Combined Joint Operations from the Sea Centre of Excellence

GUIDANCE

for developing Maritime Unmanned Systems (MUS) capability

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CONTENTS

Executive Summary

In 2008, recognizing a nascent requirement in the maritime security domain, CJOS COE was requested by NATO Allied Command Transformation (ACT) to provide an overall picture of Maritime Unmanned Systems (MUS) as a potential new capability, with a view to create an increased awareness and trigger further developments within the Alliance. The resulting MUS Study, published in November 2009, was then forwarded for endorsement by ACT, to the International Military Staff (IMS). Following this first document, CJOS COE has produced the attached Guidance document building on the initial study and aiming at supporting NATO MUS capability development.

This guidance aims to inform the capability development of Maritime Unmanned Systems (MUS), broadening beyond that currently being exploited by UAV into Unmanned Underwater Vehicles (UUV) and Underwater Surface Vehicles (USV). It covers likely attributes and tasks for MUS, and discusses some of the challenges in developing this capability.

Definition

An MUS is defined as an Unmanned System operating in the maritime environment (subsurface, surface, air) whose primary component is at least one unmanned vehicle. A UUV 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. They are further sub-divided in 4 vehicles classes (man-portable, Light Weight Vehicle (LWV) Heavy Weight Vehicle (HWV), Large Vehicle Class (LVC).

An USV is defined as a self-propelled surface vehicle whose operation is either fully autonomous (pre-programmed or real-time adaptive mission control) or under minimal supervisory control. They are further sub-divided in 4 vehicles classes (X-Class, Harbour Class, Snorkeler Class, Fleet Class).

Future Capability Requirements

The foreseen future Maritime Capability Requirements for MUS are:

a. Persistent ISR, above and below the surface;
b. Capability beyond the high water mark;
c. Cheaper systems;
d. Lower risk to personnel;
e. Less vulnerable to cyber attacks;
f. Stealth;
g. Less collateral damage;

h. Netcentric.

MUS Attributes

The areas for MUS to contribute to naval needs derive from their operational advantages, which include: autonomy, risk reduction, deployability, environmental adaptability and persistence.

UUV Missions/Tasks

Nine areas are identified where UUVs can support or conduct a mission:

(1) Intelligence, Surveillance and Reconnaissance (ISR);

(2) Mine Countermeasures (MCM);

(3) Anti-Submarine Warfare (ASW);

(4) Inspection/Identification (ID);

(5) Oceanography/Hydrography;

(6) Communication/Navigation Network Nodes (CN3);

(7) Payload Delivery;

(8) Influence Activities (IA);

(9) Time Critical Strike (TCS).

USV Missions/Tasks

The missions that could be executed by a USV are:

(1) Mine Countermeasures (MCM);

(2) Anti-Submarine Warfare (ASW);

(3) Maritime Security (MS);

(4) Surface Warfare (SUW);

(5) Special Operations Forces (SOF) Support;

(6) Electronic Warfare (EW);

(7) Maritime Interdiction Operations (MIO) Support.

Key Challenges

Based on today's capability, future advances in technology will enhance endurance, processing, autonomy, and interoperability. Many of the missions are demanding in terms of autonomy and propulsion. Achieving the level of autonomous intelligence collection required for persistent capabilities will be challenging. Autonomous modes of operation and the technology required to shift from one level of autonomous operation to another are still under development, many shortfalls have been pointed out in the area of engagement/intervention.

UUVs have a limited ability to communicate with the outside world and the use of UUVs, in particular for CN3, requires considerable electrical power for transmissions.

Cyber defense challenges include threats to the MUS vehicle itself, and its feeds and products. A careful balance between the level of autonomy achieved and the vulnerability to cyber attack will need to be developed.

General

It is considered that the realm of MUS has a lot to offer, increasing operational effectiveness, reducing risk to human life and moreover represents a potential to reduce operational costs.While the greatest cost-effectiveness could be achieved by agreeing to a set of common platforms and command and control systems for such vehicles, ongoing Research and Development (R&D) will still drive future trends in MUS technology. Each nation will need to procure onboard sensors and other payloads according to their own requirements. To date, surface and subsurface MUS capabilities have received much less R&D attention and funding than Unmanned Aerial Vehicles (UAV) and require capital investment to catch up. There is also less data available from which to conduct comparisons of operational effectiveness between manned and unmanned platforms. However, such surface and subsurface capabilities should compliment existing and emerging UAVs to ensure that NATO can effectively counter the wide range of emerging threats in the maritime environment.

The next steps

As current technological innovations create capabilities allowing MUS to conduct missions that are normally performed by multiple maritime assets, the industry, academia, and the private sector are actively using advancements in technology to shape the future of MUS procurement processes. NATO urgently needs to address the ever-changing technology, defining, as a minimum, the collective requirements for unmanned systems, which will underpin the Alliance, enabling capabilities today and in the future.

The development and acquisition of MUS and related technology must be identified as a mainstream element in the future force generation process, where they offer the potential to overcome existing and projected critical capability shortfalls. With the NATO Strategic Concept 2010, nations agreed to continue with their primary focus of safeguarding freedom and security for all members. To continue to do this in the future, technological advancements will be imperative.

The importance of procuring common platforms and their core command and control systems wherever possible cannot be overstated: it will yield enormous collective benefits in reduced training burdens, reducing supply chain diversity and improving availability, as well as offering a cost-effective procurement path by exploiting the benefits of scale.

Finally, in developing the capability endeavors to improve the effectiveness of MUS through a judicious multinational integration and Joint collaboration project, fostering the development of policies, standards and procedures that enable safe and timely operations and the effective integration of manned and unmanned systems should be considered.

1. INTRODUCTION

NATO's Maritime Security challenges have changed considerably since the formation of the Alliance. NATO's maritime forces, principally designed during the Cold War era for ocean warfare are increasingly used for Maritime Security Operations, Power Projection missions, Disaster Relief, and to ensure international access to global resources. As NATO's security and economic interests increasingly align with the concerns of the global community, these missions are increasingly occurring outside of the Alliance's traditional operating areas. The requirement to operate at extended ranges, distant from traditional support basing involves new risk and operating challenges for navies. These missions expose maritime forces to a variety of conventional, hybrid, and asymmetric threats, either on the high seas or in the littoral environments. The spectrum of potential threats requires versatile, adaptable naval forces with capabilities across multiple mission areas. Notwithstanding the current operating environment challenges, ever-reducing military budgets and force structures make tackling these challenges increasing difficult. These realities compel navies to transform force structures, and harness emerging technologies to maintain tactical and operational warfighting capability with reduced high-end capital investment in personnel and material. Consequently, modern military forces increasingly rely on the attributes resident in unmanned systems to augment manned capabilities with potentially significant cost and risk reductions.

. As seen with the integrated use of Unmanned Aerial Vehicles (UAV) in support of NATO ground operations in Afghanistan, Unmanned Systems provide enhanced operational and tactical capabilities proving to be a force multiplier and key enablers to conventional forces; however, while UAV development has been near exponential, Maritime Unmanned Systems (MUS) have seen very modest efforts applied to their development and operational employment in order to meet requirements on and below the surface of the sea. This gap in MUS capability has been recognized by NATO, and at the request of Allied Command Transformation (ACT), the Combined Joint Operations from the Sea Centre of Excellence (CJOS COE) initiated a project to explore and guide the development of MUS to meet the Alliance's future maritime capability requirements.

In the course of developing this document, CJOS COE relied extensively on current U.S. Unmanned Systems Guidance and documentation, mainly due to the lack of current NATO documentation. Additionally, the U.S. rapid development of unmanned system capabilities initiative and associated operating experience, provide a logical framework for NATO to leverage in support of the Alliance's specific capability requirements.

2. AIM

The aim of this document is to provide guidance to encourage near to far term MUS capability development. This guidance document supports future NATO maritime force capability development and planning efforts needed to conduct efficient, versatile, and sustainable operations at extended range with reduced risk and cost when compared to conventional maritime assets. The document will also assist in determining a realistic strategic vision for MUS given the reality of restricted budgets. Its main focus will be on the surface and undersea aspects of unmanned systems. Discussions on the employment of maritime UAVs is not included because other NATO entities are currently developing related operating concepts. The objectives of this document are to:

a. Define Maritime Unmanned Systems;

b. Provide an overview of the Changing Geostrategic Environment;

c. Discuss how MUS supports the Alliance Maritime Strategy;

d. Review UUV capabilities;

e. Review USV capabilities;

f. Highlight select key operational scenarios;

g. Analyze the communications of the systems;

h. Analyze the autonomy of the systems;

i. Examine the interoperability of the systems;

j. Consider new training requirements;

k. Discuss the manned-unmanned teaming;

l. Explore power and propulsion;

m. Evaluate the legal Rules of Engagement (ROE) aspects.

3. DEFINITION OF MARITIME UNMANNED SYSTEMS

MUS is defined as an Unmanned System operating in the maritime environment (subsurface, surface, air) whose primary component is at least one unmanned vehicle. An unmanned vehicle is a powered vehicle that does not carry a human operator and can:

a. be operated autonomously or remotely;
b. be expendable or recoverable; and
c. can carry lethal or non-lethal payloads.

Ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, 1st generation remotely operated vehicles (ROVs), mines, satellites, and unattended sensors without propulsion are not considered unmanned vehicles, in accordance with agreed NATO definition[1] NATO for UAV.

4. OVERVIEW OF THE CHANGING GEOSTRATEGIC ENVIRONMENT

The evolving international situation in the 21st century is shaped by the complex interdependence between states and organizations, the increasing importance of global commerce and an increased influence by non-state actors. Though the risk of an existential war against the NATO Alliance is currently low[2], there remains a potential for increasing transnational and mainly intra-national conflicts across the globe over the next 20 years. We could see the emergence of quarrels fueled by the international competition for vital natural resources and exacerbated by the proliferation of modern military capabilities, including weapons of mass destruction and ballistic missiles as well as nationalist and ethical frictions. Additionally, extremist groups will remain a threat to the stability and prosperity of the international community and the Alliance will likely face some form of persistent conflict with sophisticated adversaries employing hybrid tactics to achieve asymmetric advantages over conventional superior forces for the foreseeable future. Meanwhile, unprecedented economic pressures caused by the current financial crisis will make it harder to resource the wider range of commitments that NATO needs to undertake; the significant reduction in the numbers of maritime platforms being procured by the Alliance is a clear indicator. This new strategic context has driven a substantial re-evaluation of the roles of NATO's military forces in supporting the Alliance's strategic objectives and core missions over the next two decades.

Consequently, in November 2010, NATO leaders met in Lisbon, Portugal for a formal summit. During this summit, leaders from NATO nations discussed and adopted the new Strategic Concept. As agreed upon, the Alliance will fulfill three essential core tasks to safeguard members in accordance with international law. Paraphrased, these core tasks are:

a. Collective defense. NATO Members will always assist each other against attack, in accordance with Article 5 of the Washington Treaty.

[1] Whilst for the basis of this guidance this definition is satisfactory, there is debate ongoing on the balance between autonomy, artificial intelligence and the human operator within the overall system.
[2] MC 161-NATO Strategic Intelligence Estimate (NSIE)

b. Crisis management. NATO has a unique and robust set of political and military capabilities to address the full spectrum of crises – before, during and after conflicts.

c. Cooperative security. The Alliance is affected by, and can affect, political and security developments beyond its borders.[3]

5. THE ALLIANCE MARITIME STRATEGY

The Alliance Maritime Strategy (AMS), promulgated in March 2011, is synchronized with the NATO Strategic Concept but expands the core tasks to include Maritime Security. The AMS also emphasizes the importance of transformation, seeking the evolution of capabilities in line with the defence planning process[4]. The AMS states: "….transformation of NATO's maritime forces' organization and capabilities will be necessary to better align NATO maritime capabilities with the requirements of the missions envisaged in this maritime strategy".[5] Furthermore, the AMS envisions that alliance maritime forces will be able to rapidly respond with a broad range of capabilities in order to:

a. Control or defend Sea Lines of Communication;
b. Conduct mine counter measures operations;
c. Project power ashore, to include forcible entry if necessary;
d. Execute sea-based ballistic missile defense;
e. Provide humanitarian assistance and disaster relief;
f. Engage in diplomacy;
g. Support regional capacity building; and
h. Conduct Maritime Security Operations.

Either as a primary sensor/weapon system, or as a key enabler to other warfighting capabilities, MUS represent an untapped potential to transform the future planning and execution of these core missions. MUS employment in the field of persistent Intelligence, Surveillance, and Reconnaissance (ISR), can support a wide range of maritime operations; particularly in the coastal environment where a multitude of threats converge to create a high risk operating environment. To name a few examples of key operational tasks, MUS can conduct ISR of threatened choke points for surface threats or mines, conduct persistent monitoring of known transit routes employed by terrorists, pirates or drug smugglers, conduct harbour surveys after natural disasters, as well as conduct beach reconnaissance prior to an amphibious assault. In line with the foreseen threats of the current and future operating environment, the operational use of MUS

[3] NATO Strategic Concept 2010
[4] Annex 1 to Alliance Maritime Strategy, C-M(2011) 0023, 16 March 2001, p.1-1
[5] Alliance Maritime Strategy, C-M(2011)0023

underpins the successful completion of the above tasks, while reducing risk and costs to conventional naval forces. If judiciously developed and employed, MUS will transform the nature of maritime operations and ensure the attainment of the Alliance's core tasks.

6. FUTURE MARITIME CAPABILITY REQUIREMENTS

The future needs of naval forces are likely to include improved situational awareness, increased network centric sensors, communications and decision making. Area denial will increase in both likelihood and extent through the adversary's strategy of asymmetric warfare with the use of easily acquired weapons in innovative ways to exploit our weaknesses, rather than competing head-to-head. Access denial weapons that challenge NATO include quiet submarines, mines, tactical ballistic missiles, cruise missiles, weapons of mass destruction, and Influence Activities (IA) information warfare. This will demand improved stealth and systems that limit the risk to human life.

In addition to potential direct threats posed by adversaries to NATO forces in the operation area, diplomatic constraints or rules of engagement may also preclude the early entry of overt maritime forces. Tools are needed that avoid detection and are resistant to attack, which allow 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 being able to prepare and shape the battlespace, ensuring ultimate defeat of the area denial threat.

Maritime Forces able to deal with the new challenges of 21st century globally in order to provide security and stability for the Alliance and thus find themselves at a strategic point to lay out which future capabilities must be developed. Change must be embraced in order to take advantage of emerging technologies, concepts, and doctrine.

The foreseen future Maritime Capability Requirements for MUS are:

- i. Persistent ISR, above and below the surface;
- j. Capability beyond the high water mark;
- k. Cheeper systems;
- l. Lower risk to personnel;
- m. Less vulnerable to cyber attacks;
- n. Stealth;
- o. Less collateral damage;
- p. Netcentric.

7. MUS ATTRIBUTES

The areas for MUS to contribute to naval needs derive from their operational advantages, which include: autonomy, risk reduction, deployability, environmental adaptability and persistence.

- 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 may be reduced when sensors or weapons are operated from the smaller infrastructure of a MUS rather than entirely from manned platforms.

- Risk Reduction: Their unmanned nature lessens or eliminates risk to personnel from the environment, the enemy, and the elements of the sea. UUVs operate fully submerged with potentially low acoustic and electromagnetic signatures. They maintain a low profile when surfaced to extend antenna or aerials. The possible intent for follow-on manned operations in a route or area is not revealed and the element of surprise is preserved. UUVs have less risk of entanglement with underwater or floating obstructions than towed or hard-tethered systems.

- Deployability: By virtue of their potentially small size, MUS can provide an organic capability to a maritime force. They can also be designed as "flyaway" packages or be prepositioned in forward areas. Their launch can be adapted to a variety of platforms including ships, submarines, aircraft, and shore facilities. The MUS recovery craft need not be the same as the launch craft. Recovery may be delayed or dismissed entirely for low-cost expendable systems. Multiple MUS can be deployed simultaneously from one platform.

- Environmental Adaptability: MUS's UUV can operate in almost all water depths, in foul weather and seas, under tropical or arctic conditions, and around the clock. Their ability to operate in this medium gives them unique sensor advantages over similar towed or surface operated sensors.

- Persistence: UUVs can remain on station in the face of weather that would abort the operations of an Unmanned Aerial Vehicle (UAV) or Unmanned Surface Vehicle (USV), simply by submerging to a calmer depth. Violent weather may preclude near-surface operations, but UUVs can wait out the storm at depth, precluding a lengthy transit when conditions improve. Likewise, UUVs that lose power accidentally or intentionally in a "loiter" mode, can settle stably onto the bottom, unlike UAVs and USVs that are at the mercy of the elements as soon as they lose propulsion.

8. UNMANNED UNDERWATER VEHICLES (UUV)

a. The UUV vision is to develop and field cost-effective UUVs to enhance Naval and Joint capability to support security against traditional and also new emerging threats.
In the far-term, UUVs are expected to have the capability to:

(1) deploy or retrieve devices/payloads;
(2) gather, transmit, or act on all types of information;
(3) engage bottom, volume, surface, air or land targets.

The growing use of unmanned systems continually demonstrates new possibilities, making it rational to conceive scenarios where UUVs sense, track, identify and destroy targets autonomously and tie in with the full net-centric battlespace.

b. UUV Definition and Characteristics[6]. In this document 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.

While their inherent characteristics make them more clearly suited for some applications than others, UUVs can offer capabilities in each of these areas, particularly in preparation of the battle space in the face of area denial threats that may present undue risks to manned systems.

c. Four Vehicle Classes of UUVs. Meeting mission requirements and minimizing cost are the two major considerations that must be addressed when developing UUV acquisition programs. The four general vehicle classes identified are[7]:

(1) The Man-Portable class, which includes vehicles from about 11.33 to 45.35 kilos displacement, with an endurance of 10 - 20 hours. There is no specific hull shape for this class.

(2) The Light Weight Vehicle (LWV) class, which is nominally 32.38 cm in diameter vehicles and displaces about 226.79 kilos. Payload increases 6- to 12-fold over the man portable class and endurance is doubled.

[6] The Navy Unmanned Undersea Vehicle (UUV) Master Plan – US Department of the Navy, 2004, pag. 4

[7] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. xxii

(3) The Heavy Weight Vehicle (HWV) class, which is 53.34 cm in diameter and displaces about 1360.77 kilos, and provides another factor of two improvements in capability. This class includes submarine compatible vehicles.

(4) The Large Vehicle class will be approximately 10 long-tons displacement.

d. UUV Missions. In the future, UUVs will perform a myriad of missions (including contribution to Counter Piracy and Energy Security) supporting NATO Navies objectives both in wartime and peacetime..
Nine areas are identified where UUVs can support or conduct a mission:

(10) Intelligence, Surveillance and Reconnaissance (ISR);

(11) Mine Countermeasures (MCM);

(12) Anti-Submarine Warfare (ASW);

(13) Inspection/Identification (ID);

(14) Oceanography/Hydrography;

(15) Communication/Navigation Network Nodes (CN3);

(16) Payload Delivery;

(17) Influence Activities (IA);

(18) Time Critical Strike (TCS).

This document will also discuss UUV capabilities which include mission descriptions, the general concept of operations for each, and assessment of candidate capabilities as to whether they are appropriate for UUVs.

8.1 INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE (ISR) [8]

Persistent ISR is an identified need for the maritme domain. ISR is important not only for the traditional purpose of intelligence collection, but also as a precursor and enabler for other missions, such as Mine Countermeasures (MCM) and Anti-Submarine Warfare (ASW). The ISR mission area encompasses collection and delivery of many types of data: intelligence collection of all types, target detection and localization, and mapping (e.g. IPB and Oceanography). UUVs are uniquely suited for information collection due to their ability to operate at long standoff distances, operate in shallow water areas, operate autonomously, and provide a level of clandestine capability not available with other systems. UUVs extend the reach of their host platforms into inaccessible or

[8] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 9

contested areas. UUVs also act as a force multiplier by increasing the number of sensors in the battlespace. There are many applications, particularly of a military nature, where UUVs would be the preferred means of persistently and clandestinely gathering desired information. UUVs can operate in otherwise denied areas, and provide information without undue risk to personnel or high value assets. Possible ISR UUV missions include:

- Persistent and tactical intelligence collection: Signal, Electronic, Measurement, and Imaging Intelligence;
- Chemical, Biological, Nuclear, Radiological, and Explosive detection and localization both above and below the ocean surface;
- Near-Land and Harbour Monitoring;
- Deployment of leave-behind surveillance sensors or sensor arrays;
- Specialized mapping and object detection and localization.

UUVs could perform a barrier patrol in and around harbours to search for undersea threats to ships, piers, and harbour infrastructure. These threats can include manned and unmanned underwater vehicles, swimmers and deployed mines. Using unmanned vehicles to perform these barrier patrols can save cost by reducing the number of personnel needed to patrol harbours. While there is no need to perform the national defense mission clandestinely, in some cases it may be beneficial to place the vehicle and sensor underwater with the threat.

UUVs could perform a barrier patrol for a maritime task force by operating ahead of the force and performing a search for submerged threats. However, this mission presents a significant technical challenge for UUVs due to the requirements for long endurance and the high speeds required to operate ahead of a strike group.

a. Objective. The purpose of performing ISR missions from a UUV is to collect intelligence data above the ocean surface (electromagnetic, optical, air sampling, weather) and below the ocean surface (acoustic signals, water sampling, ocean bottom equipment monitoring, and object localization) while remaining undetected by the enemy. Specific ISR UUV capabilities would include persistent littoral ISR, harbour or port monitoring, Chemical, Biological, Nuclear, Radiological, Explosives (CBNRE) detection and localization, surveillance sensor emplacement, battle damage assessment, active target designation, and launch and coordination of UUVs. These capabilities will substantially improve indications and warning.

b. Background. UUVs provide many advantages for the ISR mission. ISR UUVs may have a multifunction capability, operate from a variety of platforms, and may enable the collection of many types of data. UUVs could effectively perform these missions in high-risk areas or where hazards to navigation preclude conventional platforms. Long-range UUVs could penetrate such areas, extending the reach of their launch platforms by more than 150 NM. UUVs could be launched from a safe standoff distance, transit to the area of interest, and return with, or transmit subsets of, the data collected. This greatly reduces the risk to manned platforms, frees them to perform other high priority missions, and is a force multiplier.

c. Concept of Operations. The vehicle is launched from its host platform, most likely a submarine, but possibly a surface ship, aircraft, USV or shore facility. The UUV then proceeds to the designated observation area. Once it reaches its area of operation, it performs the mission, collecting information over a predetermined period of time; autonomously repositions itself as necessary, both to collect additional information and to avoid threats; and provides a persistent presence in the operating area, gathering data for long time periods, perhaps as long as several weeks. 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 maximum stealth mission is required at the expense of real-time or semi-real-time transmission, the vehicle will bring the recorded data back to the host platform or to a suitable area for transmission.

d. Technology and Engineering Issues. Critical technology and engineering issues pertaining to the ISR UUV mission capability stem from the need for long transit distances, long times on station, clandestine operations, signature reduction, failsafe vehicle behaviors, vehicle stability, and extended autonomous operation. The requirement for long endurance is difficult but not impossible to achieve when choosing from today's energy source technologies. Long-range communication, though not always required, is an issue. Improvements in current UUV communication capabilities are required. In particular, there is a strong need to increase the bandwidth of communications links while reducing their vulnerability to be intercepted. As capability evolves, a major issue to be addressed is the level of autonomy. Ideally, the system will be capable of detecting, recognizing and avoiding threats of a varied and mobile nature. Near-shore obstacles and nets are particularly challenging (for sensing, autonomy, and net penetration or manipulation). Object avoidance requires a high degree of autonomy, both in threat recognition and the determination of the best means of avoidance. As capabilities improve and the threat evolves, continued enhancements will be required. Payload development for the ISR 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 for low detectability. Improvements in individual sensor performance will also be key to overall mission success.

8.2 MINE COUNTERMEASURES (MCM) [9]

MCM mission requirements are driven by the Navy's need to rapidly establish large, safe operating areas and transit routes and lanes. These areas are typified by long sea-

[9] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 11

lines of communication (SLOCs), offshore Maritime Operating Areas, Amphibious Operating Areas and Littoral Penetration Areas.
These range in size from 100 to 900 nautical square miles or even larger, and cover the water column from deep, mineable waters to on the beach in support of amphibious operations. While it is desirable to minimize risk to the navy operating in these areas, time is paramount. Seven to ten days is emerging as the requirement to complete all MCM operations in these areas, but clearly, quicker is better. These operations need to be completed before the bulk of the vessels arrive in the area. Therefore, lift, control, and replenishment of MCM assets are key considerations in the Concept of Operations.
In general, the overt nature of conventional MCM operations becomes more of a concern closer to shore. Large area operations, far out at sea, do not signal the maritime forces' intent as clearly as near-shore operations. It is becoming clear that operational deception (i.e. a tactic that appears to spread operations over so large a front that the actual objective cannot be discerned) may frequently be as effective as totally clandestine operations. This may relax some engineering and cost constraints. However, in some cases, clandestine MCM remains a requirement. The full range of MCM mission types can meet these requirements against the myriad of mine threats in operational environments. These include:

- Reconnaissance - Detection, Classification, Identification and Localization;
- Clearance - Neutralization and Breaching;
- Sweeping - Mechanical and Influence;
- Protection - Spoofing and Jamming.

Additionally, other mission areas contribute to MCM operations. For example, IPB can be accomplished with a variety of ISR assets. These assets can indicate if mine stockpiles have been accessed, mines moved, minelayers loaded, or mining operations undertaken, thereby allowing actions against these threats prior to their deployment.
UUVs can gather oceanographic data long before hostile operations to provide data on winds, bathymetry, water visibility, currents, waves, bottom geophysical parameters, kelp concentrations, sand bars, etc. to determine mineable areas. Previous bottom surveys can be compared to current ones to determine changes in mine-like contacts.

a. Objective. The objective of this MCM capability is to find or create areas of operation that are clear of sea mines without requiring manned platforms to enter suspected mined areas, and to shorten MCM timelines. The vision for future mine countermeasures is to field a common set of unmanned, modular MCM systems operated from a variety of platforms or shore sites that can quickly counter the spectrum of threat mines assuring access to NATO Forces with minimum mine risk.

b. Background. MCM is perhaps the most problematic of the missions facing the UUV. The proliferation of mine types, their availability to potential adversaries, their ease of employment over a wide spectrum of water depths, and the nature of MCM operations, where there is no tolerance for mistakes, combine to make the MCM mission one of the most challenging to achieving access . On the plus side, small UUVs are being employed successfully in support of MCM missions today and larger specialty MCM UUVs are planned for production in the future. These initiatives are considered to be a good beginning toward a spectrum of UUV-enabled MCM systems that will ultimately enable in-stride or near-in-stride access to any of the world's littorals, regardless of the mine threat.

c. Concept of Operations. The functions of MCM that lend themselves to near-term UUV solutions are minehunting and neutralization. These can be further broken down to the following phases: detect, classify, identify and neutralize. In order to determine the optimal tactics for employment of UUVs, the multiple phases of the minehunting operation were determined by examining each of the "steps" in varying combinations. The combinations were limited to those that could be accomplished in one or two passes, the steps must be in order of increasing information, and neutralization. The multiple steps strategy (detect-classify-identify) for determination of the mine threat was examined to discern an efficient strategy for the employment of UUVs. If multiple sensing steps are desired, they can be performed in a single pass or by multiple passes. Since sensor ranges for each minehunting step vary, multiple steps in one pass require that the vehicle maneuver "off-track" to investigate contacts, lowering the overall Area Coverage Rate (ACR). For multiple pass strategies, one example is that one vehicle would detect and classify with a second vehicle following to identify the objects classified as "mine-like" and to neutralize those deemed to be mines. Intuitively, execution of all phases in a single pass would appear to be the most rapid approach. The noteworthy feature of this analysis is the flattening of the curves at longer ranges. This indicates that the additional maneuvering caused by the higher contact density of the long-range sensors reaches a point of diminishing returns. For this reason, detection and classification systems that operate both steps in one pass are not recommended for efficient operation against bottom targets, particularly in high clutter environments. One of the concerns here is whether it is more efficient overall to spend the time on this classification stage, thereby reducing false alarms that would need to be re-acquired and identified in a follow-on pass, or to actually spend the extra time in the re-acquire/identify pass.

d. Technology and Engineering Issue. Near- to mid-term UUV or USV technology can realistically contribute to solve the emerging MCM requirements. It also indicates that large UUVs may not be required for these missions; while they certainly could perform the missions, larger numbers of smaller vehicles may be operationally better suited, provide greater mission flexibility, and facilitate graceful system degradation. Clearly, shallow waters continue to be a challenge. Other factors to consider are: (1) mine types may change, to larger numbers of smaller mines, which would stress the number of neutralizers required, and (2) if neutralization can be limited to defined lanes, the problem becomes more tractable. The classification sensor performance used for the above analysis is consistent with Synthetic Aperture Sonar (SAS) technology.

These systems are degraded in shallow water and as sensor motion increases. While it is desirable to produce one system that will work for all depths, this does not appear feasible in the near- to mid-term. However, the selection of smaller vehicles (250 to 1500 kilos) for the deep water problem and careful planning could push the technology into shallower waters, as the existing small vehicle technology is pushed out into deeper waters. At some point these systems may merge.

8.3 ANTI-SUBMARINE WARFARE (ASW) [10]

The ASW operation categories can be described as:

- “Hold at Risk” - monitoring all the submarines that exit a port or transit a chokepoint;
- “Maritime Shield” - clearing and maintaining a large maritime force’s operating area free of threat submarines;
- “Protected Passage”– clearing and maintaining a route for a maritime force from one operating area to another free of threat submarines.

UUVs offer significant force multiplication for ASW operations in the “Hold at Risk” scenario. While offering some advantages in the other two categories, the UUVs limited mobility and the lesser need for stealth make UUVs less ideal candidates in those cases. In all cases, UUVs can serve as offboard sensors or sources, extending the range of detection without increasing risk. The host platform can serve as the mother ship for a fleet of vehicles, providing the decision-making capabilities while remaining out of harm’s way. By establishing submarine surveillance points without escalating the level of conflict, UUVs in the Hold at Risk scenario can greatly enhance the ability of the Commander to achieve and maintain access, independent of the state of hostilities. In addition to using existing or pre-positioned sensor fields and cueing assets, the UUV may also be tasked to plant its own field (a sub-mission which falls under the category of Payload Delivery). Variations on the Hold at Risk mission, depending on the stage of conflict and the implementation of appropriate concept of operations and rules of engagement, include:

- UUV employment of non-lethal weaponry;
- employment of lethal weaponry;
- accumulation of intelligence information on threat submarines, individually and collectively.

a. Objective. This capability focuses on the Task Force ASW “Hold at Risk” scenario, in which a UUV, aided by third-party signaling, monitors and tracks the submarine traffic through an adversary port egress or other choke point. The objective of this capability is to patrol, detect, track, and hand off adversary

[10] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 12

submarines by using UUVs. A further objective is to perform this function under any ROE without taking actions that inadvertently advance the stage of conflict, (although in some cases active acoustic pinging could be intercepted by the enemy). Given the potential restriction of access due to bathymetry or threat, the fact that undersea forces may be the only forces available early enough, and the desire to track submarines regardless of the stage of conflict, the UUV is a leading candidate for the “Hold at Risk” task.

b. Background. It is vitally important to achieve and maintain access to the various littorals when and where it is required. In view of the increasing submarine threat from potential adversaries, it is critical to establish and maintain a highly effective ASW capability. Current ASW techniques are effective, but there are several factors that point to UUVs taking on a complementary ASW role in the future: due to the lack of necessity for an ocean transit or large payload, adversary submarines can be much smaller than some NATO submarines, and thus operate more easily in shallower waters). Furthermore, due to ROE or the proliferation of other technologies, air superiority may not be assured at all stages of conflict. Without local air superiority, inherently clandestine undersea vehicles (manned and unmanned) may be the only alternative early in the conflict, capable of accomplishing the IPB required in a timely manner and with reasonable risk.

In ASW, especially in submarine vs. submarine engagements, it is best to be the first submarine to attack. The number of submarines that may be 'surge' deployed near-simultaneously by adversaries mandates a force multiplier to enhance the efforts of existing ASW assets.

c. Concept of Operations. The development of a completely independent, fully autonomous, far-term UUV tracking capability with large area search is not considered to be feasible or practical in the mid-term. Even short of this ideal capability, however, there are several ASW capabilities that UUVs can provide as significant complements to existing ASW forces. For example, focusing on specific areas through which the enemy must pass (as opposed to large area search) is a necessary simplification. This simplification in Concept of Operations (CONOPS) allows relatively simple UUVs (compared to manned ASW assets) to hold an enemy “at risk.” UUV applications that complement ASW are addressed below, from technically easiest to most difficult to implement, given these simplifying assumptions. The UUV and its users are assumed to have access to some type of background intelligence on the home port and nominal readiness of adversary submarines, but are unlikely to have knowledge of specific sailing dates and 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 that is still a substantial distance away from the adversary’s dive point. The UUV is launched and transits into the intercept area—typically a port egress route or choke point–-where it establishes contact with a source of off-board cueing (e.g., other UUVs, a pre-existing deployed sensor field, or other third party source) and monitors that source for cueing. Typically the UUV will maintain its position relative to the cueing sensor in a low-energy “loiter” mode, which will facilitate its ability to remain on station for extended periods. When cued, the UUV takes up position and maneuvers to verify the cue’s initial classification. If successful, the UUV reports to its decision authorities. UUV options at this point, from easiest to hardest technically, include:

- Return to cueing barrier in “loiter” mode to wait for the next cue;
- Employ lethal weaponry against the adversary; and
- Employ non-lethal weaponry against the adversary.

The UUV would establish mid-term track of the target while avoiding counter-detection and communicating to its controllers that a track has been initiated, with periodic updates. At the end of the tracking phase (due to handoff, energy exhaustion, or orders from its controllers), the UUV would break contact and transit to a rendezvous location based on the initial sortie plan or as updated during communication intervals. Later, perhaps after a significant loiter period, the UUV would be recovered or replenished to enable another mission.
Alternate ASW Sub-Pillar options include:

- Having the UUV employ its own autonomous or semi-autonomous sensor field (e.g., Advanced Deployable Systems (ADS), Deployable Autonomous Distributed System (DADS), or Remote Deployable System (RDS);
- Having the UUV establish a barrier patrol without the benefit of cueing sensors. This option is only appropriate in very restricted choke points, since the UUV’s energy availability will not allow it to execute a significant search rate for an extended time period and still maintain adequate reserves for the tracking part of the mission. Options that can mitigate this situation somewhat include use of vehicle-mounted non-traditional tracking sensors to enhance effective search rate, and use of non-lethal weaponry to aid its own tracking efforts.

ROE and CONOPS development are required to enable some of the options noted above. Specifically permitting:

- the employment of non-lethal weaponry early in the pursuit, eliminating the requirement for longer-term track, and enabling immediate handoff to other ASW assets;
- the use of lethal weaponry from the UUV, either semi-autonomously (man-in-loop) or autonomously (UUV makes the decision). In addition to CONOPs and ROE attention, this option would require technical and operational assurances to protect friendly forces operating in the vicinity.

Any of the above options, except for the stand-alone search and track option, individually or in combination, can reduce the endurance requirements on the UUV substantially by mitigating the requirement to maintain track of the target submarine for a significant time. These changes would also reduce the complexity associated with UUV autonomy for the tracking mission, but greatly increase the autonomy complexity associated with release of weaponry, lethal or otherwise.

d. Technology and Engineering Issues. Technology issues associated with this capability include: communications, energy, propulsion, sensors, and autonomy. In the area of propulsion and energy, the speed and endurance requirements for the tracking portion of ASW will be significant challenges. Non-acoustic sensors show promise for ASW and require additional development for UUV applications. Engineering issues exist with the launch and recovery of large UUVs. Another issue worthy of reiterating is vehicle communication. Potential options for vehicle periodic reporting include use of a “floating wire” type satellite communications system, as this would enable transmission of quarry parameters without breaking contact. Additional communication options include: (1) disposable one-way communications buoys that would be programmed and deployed at appropriate times, and (2) retractable floating buoy antennae that can be deployed and retracted at will. It is expected that technical and operational advances in submarine communications at speed and depth will feed similar advances for UUVs, with appropriate scaling. This aspect is also important for active multistatic operations, which is a major advantage of having multiple UUVs distributed in the water column. There is an active research not only on submarine communications at speed and depth, but also research specifically on communication between UUVs, with a very active research programme in communications and networking at the Centre for Maritime Research and Experimentation (CMRE).

8.4 INSPECTION / IDENTIFICATION (ID)[11]

In order to keep harbours and choke points safe, there is the need to efficiently inspect ship hulls and piers for foreign objects. Currently, hull and pier inspection is generally the responsibility of Explosive Ordnance Disposal (EOD) Diver teams, and it is both time and manpower intensive. The typical targets in a hull or pier search would be unexploded ordnance, such as limpet mines or special attack charges. Critical components of the ship such as shafts, intakes and discharges must be secured before a diver can begin his search. Preparing a ship for divers may take several hours, and it requires coordination, as some damage control systems may have to remain on-line. Searching for ordnance that is typically time-fused is particularly hazardous to divers. Use of an unmanned vehicle can reduce the risk to EOD technicians and divers by providing precise location of suspicious objects, while relieving the divers of the tedious search process in cluttered environments.

[11] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 13

a. Objective. The Inspection / Identification Capability will support NATO and Anti-Terrorism / Force Protection (AT/FP) needs. It will be able to perform a rapid search function with object investigation and localization in confined areas such as ship's hulls, in and around pier pilings, and the sea-bed of berthing areas.

b. Concept of Operations. The full Inspection / Identification mission is currently outside the realm of UUV operational capabilities. However, a UUV can provide a useful asset to current hull and pier inspection operations, by performing the broader area surveys, freeing divers to concentrate on the more complex areas and designated targets that require real-time human judgment. It is critical that the UUV system be compatible with other systems in use, so that the data may be quickly interpreted and acted upon. A possible operational scenario might be as follows:

- Deliver UUV system to the operational area;
- Input known data on environment (charts, hull model, etc) into system for UUV;
- Mission planning;
- Develop inspection plan;
- Deploy support equipment (navigation transponders, communication relays, etc);
- Deploy vehicle to run programmed path and collect sensor data;
- Monitor real-time or near real-time communication from vehicle containing sensor data content;
- If a target of interest is detected, relay coordinates and any additional information to the dive team or ROV operations team;
- Continue mission;
- Self destruction if captured;
- Recover vehicle;
- Redeploy as necessary.

The Inspection / Identification vehicle must be able to operate in a range of pierside environments.

c. Technology and Engineering Issues. The technology and engineering issues associated with the Inspection / Identification capability are largely driven by the complexity of the ship's hull / pier side environment and the need for rapid response to identified targets. Typically the harbour environment is extremely cluttered with poor visibility and acoustic characteristics. This poses challenges to the execution of the technical requirements, particularly in the areas of navigation and communication.

(1) Navigation: The ship's hull / pier side environment is difficult for traditional navigation methods (acoustic, magnetic), yielding the need to address the

problem with an integrated approach of inertial, acoustic, and other methods to get the high degree of accuracy required.

(2) Communication: Real-time or near real-time communication of sensor data from the vehicle is required to effectively perform the inspection / identification mission. Component technologies such as acoustic communications, radio-frequency (RF) relays, and expendable fiber optic cables exist that may address these needs, but they have not yet been integrated into an operational system for this application.

(3) Maneuverability: The vehicle must be sufficiently maneuverable to maintain a proper sensor orientation relative to the hull or structure of interest. This requires a higher degree of control than is often found in more conventional cylindrical UUVs.

(4) Autonomy: Ideally, the vehicle will be able to operate effectively in the complex, cluttered environment without the need for direct human supervision. While this remains in the future, the ability of the vehicle to independently identify targets of interest would greatly reduce the operator workload.

(5) Sensors: Lightweight, affordable sensors that can discriminate between objects of interest and objects inherent to ships' hulls and piers will enable UUVs to communicate data to operators, allowing for continued survey or initiation of action to render safe potential threats, including unexploded ordnance and weapons of mass destruction.

(6) Compatibility with other Systems: Due to the complexity of the operating environment, it is doubtful that a UUV will be able to perform the entire inspection / identification mission independently. It is therefore critical that the system and the data it collects be complementary with the other systems in use such as divers, marine mammals, and remotely operated vehicles. The navigation and communication systems in particular must be compatible with other systems in use.

8.5 OCEANOGRAPHY/HYDROGRAPHY[12]

Knowledge of the operating environment is of key importance for both strategic and tactical operations. UUVs are well suited for many ocean survey tasks. Conventional oceanographic data collection is largely dependent on hull mounted or towed systems that require extensive surface ship support and suffer limitations imposed by tow cables. In applications such as acoustic and optical imaging, data quality is significantly enhanced when sensors are decoupled from motion of a towing platform. UUVs permit characterization of significantly greater areas at less cost by multiplying the effectiveness of existing platforms. UUVs can perform oceanographic/hydrographic

[12] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 13

surveys in near-shore shallow water areas while their host ships remain at a safe standoff range. UUV technology provides the opportunity to acquire affordable, near real-time data at required sampling densities. Data gathered by UUVs will be integrated with conventional survey data and models to provide warfighters with critical knowledge of the undersea battlespace. UUVs can autonomously collect information for later delivery and analysis for battlespace preparation or for direct transmission and real-time input into Tactical Decision Aids.

Oceanography/hydrography missions for UUV operations include:

- Bathymetry;
- Acoustic imagery;
- Optical imagery;
- Sub-bottom profiling;
- Water column characterization;
- Ocean current profiles (with tides);
- Temperature profiles;
- Salinity profiles;
- Water clarity;
- Bioluminescence;
- CBRNE detection and tracking.

These missions support safety at sea and all naval warfare areas.

a. Objective. Oceanography ranges from broad reconnaissance of large littoral undersea areas to detailed characterization of specific battlespace areas collecting high quality, accurately positioned data. There is a need to perform these missions in areas where battlespace dominance has not been achieved. The focus is on the littoral, but a deep-water survey capability is required for bottom characterization to accomplish cable route pre-installation and inspection. The shallow-water littoral region survey is useful in aiding navigation or projecting sensor performance. This type of mission may be best accomplished using small UUVs or gliders. UUV technology is a force multiplier to manned platforms and is essential to meet critical oceanography requirements. The predominant driver for adopting UUV technology for ocean survey is to increase the timeliness and cost effectiveness which helps to 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 provides warfighters with critically required foreknowledge of environmental parameters such as bathymetry, tides, waves, currents, winds, acoustic propagation characteristics, locations of hazards to navigation, and other objects of interest.

b. Background. Over the last year, prototype UUVs have been fielded for the purpose of oceanographic surveys. The UUVs were designed to collect high-quality, precision-located environmental data in the littoral regions of the world. Additionally, a capability was instituted for deep waters rated dives with integrated physical oceanography and bottom-mapping sensors. UUV capabilities also supported two types of missions: independent physical oceanographic data collections and side-scan sonar bottom-mapping surveys. Smaller vehicles are now available to execute shallow-water hydrographic and coastal oceanographic surveys.

c. Concept of Operations. All maritime platforms; manned and unmanned, surface, air and undersea; can gather oceanographic/hydrographic data to varying degrees in parallel with their other missions. Dedicated oceanographic/ hydrographic operations occur worldwide; these operations will be augmented by UUVs operating from survey ships and ships of opportunity that may be used as a platform for plug and play unmanned systems . Medium sized UUVs will support surveys in shallow to mid-depth (continental shelf) regions. Smaller UUVs will be employed for use from hydrographic survey launches, other small craft, and aircraft. These UUVs will operate in localized areas. Other small, dedicated UUVs will drift with the currents or glide using batteries or energy extracted from the oceans while profiling to gather ocean survey data over very large areas. Later when large vehicles have been fielded, oceanography payloads may be incorporated into these UUVs to provide a long-range capability. The oceanography mission must directly (and often simultaneously) support multiple warfare areas. For example, ocean survey vehicles will gather bottom object information supporting Mine Warfare (MW) and acoustic information supporting ASW. Common data elements and archives will allow for rapid access to all information for the areas of interest.

d. Technology and Engineering Issues. Deep-water ocean surveys can be executed using existing technology. Contested area surveys can also be executed using existing technologies. However, UUVs reduce the level of risk and provocation. In addition, UUVs offer advantages in terms of area coverage rate and cost per NM. Deep water UUVs will provide a substantial increase in collection capability for each UUV over present deep-towed systems. However, to achieve the full benefits of UUVs in both deep and shallow water, advances in technology are necessary. Particular technology constraints on oceanography UUV operation include needs for long-range transit and surveys, high-resolution data in both shallow and deep water, precise positioning, and rapid data recovery and transfer. Some long-range UUV missions will require significant navigational accuracy without surfacing the vehicle. Several technologies have the potential to meet these requirements, including moored or mobile acoustic transponder networks, and onboard comparison of terrain with archives of bottom features from acoustic imagery. Operational requirements mandate increases both in mission range and endurance. Higher-density energy storage and means for extracting energy from the ocean environment are essential. Miniaturized, low-energy sensors are a priority. Undersea docking stations for recharging batteries and extracting data should be viewed as far-term options. Glider UUV technology, especially with air-deployment capability, will be used to provide sustained and continuous oceanographic monitoring, significantly enhancing current drifting buoy programs.

8.6 COMMUNICATIONS / NAVIGATION NETWORK NODE (CN3) [13]

UUVs can serve as critical communication and navigation links between various platforms at sea, on shore, and into the air and space realms. As with the other missions, they can be operated from a variety of platforms, at long standoff distances, and 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 discreet antenna. As an aid to navigation, UUVs can serve as stand-by buoys, positioning themselves at designated locations and surfacing to provide visual or other references for military maneuvers or other operations. UUVs can also provide the link between subsurface platforms and Global Positioning Systems (GPS) or other navigation systems, without exposing the platform to unnecessary risk. Prepositioned 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:

- Communication: underwater network nodes for data transmission;
- Underwater connectors;
- Low aspect deployed antennas (SATCOM, GPS);
- Navigation: Deployment of transponders or mobile transponders;
- Inverted GPS capability (antenna to surface);
- On-demand channel lane markers (to support Amphibious Assault).

a. Objective. The objective of the CN3 is to provide a low-profile communication and navigation relay function for a wide variety of platforms. The advantages offered by using a UUV include extended standoff distances and greater accessibility. CN3 will provide submerged communications to undersea platforms in areas not otherwise available. Potential users include other UUVs, submarines operating at speed and depth, Special Forces units, and any other application where low-visibility communication is desirable. As a navigation aid, the CN3 UUV is envisioned as an on-site on-demand reference point for subsea or surface operations. Pre-positioned, either just prior to, or well in advance of planned operations, the vehicles will provide reference beacons (visual, radar, or acoustic) for other UUVs, submarines, Special Operation Forces (SOF), or surface operations. These could take the form of lane designators, undersea mileposts, or supplementing or replacing conventional navigation means. In critical situations, the CN3 UUV could provide an above or below water navigation capability equivalent to GPS accuracy without the need for continuous direct satellite communications. CN3 UUVs will also aid less-capable UUV systems, providing a mobile geographic reference system. An immediate application would be a self-deploying navigation transponder for use by SOF vehicle systems.

[13] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 14

b. Background. The CN3 capability is a support function enabling other systems to perform their missions more effectively. One immediate application of the CN3 would be a self-deploying transponder network to support near-shore SOF and EOD missions; currently such tasks are performed with small manned vehicles putting men in high threat areas. A CN3 UUV could be launched from a safe distance, transit to the operations area using GPS, and then deploy itself as a transponder node for operations. The mission assets could then transit into the area, orient themselves to the network, and perform their mission without the need to expose human operators. Looking to the future, the growing emphasis on networked systems will require multiple undersea components. The flexibility provided by UUV systems is especially important for mobile, dynamic systems such as submarine communications at speed and depth, operation of UUV swarms and connection with SOF.

c. Concept of Operations. The general CN3 CONOPS is to provide on-the-spot connectivity and navigation capability for a variety of platforms. The modules developed for the CN3 UUV will also support the navigation and communication requirements of ASW, MCM, and SOF missions.

On-demand navigation references could be useful to platforms of all types. The vehicles would be programmed to transit to desired marker locations. Delivery of the vehicles could be performed by a variety of platforms (including aircraft), well in advance of the intended need. The vehicles would then proceed to the designated locations, navigating inertially or with GPS. They would sit dormant until the time of operation (either preset or on-command). Once activated, the vehicles would deploy navigation beacons, either pop-up buoys, acoustic transponders, or other markers. Once their operations are complete, the vehicles would have the options of scuttling or returning to a home base for recharging and reuse. For use as a communications relay, the UUV would be outfitted with the desired mode(s) of communication: optical fiber spool and connector, acoustic modem, laser communication, Radio Frequency (RF), or satellite communications antenna. The vehicle is launched from its host and makes the desired connection, either with a subsea fixture, another platform, or the surface for Satellite Communication (SATCOM) transmissions. The data exchange would take place, either one-way or two-way with minimal impact on host platform operations. Once communications are concluded, the vehicle could either be scuttled or recovered. While this function is most obviously an asset to submarines, SOF, other UUVs, or surface ships requiring connectivity to a subsea entity could also use it effectively.

d. Technology and Engineering Issues. There are no critical path developments preventing the construction and deployment of the initial systems described. All of the key technologies have been demonstrated as feasible by individual autonomous systems. However, enhancements to the integral functions will permit the systems to achieve a wider range of operational capabilities. System complexity and far-term deployment will be key factors in the development of cost effective 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, security, and reliability. Networking is critical, and the compatibility conferred by the adoption of open architectures and communications standards is a must[14]. The key engineering issue for the employment of these systems is largely one of the infrastructures required. There must be 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 extended use. Both the vehicles and all supporting infrastructure must be designed to operate in a rugged and reliable manner for long duration deployments.

8.7 PAYLOAD DELIVERY[15]

Large UUVs can facilitate logistics by providing covert supply and support without exposing high-value platforms. Potential payloads include:

- Sensors or vehicles deployed in support of ISR, ASW, Mine Warfare;
- Oceanography, CN3 or Time Critical Strike;
- Weapons to deploy or preposition;
- Supplies to preposition for Special Operations Force or EOD missions;
- MCM neutralization devices;
- Cargo as a follow on behind Swimmer Delivery Vehicles.

a. Objective. The objective of the Payload Delivery Capability is to provide a covert method of delivering various payloads to support other mission areas. The missions supported would include MCM, CN3, ASW, Oceanography, SOF Support, and Time Critical Strike (TCS).

b. Background. Payload delivery is not a mission in itself, but is necessary to support a number of other mission areas. As a payload delivery platform, the UUV would essentially act as an underwater truck. The UUV would provide the energy, navigation, autonomy, and payload deployment systems necessary to support the other missions.

c. Concept of Operations. The concept of operation for payload delivery depends on the particular mission being supported. Since a payload delivery UUV would be large and would include fairly robust autonomy, navigation, energy, and propulsion, in most cases vehicle recovery would be desired following delivery of payloads. Some of the mission areas and concepts of operation include the following:

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[14] G. Zappa, I. Nissen, and J. Potter, "Doppler compensation for JANUS applied to data collected in the Baltic Sea," 4th Intl. UAM Conference, pp. 1537-44, June 2011.

[15] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 14

(1) MCM: To support the MCM mission, a large UUV would provide the capability of inserting smaller devices into forward areas. It could deploy sensors that would detect mine laying operations, a swarm of smaller vehicles that perform mine reconnaissance, or mine neutralization devices or mine neutralizing UUVs.

(2) Oceanography: To support Oceanography, a large UUV could deploy sensors used to collect far-term oceanographic data. This UUV could also deploy a group of smaller vehicles to survey shallow water.

(3) ASW: To support the ASW mission area, a large UUV could deploy underwater sensor arrays used to detect the passage of enemy submarines. A UUV could also deploy either lethal or non-lethal weapons.

(4) CN3: To support the CN3 mission area, a large UUV could deliver underwater communications nodes or acoustic-to-RF communications transponders. A UUV could also deliver transponders used to provide accurate navigation for other manned and unmanned platforms.

(5) SOF Support: A large UUV could be used to resupply SOF personnel with weapons, food, batteries, fuel, and other supplies. It could also carry transport devices (i.e. motorcycles or All-Terrain Vehicles (ATVs)) increasing the mobility and operating range of the forces.

(6) Time Critical Strike: To support the Time Critical Strike mission, a UUV could deliver an underwater weapons cache or buoyant missile launch capsules that would loiter in place awaiting launch instructions, or the UUV itself could carry the weapons and loiter.

d. Technology and Engineering Issues. Critical technologies needed to support UUV Payload Delivery missions include: energy density for covert long-range transit, vehicle reliability, accurate navigation, vehicle ballasting and control systems, and underwater payload delivery systems.

8.8 INFLUENCE ACTIVITIES (IA)

Two IA roles are considered well suited to UUVs; first, as a platform to jam or inject false data into enemy communications or computer networks, and second as submarine decoy. The small size and stealth inherent in UUVs would enable it to operate in coastal areas difficult or impossible for other platforms, where they could carry antennas and transmitters into locations that support Electronic Warfare (EW). The degree of difficulty increases as the capability moves from jamming to denial of services, to injection of false data. Submarine decoys and ASW training targets have existed for decades. These simple vehicles could be effectively used in an IA role to convince an enemy that submarines are operating in an area where they, in fact, are not. Today's capabilities could improve on this old technology by extending the range, duration and autonomy of the vehicles to provide an improved deception capability. This capability could be used to impede enemy maritime operations out of fear of attack by a non-existent or minimal submarine threat. In addition, they would enhance the safety of friendly submarines by causing the enemy to dilute its ASW forces into areas where friendly submarines are not operating.

a. Objective. The objective of Information Operations (IO) is to “deceive, deter and disrupt enemies.” These operations can use virtually any platform, weapon or means. UUV capability to operate covertly in shallow waters and areas too hazardous for a manned platform makes them ideally suited for several IA missions which could not be performed by other platforms. The two IA roles that UUVs seem best suited for are use as communications or computer node jammer and employment as a submarine decoy.

b. Background. The technology to support IA exists or can be easily leveraged from other sub-pillars. Submarine simulators have long been employed as ASW targets. The basic targets had little if any intelligent autonomy, navigating a pre-assigned route while transmitting the acoustic and magnetic signature of a selected submarine.

c. Concept of Operations. An IA UUV could also be used as a platform to jam enemy communication nodes. The natural stealth and small size of a UUV allow it to operate in littoral areas that would be difficult or impossible for other platforms to reach. This enables the transport of a transmitter and antenna to close proximity of susceptible communications nodes. Injection of false data would be much more difficult, requiring either a reliable communications link with the vehicle or a sophisticated degree of autonomy which would recognize and act on the opportunity to inject the erroneous data. Enhancements in the autonomy and sophistication of UUVs may make this a feasible mission in addition to jamming. Submarine decoys could be used in several different scenarios. A simple decoy could be used to transit an area known to have enemy ASW forces or sensors. It could transit a pre-programmed path designed to attract attention and enemy response. A more sophisticated vehicle could be designed to react to prosecution, becoming evasive and perhaps gradually lowering its acoustic signature and causing the prosecuting forces to lose contact. It could then go dormant for a period of time and then repeat its decoy action. These submarine decoys could be used to pulse enemy ASW forces causing them to expend effort that would otherwise be used to endanger friendly submarines. In addition, these decoys could be used to cause the enemy to alter its plans, perhaps deciding not to sail its ships from an area thought to be in danger from the spoof submarine.

d. Technology and Engineering Issues. There are no critical path developments preventing the construction and deployment of systems similar to those described for the IA missions. Submarine targets and decoys could be used in their current forms for the submarine decoy mission. Enhanced range and autonomy would increase their operational utility. The same is largely true of the jamming mission. Although UUVs have not been built for this mission before, all the necessary component technology is mature enough for a rudimentary jammer to be built and deployed.

8.8 TIME CRITICAL STRIKE (TCS) [16]

Warfighters need the ability to strike time critical targets at precisely the right moment in battle. UUVs will be able to perform some of the necessary functions for TCS, for example, clandestine weapon delivery or remote launch. Stealth and long-standoff distance and duration allow a UUV to be an effective weapon platform or weapon cache delivery vehicle for TCS missions. Launching a weapon from a UUV or from an emplaced cache allows a launch point closer to the target resulting in reduced fuel weight requirements and quicker response time for prosecution. It also moves the “flaming datum” away from high value platforms so that their positions are not exposed. The autonomous weapon or weapon launch option is controversial and further consultation/regulation is required in the Alliance. Man-in-the-loop control of weapon launch will be required for the foreseeable future.

a. Objective. The objective of TCS is to deliver kinetic effects weapons against multiple targets of interest within extremely short periods of time. The capability to operate covertly in shallow waters and areas too hazardous for a manned platform and to loiter covertly for extended periods of time, makes UUVs ideally suited for certain aspects of the TCS mission. The two TCS roles that UUVs seem best suited for are as a delivery platform for leave-behind weapon caches and as a remote weapon launch platform for close-in attack against time-sensitive targets.

b. Background. TCS is one of the lower priority missions for UUVs. An autonomous weapon launch capability is controversial, and man-in-the-loop control of weapon launch will be required for the foreseeable future. However, UUVs can provide low-risk, high payoff augmentation to strike missions, providing an ability to covertly deliver weapons to close-in launch points. The TCS mission was ranked as moderately suitable for UUVs. When viewed as a specialized “Payload Delivery” mission where the payload is a missile, the TCS mission was kept on the list of recommended UUV sub-pillar capabilities.

c. Concept of Operations. UUVs could provide TCS capability using several different CONOPS. The first scenario involves missile launch from the UUV. In this scenario, the vehicle is launched from a platform of opportunity, either a surface ship or submarine, and transits to a predetermined launch point. The UUV anchors or loiters in the area awaiting the launch command. When commanded, the UUV either:

[16] The Navy Unmanned Undersea Vehicle (UUV) Master Plan - US Department of the Navy, 2004, pag. 15

- Launches the missiles while submerged, similar to a Ballistic Nuclear Strategic Submarine (SSBN) or Nuclear Attack Submarine (SSN);
- Surfaces to launch the missiles;
- Or releases a buoyant missile capsule that floats to the surface and launches the missile.

When all missiles are launched, the UUV transits to a recovery point for refurbishment and reloading.
The submerged launch option is not highly recommended because of the complexity of the vehicle systems required, i.e. floodable launch tubes, trim and ballast systems, and reliable underwater communication systems as well as a sea-adapted missile. All options in this scenario place the burden of the operation on the UUV.
The second scenario is similar to the first, except that the UUV surfaces to launch missiles. This avoids the complexities of submerged launch and communications. The UUV would anchor or loiter in the launch area with an antenna on or above the surface awaiting a launch order. When alerted, the UUV could raise a higher bandwidth antenna to receive any new targeting information. When ordered the vehicle would surface and launch its missiles under the control of a remote operator.
The third scenario involves a UUV that carries the missiles as a deployable payload. The UUV is launched from a platform of opportunity outside of the battlespace. The vehicle transits to a predetermined location where the weapon cache is deployed. The weapon cache rests on the bottom or floats on the surface until commanded to launch missiles. The UUV returns to the host for another weapon cache module. This scenario places the burden of the operation on the deployed weapon cache.

d. Technology and Engineering Issues. Critical technologies needed to support UUV TCS missions include: secure and clandestine underwater communications, depending on the specific concept of operation; energy density for long range transit and loiter; weapon cache, missile, and weaponized buoy launch techniques; and vehicle reliability.

9. UNMANNED SURFACE VEHICLES (USV)

a. The USV vision is:

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

In support of this USV vision, the following objectives are set forth:

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

Evaluate USV Technology needs. In order to assess the technological readiness and recommend the technology investments that should be made to enable the development of vehicles and payloads to accomplish the required USV capabilities.

These capabilities should be allowed to evolve over time as the operators gain experience and confidence in the systems while the technologies advance.
In executing these objectives in support of the vision, it is implicit to:

- Evaluate national guidance, to craft a vision for the leadership and ensure that the resulting product would meet NATO needs;
- Gain an understanding of operational priorities, technical requirements, and practical limitations relative to USV operations, current and future;
- Gain an understanding of the present state of USV development, and of the types of boat hulls that might be of use in current and future USV applications;
- Review the current and likely future state of technology available to assist in crafting reasonable USV capability packages;
- Conduct technical and operational analysis to the extent needed to gain a feel for practicability and potential military utility of USV capability packages.

b. USV Definition. In this document an Unmanned Surface Vehicle is be defined as a:
Self-propelled surface vehicle whose operation is either fully autonomous (pre-programmed or real-time adaptive mission control) or under minimal supervisory control.

c. USV Craft Types[17]. USVs are tactical systems capable of air or sea transport. As a result, the types and sizes of vehicles considered in this document were limited to those that could be transported by standard ships, including those sizes and hull shapes already in use in the Navies. USV is a vehicle that operates at or near the sea surface, hence a major design driver for USVs is the interface of the vehicle with the sea surface. By definition, a USV will have no vehicle operators on board, although it may have the capability of being manned for testing, troubleshooting or when required for a manned

[17] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. xi

mission. Operating at or near the sea surface gives USVs the ability to continuously communicate with suitably equipped surface, air and underwater assets. Mission requirements and currently available technologies result in USVs having varying levels of autonomy. With these considerations in mind, the following craft types were considered for this document.

(1) Semi-Submersible (SS) Craft. Operating with most of its volume below the surface, the semi-submersible design exhibits lower drag and platform motion than conventional hull designs. When wave-making drag is eliminated, the total craft drag is significantly reduced, thus allowing for a larger percentage of the craft's power to be available for other purposes, such as towing or powering payloads. Power required for propulsion, in general, is a function of speed cubed. Due to the relationship of form drag to power required, speeds are limited to around 25 knots for a 7 meters (m) SS. Being speed limited, the semi-submersible can be fitted with highly efficient (low speed, large diameter) propulsion systems, making them competitive with other craft designs. Nominally a 7m SS is comparable to an 11m planing hull in terms of towing capability.
Operating below the surface, the SS is less affected by sea state, giving it a larger operational weather window. Sea-state related motions are reduced which is useful for sensor and payload stabilization, such as MCM high-resolution sonar and directional antennas. This hull form is also more conducive to deployment and retrieval of a variety of payloads. With payloads carried on conventional hulls, the difficulty arises in raising the payload off the USV deck, over the side and through the air/sea interface. None of the above needs to occur when an SS carries its payload beneath the interface to begin with.
With the majority of the hull under water the SS has reduced radar and visual signatures and is therefore more conducive to missions requiring stealth. The SS is somewhat more costly than conventional hull designs due to the increased complexity of its systems and its uniqueness.

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

At low speeds these craft may be less stable in a seaway and tend to roll when at rest, while at high speeds they may pound (slam) and are somewhat inefficient at transitional speeds. At normal operating speeds, they are likely to exhibit more motion than other hull types. These conventional planing hull types tend to be lower in cost as a result of commonality with commercial craft and the resulting manufacturing economies of scale.

(3) Semi-Planing Hull Craft. The Semi-Planing hull provides lower drag and higher sea-state capability than the conventional V-Hull and its variants when operated at moderate speeds. It also exhibits lower sea state sensitivity and provides a more stable sensor platform for a given size at approximately the same cost. This hull type is capable of speeds up to 30 knots, can be highly efficient across a broad range of speeds, and can also perform towing.
This hull form typically has a lower payload fraction than conventional planing hulls for a given waterline length and tends to be more slender with higher length-to-beam ratios.

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

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

d. The Four USV Classes are:[18]

(1) X-Class:Cheap, expendable, probably special-purpose and purpose-built, details not important from an overall perspective.

(2) Harbour Class. Maritime Security is an all-Navy concern, and this

[18] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. xii

is the size of boat carried on most or all Navy vessels.

(3) Snorkeler Class. MCM Search requires: (a) the ability to pull a tow body, (b) stability in sea states, up to and including (and possibly beyond) Sea State 3 and (c) mission endurance.

(4) Fleet Class. Required to provide (a) adequate power and payload for ASW, (b) power and tow force for MCM Sweep, and (c) endurance for these and other missions.

e. Descriptions of Four Classes

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

(2) Harbour Class (7m). The Harbour Class USVs use a seven meter RHIB with moderate endurance as the basis for its missions. The requirements for the Harbour Class are driven by the need to be hosted by the majority of warships to perform ISR and MS missions. The ISR payload will be arch-mounted such that it can remain in place for manned operation of the craft.

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

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

f. USV Missions. The missions that can be executed by using USV are:

(8) Mine Countermeasures (MCM);

(9) Anti-Submarine Warfare (ASW);

(10) Maritime Security (MS);

(11) Surface Warfare (SUW);

(12) Special Operations Forces (SOF) Support;

(13) Electronic Warfare (EW);

(14) Maritime Interdiction Operations (MIO) Support.

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

9.1. MINE COUNTERMEASURES (MCM) [19]

MCM mission requirements are driven by the need to rapidly establish large, safe operating areas, transit routes and lanes. The objective of MCM capability is to find or create Operating Areas that are clear of sea mines without requiring manned platforms to enter suspected mined areas, and to shorten MCM timelines. Further, this capability is required to operate independently of other warfighting capabilities. The vision for future MCM operations is to field a common set of unmanned, modular MCM systems operated from a variety of platforms or shore sites that can quickly counter the spectrum of threat mines, assuring access to NATO Forces with minimum mine risk.
The full range of MCM mission types must be brought to meet these requirements against the myriad mine threat types and operational environments. The lexicon of mine countermeasures includes the following terms and their definitions:

- "Detection": the discovery by any means, of the presence of a mine or mine-like object with potential military significance.
- "Classification": the evaluation of an object to determine if it is a mine-like object.
- "Localization": establishing the precise position of an underwater object relative to a specific geodetic position.
- "Identification": determination of the exact nature of a mine-like object as a mine. Currently visual identification is being done by a diver or camera, but

[19] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 13

advances in sonar technology may provide adequate capability in the foreseeable future.

- "Neutralization": rendering (by external means) a mine incapable of firing on a passing target or sweep. The classic end-to-end response to a mine threat is Detect, Classify, Localize, Identify, Neutralize (DCLIN). This is more of a technical sequence than an operational one, however, and it is rare that this chronology will take place in anything other than a controlled laboratory or experimental setting.

The following terminology is used to describe actual MCM behaviors as addressed:

- "Reconnaissance": That phase of the exploratory objective designed to make a rapid assessment of the limits and density of a minefield.
- "Search": the use of sonar or divers to detect and classify mines or mine-like objects.
- "Hunting": the act of searching for mines. Hunting operations can also include marking and neutralization of mines.
- "Breaching": breaking through a minefield, thereby opening a clear path or channel.
- "Clearance" or "clearing objective": removal of detectable mines from an assigned area. Since it is generally impossible to guarantee that all underwater mines have been detected and cleared, a goal is assigned to coincide with a percentage of risk that a potential number of mines remain.
- "Sweeping": the act of towing mine countermeasures gear intended to actuate mines by generating a ship-like signature, or mechanically cutting mooring cables of moored mines.
- "Jamming": overwhelming an influence-activated mine's sensors with external influences, such as noise or a strong magnetic signature, thereby masking a passing ships signature and causing the mine to not detect the passing vessel.
- "Signature": the characteristic pattern of a ship's influence as detected by an influence sea mine (such as magnetic signature, acoustic signature, pressure signature).

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

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

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

The development of a completely independent, fully autonomous, far-term USV MCM capability with large area search, autonomous target ID, and fully autonomous neutralization is not considered to be feasible in the immediate future. Even short of this ideal capability, however, there are several MCM capabilities including sweeping that USVs can provide as significant complements to existing MCM forces, which will only become more useful as the enabling technologies mature. The ultimate goal is a fully autonomous USV MCM capability to enable the NATO Forces to access the world's littorals when and where it is required, regardless of the mine threat.

The specific sub-missions of MCM selected were MCM Search, MCM Sweep, and MCM Neutralization.

9.1.1. MCM SEARCH[20]

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

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

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

In the future, USVs may also deploy and retrieve multiple UUVs that will perform the search functions, instead of or in addition to towing sensors. This approach provides for very high area coverage rates through the use of many search assets in parallel.

b. MCM Search System Concepts. The near-term system with an MCM

[20] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 15

search application is a semi-submersible USV that tows a sensor system. The system can vary the tow scope/sensor depth and operating modes to search the water column from near-surface to the bottom for all mineable environments. Sensor imagery and Computer-Aided Classifications are provided to an operator for target acquisition.
Future USV systems deploy UUVs to gain the advantage of higher area coverage rates through multiple, simultaneous operations, without the need for additional operators (implying that UUV- based MCM search is the envisioned future technical solution). While the particular types of USVs and the distribution of search functions across various UUVs will be determined from detailed studies, initial analysis shows that both semi-submersible and planing hull USVs have similar capabilities to manage the UUV payloads. Cost, complexity, and host interface issues will determine the selection.

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

d. MCM Search Technology and Engineering Issues. Although there are technical challenges, future USVs will benefit from the capability to automatically deploy and retrieve UUVs in high sea states at the far reaches of their operating area, without operator intervention and will require autonomous obstacle and threat avoidance capabilities.

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

9.1.2. MCM SWEEPING[21]

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

a. MCM Sweeping Concept of Operations. The MCM mantra to date has been: "hunt when you can, sweep when you must". This means that while mine-hunting can be an effective means of clearing mines, external influences such as highly reverberant and high-clutter environments, mine burial, and stealthy mine cases can make mine-hunting ineffective, so minesweeping may become necessary.

[21] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 17

Influence systems generate acoustic and/or magnetic energies sufficient to satisfy the triggering logic of these mines. Regardless, it can be a dangerous mission. Present sweep systems are towed behind MCM ships and helicopters and can pose a significant hazard to those personnel engaged in these operations. Mission analyses conducted have shown the possibility of accomplishing this difficult mission through the employment of USV based sweep systems, achieving very significant timeline reductions, while keeping the man out of the minefield.

b. MCM Sweeping System Concepts. Current mine-sweeping systems rely upon powerful manned platforms to tow the sweeping devices at sufficient speeds to be effective.

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

9.1.3. MCM NEUTRALIZATION[22]

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

The proliferation of mine types with various operational positions - resting on or buried under the seabed and throughout the water column - poses a serious challenge to the ability to neutralize them in a timely manner with either manned or unmanned systems or a combination of both.
Nonetheless, neutralization of identified mines is necessary in order to remove the hazard they present to navigation and maneuver. Contributing factors to neutralization planning include: (1) threat mine types may change or larger numbers of smaller mines may be encountered, which would stress the number of neutralizers required, and (2), if neutralization can be limited to defined lanes, the problem becomes more tractable.
The ultimate goal is to have a fully automated system which performs all detection, identification, localization, and neutralization, in a single pass, making reacquisition unnecessary. In the near-term, however, it is unlikely that the Maritime Task Force Commander will be able to conduct mine neutralization in stride with detection and classification operations, unless a dedicated MCM vessel is available to perform the entire detect-to-engage sequence. Near-term unmanned systems configured with MCM sub-systems are not expected to have the ability to detect, identify and engage within a

[22] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 19

single platform and will have to work cooperatively with other manned and unmanned systems equipped for mine neutralization in order to perform neutralization “in stride”.

a. MCM Neutralization Concept of Operations. For a bottom or moored mine, a neutralization system will be deployed from a loitering USV and will transit to the targeted mine under its own power. The system will relay (1) a sonar picture for precise location of the mine and (2) a visual display to the host vessel’s MCM contact evaluator for identification verification prior to neutralization.

The purpose of the ID step is to preclude wasting neutralization ordnance on non-mine threats. Once the mine is correctly identified, the Officer in Charge of MCM operations will clear the neutralizer to fire remotely. The neutralization device is an explosive charge effective against both bottom and moored mines. It may be self-mobile (e. g., a mini-torpedo), or a bulk charge which is attached to the mine casing. The charge can either be triggered by acoustic remote control or a timer. All near-term autonomous neutralizers will have to be capable of re-acquiring the target, based on original locations produced during the Search phase.

b. MCM Neutralization System Concepts. Three neutralization systems approaches are envisioned within the Neutralization Concept of Operations:

(1) A Remotely Operated Vehicle (ROV)-type neutralizer that is automatically deployed by the USV and is self-propelled to the mine. Its camera will provide a positive visual ID prior to it receiving a firing signal, at which point it will launch a neutralizing sub-munition. This system may be based upon present ROV-type airborne neutralizing systems.

(2) A stationary explosive charge that is placed by a UUV which has been delivered to the mine danger area and deployed by a USV transporter. The charge is remotely detonated later using an acoustic command or a timing mechanism. The cost of such charges, which already exist in the mine clearance community, would likely be significantly less than the more sophisticated autonomous neutralizers, but somewhat more difficult and risky to place accurately.

(3) An autonomous neutralizer in the class of a Man Portable UUV - essentially a small anti-mine torpedo - ferried by the USV to the mine danger area and deployed. This UUV system would self-deploy to the mine. This option could also used be for “Q-Route” or SLOC-clearance missions. The USV ferry method could potentially allow for rapid search and neutralization by a small number of USV’s loaded with autonomous neutralizers.

The number of neutralization sorties is driven by the USV's capacity to carry the neutralization devices. Until robust and reliable Computer-Aided Detection (CAD) and Computer-Aided Classification (CAC) are available, neutralization methods need to provide an operator-in-the-loop function, to put “eyes” on the image of the identified target prior to neutralization. Neutralization using autonomous neutralizers capable of reacquiring the targets, transported to the area of operation by USV, is an attractive option for reducing operational timelines.

c. MCM Neutralization Technology and Engineering Issues. Primary challenges with releasing mine neutralization systems from USVs include the ability to reliably reacquire the mine and achieve proper orientation for effective neutralization. Maintaining communications for man-in-the-loop operations will be a challenge, particularly over the horizon. However, the prospect of operating manned platforms in a suspected or known minefield should encourage greater development of autonomy for these devices. High sea states may pose problems with USV station keeping and system deployment. While the above Concepts of Operation and Systems Concepts are not definitive, they clearly indicate that near to mid-term combined and cooperative USV and UUV technologies can realistically contribute to solving current and emergent MCM requirements. USVs delivering a large number of smaller neutralizers appear to be the best operational approach in providing greater mission flexibility, and facilitating graceful system degradation. With a range of neutralizer systems, shallow waters will become less of a challenge. While it is desirable to produce one system that will work for all depths, this does not appear feasible in the near to mid-term. A family of approaches (transport vehicles, sensors, processing and effectors) will most likely be necessary to cover the entire range of potential MCM threats.

CAD/CAC has been demonstrated and it is assumed that Computer-Aided Identification (CAI) is or will become an available technology. This technology is necessary to meet the required mission time, especially for target reacquisition and ID for neutralization purposes. The additional time necessary for the operator to make identification on each classified contact can radically grow the timeline and number of vehicles required, therfore false alarm reduction in the hunting phase is required. The challenge facing successful integration of CAD / CAC is to get operators sufficiently confident in the algorithm’s results so they will actually use this important tool, especially in high contact environments. Rapid reacquisition and homing on targets with small, low-cost sensors is necessary to produce a cost effective autonomous neutralizer.

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

Development of autonomous cooperative behaviors will significantly accelerate MCM operations. Today’s fielded autonomous systems consist of individual vehicles that provide data for follow-on decision making (e.g., neutralize, avoid) and have limited ability to work with other vehicles. Simple coordinated behaviors have been demonstrated with dissimilar unmanned systems such as one entity detecting contacts of interest and passing them to a follow-on vehicle with a sensor for identification or further action. Intelligent behaviors between separate vehicles with different sensor

classes can result in a rapid acceleration of the MCM timeline. Absent this capability, the only way to shorten the timeline is deploying lots of similar systems uniformly searching and sweeping an area.
Unmanned MCM in the very near future is considered possible, but the envisioned fully independent cooperative autonomy is not likely until further in the future. As noted in many other USV missions areas, this area is ideally suited for a crawl-walk-run approach, where an initial capability with heavy man-in-loop interaction can not only provide immediate value to the MCM operations, but can serve as a source for experience and lessons learned in the development of later, more autonomous unmanned MCM systems.

9.1.4. MCM UUV DELIVERY[23]

While not a separate mission, there are two methods of executing the MCM sub-missions discussed above that make use of subordinate UUVs, notably MCM Search and MCM Neutralization. As noted in the MCM Search part, future USV systems may deploy UUVs to gain the advantage of higher area coverage rates through multiple, simultaneous operations, without the need for additional operators. UUVs are expected to play a major role in the mid to far-term in the terminal phases of the MCM Neutralization mission. In both cases, UUVs will act as payloads or submunition and the USVs will provide transport, placement, and intermediate communications between the host platform and the USV/UUV combination. As a result, significant USV characteristics will be:

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

The initial capability for these missions will require significant man-in-loop interaction. As the technologies, especially autonomy, mature and more confidence gained in the vehicles' standalone capabilities, the need for reliable, secure, and high-data-rate communications will decrease.

9.2. ANTI-SUBMARINE WARFARE (ASW)[24]

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

- Most of the threat submarines will be conventional (diesel-electric) and designed for local or regional coastal defense. As such, they will have reduced open-ocean transit and magazine (payload) requirement.

[23] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 22
[24] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 23

- This factor, in combination with local knowledge of near-shore bathymetry, will allow them to operate more easily in shallower waters. It is likely that these submarines will be able to submerge near their homeports and outside the reach of NATO Forces and make their way to offshore operating areas.
- The number of submarines that may be 'surge' deployed near-simultaneously by adversaries' mandates a force multiplier to enhance the efforts of existing ASW assets.

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

a. ASW background. Standard nomenclature for the three major categories of ASW are:

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

USVs offer significant force multiplication for ASW operations in a Maritime Shield and Protected Passage scenarios, in that they can perform the ASW mission at some level of autonomy. This provides a layer of ASW defense-in-depth for the manned surface group, while freeing the manned combatants for other duties, as well as reducing risk to the manned platforms that would otherwise have been conducting the ASW mission themselves. While offering some advantages in a Hold at Risk scenario, the USV's limited stealth make them generally less ideal candidate vehicles in this category. In all cases, USVs can serve as off-board sensors or sources, extending the range of detection and effect without increasing risk. The manned host platform can serve as the mother ship for a fleet of vehicles, providing the decision-making capabilities while remaining out of harm's way.

In a Maritime Shield scenario, USVs can provide major force multiplication for existing ASW forces. By establishing stand-off submarine surveillance barriers without escalating the level of conflict or placing manned vehicles at risk, USVs in a Maritime Shield scenario can greatly enhance the ability of the Commander Task Force (CTF) to achieve and maintain access, independent of the state of hostilities. In addition to using third-party sensors and cueing assets, or using platform sonars as sources for multi-static prosecution, the USV may also be tasked to plant its own supporting sensor field (e. g., sonobuoys). USVs can also provide force multiplication for existing ASW forces in the Protected Passage scenario. By establishing a submarine-free corridor without placing manned vehicles at risk, USVs in a Protected Passage scenario can greatly enhance the ability of the CTF to move forces at will, independent of the state of hostilities, while freeing manned assets for other duties (e.g., missile defense for the High Value Units). As in the Maritime Shield case, USVs may use third-party sensors and cueing assets in addition to its own organic sensors. Variations on the Maritime Shield and Protected Passage missions, depending on the stage of conflict and the implementation of appropriate CONOPs and Rules of Engagement, include: (1) USV employment of non-lethal weaponry, (2) USV employment of lethal weaponry, (3) USV accumulation of intelligence information on threat submarines, and (4) USV engaging in diversionary maneuvers and behaviors. At a minimum, the USV ASW forces can provide a deterrent or distracting effect against threat submarine aggressors.

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

c. ASW concepts of operations. The development of a completely independent, fully autonomous, far-term USV tracking capability with large area search is not considered to be feasible in the immediate future. Even short of this ideal capability, however, there are several ASW capabilities that USVs can provide as significant complements to existing ASW forces. USV applications that complement ASW are addressed below, from technically easiest to most difficult to implement, given these simplifying assumptions.

d. Maritime Shield. When a surface group has been assigned an operating area, it is advantageous to have USVs maintain an ASW barrier around its perimeter. USVs are deployed in a line around the perimeter and are equipped with sensors. The nature of these sensors is not specified, but will probably be monostatic active (e. g. dipping sonar). A multi-static arrangement with sources aboard either the manned platforms or some of the USVs, with passive receivers on the rest, is another reasonable option.

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

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

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

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

Options in the event of contact on a threat submarine, from easiest to hardest technically, include:

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

Additional CONOPs considerations include maintaining the barrier while meeting individual vehicle refueling and maintenance needs, or while one or more of the vehicles is assigned to do an off-barrier track of the target.
An effective moving barrier can be provided with a relatively small number of USVs, provided their speeds, sensor ranges, and dip cycle times are adequate

for the task. As such, this mission capability can provide significant ASW capability to the CTF with a reasonable investment of unmanned assets.

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

An additional factor in ASW prosecution is the relatively limited space for ASW weaponry and associated launch and Command and Control (C2) equipment. The most likely options for USV ASW weapon payloads in the near- to mid-term future are the Common Very Light Weight (CVLWT) and Light Weight (LWT) torpedoes.

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

h. ASW system concepts. Many of the fundamental technologies required to make the USV ASW mission a reality (sensors, processing, weapon setting and launch) are already in existence, though not necessarily scaled or adapted to the USV applications. Given the Navies' current interest in armed unmanned vehicles and the ASW mission, it is reasonable to assume that USV specific developments will soon make the ASW mission a practical reality.

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

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

9.3. MARITIME SECURITY (MS)[25]

MS consists of securing allied domestic ports, and protecting ship and maritime infrastructure (piers, docks, anchorages, warehouses) against the spectrum of threats from conventional attack to special warfare to specifically targeted terrorist attacks. MS mission effectiveness stems directly from Maritime Situational Awareness (MSA) and the ability to do something about it. The "MS" mission rubric, therefore, includes persistent ISR.

MS represents a fundamental USV mission and is essential not only for the traditional purpose of intelligence collection and threat deterrence, but also as a precursor and enabler for essentially all other missions.

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

Possible MS USV missions include:

- Strategic and tactical intelligence collection: Signal, Electronic, Measurement, and Imaging Intelligence (SIGINT, ELINT, MASINT, and IMINT);
- Chemical, Biological, Nuclear, Radiological, and Explosive (CBNRE) detection and localization (both above and below the ocean surface);
- Near-Land and Harbour Monitoring;
- Deployment of leave-behind surveillance sensors or sensor arrays;
- Specialized mapping and object detection and localization;
- Non-lethal and lethal threat deterrence;

[25] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 32

- "Riverine" operations, such as monitoring civilian boat traffic on inland waterways for threat personnel movements, contraband or threat weaponry smuggling, and similar undesirable activities.

a. Maritime Security Objective. The USV MS missions are: (1) to collect intelligence data above the ocean surface (e. g., electromagnetic, optical, air sampling, weather) and below the ocean surface (e. g., acoustic signals, water sampling, oceanographic or bathymetric info) and (2) deter enemy attacks on established allied positions and material, including ships, while (3) keeping manned platforms out of harm's way. Specific MS USV capabilities would include persistent littoral ISR, harbour or port monitoring, CBNRE detection and localization, surveillance sensor emplacement, Battle Damage Assessment, and active target designation*.* Non-lethal technologies (i.e. paint ball designators, water cannons) can be used to deter or designate threat forces. Lethal systems including guns and/or rockets could be employed to establish a more threatening posture.
These capabilities will provide force multiplication, substantially improved Indications and Warning (I&W), all-source Intelligence Preparation of the Battlespace and threat deterrence.

b. Maritime Security Background. USVs provide many advantages for the MS mission. USVs will have a multi-function capability, operate from a variety of platforms, and will enable the collection of many types of data. USVs could effectively perform these missions in high-risk areas or where hazards to navigation preclude conventional platforms. USVs could be launched from a safe standoff distance, transit to the area of interest, and return with - or transmit subsets of - the data collected, extending the reach of their launch platforms by more than 150 NM. This greatly reduces the risk to manned platforms, frees them to perform other high priority missions, and is therefore a force multiplier.
The purpose of this mission is to secure ports and infrastructure against adversaries of all descriptions (criminals, terrorists, sovereign nation military and intelligence operatives).

c. Maritime Security Concept of Operations. The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches its Area of Operation, it performs the mission, collecting information and or deterring aggressive actions over a predetermined period of time. The USV autonomously repositions itself as necessary, both to collect additional information and to avoid or intercept threats and provide a persistent presence in the operating area, perhaps for several weeks. The information collected and actions taken are either transmitted back to a relay station on demand or when "self-cued" (i.e., when the vehicle records a threat change and determines that transmission is necessary). In most cases, the vehicle will be in real-time or near real-time communications with the host platform and can provide information as desired, as well as receive updated instructions from the host platform. This ready availability of communications for Command and Control and Intelligence (C2I)

transfer is considered to be one of the major advantages of a USV in this scenario, as opposed to a stealthier UUV. For most USV ISR missions, it is assumed that near real-time communications are available and will be used to support the mission via "reach-back" (i.e., transfer of raw data to a remote processing center for analysis). This approach places much less onus on vehicle information processing and autonomy, and relieves some serious information security issues associated with vehicle-borne intelligence processing. In some cases where a maximum stealth mission (which will necessarily be conducted by a semi-submersible) is required at the expense of real-time or near real-time transmission, the vehicle will bring the recorded data back to the host platform or to a suitable area remote from the Area of Interest (AOI) for transmission.
Additional options for the MS mission include active response to detected entities. The spectrum of responses ranges from warnings (e.g. a loud-hailer challenge), through marking (e. g. paint ball or radio tag) to actually engagement (e.g. gun, missile, or torpedo). Some of these options overlap with other missions in this document at this point, such as SUW or MIO.

d. Maritime Security System Concepts. There are nearly infinite variations, but this capability consists of one or more of these components:

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

These components will be recognized as mapping to the Observe, Orient, Decide, Act loop (OODA) framework.
Sensing includes the complete spectrum of phenomenology, from visual/IR to electronic, chemical, and others. ISR to some extent forms a part of nearly every conceivable variant of the MS mission.

e. Maritime Security Technology and Engineering Issues. Critical technology and engineering issues pertaining to the MS USV mission capability stem from the need to maximize its reliability and autonomy for the higher-end missions. Fail-safe vehicle behaviors, signature reduction, vehicle stability, and extended autonomous operation are some of the major contributors to the baseline MS mission. Reliable long-range communication is also an issue, especially in mission variants where real-time intelligence reach-back is used for intelligence analysis or long stand-off missions. On the other hand, the use of reach-back reduces the vehicle's need for advanced autonomy and on-board processing with associated information security issues. However, the use of reach-back does place greater emphasis on the aspects of information security associated with communications cryptography and cyber defence.
As USV capability evolves, a major issue to be addressed is the level of autonomy. Ideally, the system will be capable of detecting, recognizing, avoiding

and/or engaging threats of a varied and mobile nature. Threat avoidance requires a high degree of autonomy, both in threat recognition and the determination of the best means of avoidance. As capabilities improve and the threat evolves, continual enhancements will be required.
Payload development for the ISR capability is considered to be largely a non-issue in terms of size, weight, and power consumption, given that many ISR sensors are developed for platforms (e. g., Unmanned Aerial Vehicles (UAVs), satellites) with significantly greater limitations in these areas. Even so, minimal size, weight and power for a given capability are desired, even if the USV application does not drive the design problem. The USV application may, however, impose unique requirements on sensor integration and packaging and fail safe operations such as:

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

9.4. SURFACE WARFARE (SUW)[26]

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

a. SUW objective. The purpose of performing SUW mission support by a USV is to provide the ability to engage targets through the use of lethal and/or non-lethal weapons while protecting or keeping manned platforms out of harm's way. SUW USV capabilities will provide force multiplication and all-source Battle Space Awareness (BSA).

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

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

[26] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 39

- Coastal Patrol/National Security/Port Security (example). The USV is launched from its host platform, a surface ship or shore facility and proceeds to the designated patrol area. Once it reaches the area, it performs the mission: patrolling the area, monitoring and addressing or interrogating ‘threats’ as appropriate, repositioning itself as necessary, either with man-in-the-loop direction or autonomously, and providing a persistent presence in the operating area.
- SOF Support (example). The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches the area, it provides SOF mission support by: performing ISR operations and reporting any penetrations into the area, repositioning itself as necessary, either with man-in-the-loop direction or autonomously, and providing a persistent presence in the operating area. If its area is penetrated, it may have the ability to engage, providing additional opportunity for SOF relocation/extraction.
- SUW Engagement (example) - The vehicle is launched from its host platform, a surface ship or shore facility. Once it reaches its area, it patrols the area and monitoring or for ‘threats’ as appropriate, repositioning itself as necessary and provides a persistent presence in the operating area. If its area is penetrated it has the ability to engage. Each of these steps may be under the direct control of a human operator (man-in-loop) or semi-autonomous (e. g., human verification and permission to fire on a USV-perceived valid target).

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

e. Mission Payloads Analysis. A brief weapons effectiveness analysis was conducted, including small arms (guns), torpedoes, and missiles.

- Small Arms –assets capable of firing rounds ranging from 7.62mm through 25mm;
- An USV would only be effective against most threats at less than 1NM;
- Torpedoes - Torpedoes provide dual-use capability (ASW, SUW). Torpedoes could also conceivably have a “dial-a-blast” effect (detonate short of target to vary “shock” factor);
- Missiles – Missile system capabilities that would be desired include: inertial navigation system, fixed box launcher (reconfigurable/modular), sealed units (fire-through end cap), network-able, discrimination achieved via multiple sensor sources, maritime environment operations capable ("marinized").

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

In summary, the weapon of choice in a scenario like this appear to be the torpedo, since their size makes

them capable of being carried on USVs, they alone have the range to engage the enemy outside the threat's counter-boat weapon range. There is also a much greater chance of the target being unalerted by a torpedo attack than a gun or missile attack.

In any case, in order to execute an autonomous armed mission, significant work will be needed to investigate and generate the USV rule sets to comply with international law.

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

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

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

9.5. SPECIAL OPERATIONS FORCES (SOF) SUPPORT[27]

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

[27] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 42

SOF units require support for conducting missions involving unconventional warfare, counter-terrorism, reconnaissance, direct action and military assistance, among others. SOF roles are typically those in which the aim is to achieve disruption by "hit and run" and sabotage, rather than more traditional "force on force" combat. Other significant roles lie in providing essential intelligence from close to or among the enemy, and increasing roles in combating terrorists, their infrastructure and activities.
Due to the variety of missions and related environments that SOF can be called upon to operate in, SOF-Support USVs will also be required to cover operational environments from coastal to riverine. Each environment presents unique challenges to effective and reliable operation.

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

b. SOF SUPPORT background. In the ISR role, USVs can provide persistent coverage and effective support for SOF mission areas that would preclude conventional platforms, providing early warning and maintaining a perimeter in areas of high risk to personnel. Many mission scenarios utilizing small arms as well as other lethal and non-lethal weapons could be effectively performed by USVs. In this sense, this mission area bears a lot in common with the MS mission.
USVs can also effectively provide mission support in high-risk areas or where hazards to navigation or personnel preclude conventional CONOPS. USVs could be launched from a safe standoff distance, transit to the area of interest, and return with or transmit subsets of the data collected. Other options include planting stand-alone sensor packages, dropping off advance or real-time resupply packages (ammo, food, fresh water, batteries), and providing maritime diversion, distraction, or deception in support of the SOF mission.

c. SOF SUPPORT Concept Of Operations.

(1) Insertion/Extraction of SOF Personnel and/or Equipment. Serving as a logistical support asset, larger USVs could provide SOF with an alternative to utilizing manned platforms for these purposes. USVs could be pre-positioned and lie in waiting for the appropriate time to provide support.

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

the data and return to the manned platform. Operating in this manner, the USV is essentially serving as a round-the-bend ISR platform.

(3) Other Missions. SOF is innovative in adapting the systems and equipment at hand to fit emergent mission needs and environment. The modularity inherent in USVs can be a great asset in supporting mission innovation.

d. SOF SUPPORT technology and engineering issues. In the near-term, the technology and engineering issues relating to USVs providing SOF support are the need to minimize the vehicle's size and observability while maximizing power density and reliability. As with all USVs, suitable and reliable communication is an issue, especially in mission variants where real-time intelligence reach-back is used for analysis. SOF USV applications will impose unique requirements on sensor integration and packaging due to size constraints:

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

9.6. ELECTRONIC WARFARE (EW)[28]

USVs have broad application to Joint and Naval Warfighting requirements supporting Conventional Warfare, Asymmetric Warfare through strategic use of EW and Influence Activities (IA). This capability is synergistic with the MS Mission.

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

b. EW concept of operations. The specifics of the Electronic Warfare mission are classified; it is a subset of IA and closely related to Intelligence, Surveillance and Reconnaissance (ISR). Many technologies exist to enable this mission area. For example, it could be possible for a USV to generate false targets for deception in support of anti-ship missile defense, initiate a denial of service, or instigate spoofing, local area network jamming, and other disruptive IA missions.
In a related application in the same scenario, the USV is used as a picket ship for that same Strike Group. The USV is equipped with an Electro Optics/Infrared (EO/IR) sensor on a retractable/extendable mast with receiver(s) in the body of the vehicle capable of conducting passive spectrum detection and threat warning for the battle group. That same USV, given the appropriate repeater and/or

[28] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 45

transponder device, could be used within the maritime force to aid in force Anti-Ship Missile Defense (ASMD). An economic advantage of using the USV in this role is that the repeater and/or transponder are reusable assets whereas some of the other options are not.

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

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

9.7. MARITIME INTERDICTION OPERATIONS (MIO) SUPPORT[29]

a. MIO SUPPORT objective. MIO is traditionally defined as activities by naval forces to divert, disrupt, delay, or destroy the enemy’s merchant marine trade. Preemptive protective measures can protect not only maritime assets, but also ground forces by disruption of sea-based lines of supply to the enemy. For MIO in this context, emphasis is on vessel boarding, search, and seizure capabilities.

MIO is by definition a manned mission. The MIO role of USVs is to enhance situational awareness in support of the manned mission. In general, this MIO effort would require a small USV system that would support a boarding party by investigating the threat vessel at the waterline and below. Potential support payloads for this role include ISR, EO/IR, CBRNE, Weapons of Mass Destruction (WMD) detectors, ROVs, UUVs, and UAV.

b. MIO SUPPORT concept of operations. The USV will support the MIO

[29] The Navy Unmanned Surface Vehicle (USV) Master Plan - US Department of the Navy, 2007, pag. 47

mission by providing a capability to detect a threat through a variety of devices and sensors to enhance situation awareness. Examples:

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

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

c. MIO SUPPORT technology and engineering issues. Critical technology and engineering issues pertaining to the MIO USV mission capability stem from the requirements for vehicle stability and failsafe vehicle behaviors. At least initially, the requirement for long time on station and significant autonomy is considered to be minimal, since the MIO Support mission will be operated in close proximity to a manned MIO craft. This situation may change as mission experience is gained and autonomy technologies advance. Reliable communications capability is required, even in the initial implementation, to ensure that the MIO crew is able to make effective use of its USV "assistant", as well as learning of its activities and their results in real time.
The challenge for the MIO support USV will be the “height of eye” issue for both observation and communication. An enhanced surveillance and communications relay capability may be achieved by working in conjunction with an UAV, and normally inaccessible underwater observations may be facilitated by the use of an UUV.
Launch and retrieval issues of a 3m USV from an 11m RHIB may include mechanical interactions between launch/retrieve system and vehicle and fluid interaction between launch/retrieve system and vehicle.
Autonomy issues need to be addressed. Threat recognition and determining the means for object avoidance must be considered. Continued enhancements will be required as the threat evolves.

10. CHALLENGES

Based on today’s capability, future advances in technology will enhance endurance, processing (Data analysis and knowledge), autonomy, interoperability (CGCS – Common Ground Control Station, CCS – Common

Control Station).

a. ISR. Many of the ISR missions are demanding in terms of autonomy and propulsion. Achieving the level of autonomous intelligence collection required for persistent capabilities will be challenging. This challenge will be heightened if, as often occurs, a threat of deliberate or incidental detection of the vehicle arises. In that case, additional sensors and autonomy are needed for situational awareness to prevent the vehicle from being retrieved and exploited. The collection of time-sensitive oceanographic data occurred shows the use of MUS to collect oceanographic information.

b. MCM. UUVs for MCM are better developed than UUVs for any other mission. Missions such as mechanical sweeping, jamming, and spoofing will be challenging. Considerable additional power is required to clear mines from large areas. Jamming and spoofing require less power but raise the question of how to be confident that a mine has been jammed or that a mine will be spoofed.

c. ASW. ASW missions for UUVs could be challenging because they require vehicles with limited sensors and processors to autonomously detect and classify threat submarines. UUVs have a limited ability to communicate with the outside world.

d. Communication. The use of UUVs for CN3 requires extensive mast exposure, which would compromise such vehicles' covertness. This mission also requires considerable electrical power for transmissions.

e. Interoperability. The interoperability challenge is transferring control of a given unmanned system and/or payload from one Ground Control Station (GCS) to another controlling entity (perhaps operated by another Service or coalition member).

f. Autonomy. Autonomous modes of operation and the technology required to shift from one level of autonomous operation to another are still under development, many shortfalls has been pointed out in the area of engagement/intervention. Specifically, there is a need for technology that allows vehicles to:

- avoid entrapment by fishing nets or nets specifically emplaced against them;
- escape those nets once entangled.

g. TCS. Positive ID has to be consistent with a shared database in order to achieve very reliable information that could allow use of deadly force against threat which is not immediately related to military activities (i.e. fishing/recreational vessels).

h. Cyber Defence. There are two distinct cyber defense challenges that need to be considered. The possibility of jamming and spoofing the MUS vehicle itself, and the actual issue of interference with the feeds and products that the MUS produces. The command and control element of MUS needs to be closely monitored and protected so that ultimate control of the vehicle is not lost. Pre-programming of the MUS would be a possible solution to defeating cyber threats so that the enemy cannot gain control. A careful balance between the level of autonomy achieved and the vulnerability to cyber attack will need to be developed.

11. FINDINGS AND RECOMMENDATIONS FOR MUS

The overall recommendations from the MUS Guidance are:

- Nations should be provided with a common basis from where to start building MUS capabilities, since there is room to improve coordination among them. The objective of the MUS Guidance is to create awareness and try to help nations to better coordinate their capability development efforts;
- Reduce requirements for communication bandwidth. Greater autonomy should be developed to reduce data requirements sent “to” the MUS, and more advanced automated target recognition must be developed to reduce the data requirements “from” the MUS;
- Align acquisition strategies/ approaches to the different classes of vehicles, with common core systems and interfaces to the greatest degree possible;
- Make use of the MUS's ability to deliver capability in "crawl-walk-run" sequence. Deliver the initial man-in-loop capabilities now, and use that experience to guide development of future semi-autonomous and fully autonomous upgrades;
- Conduct risk reduction for technology and operations;
- For the weaponized MUS options, investigate or develop the necessary rules of maritime law and law of war associated with operating autonomous armed vehicles. Apply these rules early and throughout the design and development process;
- Invest in a balanced MUS technology program, which includes five technical imperatives:
  - autonomy;
  - obstacle / collision avoidance;
  - coupled payloads / weapons;
  - launch and recovery; and
  - advanced hulls, mechanical, and electrical, systems.
- Continue the outreach to NATO Navies operational, doctrine, and training commands to develop CONOPS for MUS, to ensure they are integrated and aligned with the concepts of transformation.

11. MUS MISSION CAPABILITY STATUS

UUV MISSIONS				
TYPE	**NOTE**	**NEAR**	**MID**	**FAR**
ISR	There is a limited capability mainly used for demonstration.			
MCM	It is a capability that can be considered already available, but only for a very local area. In the Long term, it will be possible to support transit with moving platform.			
OCEANOGRAPHY	Great capability for sensing and survey potential.			
ASW	In the near term, it's available with acoustic monitoring, without target designation capability.			
COMMS	Near term capability is LOS limited systems. The mid-term it's expected to provide collaborative network among systems.			
TCS	Strike capability is strictly connected to weaponization. Recognized not to occur any time soon.			

Following tables highlight available technology in support of the MUS mission capabilities projected to the near (green), middle (yellow) and far term (red).

USV MISSIONS				
TYPE	**NOTE**	**NEAR**	**MID**	**FAR**
Maritime Security (MS)				
MCM				
Anti Submarine Warfare (ASW)				
Anti Surface Warfare (ASUW)				
Maritime Interdiction Operations (MIO)				

Note: Due to mission complexity, despite the bigger investments are directed to UUV, USV missions are mostly near term available.

Annex A
CJOS COE - MUS Guidance

MUS SCENARIOS

Scenario # 1:

In the recent years, NATO has built a strong relationship with the newly formed government of Dorsettland. This relationship has become increasingly beneficial to all countries related due to Dorsettland's geographical location for maritime transit and its vast amount of natural resources. While Dorsettland was transitioning into a democracy, its former ally and neighbor, Vickland was becoming more and more hostile toward them, NATO and its allies. While Dorsettland has begun to prosper with their new alliance with NATO, the opposite has started to occur with Vickland. Vickland is still a dictatorship with a belligerent and hostile posture towards the world's democracies, and has developed a large military force. In the not so distant past, Vickland has deployed mines at the edge of their territorial waters through surface ships and sometimes through its submarine force. While Vickland claims to be close to developing WMDs, which would be able to reach most places around the globe, recent intelligence has determined their technological know-how is lacking, but the threat to enable other unfriendly organizations is a truly viable threat. With the United Nations' (UN) sanctions already being enforced against Vickland, and tensions escalating with Dorsettland, a NATO Maritime Task Force (MTF) has been deployed to the region as a deterrent and is prepared to defend Dorsettland and the maritime transit area. Any act of aggression against Dorsettland will impact vessels seeking safe passage through its waterways, greatly affecting the economies of many nations, including NATO countries.

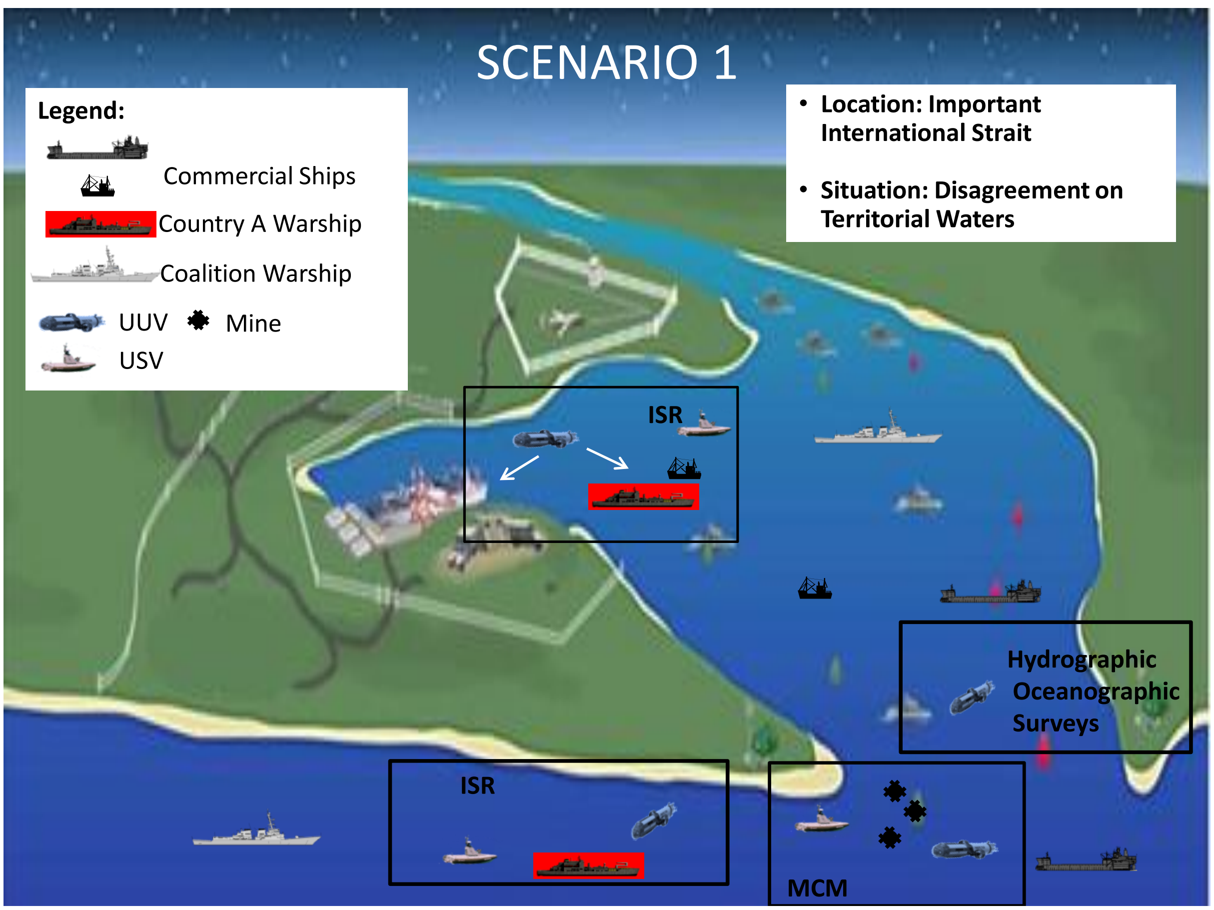
While economic sanctions against Vickland have not produced any tangible results, there has been a noticeable radicalization of the anti-NATO demonstrations. Intelligence reports indicate a possible increase in Vickland's naval mine activity and decided to deploy UUVs to gather intelligence within the region. In the first stages of the operation, intelligence gathering was deemed a high priority among the NATO nations. The MTF has also deployed UUVs in an effort to reduce the number of ships in the area while minimizing the risk to human life. The MTF have deployed multiple UUVs in a coordinated pattern to gather information on possible submarine activity, mine activity and general ship movement. The UUVs are being sent out from ships, submarines as well as ports to continuously monitor naval activities trends in the area and relay any information to MTF HQ.

UN sanctions are not having the desired effect on Vickland. The country has been actively deploying mines throughout the strait in order to directly impact the commercial shipping industry. Dorsettland has called on the NATO MTF to intervene and increase operations to keep the area clear and safe thus sending a clear message to the Vicklandian government. With the entire MTF resources being deployed in the region, Dorsettland has requested an increase in countermine measures as they have currently lost two commercial ships and received damage to one warship due to the intensified mine activity. The CTF responded with additional MUS deployment, to include USVs.

In a coordinated effort, the UUVs and USVs have been deployed to reflect an increased pattern of ISR activity focusing on intelligence gathering, harbour monitoring, and deployment of stay behind surveillance sensors, as well as specialized mapping, hydrography and oceanography. With the MUS assistance, there has been a significant increase in mine detection resulting in accurate reporting of the mine positions and clearance of the threat in the area. The UUVs have also been able to determine an increase in submarine activity by the Vicklandian navy.

With the current information gathered from the UUVs and USVs, the MTF has been able to establish an active defense to locate and neutralize the mine threat in the area. Specific intelligence is transmitted to naval vessels in the immediate vicinity of the threat in order for mine specific platforms to be dispatched to the location in order to destroy the mines where they are. Information on submarine activity is also gathered and transferred to coalition submarines and surface ships for further analysis, dissemination and operational planning.

In close collaboration with the government of Dorsettland, the MTF is now able to gain maritime dominance in the region and open the shipping lanes for commercial traffic. With UUVs and USVs still operating in the area, the MTF can withdraw from the congested zone and remotely operate the MUS thus minimizing risk, costs and manpower to all involved. Dorsett is now able to resume normal sea activities and normal economic functions in relative peace.



Graphic adapted from NECC Command Briefing by RADM Tillotson, dated 14 March 2008

Scenario # 2:

By the year 2025, Vickland has developed relationships with terrorist organizations and countries known to have tensions with NATO and its allies. Vickland believes the future is with the development of a large naval force including new submarines, in order to ensure its trade routes throughout the world's waterways. UN sanctions have hurt the country's trade and are causing unrest amongst its people. In the recent years Vickland has continued to work with its new allies to gain military technological know-how. Intelligence sources assess the action of Vickland poses a viable threat to the security of NATO and its partners. Vickland's leader has become more and more determined to fight against the UN sanctions imposed against his country and has stated the "actions of the UN are a direct threat to the security and prosperity of this country". While Dorsettland has become a strong ally with NATO, it stands to be an easy target for Vickland's aggression, and has been a focus of blame for the economic downturn of the dictatorship. While Vickland is still in economic turmoil, Dorsettland is concerned their Oil Platforms (OPLATs) could be a target for Vickland's aggression.

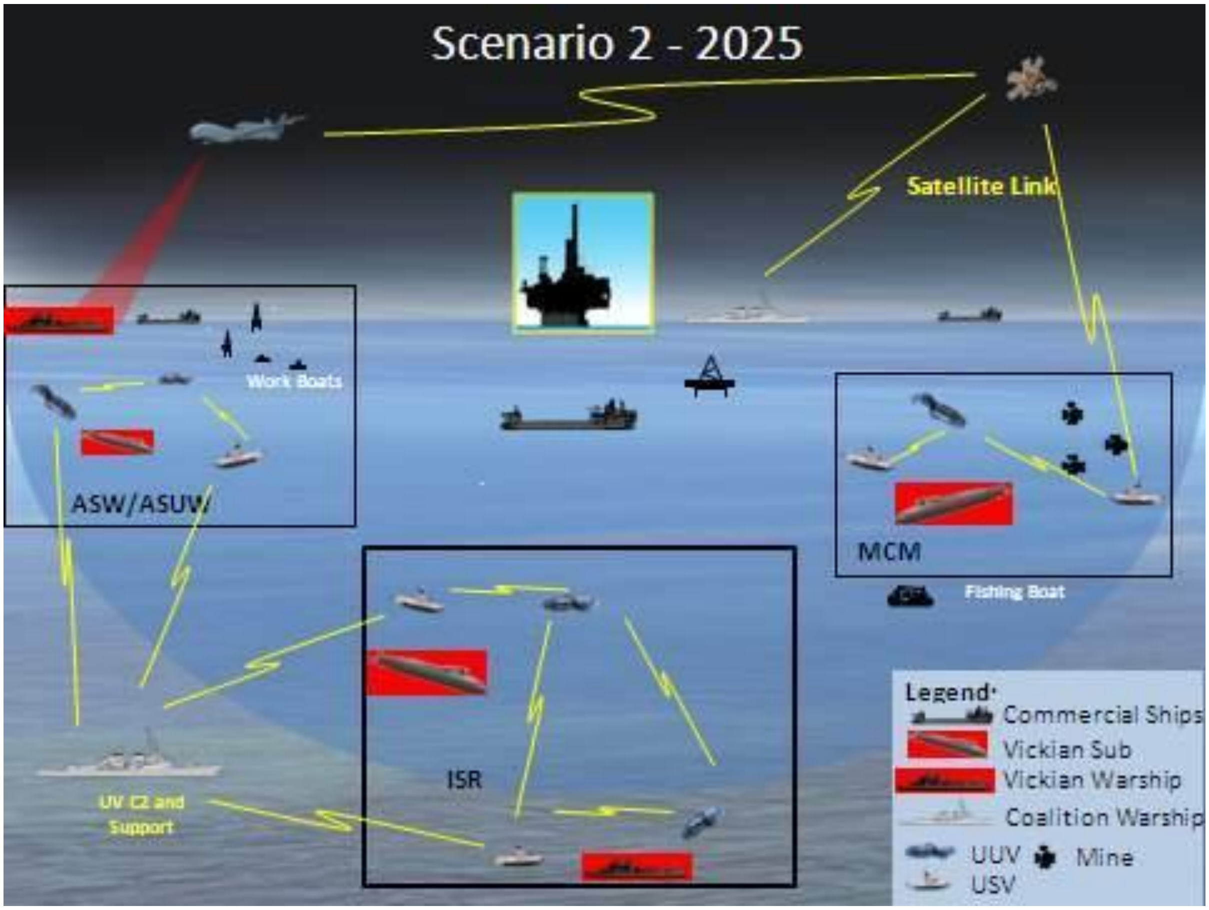
The MTF deploys UUVs on a set, programmed track throughout the area to track submarine activity, gather ISR and conduct ASW/ASUW operations as needed. While there is still initial human involvement with the deployment of the UUVs, the primary mode of movement is autonomous. During the routine patrol, the UUVs have detected a high number of unknown submarines in the area . While gathering this information, the UUVs transmit the information to each other and to a base headquarters in order to deploy more unmanned systems. With a deployment of more unmanned systems, through autonomous decision making, the deployment of USVs has been set to aid in the possibility of OPLATs defense. Through an increase in intelligence gathering, an increase in small boat activity has been observed and has been relayed to Dorsettland's naval operations center. Through pre-programmed data, USVs are deployed to international waters to evaluate the actions of the small boats.

Vickland has been increasing submarine activity in a pattern to show a focal point towards the OPLATs and what could be considered a tactical application towards guarding against ship movement to protect the structures. The unmanned systems track Vickland's submarines; adjust their patterns to match the movement of each submarine for tracking continuity. When the fuel begins to run out for the UUV on the tactical mission, it sends a message to other unmanned systems to assume the track line to keep connectivity of tracking each threat.

With the increase in submarine activity, NATO forces have been increasing their presence in the region. With the increase imminent, Vickland has deployed submarines to the straits to deploy mines to hinder ship movement and search for NATO assets. Along with the submarines, there was a coordinated small boat movement towards the OPLATs that appears to be aggressive in nature.

To counter the mine activity and clear the straits for the manned ships, the UUVs transmit the mines' location to another MUS while continuing to track the submarine. With countermine technology, the other MUS detonate the mine and eliminate it as a threat.

In the spirit of connectivity and interoperability, USVs and UUVs are deployed to set up a defensive barrier around the OPLATs in a coordinated pattern while evaluating the small boat movements. The unmanned systems evaluate the movements of the small boats and self-determine if the movements could be considered hostile and report all findings to the NATO MTF HQ.



Graphic adapted from Naval Warfare Development Center presentation, dated January 06, 2011

Annex B
CJOS COE - MUS Guidance

MARITIME UNMANNED SYSTEM COMMUNICATIONS

Definition

Communications at the Strategic, Operational and Tactical levels vary significantly in form and in function. A broad definition for communication would be: “The process of assimilating, organizing, processing, analyzing and disseminating of information/data.” As an example NATO Policy on Strategic Communication defines Strategic Communication as: "the coordinated and appropriate use of NATO communications activities and capabilities – Public Diplomacy, Military Public Affairs, Information Operations and Psychological Operations, as appropriate – in support of Alliance policies, operations and activities, and in order to advance NATO's aims" (SG(2009)0794). The key point to highlight is that communication is in and of itself a process, rather than a physical system, that supports or enables efforts to achieve defined NATO Alliance objectives.

MUS are an enabling capability for acquiring data. At the strategic, operational and tactical level non-autonomous MUS need a process for control and distribution of their mission data. For some land systems these types of exchanges of information could be via a cable, but for mobile MUS operations (i.e. operating on the land, on the sea and in the air) the exchange must be via signals sent through the ElectroMagnetic Spectrum (EMS) or some other means (e.g. optical systems). The EMS is highly regulated at the international[30] level and therefore any development of MUS must take this into account in order to avoid future operational constraints.

Problem Statement

The future development of a successful MUS communications architecture depends on NATO’s ability to identify a common communication architecture standard that is cost effective and at the same time meets the warfighter’s capability requirements. NATO’s goal should be to operate MUS so that communication constraints do not adversely impact successful mission execution. The challenges in attaining this goal include developing, procuring, and fielding communication systems that can operate with greater effectiveness, efficiency, and flexibility even in congested environments to ensure superior support to the warfighters in an ever increasing complex set of missions and environments.

Current MUS Communication Capabilities

Due to the predominance of land based operations over the last 10 years, air and land unmanned communication capabilities are progressing at a rapid rate. This rapid development has resulted in significant advancements in technologies by private companies that meet critical capability requirements of the warfighter but at the same

[30] International Telecommunication Union. Radio Regulations. Geneva, Switzerland. 2007 Edition

time this unconstrained development comes at a high cost in terms of redundant capability development, a streamlined acquisition process, interoperability problems, unforeseen operational issues and potential costly force regeneration.

In comparison to Air and Land Unmanned Systems, the development of MUS has lagged significantly behind, and therefore the development of communication methods/architectures for Maritime Unmanned Autonomous Systems Navigation is in its early stages. This gives MUS a unique advantage in that it can leverage existing technologies but at the same time control the process to ensure flexibility, compatibility, and interoperability of all systems considered.

Challenges

Given the success of MUS within the current warfighting areas[31], it is expected that there will be a significant increase in the number of such systems both within current areas of operations and within future conflicts. As a result, the common challenges among the MUS's communication sub-systems would be:

- the ability to deal with a higher density of MUS within relatively small areas;
- to have more commonality and interoperability among those sub-systems to ease logistic, procurement, and operational challenges;
- to handle an increased amount of collected information that is expected to come from improved and multi-spectral sensors on those MUS;
- the ability to ensure the transfer of secure information;
- decreasing the occurrences of lost communication link.

These factors will be exacerbated by an expected decrease in the EMS (Electro Magnetic Pulse) that is available for all of these systems to access due to an increase in the civil uses of spectrum.

Conclusion

The future development of any new communications system must strive to attain the following attributes to ensure a useful capability: (1) improved interoperability (2) increased agility, (3) greater adaptability, (4) improved spectral efficiency, and (5) maintain compliance with all NATO member nations' spectrum policies. These systems should conform to a standards-based architecture which supports multiple networks and enables rapid and transparent configuration changes without removing the radios from operation. Such multi-input, multi-output (MIMO), multi-carrier, and multi- waveform capabilities plus the software control of these functions are needed within future subsystem developments. Ultimately, it is desired that these functional changes be done "automatically" and the systems will adapt with dynamic reconfiguration in response to sensed changes in the operational environment[32].

The need to support operations in which there are intermittent wireless propagation links has become common place. This has resulted in increased use of advanced error control coding, MIMO configurations, various path diversity techniques,

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[31] From an EMS perspective, those current warfighting areas have had a relative benign environment

[32] Also see the annex on autonomy

and the use of integrated networking, and data diversity; all this to provide improved end-to-end quality of service.

Although unmanned systems do not directly support network-centric capability it does have a contributing role.[33] The development of network-centric and unmanned systems raises questions that are far greater than purely technological ones. The ability to remotely detect, analyze, target and attack elements of the battlefield and instantly share information requires a substantial review of existing military doctrines and philosophy. The actual consequences of these trends can only be guessed. For example, network-enabled capability will allow strategic leaders, up to commander-in-chief, to make decisions even on a tactical level. On the other hand, commanders on the ground will have full situational awareness and will be able to act without instructions from their superiors. How these two contradictory trends will interact remains to be seen, but it is obvious that the traditional hierarchical decision-making method will change profoundly.[34]

[33] From the United States FY2009–2034 Unmanned Systems Integrated Roadmap

[34] Transforming The Future of Warfare: Network-Enabled Capabilities and Unmanned Systems, Pierre Claude 2007

Annex C
CJOS COE - MUS Guidance

MARITIME UNMANNED SYSTEM AUTONOMY

Definition

Although there is not one unanimously accepted definition for the term autonomy, there is a common understanding of the properties that an autonomous system should have. Autonomous systems are systems that develop, for themselves, the laws and strategies by which they choose their behavior. An autonomous system has control over its own behavior and also chooses the goals it seeks to reach this suitable behavior.[35] To be autonomous, a system must have the ability to operate without human intervention. In addition, autonomous systems optimize behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the optimal solution).

By contrast, automatic systems are fully pre-programmed, and act repeatedly and independently of the situation and benefit for success. An automatic system can be described as self-steering or self-regulating and is able to follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to define the path according to some given goal or to choose the goal dictating its path.

The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations. This ability is a significant improvement in capability compared with the capabilities of automatic systems that are fully pre-programmed and act repeatedly and predictably independent of the situation and benefit for success. An autonomous system is able to make a decision based on a set of rules and/or limitations. It is able to determine what information is important in making a decision. It is capable of a higher level of performance compared with the performance of a system operating in a pre-determined manner.[36]

Problem Statement

The manpower required to operate unmanned systems is adding stress to the overall workload of the forces, and is emphasizing the need to transition to a more automated, modern system of warfare. For unmanned systems to achieve their potential, they must be able to achieve a highly autonomous state of behavior and interaction with their surroundings. This will require an ability to understand and adapt to their environment, collaborate with other autonomous systems, and develop new verification and validation techniques. Each of these topics is discussed in more detail following.

[35] Steels, L.; Brooks, R.: The artificial life route to artificial intelligence. New Jersey: Lawrence Erlbaum Associates, 1995.
[36] NATO Industrial Advisory Group, Study Group 75, Annex C - Autonomous Operations, 2004.

Current MUS Autonomy Capabilities

Autonomous capabilities have been enabled by advances in computer science (digital and analog), artificial intelligence, cognitive and behavioral sciences, machine training and learning, and communication technologies. Advanced algorithms that provide robust decision-making capabilities, such as machine reasoning and intelligence are required. Additionally, automated integration of highly disparate information and the computational construct to handle data sets with imprecision, incompleteness, contradiction, and uncertainty is paramount in the dynamic unmanned system environment.

In 2010, the US Air Force released the results of a year-long study highlighting the need for increased autonomy in modern weapon systems, especially given the rapid introduction of UAS. This study, entitled "Technology Horizons," identified the need for greater system autonomy as the "single greatest theme" for future Air Force science and technology investments. The study cited the potential for increased autonomy to improve effectiveness through reduced decision cycle time while also enabling manpower efficiencies and cost reductions.

The rapid fielding of unmanned systems has raised the sense of urgency to implement greater autonomy in these systems. Each new Predator/Reaper orbit requires 175 personnel to operate and sustain. Each new orbit also generates a huge quantity of data to process, exploit and disseminate (PED)—a process that is currently manpower intensive. This increasing manpower requirement is occurring at a time when constrained budgets are limiting growth in manpower authorizations. This challenge is not limited to the Air Force, but is facing all the military services. Today's unmanned systems require significant human interaction to operate. As these systems continue to demonstrate their military utility and are fielded in greater numbers, the manpower burden will continue to grow. Autonomy can reduce this burden.

Challenges

Significant advances have been made in autonomy, but many challenges still exist. For relatively static environments and simple missions/objectives, rule-based autonomous systems can be highly effective. However, most environments and mission objectives for autonomous systems must have the ability to operate in complex and uncertain environments, along with the ability to interact and collaborate with human operators and human teammates. Additionally, autonomous systems will need to interact and work together with other autonomous systems, to adapt to and learn from changes in the environment and missions, and to do so safely and reliably.

Transcending to Higher Levels of Autonomy

Autonomy reduces the workload required to operate systems, and enables the optimization of the human role in the system. It also enables operations beyond the reach of external control, or where such control is extremely limited (such as ground vehicles exploring caves or undersea vehicle operations). Advances in autonomy will further increase operational capability, manpower efficiencies, and cost savings.

While reduced reliance on the human operator is the goal of autonomy, one of the major challenges is how to maintain and facilitate interactions with the operator and other human agents. An alternative statement of the goal of autonomy is to allow the human operator to “work the mission” rather than “work the system.” This means that the autonomy must be developed to support natural modes of interaction with the operator. These decision-making systems must be cognitively compatible with humans in order to share information states, and to allow the operator and autonomy to interact efficiently and effectively. The level of autonomy should dynamically adjust based on workload and the perceived intent of the operator. It is not about a better interface, but rather how to design the entire autonomous system to support the role of the warfighter and ensure trust in the system.

There have been various metrics developed that generally focus on one area, or make one or more assumptions, but the most commonly used[37] metric is the four levels that are described in the table below.

Table 1: Four Levels of Autonomy[38]

Level	Name	Description
1	**Human Operated**	A human operator makes all decisions. The system has no autonomous control of its environment, although it may have information-only responses to sensed data.
2	**Human Delegated**	The vehicle has the capability to perform many functions independent of human control, when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by a human input and act in mutual exclusion with human operation.
3	**Human Supervised**	The system can perform a wide variety of activities given top level permissions or direction by a human. Both the human and the system can initiate behaviors based on sensed data (e.g. conflict avoidance maneuver), but the system can only do so if within the scope of its currently directed tasks.
4	**Fully Autonomous**	System receives goals from humans and translates them into tasks performed without human interaction. A human would still be capable of entering the loop in an emergency, or changing the goals.

Ability to Understand the Environment

To operate in complex and uncertain environments, the autonomous system must not only be able to sense the environment, but it must be able to understand the

[37] Also commonly used is the NIST (National Institute of Standards and Technology) project “Autonomy Levels for Unmanned Systems,” e.g., http://www.nist.gov/el/isd/ks/upload/ALFUS-BG.pdf
[38] NWDC working document.

environment. This implies creating a world model by conducting Multisensor Data Fusion (MDF) and converting this data into meaningful information that supports a variety of decision-making processes. The perception system must be able to infer the state of the environment from limited information, and be able to assess intent of other agents in the environment. This understanding is needed to provide future autonomous systems the flexibility and adaptability for planning and executing missions in a complex, dynamic world.

Although such capabilities are not currently available due to the slow advancement of computational intelligence, recent advancement in computational intelligence (especially neurofuzzy systems), neuroscience and cognition science provide possibility to implement some of the most critical functionalities of heterogeneous sensor net based MDF systems. The following developments will help mature these types of processing capabilities:

a. Reconfigurability of sensor weighting: When a heterogeneous sensor net is used for an MDF system, each sensor has a different weight for different applications. As an example, one uses a multisensor (dissimilar or heterogeneous) data fusion methodology to identify an object-an image sensor data has much higher weight than a radar data. On the other hand, when an MDF methodology is used to measure a distance from the sensor to an object, a rangefinder or radar has a much higher weight than an image sensor. An image sensor cannot provide information to measure distance.

b. Adaptability of malfunctioning sensors and/or misleading data: Even if an MDF methodology is used for the identification of an object, an image sensor cannot perform if it is faced to the sun. Data from the image sensors will either be saturated, or they will need to be calibrated. Additionally, the image sensor data needs a continuous calibration if the weather is cloudy and changing, because the measured data will be different based on shadows and shading. Therefore, the environment of a heterogeneous sensor net is a key parameter to be considered for design and implementation of an MDF system.

c. Intelligent and adaptive heterogeneous data association: Heterogeneous, sensor net-based MDF systems must process different data simultaneously, such as 1-D radar signal, 2-D imaging sensor data, etc. As the combination of heterogeneous sensors change, the data combination is changed. Therefore, it is essential to do adaptive data association before conduction MDF and feeding the data to the decision making module.

d. Scalability and resource optimization of self-reconfigurable fusion clusters: The critical issue of the MDF system is the scalability of self-reconfiguring the fusion cluster to adapt to a changing battlefield and/or the malfunction of one or more sensors. As the number of sensors used for a sensor net increases, the combinatorial number of reconfigurations exponentially increases. To manage such complexity, it will require a highly intelligent, fully autonomous, and extremely versatile reconfigurable algorithm, including sensor resource optimization, which is currently unavailable. Such capability can be obtained only from intelligent computing technology, which is currently in its infancy.

e. Ability to Adapt to the Operational Environment: While robustness to environmental change is necessary, the future need is to adapt and learn from environmental changes since every possible contingency cannot be pre-programmedi. This adaptation must happen fast enough to provide benefit within the adversary's decision loop, and the autonomy should be constructed so that these lessons can be shared with other autonomous systems that have not yet encountered the situation. Yet even in a hostile, dynamic, unstructured, and uncertain environment, this learning must not adversely impact safety, reliability, or the ability to collaborate with the operator or other autonomous systems.

Ability to Collaborate with other Autonomous Systems

In addition to understanding the operational environment, unmanned systems must also possess the ability to collaborate by sharing and/or de-conflicting tasks. Collaborative autonomy is an extension of autonomy that enables a team of unmanned systems to work together to achieve goals defined by the operator. This trend in autonomy will continue to reduce the human role in the system. It will shift toward strategic decision-making for a team of vehicles and away from direct control of any single vehicle. Concurrently, authority for certain tactical decisions, such as weapons release, will still be available to the operator.

The ability to collaborate is key to reducing force structure requirements. Collaborative autonomy must be developed that is scalable to both larger numbers of heterogeneous systems, as well as increased mission and environment complexity. Collaborative autonomy must be able to manage the air/water/ground traffic environment, and adapt to changes in team members, operators, and operations tempo.

Development of new approaches to Verification and Validation

Realizing the benefits of autonomous systems will require new approaches to Verification and Validation (V&V) to ensure the safety and reliability of the autonomous system. Today's V&V processes will be severely challenged by the growth in the amount of software and the complexity of the algorithms to be evaluated. Without new V&V procedures, the result will either be extreme cost growth or limitations on fielded capabilities.

Efforts leading to advancements in computational intelligence as well as the appropriate V&V processes are essential. Enhanced V&V technologies would provide both near-term cost reduction and enhanced capabilities for current autonomous systems, and would enable otherwise cost prohibitive capabilities in the future. New autonomous system test and analysis capabilities are also required to assess intelligent single vehicle and group behaviors. These technological enhancements and policy actions would lead to more effective development, testing, and operations of current and future autonomous systems.

Conclusion

Autonomy advances are being made as the need to field greater numbers of autonomous systems stresses the limited numbers of operators available. Challenges in the area of autonomy address not only functionality, but transparency to the operator, safety, and reliability. It should be noted that the underlying technologies that enable full autonomous control are those that also enable enhanced data and information processing, and integration for rapid, accurate decision-making. Ultimately, autonomy will increase warfighter effectiveness by augmenting unmanned systems capability and expanding their capacity to create effects in the battlespace.

Annex D
CJOS COE - MUS Guidance

MARITIME UNMANNED SYSTEM INTEROPERABILITY

Definition

NATO defines Interoperability as: "Interoperability of systems and equipment largely determines the degree of flexibility inherent in the use of joint and multinational forces. Interoperability of systems and equipment employed by NATO essentially rests upon standardization, especially in order to comply with interchangeability, commonality or compatibility criteria all along their lifecycle (design and development, production, use and support). Interoperability of systems and equipment needs to meet Alliance Standardization Requirements while at the same time remaining cost effective. Consequently, acquisition and/or modernization of systems and equipment should always take into account interoperability requirements to become or remain interoperable in all joint and multinational environments"[39]. JP1-02 defines Interoperability as the ability to operate in synergy in the execution of assigned tasks. Properly implemented, it can serve as a force multiplier and can simplify logistics.

Interoperability increases mission flexibility and efficiency through sharing of assets and information generated from Unmanned Systems. The goal of interoperability is to establish effective standards to enable data transmission between the Ground Control Station (GCS), the Unmanned System, and the Command, Control, Communication, Computer, and Intelligence (C4I) network. Currently, the level of interoperability among UAS varies widely, from systems that can pass full control of the aircraft and/or payload from one operator to another, to systems that can only transmit sensor data to various recipients.

Thus interoperability must be examined in larger context encompassing all the unmanned systems employed on land, in the air or in a maritime environment including surface and sub-surface systems.

Interoperability Levels

Unmanned Aerial Systems (UAS) have dominated the application of unmanned systems in the current operating environment. Although more advanced than their land and maritime counterparts, UAS are still struggling to achieve interoperability levels as defined in NATO Standardization Agreement (STANAG) 4586. As of 2008, UAS predominantly did not execute levels of interoperability 3, 4, and 5 described below, but some are expected to in the future. The following Levels of Interoperability (LOI) from NATO Standardization Agreement (STANAG) 4586 should be used to identify the flexibility in control for all active UAS.:

> STANAG 4586, Standard Interface of the Unmanned Control System (UCS) for NATO UAV Interoperability

[39] NATO Policy for Interoperability – C-M(2005)0016 dated 2 March 2005.

Level 1 - Indirect receipt/transmission of Unmanned Aircraft (UA) related payload data.

Level 2 - Direct receipt of ISR/other data where "direct" covers reception of the UA payload data by the RVT when it has direct communication with the UA.

Level 3 - Control and monitoring of the UA payload in addition to direct receipt of ISR/other data.

Level 4 - Control and monitoring of the UA, less launch and recovery.

Level 5 - Level 4, plus launch and recovery functions.

As with UAS, MUS must adhere to established standards and conventions in order to be easily integrated in combat systems present and future. In order to achieve this, organizations developing MUS concepts and systems should initially establish the desired levels of interoperability for the MUS. Prior to assembling hardware, the second step is to revise current and emerging architectures, protocols and interfaces to ensure the utmost interconnectivity.

As mentioned earlier UAS are at the forefront of technological development, following the trend MUS should base their technical architecture, digital backbone, communications and robotic interfaces on established parameters. Logically, NATO will look in its own organizational backyard and relate to STANAG 4586 to develop the MUS standardization parameters.

STANAG 4586 provides a non-proprietary open architecture standard for GCS, UA, and C4I network data interfaces. Several new Department of Defense (DOD) UAS (e.g., Sky Warrior, BAMS UAS, and Small Tactical UAS) programs of record have been developed or are in development that are STANAG 4586 compliant. The objective is for NATO countries to develop their own UAS software module and improved interoperability. In addition to STANAG 4586, adopting the standards outlined in the following STANAGs is integral to the interoperability of NATO UA and their payloads:

3809 Digital Terrain Elevation Data Geographic Information Exchange Standard.
4575 NATO Advanced Data Storage Interface (if advanced storage is required).
4545 NATO Secondary Imagery Format.
4559 NATO Standard Image Library Interface (if interface with image library is desired).
4607 NATO GMTI Data Format (Emerging Standard).
4609 NATO Digital Motion Imagery Format (Emerging Standard).
5500 NATO Message Test Formatting System AdatP-3.
7023 Air Reconnaissance Imagery Data architecture.
7024 Imagery Air Reconnaissance (Digital Tape Storage) (if tape storage is required).
7085 Interoperable Data Links for Imaging Systems + Digital Point to Point Annex of STANAG 7085 (compatible with CDL/TCDL specification).
7074 Digital Geographic Information Exchange Standard (Version 2.1).

Other committees and organizations are working on standardization processes for MUS; in particular in the UUV domain, Science Applied International Corp. /

Association for Unmanned Vehicle Systems as well as the American Society for Testing and Materials (ASTM), and Battle Applied Coastal and Environmental Services, have produced a paper outlining the best employment for UUV[40].

2006, saw the approval of an initial set of standards pending the resolution of technical comments in the next iteration. These initial UUV standards were noted by the ATSM as follows:

* F 2541 – 06: Standard Guide for Unmanned Undersea[41] Vehicle (UUV) Autonomy and Control Architecture.
* F 2545 – 06: Standard Guide for Unmanned Undersea Vehicle (UUV) Mission Payload Interface
* F 2556 - 06: Standard Guide for Unmanned Undersea Vehicle (UUV) Communications
* F 2557 - 06: Standard Guide for Unmanned Undersea Vehicle (UUV) Data Formats and Data Storage Media

The F 25 series industry standards are developed in close collaboration with governmental, military, academia with an interest in UUV development and interoperability.

Challenges

The proceeding of the International Society for Optical Engineering (SPIE) notes that future of unmanned systems interoperability faces many challenges in the areas of increased levels of autonomy, teaming and collaboration with other systems, long endurance missions as well as integration with civilian and other military spaces[42].

> "*Several currently available methods and technologies may aid in meeting these and other challenges: consensus standards development, formal methods, model-based engineering, knowledge and ontology representation, agent-based systems, and plain language research. We believe the future of unmanned systems interoperability depends on the integration of these methods and technologies into a domain-independent plain language for unmanned systems."*

Conclusion

In summary it becomes quite obvious that the Guidance for the development of MUS capabilities must adhere to current and emerging standards. In addition, one must take into account the joint and international perspective and enable developing projects to retain the tenants of interoperability in the initial plan as an important part of the projects' evolution. This approach permits the simplification of digital backbone development and interface between the various Unmanned Vehicle systems.

[40] Development of UUV Standards, an Emerging Trend, 2007
[41] In the current terminology "underwater" has prevailed on the term "undersea".
[42] Proceedings of the International Society for Optical Engineering (SPIE) 9 May 2006.

Annex E
CJOS COE - MUS Guidance

TRAINING

Aim

The primary focus of MUS training is to develop competent operators and supervisors. To achieve this goal, the training must rely on system fidelity as well as situational and graphical realism. In order to produce competent and efficient operators of MUS, a thorough, accessible and affordable training program must be instituted concurrently with the acquisition plan for the given system.

Current Situation

At the moment, even UAS training suffers from lack of commonality in interface and training standards even though these systems are prevalent in the modern operating environment. In the maritime domain, MUS, either UUV or USV are at an emergent stage, capabilities are identified and addressed but the medium in which they operate proves to be more complex. Additionally, the systems' lack of commonality and interoperability are still major impediments to the development of MUS. Most MUS training is being conducted in system specific isolation creating operators that cannot be employed on other systems. Additionally, MUS training, as most specialized training, is a perishable skill resulting in operators having to receive periodic refreshers to maintain currency as well as retraining each time the operator is assigned to a different or upgraded system.

Challenges

As with most rapidly introduced technologies, MUS lacks a comprehensive standardization plan to include service, joint and international requirements. Unfortunately, material solutions are currently leading the Doctrine, Organizations, Training, Leader development, Material, Personnel and Facilities notions of the DOTLMPF (Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities). The technical issues are by themselves quite demanding, and rarely encompassed a global vision rather exploiting commercial confidentiality for economic exclusivity.

MUS projects lack well defined standardized and approved training requirements. Usually MUS training comes as an afterthought and is not included as a formalized course within Professional Military Education (PME). Furthermore there is no human resources and personnel career management involvement in the introduction of unmanned systems resulting in a lack of advocacy for an unmanned systems' career path within the services.

Additionally, there is a void of vetting by the training establishments, using developmental and/or operational testing protocols that would determine any required changes to MOS training, Course Training Standards and Course Training Plans reflecting the introduction of MUS in the services inventory.

Solutions

To achieve its aim, MUS training primary focus resides in fidelity and realism. In order to achieve both, the training methodology must address the pedagogical as well as the technological aspects. It is thus essential that the MUS and the operator be integrated as early as possible during the training program. The Training Plans (TP) and Training Standards (TS) must be synched with a standardized protocol that can be applied to the MUS in the actual inventory and cater for modernization programs and new acquisitions.

Individual Training

As MUS operator skills are highly perishable, proficiency of MUS operators will deteriorate over time hence the requirement to provide easy venues to conduct refresher and continuation training using standardized TS based on the system currently in use.

The training environment shall also provide real world scenarios and fidelity while being able to be operated in a networked environment permitting interactions with other MUS operators and supporting/supported entities. As with UAS operators a STANAG, similar to STANAG 4670 need to be developed for MUS. This recognized standard needs to meet or exceed civil training standards and accommodate all known systems.

Collective Training

As mentioned above MUS training must be integrated at all employment levels. Commanders need to be aware of their capabilities and how to employ them effectively. To that effect it is imperative to develop unit level Standard Operating Procedures (SOP) and incorporate MUS training at all levels of the annual trg plan. Another important best practice for commanders is to develop and incorporate man-unmanned institutional Tactics Techniques and Procedures (TTP).

The unit/formation training cycle shall utilize the MUS systems during all training events (i.e. live, virtual, synthetic and/or simulated). Ideally the system has built-in training capability such as a virtual/simulation mode that can be operated without external resources. Realism in integrated simulation training is the key to operator success; giving simulated data but real operating environment and equipment. It is essential to simulate complex battlefield environments and communications systems so that training applications meet the required levels of realism in training.

Technical Aspects

Ideally and highly recommended in any future MUS acquisition program, the embedded training capability of the MUS should host 100% of all the training requirements and allow operators and units to rehearse and train mission tasks on every system without the need for supplementary external equipment. Procurement should also strive to acquire a commonality of systems and interfaces such as a common Control Unit which would substantially alleviate costs and training requirements as well as enhance joint and multinational interoperability.

Standardization

As recommended in the Office of the Secretary of Defense Unmanned Systems Roadmap[43], the main idea is to drastically reduce the training requirements (and costs) resulting from a wide diversity of MUS types, capabilities and operator skill levels. There is thus a need to create a Joint, Multinational training core enabling the creation of a core skill set applicable to MUS operation.

Way Ahead

We foresee that as MUS technical capabilities continue to improve and nations are developing their own programs in isolation, there is an urgent need to generate joint training plans and facilities based on MUS standards that should be defined by a STANAG. These standardized training plans would incorporate individual and collective training objectives for all levels of training such as foundation, refresher, institutional, and specialized. It is therefore essential that training requirements and interoperability standards be incorporated in any MUS acquisition plan right from the start.

[43] Office of the Secretary of Defense (December 10 2007): US Unmanned Systems Roadmap 2007-2032

Annex F
CJOS COE - MUS Guidance

MANNED UNMANNED TEAMING

Introduction

Manned – Unmanned (MUM) teaming refers to the relationships established between manned and unmanned systems prosecuting a common mission as an integrated team. MUS offers tantalizing capabilities to the warfighter, such as tireless observation, quick recognition, and rapid reaction to today's changing battlespace. These trends are important because they aid warfighters in their duties. Today, unmanned systems exist that extend the vision and the reach of the warfighter. However, they spend so much time managing these assets that they lose effectiveness as a warfighter. This is a particular problem if the warfighter's role is one demanding continuous sensory and mental workload.

Architecture

The architecture is segmented into seven major components[44]:

- Mission Planning – develops plans for the team and for individual vehicles;
- Collaboration – manages team formation and interaction among team members;
- Contingency Management – detects, assesses, and responds to unexpected events;
- Situational Awareness – creates Common Relevant Operating Picture (CROP) for team;
- Communications Management – Manages the interaction with the vehicle's communications systems.

These components work in concert to achieve objectives without violating constraints. This system architecture offers substantial advantages over existing approaches, such as recognizing the need to partition components requiring distinct disciplines for analysis, development, and operation as well as the need for autonomy to be collaborative both with other autonomous systems of the team and systems external to the team.

Mission Planning

Mission Planning onboard the autonomous system performs pre-mission and dynamic in-mission replanning for the collaborative team. Mission planning develops collaborative synchronized plans for sensor employment, paths, communications, and engagements.

[44] Collaborative Autonomy for Manned/Unmanned Teams, Steve Jameson and Jerry Franke - Lockheed Martin - Advanced Technology Laboratories (Internet)

Collaboration

Collaboration, i.e. the ability of multiple vehicles to interact to carry out a team mission, is inherent in the Collaborative Autonomy architecture.

Contingency Management

A key challenge to successful autonomous operations is detection and reaction to unplanned events that affect the execution of the vehicle system's mission. Contingency Management watches for unexpected influences that affect team plan success, such as payload failure, modified orders, new operational constraints, changing environmental conditions and other unexpected changes in the battlespace. It works with the Mission Planning component to generate an effective response to the contingency so the mission can be continued.

Situational Awareness

The Situation Awareness collects and maintains other types of information such as weather data, environmental information, and obstacle maps. This information is also used by Mission Planning and other components to make autonomous decisions that guide vehicle behavior.

Communications Management

Communications Management provides and manages data links to connect team members with each other and with external assets (e.g., ISR and Networked fires) over battlefield networks.

Annex G
CJOS COE - MUS Guidance

POWER AND PROPULSION

Introduction

The power and propulsion consists of the prime power to provide thrust and electrical power conversion, management and distribution necessary for the operation of the electrically driven subsystems required to perform the vehicles mission. The power and propulsion is one of the problems that need to be considered especially in the development stage so that MUS can better address the operational requirements by increasing the range and endurance. The MUS missions will rely highly on efficient, powerful, portable, and logistically supportable sources of power and propulsion.

Current State

There are different propulsion systems that have potential usage today; combustion engines powered by heavy fuel or gasoline, jet engines, electric power, fuel cells, hybrid power systems and solar. Power systems which are in use are; batteries, engine driven generators, hybrid and solar. The advantages and disadvantages of each of these systems are to be taken into account when deciding to employ on any MUS with specific missions according to their unique nature.

Challenges and Way Ahead

The endurance is one of the most demanding aspects of MUS; the need to operate longer and farther away will be challenging because the operational requirements are going to be more demanding as MUS becomes part of the daily operations. The limitations on the speed, time and range are going to be directly related to the accomplishment of the mission. Future systems will have to be minimal in size and weight while providing reliable and sufficient power for the mission. Therefore there will be a persistent demand from the planners and the operators to maximize the limits.

Technical challenges cannot only be dealt with by industry. The MUS mission requirements and the concept of operations must be defined first to lead the industry develop the technical solutions necessary for power and propulsion systems. The optimized designs for specific missions should be worked up in close cooperation with industry.

More efficient power and propulsion solutions are a key enabler to the acceptance of MUS as a new capability.

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Annex H
CJOS COE - MUS Guidance

LEGAL ASPECT OF MUS EMPLOYMENT

Introduction

Unmanned systems have been used by the military since 1940. Since that time, military forces have introduced and employed a variety of these innovations including torpedoes, cruise missiles, satellites, and target drones. As discussed in previous sections, the definition and capabilities of unmanned systems have evolved due to their increased capability to operate autonomously. Unmanned systems are becoming ubiquitous in the oceans, and naval forces throughout the world are primary operators of unmanned vehicles and vessels. International law governing activities on, over and under the sea emerged well before the development of unmanned systems. As unmanned systems become more advanced through technological improvements, legal and policy issues are also becoming more complex and nuanced. With this background, it is critical that military operators develop and understand the definitions, status, and applicable rules of engagement (ROE) of unmanned systems.

ROE definition challenge

In peace or war, ROE have risen in strategic importance as limits to military force have been influenced by international conventions and laws as well as national governmental policies. As a result, ROE are now an integral part of any military operation, and appear to be the best way to bridge the requirements between law, policy, and security. Each nation in an alliance brings with it its own ROE requirements and caveats. While much of the ROE can be agreed upon between member nations, each nation also brings to the fight its own national caveats. The principle of national sovereignty, when a nation is part of an Alliance relying on political and military cooperation, continues to be a sensitive topic considering these caveats. Within NATO, commanders must understand the differences in member capabilities and ROE. This understanding enables commanders to effectively employ forces and tailor multi-national capabilities to individual mission sets. As ROE is developed by member nations to address threats possed by MUS and for the operational employment of friendly MUS, the same sensitivities discussed above will be present. The best time to address these sensitivities is prior to hostilities, so that all NATO members understand the ROE and can train to that ROE.
Assessing whether a manned threat is exhibiting hostile intent is very difficult to determine in peacetime and this difficulty exists for MUS as well. A deviation from

expected behavior alone may not serve as a trip wire for the exercise of self-defense. As the commander assesses various indicators of hostile intent, the final determination is largely subjective. The idea that ROE can be a black and white solution to a difficult subjective decision is misleading and in some ways even dangerous. NATO desires that every member be proactive in this field to achieve a set of procedures that reflects common principles by facilitating the exchange of information between allied countries potentially affected by the same event. These procedures will provide a framework for analysis, but will not substitute for the independent thinking of operational commanders. Also, the ROE cannot exceed the limits imposed by international law.

The San Remo Manual on International Law Applicable to Armed Conflicts at Sea is a useful doctrinal reference to help develop appropriate ROE for the offensive and defensive use of MUS. The San Remo Manual recognizes that the exercise of the right of individual or collective self-defense contained in Article 51 of the Charter of the United Nations is subject to the conditions and limitations laid down in the Charter and arising from general international law, particularly the principles of necessity and proportionality. The principles of necessity and proportionality equally apply to armed conflict at sea and require that the conduct of hostilities by a State should not exceed the degree and kind of force required to repel an armed attack against it and to restore its security.

The San Remo Manual does not refer clearly to Unmanned Systems. It is possible to get an appropriate definition, if we extrapolate from the reference to military aircraft: "it is a military aircraft operated by commissioned units of the armed forces of a State having the military marks of that State, commanded by a member of the armed forces and manned by a crew subject to regular armed forces discipline"[45]. By extension it is reasonable to apply, and many nations do, the same rules to unmanned systems. When considering action against a manned platform, as opposed to an unmanned system, policy may require a higher threshold for the use of force because of the potential for the loss of human life, in addition to the potential for escalation. When considering action against an unmanned system, the loss of life impact is removed from the equation, although collateral effects may still be present. It seems logical then, that rules governing action against an unmanned system, may be less stringent than those that govern action against a manned aircraft.

ROE Considerations

Military operators employing and confronting unmanned systems face numerous legal and policy challenges in the maritime environment. The distinctive feature of this environment is that it includes areas subject to the territorial sovereignty of nations

[45] San Remo Manual on International Law Applicable to Armed Conflict at Sea, 1994 – Section V/13(J)

(national waters and national airspace) and areas not subject to the territorial sovereignty of any nation (international waters and international airspace).

The principal legal considerations when drafting ROE for maritime operations are:

a. The sea area where operations are to take place and the legal regime that applies, including navigation and over flight rights, the duties and rights of the coastal and flag states, and the rights and duties of neutrals and other non-participants.

b. The legal basis for the operation, including any specific legal authority for conducting operations in national waters or for conducting maritime interdiction operations.

c. The principle of sovereign immunity.

Absence of specific ROE to the contrary, will generally force military operators to follow the same ROE for manned systems. Whether a system is unmanned may be a relevant factor to consider when determining hostile intent before employing force in self defense. Additional considerations may also be whether the unmanned system is armed or retrievable.

Legal Support to Military Operations Planning

Unmanned systems present new challenges to the already complex international legal framework of the Law of Armed Conflict. Consequently, it is imperative that legal advisors actively participate in the entire planning process, from intelligence preparation of the operational environment, to mission analysis, to course of action development and recommendations, through execution. Legal advisors are able to advise on the myriad of regulations, laws, policies, treaties, and agreements that apply to military operations. Whether military operations involve manned or unmanned systems, traditional law of war principles such as military necessity, unnecessary suffering, distinction, and proportionality remain critical planning considerations.

What NATO can do

Based on these considerations, it is possible to identify NATO's role in the development and the subsequent employment of ROE. Recognzing that ROE must satisfy a nation's strategic and operational objectives, attention must also be given to the the needs of the service members who employ them.

As military operations develop, so too must ROE evolve. Increasingly, operational commanders will have to decide whether to use force to reduce or prevent the use of unmanned systems by opposing forces. Nations must provide their military commanders with effective ROE that allow them to protect their force while operating in compliance with the law of armed conflict and to maintain legitimacy .

Through its unique political and military structures, NATO is positioned to facilitate efforts among Alliance members to develop effective ROE to confront unmanned systems. The NATO Alliance is experienced in developing doctrine and conducting operations in a multi-national environment that recognizes the differences in legal regimes and cultures of its member nations, in support of a common effort. Hence, NATO represents an ideal body to socialize both the concerns and challenges with respect to unmanned system ethics and ROE. The process will be difficult, but collaborative efforts will lead to a new ROE framework for MUS. The end state would be a step toward the achievement of a legal framework in support of an operational capability ready to be employed for future military operations. As the military requires the legal justification for conducting operations, legal experts should continue to support the operational planners to ensure compliance with applicable domestic and international law.

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LIST OF ACRONYMS

ACR	Air Coverage Rate
ACS	Autonomous Control Level
ACT	Allied Command for Transformation
ADS	Advanced Deployable Systems
ATR	Automatic Target Recognition
AT/FP	Anti terrorism/Force protection
ADS	Advanced Deployable system
AMS	Allied Maritime Strategy
AOI	Area of Interest
AOR	Area of Responsibility
ASLP	Archipelagic Sea Lanes Passage
ASMD	Anti Ship Missile Defense
ASW	Anti Submarine Warfare
AOU	Area of Uncertainty
BSA	Battle Space Awareness
C2I	Command Control and Intelligence
C3	Command, Control and Communication
CAC	Computer- Aided Classification
CAD	Computer-Aided Detection
CAI	Computer-Aided Identification
CN3	Communications/Navigation Network Node
CBNRE	Chemical, Biological, Nuclear, Radiological, Explosives
CCS	Command Control Station
CGCS	Command Ground Control Station
COE	Centre of Excellence
CONOPS	Concept of Operation
CSG	Carrier Strike Group
CVBG	Craft Vessel Battle Group
CVLWT	Common Very Light Weight Torpedo
DADS	Deployable autonomous distributed system
DCLT	Detection, Classification, Localization and Tracking
DOTLMPFI	Doctrine, Organizations, Training, Leader development, Materiel, Personnel, Facilities and Interoperability
EEZ	Exclusive Economic Zone
ELINT	Electronic Intelligence
EMS	Electro Magnetic Spectrum
EOD	Explosive Ordnance Disposal
EO/IR	Electro Optical/Infra red
ESG	Expeditionary Strike Group
EW	Electronic Warfare
FTG	False Target Generator
GPS	Global Positioning System
HLD	Home Land Defense
HWV	High Weight Vehicle

ID	Identification
I&W	Indication and Warning
IMINT	Imagery intelligence
IPB	Intelligence Preparation of the Battlespace
ISR	Intelligence, Surveillance, Reconossaince
JAPCC	Joint Air Power Competence Center
JOA	Joint Operations Area
LCS	Littoral Combat Ship
LCG	Longitudinal Center of Gravity
LWT	Lightweight
LWV	Light Weight Vehicle
LOI	Levels of Interoperability
MASINT	Measurement Intelligence
MCM	Mine Counter Measures
MDF	Multi Data Fusion
MS	Maritime Security
MSO	Maritime Security Operations
MIED	Maritime Improvised Explosive Device
MILDEC	Military Deception
MIMO	Multi-Input, Multi-Output
MIO	Maritime Interdiction Operations
MIW	Mine Warfare
MS	Maritime Security
MSA	Maritime Situational Awareness
MUS	Maritime Unmanned Systems
NTT	Non-traditional tracking
NURC	NATO Undersea Research Center
OODA	Observe, Orient, Decide and Act
OPAREA	Operations Area
OPLAT	Oil Platforms
PID	Positive Identification
PED	Process, Exploit, Disseminate
PSS	Port Security Services
QoS	Quality of Service
RF	Radio Frequency
RHIB	Rigid Hull Inflatable Boat
RDS	Remote deployable system
ROE	Rules of Engagement
ROV	Remote operated vehicle
SA	Situational Awareness
SAS	Synthetic Aperture Sonar
SATCOM	Satellite communications
SIGINT	Signal Intelligence
SLOC	Sea Lines Of Communication
SOA	Speed Of Advance
SOF	Special Operations Forces
SS	Semi Submersible

SSBN	Submarine Ballistic Missiles, Nuclear
SSG	Surface Strike Group
SSN	Submarine Nuclear
SSV	Semi Submersible Vehicle
STANAG	Standardized NATO Agreement
SUW	Surface Warfare
SWATH	Small Waterplane Area Twin Hull
T&E	Test and Evaluation
TFC	Task Force Commander
TBMD	Theatre Ballistic Missile Defence
TCS	Time Critical Strike
UA	Unmanned Aircraft
UAV	Unmanned Aerial Vehicle
UCS	Unmanned Control System
UGS	Unmanned Ground Vehicle
UNCLOS	United Nations Convention on the Law of the Sea
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
V&V	Verification and Validation
WMD	Weapons of Mass Destruction