and concept development. These efforts led to his selection as the head of the Mine Warfare Systems Engineering Group. Currently, Mr. DeMartino is the Senior Systems Engineer for the Science, Technology, Analysis, and Special Operations Department. The impact of autonomous and organic concepts and systems is a particular focus. Mr. DeMartino holds Bachelor and Master degrees in Electrical Engineering. He is a Senior Member of the Institute of Electrical and Electronics Engineers, has received a Meritorious Civilian Service Award, and numerous achievement awards.

<u>Robert Wernli, Space and Naval Warfare Systems Center, San Diego</u>

Mr. Wernli has worked in the field of underwater robotics research and development at the Space and Naval Warfare Systems Center (SSC) San Diego (formerly the Naval Ocean Systems Center) since 1973. His work there has focused on the development of advanced undersea work systems, manipulators and tools for use to full ocean depths by both manned and unmanned vehicles. He has been actively engaged in promoting the oceans, including the use of remotely operated vehicles, by creating and chairing the first 10 Remotely Operated Vehicle conferences (ROV ‘83-ROV ’92), co-chairing OCEANS MTS/IEEE ’95, and will co-chair the upcoming OCEANS MTS/IEEE ’03. He has nearly 30 technical publications and was editor and co-author of the book

Operational Effectiveness of Unmanned Underwater Systems, published on CD-ROM in 1999. Mr. Wernli holds a BS in Mechanical Engineering and an MS in Engineering Design. Mr. Wernli is a member of the American Society of Mechanical Engineers, the Institute of Electrical and Electronics Engineers' Oceanic Engineering Society, and a fellow of the Marine Technology Society (MTS). He is a recipient of the MTS Special Commendation and Award, the SSC San Diego Exemplary Service Award and the Navy Meritorious Civilian Service Award.

Barbara Fletcher, Space and Naval Warfare Systems Center, San Diego

Barbara Fletcher is an engineer and project manager at the Space and Naval Warfare Systems Center in San Diego specializing in ROV and AUV applications. From 1993-1998, she was a founding member and systems engineer at Imetrix, Inc., where she was involved in a wide variety of programs and systems applications. She was Co-Principal Investigator and Project Manager for the three year ONR Program on *Training for Remote Sensing and Manipulation* (TRANSoM), developing the application of virtual environment technologies for remotely operated vehicle (ROV) operations and training. She was responsible for a number of ROV tracking and control systems, including those developed for the Naval Surface Warfare Center Advanced Hull Maintenance Vehicle, MIT Sea Grant, General Electric Nuclear Energy, and Hydro-Quebec. During her previous 10 years at the Naval Ocean Systems Center, she worked in areas of underwater security, mine countermeasures, deep submergence, and surveillance. Ms. Fletcher earned Bachelor and Masters degrees in Mechanical Engineering.

Joe Hanlin, CNO N0943H

Mr. Hanlin is an engineer with more than 25 years combined experience in submarines, UUV technology, diving, salvage and rescue, and ship engineering. He serves on the Navy staff (N0943H) and holds a Bachelors in Mechanical Engineering, an MS in Systems Management and attended the Defense Acquisition College.

Carey Ingram, Naval Meteorology and Oceanographic Command

Mr. Ingram is employed with the Naval Oceanographic Office, where he currently serves as Deputy Director, Ocean Projects Department. Professional interests and experience have centered about oceanographic ship design and operations, design and deployment of precisely-positioned towed acoustic and optical imaging systems, and the design, integration and operational fielding of cost-effective autonomous data collection systems, including Unmanned Undersea Vehicles, that maximize the utilization of Commercial Off The Shelf components. Mr. Ingram received his BA in Geology and an MA in Marine Science. In addition, he has completed the Managerial Grid Seminar, Management Development Seminar and Executive Development Seminar, as well a various US Navy programs in Anti Submarine Warfare and Mine Warfare. He holds two US Patents and has received two Meritorious Civilian Service Awards and numerous commendations from the Chief of Naval Operations.

Martha Head, Naval Meteorology and Oceanographic Command

Martha E. M. Head is an Oceanographer with the Naval Oceanographic Office (NAVOCEANO), where she has been employed since 1983, following a career in academia. At NAVOCEANO she has managed programs in the areas of Acoustics, Ocean Modeling, Remote Sensing, Geophysics, Data Bases, Prediction Support, Program Modernization, and Autonomous Underwater Vehicles. Ms. Head earned BS and MS degrees in Physics and Mathematics, and received her Ph.D. in Physics from Tulane University. She is a member of the American Physical Society and the Acoustical Society of America.

Pat Madden, Johns Hopkins University Applied Physics Laboratory

J. Patrick Madden has been employed by The Johns Hopkins University Applied Physics Laboratory since 1990 where his work has focused on conceptual design of Unmanned Undersea Vehicle (UUV) systems for application in the area of Mine Warfare. He manages JHU/APL's work in support of the Navy's acquisition of the Long-term Mine Reconnaissance System (LMRS). Earlier he managed JHU/APL's work on the DARPA UUV Program and was test director for five months of at-sea testing in 1996 with the Autonomous Minehunting and Mapping Technologies (AMMT) vehicle. Before joining JHU/APL he served 7 years in the Navy's submarine force with tours as a Chief of Naval Operations staff acquisition specialist and a three-year submarine duty assignment. Mr. Madden has a BS in Mechanical Engineering and graduated from the Defense Systems Management College (DSMC) 14-week Advanced Program Management Course.

Core Team Advisors

In addition to the Core Team, and separate from the Innovation Workshop participants listed below, several people experienced in the UUV field provided input to the UUV Master Plan. These advisors to the core team included:

J. Brad Mooney, RADM, USN (Ret.)
CAPT John Polcari, DARPA
Tom Curtin, Office of Naval Research
Mack O'Brien, Charles Stark Draper Laboratory
Lt Larry Estrada, SUBDEVRONFIVE

Oversight Board

Stakeholders in UUV development were represented by the Oversight Board, chaired by the Assistant Secretary of the Navy (Research, Development and Acquisition). They were briefed at regular intervals during preparation of the Master Plan, and provided guidance as to the direction and content. Board members included:

Dr. Lee Buchanan, ASN (RD&A)
Dr. Paris Genalis, USD(A&T) Naval Warfare
Mr. Dale Gerry, DASN(M/UW)
Mr. Tim Douglass, PEO(USW)
RADM Ray Smith, CNO N81
RADM W. Clyde Marsh, CNO N85B
RADM Paul Schultz CNO N86B
RADM Winford Ellis, CNO N873
RADM Paul Gaffney, CNR/CNO N091/USMC Assistant DCOS(S&T)

RADM Charlie Young, NAVSEA 93/COMNUWC
Dr. John Sirmalis, NUWC Technical Director
RADM Ken Barbor, COMNAVMETOCCOM
Mr. Paul Lowell, Deputy DNI

Innovation Workshop

To insure that a full spectrum of innovative concepts was considered, an Innovation Workshop was held on 8 June 1999. Using the Group Systems software at the Navy Acquisition Center of Excellence, a variety of underwater experts brainstormed UUV applications and technologies. Participants included representatives from the Office of Naval Research, independent consultants, industry, and various Navy laboratories.

At the workshop, computer groupware tools were use to solicit and organize ideas and concepts for UUV applications. As a starting point, a list of current critical at-sea tasks was compiled including MCM, ASW, power projection / strike, ISR, logistics, tactical oceanography, force protection, search and rescue, personnel evacuation, inspection, work, and object recovery. Working from these tasks, important breakthrough missions for Navy UUVs were identified and ranked. In priority order, these included: clandestine intelligence gathering, mine countermeasures, power projection, ASW sanitization, combined ASW / MCM mission, truck / delivery device, dual use bathymetric survey, global monitoring of ocean health and status, and replacement of SSNs for littoral operations.

Participants in the Innovation Workshop were:

Jack Bachkosky, Naval Research Advisory Council
Dick Rumpf, RAI
J. Brad Mooney, RADM, USN (Ret.)
Tom Curtin, Office of Naval Research
Henry Gonzalez, former deputy Program Manager PMS 403B
Tom Frank, Naval Undersea Warfare Center
Sam Hester, Naval Undersea Warfare Center
Chris Hillenbrand, Office of Naval Research
David Jourdan, Nauticos
Harvey Ko, Johns Hopkins University Applied Physics Laboratory
Paul Dunn, Naval Undersea Warfare Center, Newport
Dave DeMartino, Naval Surface Warfare Center, Panama City
Barbara Fletcher, Space and Naval Warfare Systems Center, San Diego
Joe Hanlin, Fleet Support Activity Navy
Pat Madden, Johns Hopkins University Applied Physics Laboratory
Steve Mack, Facilitator – Navy Acquisition Center of Excellence (ACE)

Appendix C: UUVs of the World

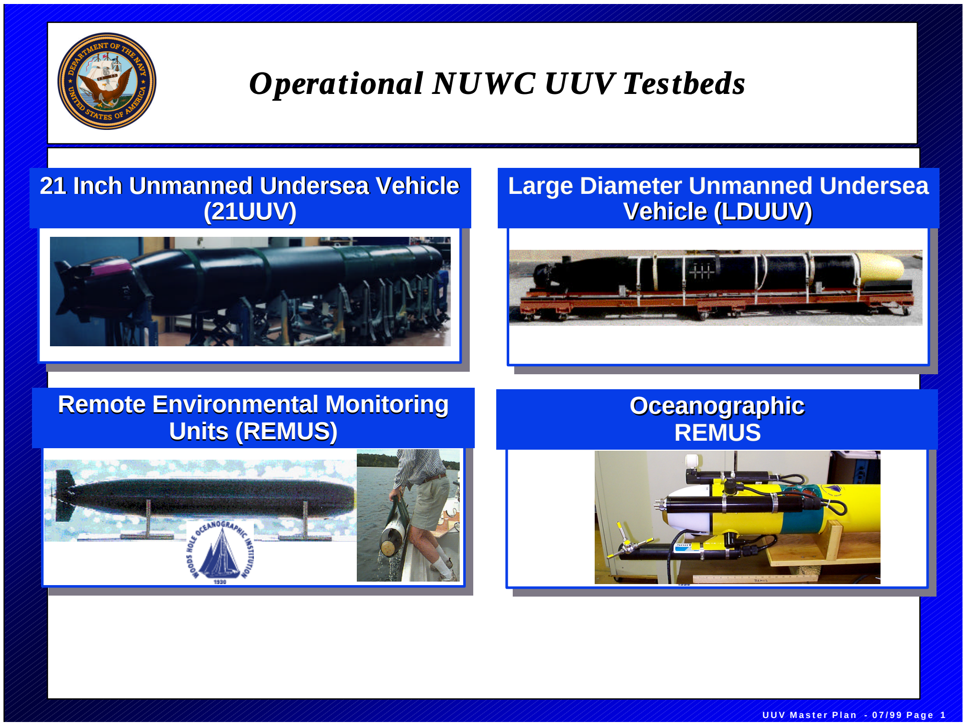
COUNTRY/VEHICLE	STATUS	ORGANIZATION	CONTACT
UNITED STATES			
21UUV	OPERATION	NUWC	http://www.npt.nuwc.navy.mil/
ABE	OPERATION	MIT	http://www.marine.whoi.edu/ships/auvs/auvs.htm
ALTEX	DEVELOP	MIT SEA GRANT LEAD	http://auvserv.mit.edu/
AUSS	STANDBY	SSC SAN DIEGO	http://www.nosc.mil/robots/
CETUS	DEVELOP	LOCKHEED-MARTIN/MIT	http://auvserv.mit.edu/cetus.html
CRYROBOT	DEVELOP		
COLUMBUS CLASS	ACQUISITION	NAVOCEANO	http://cnmoc.navy.mil
EAVE-III	R&D	AUSI/MSEL	http://cdps.umcs.maine.edu/MSEL/
EMATT	OPERATION	NAVSEA PMS403 /NUWC	http://www.npt.nuwc.navy.mil/
FETCH	OPERATION	SIAS/PATTERSON INC.	www.spiauv.com
FREESWIMMER	INACTIVE	SSC SAN DIEGO	http://www.nosc.mil/robots/
HERMES			
HYDROBOT	DEVELOP		http://www.jpl.nasa.gov/ice_fire//europao.htm
LAZARUS	OPTEST	NAVOCEANO	http://cnmoc.navy.mil
LDUUV	STANDBY	NUWC	http://www.npt.nuwc.navy.mil/
LMRS	DEVELOP	NAVSEA PMS403 /NUWC	
LRAUV	DEVELOP	AUSI/MSEL	http://cdps.umcs.maine.edu/MSEL/
LSV	OPERATION	NSWC	http://www.dt.navy.mil/div/corporate/sites/bayview
MTV	OPERATION	NUWC	http://www.npt.nuwc.navy.mil/
MK30 MOD 1	OPERATION	NAVSEA PMS403 /NUWC	
Mk30 MOD 2	DEVELOP	NAVSEA PMS403 /NUWC	
MUST	OPERATION	LOCKHEED-MARTIN	http://www.perrytech.com/mustlab2.html
NMRS	CONTINGENCY	SUBDEVRON FIVE DET UUV	
OCEAN EXPLORER	OPERATION	FAU	www.oe.fau.edu/AMS/auv.html
OCEAN VOYAGER II	OPERATION	FAU	www.oe.fau.edu/AMS/auv.html
ODIN	R&D	UNIVERSITY OF HAWAII	www.eng.hawaii.edu/~asl/odin.html
ODYSSEY IIB	OPERATION	MIT SEA GRANT	http://auvserv.mit.edu/
OTTER	R&D	MBARI/STANFORD UNIV.	http://sun-valley.stanford.edu/projects/underwater_robots/
PHOENIX	R&D	NPS	www.cs.nps.navy.mil/research/auv/
PROFILERS	OPERATION	NAVOCEANO	http://cnmoc.navy.mil
REMUS	OPERATION	WHOI	http://adcp.whoi.edu/REMUS/
ROBOTUNA	R&D	MIT SEA GRANT	http://web.mit.edu/towtank/www/tuna/
SLOCUM	DEVELOP	WEBB RESEARCH CORP.	www.webbresearch.com/slocum.html
Solar AUV	DEVELOP	AUSI/MSEL	http://cdps.umcs.maine.edu/MSEL/
URSULA	OPERATION		
VIMSS	DEVELOP	APL UW	
XP-21	INACTIVE	RAYTHEON	

UK			
AUTOSUB-1	OPERATION	SOC/NERC	www.soc.soton.ac.uk/autosub
MARCONI AUV	OPERATION		
MARLIN	DEVELOP	GEC-MARCONI/DERA	
RAUVER	R&D	HERIOT-WATT UNIV.	http://www.cee.hw.ac.uk/oceans/
SINKA	R&D	HERIOT-WATT UNIV.	"
NORWAY			
HUGIN	OPERATION	CONSORTIUM	http://www.nui.no/hugin2.html
PORTUGAL			
MARIUS	R&D	INSR	http://fire.ist.utl.pt/isr
SWEDEN			
MACAROV	R&D	SUTEC	
FRANCE			
SIRENE	OPERATION	IFREMER/MAST	www.ifremer.fr
MAUVE	OPERATION		
TAIPAN	R&D	LIRMM	www.lirmm.fr/~vaganay/taipan/index.html
REDERMOR	R&D	GESMA	
DENMARK			
MARIUS	INACTIVE	MARIDAN	www.maridan.dk
MARTIN 200 & 1000	OPERATION	MARIDAN	www.maridan.dk
JAPAN			
R-1	OPERATION	UNIV OF TOKYO	http://underwater.iis.u-tokyo.ac.jp/robot/robot-e.html
TWIN BURGER	R&D	UNIV OF TOKYO	http://underwater.iis.u-tokyo.ac.jp/robot/robot-e.html
MANTA-CERESIA	R&D	UNIV OF TOKYO	http://underwater.iis.u-tokyo.ac.jp/robot/robot-e.html
PTEROA 150	R&D	UNIV OF TOKYO	http://underwater.iis.u-tokyo.ac.jp/robot/robot-e.html
ALBAC	R&D	UNIV OF TOKYO	http://underwater.iis.u-tokyo.ac.jp/robot/robot-e.html
AQUA EXPLORER 1000	R&D	TOKAI UNIVERSITY	http://mdesign.os.u-tokai.ac.jp/katolab/katolabe.html
LONGRANGE AUV	PLANNED	JAMSTEC	www.jamstec.go.jp/jamstec-e/tech/now.html
10,000 METER UROV	PLANNED	JAMSTEC	www.jamstec.go.jp/jamstec-e/tech/now.html
CANADA			
ARCS	OPERATION	ISE	www.ise.bc.ca
THESEUS	OPERATION	ISE	www.ise.bc.ca
AURORA	DEVELOP	ISE	www.ise.bc.ca
PURL I & II	R&D/OPER	SIMON FRASER UNIV.	www.ensc.sfu.ca/research/url/purl
RUSSIA			
TYPHLONUS	OPERATION	IMTP	http://www.itri.loyola.edu/subseafe/
SEA LION (MT-88)	OPERATION	IMTP	http://www.itri.loyola.edu/subseafe/
TUNNEL SEA LION (US)	OPERATION	IMTP	http://www.itri.loyola.edu/subseafe/

ITALY			
SARA	DEVELOP	Technomare/ENEA	www.ian.ge.cnr.it/antartic.html
SAM	CONCEPT	Naional Research Program	
GERMANY			
C-CAT	DEVELOP	STN ATLAS Elektronik GmbH	
CHINA			
CR-01A	R&D	Chinese Academy of Sciences	
HIUV	R&D	Harbin Engineering University	
KOREA			
OKPA	OPERATIONAL	Daewoo	jswoo@daewoo.dhi.co.kr
AUSTRALIA			
KAMBALA	R&D	Australian Nat. Univ.	http://wwwsyseng.anu.edu.au/rsl/sub/
OBERON	R&D	University of Sydney	http://mecharea.mech.eng.usyd.edu.au/projects/development/subsea/

Adapted from a listing developed by Mr. Robert Wernli of Space and Naval Warfare Systems Center, San Diego, 1999.

The following pages present pictures of real-world UUVs.


Operational NUWC UUV Testbeds
21 Inch Unmanned Undersea Vehicle (21UUV)
Large Diameter Unmanned Undersea Vehicle (LDUUV)
Remote Environmental Monitoring Units (REMUS)
Oceanographic REMUS
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"Operational" (Prototype) UUVs
NMRS (MARCOT 1998)
NMRS (1999)
AMMT (transferred to NAVOCEANO)
Odyssey IIB
FAU Ocean Voyager II
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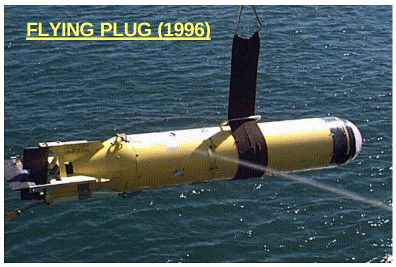
"Operational" (Prototype) UUVs (continued)

(there are many others)



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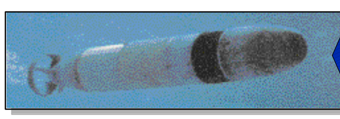
Fleet UUVs

- The only UUVs that have been procured in significant numbers to date are targets



EMATT:
- 25.5 lb. (4.7" x 36")
- $2500.
- In excess of 10,000 produced
- 3 hours per dive
- >80% mission success

Mk 30 Mod 1:
- IOC 1975, 63 in Fleet
- 5 IMA's
- 1000 runs per year
- 5000+ dive hours
- ~91% mission success

- LMRS will IOC in 2003 (no pictures yet)

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Appendix D: Shallow Water Autonomous Reconnaissance Modules (SWARM)

Introduction

As part of the UUV Master Plan study, the technological and engineering feasibility of UUVs for large area in-stride mine reconnaissance, and neutralization was examined.

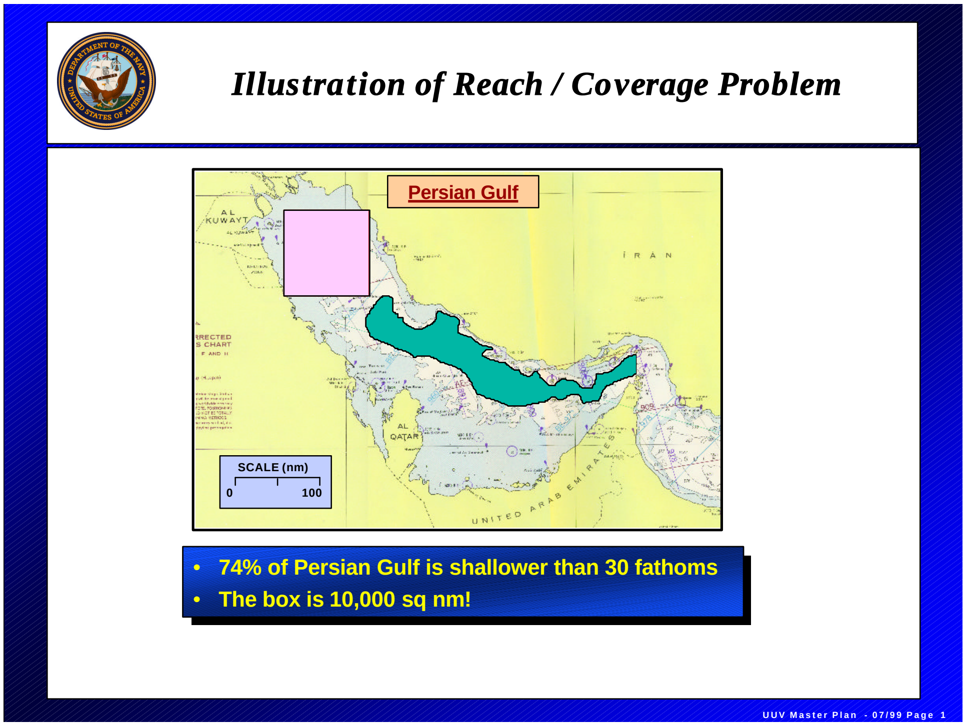

Figure 1: Littoral Coverage Example in the Persian Gulf

As shown in Figure 1 above, significant portions of current areas of interest are relatively shallow, making mining a more attractive option of any adversary. Being able to assure access through such an area, such as the Straits of Hormuz shown above, is a difficult problem. An even more challenging problem is to clear large areas "in-stride", as forces move through the area. It was in response to just such a scenario that the Shallow Water Autonomous Reconnaissance Modules (SWARM) concept was developed.

This appendix discusses the SWARM concept. It is important to note that this appendix is only a discussion of engineering and technological feasibility. Fielding a system such as SWARM requires other enablers to be in place, such as improvements in Synthetic Aperture Sonar capabilities, improvements in energy storage, demonstration of the Communication/Navigation UUV, and better understanding of group behavior issues. The sum of these improvements can lead to the vehicles envisioned for the SWARM concept. If this concept can be fully developed, an order of magnitude improvement in capabilities will result. Characteristics presented below are notional, based on current and projected capabilities. More detailed engineering analysis is required to verify the details of the capability.

SWARM Concept

The SWARM concept that is postulated in Chapter 3 is designed to address the difficult problems presented in conducting large scale or in-stride mine reconnaissance in a timely manner. Large scale is assumed to be on the order of 1000 NM^2, roughly the size of a carrier operating area, an Amphibious Operating Area, or a long transit through a choke point. This has been one of the most intractable of the MCM problems due to its very large size and short time allocation. The solution is to have many systems operating simultaneously. In order to make this feasible from a fleet employment perspective; these systems must be very small and simple to operate. Further, it would be beneficial if they were inexpensive. We believe that current technology supports the achievement of these goals. A study undertaken to determine if this concept is feasible, resulted in the following SWARM characteristics:

- Weight = 500 pounds
- Diameter = 12 inches
- Length = 125 inches
- Search Speed = 8 knots
- Identification Speed = 4 knots
- Search Swath Width = 405 yards
- Search Resolution =1x1 inch (Classification)
- Identification Resolution = ½ x ½ inch (ID)
- Range = 70 miles
- Operating Altitude (nominal water clarity) = 20 feet
- Unit Production Cost = $100K (1000 built); $50K (>>1000's built)

The SWARM sensors operate continuously while the vehicle searches at 8 knots. The SWARM alters its altitude dynamically, to accommodate the ID sensor‘s performance (typically 20-40 feet for average water quality). The ID sensor fills the gap in the search sensor’s coverage, providing classification quality data. When either sensor classifies an object of interest, the vehicle slows to 4 knots and circles to view it with the ID sensor, which provides identification quality images at that speed. A small ahead looking sonar is used for reacquisition of targets and obstacle avoidance. Embedded algorithms make classification and identification calls automatically. The sensors provide range, bearing, object type, and confidence level for each sensor call, to the vehicle control computer. The control computer can communicate the sensor calls to the net or a local Comm/Nav Aid UUV.

The sensors postulated here are the next generations of the existing synthetic aperture side-scan sonar and electro-optics identification systems developed by the ONR Advanced Sensors 6.2 program, completed in 1998. The sensors and technology are proven and considered low risk for the size and performance cited herein.

Communications and Navigation Options

Long range communications and high accuracy navigation systems are expensive subsystems for the SWARM. This expense is realized as volume, power, and unit production costs. An alternative is to utilize a support system to aid in the communications and navigation functions. Such a system is the Comm/Nav Aid UUV described in Chapter 3. One Comm/Nav Aid UUV for every 10 SWARM systems puts the greatest acoustic range at less than 2500 yards, which is more than adequate for the data rate envisioned.

Employment Options

The chief drawback of the SWARM concept is its short range. What this means is that it is unlikely that the system would ever be employed directly by a manned ship. To do so would necessitate bringing the platform very close to the suspected mined area. Therefore, the employment technique is to deliver the SWARM from a secondary platform or directly from aircraft.

For airborne delivery, the vehicles would use drogue chutes to retard their entry into the water. Upon delivery, each vehicle immediately begins its mission, which results in a staggered formation as they cover the battlespace. This formation facilitates the operation for two reasons. The active sensors are not operating in immediate proximity to each other. Therefore, mutual interference or the need for multiple operating frequencies is eliminated. Also, a leader-follower, flocking behavior ensures that follower vehicles maneuver as required to eliminate holidays in coverage. The result is that the loss of a vehicle or drift in navigation does not produce coverage holes in the OPAREA. The resulting area covered may not be the exact area planned, but an area of uniform and total coverage will be produced and to a large extent, it will be the desired OPAREA.

The vehicles run preprogrammed tracks across the OPAREA sampling the environment at intervals and continuously gathering small object/mine data. Navigation fixes, group behavior, and data relay are facilitated by the Comm/Nav UUVs, at intervals determined by the mission and real-time events. The Comm/Nav UUVs may periodically surface to communicate to the command station or obtain navigation updates. Figure 2 shows notional concepts for employment of the SWARM.

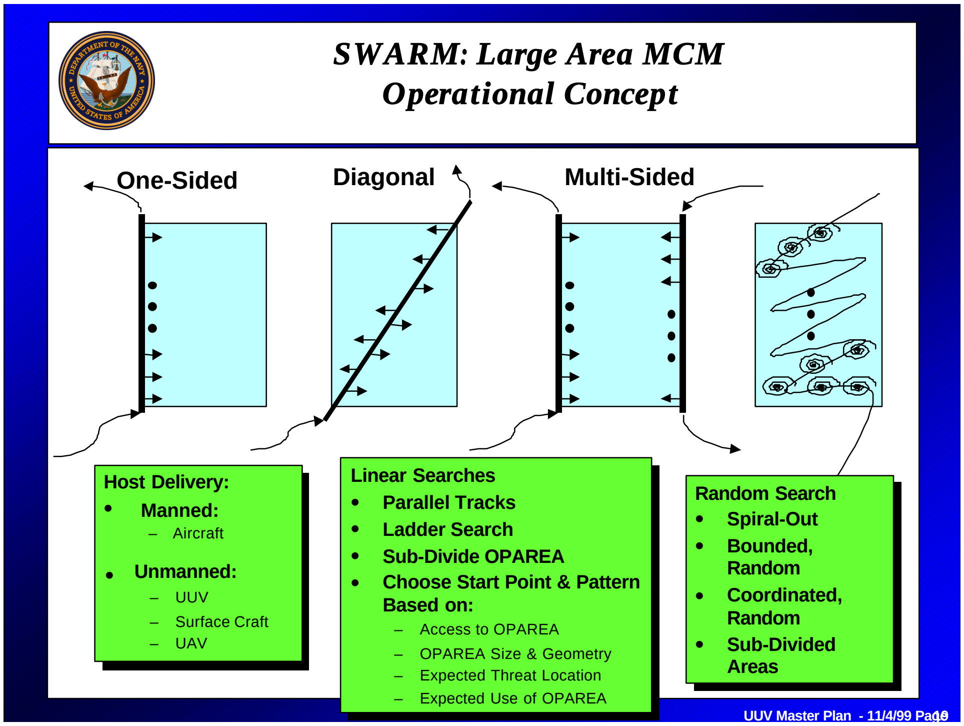

Figure 2: Large Area MCM CONOPS

A reference mission is the reconnaissance of a Fleet Operating Area (FOA). Consider a typical FOA that is 900 nmi^2 (30 nmi x 30 nmi). 75 SWARM systems could complete this area within 8 hours of delivery. A very large FOA that is 2700 nmi^2 (45 nmi x 60 nmi) is probably the largest single area that would ever require MCM operations and is quite a bit larger than those specified as reference sizes in the Draft MCM Capstone Requirements Document. 225 SWARM systems could complete this area within 8 hours of delivery. This mission time is 1-2 orders of magnitude faster than any other system or concept currently under consideration.

The challenge is the delivery of the SWARM systems. Some promising alternatives are:

- LCAC (Autonomous) — 1 Sortie could carry the entire 225 or 75 vehicles.
- B-52 — 2 Sorties for 225 — 1 Sortie for 75
- B-2 — 3 Sorties for 225 — 1 Sortie for 75
- F/A-18 — 25 Sorties for 225 — 9 Sorties for 75 (9 SWARM and 2 self defense weapons per sortie)

The additional use of the Comm/Nav Aid UUV, as discussed above, would have a minimal impact on the employment timelines or operations. For these operations approximately 22 or 4 Comm/Nav Aid UUVs would be required. For the larger area, the F/A-18 option would require three additional sorties. The other options would be unchanged.

Storage of the SWARM on the likely hosts (aircraft carrier or amphibious ship) is not nearly as difficult as some of the existing MCM system approaches. SWARM is similar in size to a lightweight torpedo, without the warhead considerations. While these employment options are not clandestine (here an argument can be made for the B-2 option), they are combat options that do not require total air superiority. The worst case option of flying in from CONUS still completes the total mission in an order of magnitude less time than any other approach. The aircraft employment options outlined above provide a quick response or contingency capability that does not currently exist. In particular, long-range bomber delivery options could provide worldwide response within hours.

Configuration Options

The SWARM concept was developed as an expendable device. This approach allows for use of high performance primary batteries while simplifying the logistical considerations. The system could be made re-useable at the cost of shorter endurance (utilizing current technology). The vehicle range would be reduced from 70 nmi to approximately 45 nmi, operating at the original 8 knots. This is still sufficient for the FOA application. A mix of re-useable and expendable (warshot) systems could be fielded or a swappable battery section could be incorporated, if desired. Re-usability raises the issue of at-sea recovery. While this would certainly be desirable for training evolutions, it may be too problematic for combat situations. Concepts for after action recovery, possibly by non-combatants, or other approaches have not been analyzed and merit attention.

The SWARM system concept was developed to consist of interchangeable payload modules with well defined and carefully selected interfaces that together can perform as desired and maintain a path to future improvements. The range of operating characteristics and delivery options allows the warfighter to select the combination that is appropriate for the tactical situation. Its high-resolution sensors will provide an accurate, geo-located picture of areas of interest, including small objects and some oceanography. The oceanography products are physical environmental data. The small object products include volume and bottom mines, cables and junction elements, wrecks and hazards to navigation, and any large stationary objects.

The components of the SWARM are a modular Unmanned Underwater Vehicle that accepts interchangeable payloads, either a small object sensor payload, or a mine neutralization payload.

For neutralization, the incorporation of a warhead and fuse could be accommodated. This is especially attractive if the system is designed to be expendable. It is possible that a re-useable SWARM could dispense a small number of neutralization devices so that the SWARM itself is not sacrificed. This requires a much more sophisticated device than the addition of a warhead approach. Therefore, this approach may be more suitable for a follow-on product improvement.

Clandestine delivery of the SWARM is required if it is to perform any truly clandestine missions. Detailed analysis of clandestine delivery options for SWARM has not been performed. However, since the range of the SWARM is so short, it is tactically limiting and probably very risky to insert the required number of SWARM systems directly from a manned vessel. A more attractive method would be to deploy the SWARM systems from an unmanned underwater vehicle or, as practical, an unmanned surface vehicle that is either low observable or disguised. In concept, both of these delivery vehicles could be launched from a surface ship or submarine. In both cases, extensive analysis of the options, impacts, and required modifications would be necessary to determine a truly feasible approach.

SWARM Technology and Engineering Issues

The technology to support the development of the SWARM is mature and most aspects have been proven in the field. Some areas will require engineering development and one area in particular will require additional technology development.

The initial SWARM approach separates target acquisition from target neutralization. This is done for several reasons: 1) not all missions require both reconnaissance and neutralization; and 2) the volume of the sensor package and neutralization package together (based on near term technology) will drive the overall vehicle size to a large and unwieldy size. Because of this separation, the reconnaissance must be done with target localization accuracy, in absolute geographic coordinates, sufficient for reacquisition by the neutralization system. If every SWARM had to carry a navigation system adequate for the task, the vehicle size would, again, grow to a large size. This problem is mitigated through the approach of using the Comm/Nav Aid UUVs to augment the SWARM navigation. In order to make this work, group behaviors and underwater acoustic position updates from moving reference stations are required. These technologies exist, but must be engineered for this application.

The desire is for the neutralization payload to be able to operate autonomously in order to mitigate data passing, manning needs, and to speed-up overall operations. These types of operations are currently performed in remote-operated fashion. Prototypes and systems currently in acquisition are more semi-autonomous. It appears that current directions will allow this capability to go fully autonomous in the near future. It should be noted that this overall approach sends the autonomous neutralizers to targets that have been confirmed and designated by an operator.

Area coverage rate (ACR) is one of the key performance parameters for the SWARM concept. The three primary drivers for ACR are sensor path width, system speed of advance, and mission time. Given that we desire a short overall mission time, we must improve path width and speed. For most sensors these parameters are inversely proportional. The SWARM concept uses a sensor approach that mitigates this problem, has a clear path to future improvements, and is small in weight and volume. This sensor approach is the synthetic aperture sonar (SAS). This technology is becoming mature and has been demonstrated; some additional work is required for its application to SWARM. The limit on SAS technology is our ability to measure vehicle body rates and process the raw data in-situ. Digital signal processing capability is continuing to advance at such a high rate that we do not foresee this as an issue. Body rate measuring capability is also improving but may lag our need for small, low power sensors. A clear path exists for SAS performance improvements in range and resolution without array hardware changes.

Additionally, the shift to broadband waveforms shows promise for bottom penetration, which may allow classification of buried targets in the future.

The other SWARM primary sensor is an electro-optical identification sensor (typically, a laser line scanner). These sensors have proven their capability to provide the image quality required for an operator to make identification calls. The SWARM concept desires that these calls be made autonomously in order to minimize data transfer requirements and to speed up operations. This technology has not been developed. Adaptation of morphological techniques from other areas holds promise for this application.