Skip all front matter: Jump to Page 1

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U.S. Navy Employment Options for UNMANNED SURFACE VEHICLES (USVs)

Scott Savitz, Irv Blickstein, Peter Buryk, Robert W. Button, Paul DeLuca, James Dryden, Jason Mastbaum, Jan Osburg, Philip Padilla, Amy Potter, Carter C. Price, Lloyd Thrall, Susan K. Woodward, Roland J. Yardley, John M. Yurchak

RAND CORPORATION

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

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Preface

In recent years, unmanned vehicles have become increasingly important for military operations. However, there has been relatively little focus on or operational employment of unmanned surface vehicles (USVs)—that is, uninhabited maritime vessels. The purpose of our research was to analyze how, in what contexts, and to what extent the U.S. Navy can employ USVs. This report identifies the U.S. Navy missions and functions for which USVs are suitable while also highlighting operational issues and technological and programmatic requirements that should be considered to ensure that USVs are effectively integrated into naval operations.

This research was sponsored by the Assessment Division of the Office of the Chief of Naval Operations (OPNAV N81) and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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Contents

Figures

Tables

Summary

Over the past two decades, the military roles and contributions of unmanned vehicles have grown dramatically, and this trend appears likely to continue. However, unmanned surface vehicles (USVs)—maritime vehicles uninhabited by personnel that maintain continuous, substantial contact with the surface—have received less attention and investment than unmanned vehicles that operate in the air, on the ground, or under the sea. Given this anomaly, the Office of the Chief of Naval Operations, Assessment Division (OPNAV N81) asked RAND to research the prospective suitability of USVs for U.S. Navy missions and functions.

Scope

The purpose of our research was to ascertain to what extent and in what ways USVs are likely to be suitable for contributing to the fulfillment of U.S. Navy missions and supporting functions. This is a qualitative study that aims to link U.S. Navy needs and considerations with the capabilities that USVs can provide.

In delineating the scope of this report, it is important to emphasize that it is not intended to be an update to or replacement for *The Navy Unmanned Surface Vehicle Master Plan* (2007) or the USV portions of *The Unmanned Systems Integrated Roadmap FY2011–2036* (2011). In fact, one of our key recommendations is that a new USV master plan, roadmap, or both be pursued. Rather, this report is intended to provide insights to those seeking to understand how USVs can be employed in U.S. Navy operations, to lay a foundation for future roadmaps or master plans, and to offer a starting point for stakeholder community discussion of how best to proceed with USV development.

Analysis of the USV Marketplace

We began our analysis by reviewing current and emerging USV markets: what USVs are available or in development, the missions of those USVs, their capabilities, their attributes, and the countries in which they are being developed.[1] We found 63 USVs in what we deemed to be the current market—i.e., they had been tested and demonstrated. The overwhelming majority of these USVs were relatively small (11 meters or shorter), with correspondingly limited endurance, power output, and payload capacity. Approximately half of these USVs are made in the United States, and nearly all of the rest are manufactured in friendly nations. While several of these USVs are capable of multiple missions, most USV capabilities are directed toward only a handful of mission categories: observation and collection, characterization of the physical environment, mine countermeasures (MCM), security against small boat threats, and testing or training platforms. We also found an additional 22 USVs in a less advanced state of development. These are primarily small, low-endurance, low-payload platforms and are likewise manufactured in the United States or countries with which the United States has close ties.

Development of USV Concepts of Employment

Next, we developed and evaluated the prospective ways in which the U.S. Navy could employ USVs. We analyzed 62 different naval missions and functions (see Table S.1) to understand how USVs could con-

1 During this review of USV markets and throughout the study, our analysis was informed by repeated engagement with subject-matter experts from other organizations. A full list of these organizations appears in the Acknowledgments section and in Chapter One.

Table S.1
Potential Naval Missions and Functions for USV Employment

C^4ISR	Military Deception/ Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	Anti-Submarine Warfare (ASW)	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
Persistent ISR in permissive environments	Disposition/ intentions deception	Armed escort	MCM intelligence preparation of the battlespace (IPB)	Unarmed ASW area sanitization	Unmanned vehicle support	Short/ medium-range ground attack	Sensing and warning—unit level	Search and rescue of conscious victims	Blockship operations/ port detonations
Environmental collection in permissive environments	Communic-ations/ signals deception	Counter fast attack craft (fully autonomous)	Reacquisition minehunting and neutralization	Act as an ASW sensor node	Autonomous ship-to-shore connector	Long-range ground attack (arsenal ship, optionally manned)	Sensing and warning—force level	Complex search and rescue	Deliberately allowing capture
ISR in hostile environments	Radar/ signals deception	Counter fast attack craft (remote control)	Autonomous in-stride minehunting and neutralization	Cued overt ASW tracking	Opposed amphibious landing resupply		Non-kinetic unit defense	Test platform	Impairing adversary sensors

Table S.1—Continued

C^4ISR	Military Deception/ Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	Anti-Submarine Warfare (ASW)	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
USV with tethered unmanned undersea vehicle (UUV) to deploy sensors or networks	Acoustic/ signals deception	Presence patrol	Mechanical mine-sweeping and mine harvesting	Armed wartime ASW area sanitization	Covert/ clandestine special operations forces (SOF) cargo delivery		AMD kinetic force defense (using projectiles or directed energy)	Training support	Provocative, high-risk presence
Environmental collection in hostile environments	Decoy/ counter-measures	Open-water ship-vs.-ship conflict	Influence mine-sweeping	Uncued covert ASW tracking	Unmanned vehicle refueling				Vehicle as surface weapon
Processing, exploitation, and dissemination	Military information support operations	Countering swarms	Minefield proofing	Cued covert ASW tracking	Resupply for manned ships				
Communic-ations relay	Tactical jamming		Minelaying	Cued/ uncued ASW engagement	Military interdiction operations support				

Table S.1—Continued

C4ISR	Military Deception/ Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	Anti-Submarine Warfare (ASW)	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
Deploy individual sensors	Disguised mission								
Deploy independent sensor network	Info systems (cyber/tech)								
	Computer network attack								
	Diversion								

tribute to their fulfillment. We grouped these missions and functions into ten categories.

For each of the missions and functions listed in Table S.1, we developed concepts of USV employment. We drew on subject-matter expertise to devise ways in which USVs could complement or supplant existing platforms or even perform missions or functions in wholly novel ways. Once we developed one or more concepts of employment for a particular mission or function, we had panels of subject-matter experts analyze and refine them in a series of sessions, modifying and extrapolating from the original concepts.

Assessing Suitability

We assessed the suitability of the USV concepts of employment for these missions and functions based on the criteria summarized in Table S.2. We defined *suitability* as the sum of the net benefits and liabilities associated with using USVs for a particular mission, taking into account the impact on mission effectiveness, risks, costs, capital asset requirements, time lines, the desirability of alternative platforms, USV support requirements, and compatibility with existing programs.

The overall suitability characterization is necessarily qualitative and involves some subjectivity. However, we aimed to minimize the degree of subjectivity involved by using a thorough and traceable methodology. Specifically, we developed a spreadsheet in which we characterized the following regarding USV usage for each of the 62 missions:

- prospective benefits or disadvantages of employing USVs relative to current approaches
  - mission effectiveness
  - mission time lines
  - risk to people and/or capital assets
  - requirement for capital assets
  - degree to which USVs could counter emerging adversary capabilities

Table S.2
Criteria for Evaluating the Suitability of USV Concepts of Employment for Particular Missions or Functions

Degree of Suitability	Criteria
Highly suitable	• Significantly increases effectiveness or addresses capability gaps • Reduces risks, costs, need for capital assets, and/or time lines • More appropriate than alternative unmanned or manned platforms • Acceptable transportation, hosting, and support requirements • Programmatic compatibility
Possibly suitable	• Moderately increases effectiveness • Little/no reduction in risks, costs, need for capital assets, and/or time lines • Alternative unmanned or manned platforms potentially more appropriate • Challenges relating to transportation, hosting, and support • Limited programmatic compatibility
Less suitable	• Very limited benefits (or net negative impact) in terms of effectiveness • Increased risks, costs, requirements for capital assets, and/or time lines • Less appropriate than alternative unmanned or manned platforms • Serious impediments relating to transportation, hosting, and support • Programmatic incompatibility

  - potential to cause an adversary to expend resources to counter USVs
  - reliability considerations
  - redundancy considerations
  - ability to achieve the desired degree of stealth or overtness
  - secondary missions and ancillary benefits
- any specific USV attributes that are relevant to the mission
- the degree to which the mission is conducted in particular environments
  - open waters
  - confined waters
  - hostile waters

  - friendly waters
  - high-traffic conditions
  - low-traffic conditions
  - high sea states
  - low sea states
- technological development of USVs for the mission
  - technology readiness level (TRL)
  - qualitative characterization of technology needs
  - technological development risks
  - ability to leverage technological developments also required for USVs to fulfill other missions
  - ability to leverage technological developments also required for other emerging platforms (notably unmanned systems) to fulfill other missions
- programmatic issues associated with using USVs for the mission
  - tactical integration
  - organizational acceptance
  - training requirements
  - qualitative cost considerations
  - program risk
- autonomy, communications, and preprocessing requirements
  - navigational autonomy requirements
  - assured communications requirements
    - for all purposes
    - specifically for the employment of weapons
  - preprocessing requirements
  - networking with other unmanned vehicles
  - ability to trade off between autonomy and assured communications
- relative desirability of other platforms for the mission and relevant attributes for consideration
  - UAVs
  - UUVs
  - manned platforms
- prospective impact of having an optional manning capability while conducting a mission

- prospective utility of replenishment at sea for the mission
- prospective impact of payload modularity on mission capabilities
- prospective utility of an energy scavenging capability
- classes of USVs that might be desirable for this mission.

The material in this spreadsheet was then used as a basis for qualitatively characterizing both the suitability of USVs for the mission (highly suitable, possibly suitable, or less suitable), as well as the degree of technological maturity associated with USV development for the mission.

Comparison of USVs with Other Platforms

One criterion—the appropriateness of USVs relative to other platforms—deserves special attention. USVs are always in competition with manned and other unmanned platforms for missions. To help determine the degree to which USVs are more or less appropriate for a given mission than other unmanned platforms, we compared the performance attributes of USVs with those of unmanned aerial vehicles (UAVs) and UUVs, as shown in Figure S.1.

As indicated in Figure S.1, USVs have greater potential payload capacity and endurance than comparably sized unmanned systems in other domains. They are able to use higher-density energy sources than UUVs (hydrocarbons instead of batteries), and, unlike UAVs, they do not need to burn fuel merely to maintain their vertical position; if desired, they can move relatively slowly for days or weeks without refueling. A comparison of the relative sizes and payloads of some aircraft and vessels is illustrated in Table S.3.

USVs also have the unique ability to operate sensors and communicate both above and below the waterline. Broadly speaking, missions in which payload weight, endurance, and multi-domain capabilities are important—and risk, cost, or other considerations make unmanned platforms preferable to manned ones—are likely to be more appropriate for USV employment. Likewise, missions in which speed is critical are likely to be more appropriate for UAVs, and missions in which stealth is paramount will favor UUVs. In most cases, there will be trade-offs among several desired attributes.

Figure S.1
USV Attributes Compared with Other Similarly Sized Unmanned Vehicles

● Clear advantage for USV ◖ Near parity ○ Clear disadvantage for USV

	USV Comparison with UAV		USV Comparison with UUV	
Attribute	Relative Advantage	Comment	Relative Advantage	Comment
Endurance	●	Advantage most pronounced when USVs can operate at low speed	●	Hydrocarbon fuels with unlimited oxidizers versus batteries and/or fuel cells
Power				
Propulsion	◖		●	UUVs are more volume-limited for propulsion systems; heat dissipation can be an issue
Mission packages	◖		◖	USVs have more power; UUV packages have lower power requirements
Speed	○		●	UUVs are speed-limited to a few knots
Range	○		●	
Payload capacity	●	UAV space, weight, and power for payloads are limited	●	Low energy density reduces UUV internal volume for payloads
Sensors				
Above the surface	○		●	
Subsurface	●		○	UUVs have more types of sensors and can position them better
Communications	◖	UAVs have better vantage points, but USVs have cross-domain capabilities	●	
Stealth	◖	Both USVs and UAVs have potential to be stealthy	○	
Autonomy requirements	○	UAVs have fewer traffic-avoidance problems and no seakeeping issues	◖	UUVs have limited seakeeping issues and fewer traffic-avoidance problems, although they need to avoid undersea hazards; USV autonomy demands are mitigated by better reachback capability

RAND *RR384-S.1*

Table S.3
Comparison of Vessel and Aircraft Sizes and Payload Capacities

Platform	Domain	Dimensions (m)	Payload Capacity (kg)	Payload Divided by Length x (beam or wingspan) (kg/m²)
7-meter rigid-hull inflatable boat (RHIB)	Surface	7 (length) 3 (beam)	700	100
Predator UAV	Air	8 (length) 11 (wingspan)	500	63
11-meter RHIB	Surface	11 (length) 3 (beam)	1,500	136
X-47B	Air	12 (length) 19 (wingspan)	14,000	61
Hercules C-130J-30	Air	35 (length) 40 (wingspan)	20,000	14
Landing Craft Air Cushion (LCAC)	Surface	26 (length) 14 (beam)	68,000	187
Landing Craft Utility (LCU)	Surface	41 (length) 9 (beam)	113,000	306
C-17	Air	53 (length) 52 (wingspan)	137,000	50

NOTE: Aircraft are shown in brown, while vessels are shown in black.

Results of Suitability Analysis

Table S.4 divides the 62 missions and functions we evaluated into three levels of suitability for USV employment (highly suitable, possibly suitable, and less suitable) and three levels of USV technological development (in or near market, emerging, and incipient). Of the 62 missions and functions, we deemed 27 to be highly suitable for USV employment.

As the left-hand cell of the top row shows, USV applications that are already in or near the combined civilian/military market are almost all highly suitable for U.S. Navy missions and functions. For example, USVs for the search and rescue of conscious victims have already

Table S.4
Naval Missions and Functions by Level of Suitability for USV Employment and Level of USV Technological Maturity

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Highly suitable	C^4ISR: • Persistent ISR in permissive environments • Environmental collection in permissive environments Mine warfare: • Influence minesweeping • Mechanical mine-sweeping and mine harvesting Functions: • Test platform • Training support • Search and rescue (SAR) of conscious victims	Mine warfare: • MCM IPB • Reacquisition minehunting and neutralization Surface warfare: • Armed escort Military deception/information operations/electronic warfare: • Disposition/intentions deception • Comms/signals deception • Radar/signals deception • Acoustic/signals deception • Decoy/countermeasures • Military information support operations ASW: • Unarmed ASW area sanitization Functions: • Unmanned vehicle support • Processing, exploitation, and dissemination	C^4ISR: • ISR in hostile environments • Environmental collection in hostile environments Mine warfare: • Autonomous in-stride minehunting and neutralization • Minelaying Surface warfare • Counter–fast attack craft (fully autonomous) Functions: • Autonomous ship-to-shore connector • Complex SAR Missions not currently performed: • Impairing adversary sensors
Possibly suitable	Surface warfare: • Counter–fast attack craft (remote control)	C^4ISR: • Communications relay among manned assets • Deploy individual sensors • Deploy independent sensor network Surface warfare: • Presence patrol	Ground attack: • Short/medium-range ground attack • Long-range ground attack (arsenal ship, optionally manned) AMD: • AMD kinetic force defense

Table S.4—Continued

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Possibly suitable (cont.)		Missions not currently performed: • Provocative, high-risk presence • Vehicle as surface weapon AMD: • Sensing and warning (unit level) • Sensing and warning (force level) • Non-kinetic unit defense Military deception/information operations/ electronic warfare: • Tactical jamming • Disguised mission • Info systems (cyber/tech) • Computer network attack • Diversion Functions: • Opposed amphibious landing resupply	Functions: • Covert/clandestine SOF cargo delivery Missions not currently performed: • Blockship operations • Deliberately allowing capture
Less suitable		ASW: • Act as an ASW sensor node • Cued overt ASW tracking Functions: • Maritime interdiction operations support	ASW: • Armed wartime ASW area sanitization • Uncued ASW tracking • Cued covert ASW tracking • Cued/uncued ASW engagement Surface warfare: • Surface warfare (open water, ship vs. ship) Functions: • Resupply for manned ships

been used to save lives in civilian contexts,[2] and other nations' navies already employ USVs for influence minesweeping.[3] The U.S. Navy could acquire USVs to fulfill the concepts of employment listed in this cell within the next several years.

The concepts of employment listed in the center and right-hand cells of the top row are also highly suitable for naval missions, but they depend on technological capabilities that are at an earlier stage of technological advancement. The U.S. Navy could consider investing in research and development (R&D) to bring these technologies to fruition.

The U.S. Navy could also consider investing in USV technologies to support naval missions for which these technologies are "possibly suitable" (middle row). Employing USVs for these purposes may provide fewer benefits, greater liabilities, or both compared with the missions and functions listed in the top row; however, there may be net benefits that justify such investment. U.S. Navy investment in USVs for those missions for which they are "less suitable" (bottom row) is not recommended due to a combination of low or negative effects and considerable liabilities.

Overall, we found that USVs could improve the effectiveness with which a number of missions are performed. This improvement stems, in part, from the USVs' potential for long endurance, which is advantageous for persistent ISR; MCM; and other missions.

As expected, USV concepts of employment reduced tactical and operational risks relative to current practices. In dangerous environments, such as minefields, it is far better to use unmanned platforms than manned ones. Moreover, a reduction in operational risk could allow a more aggressive posture that would force an adversary to change tactics or increase resource expenditures.

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2 One prominent rescue USV is the Emergency Integrated Lifesaving Lanyard (EMILY).

3 Influence minesweeping entails having a towed body emit acoustic, magnetic, and other signatures that resemble those of a ship. This causes influence mines to detonate without inflicting harm on an actual ship.

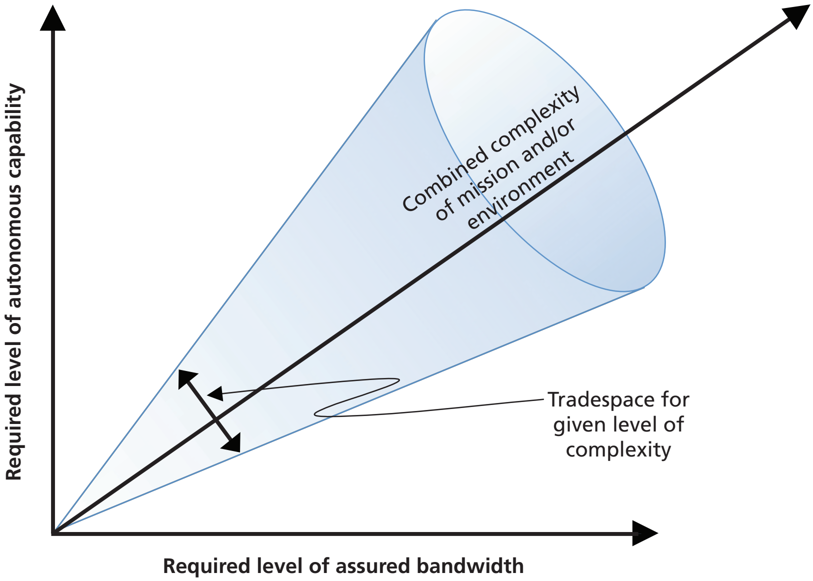
Opportunities with Respect to USVs

In the course of our analysis, we found three mission-transcendent opportunities with respect to USVs. First, USVs could uniquely enable cross-domain integration, increasing the capabilities of other unmanned vehicles or networks. USVs can leverage their relatively large payloads, large reserves of power, and long endurance to provide services for other unmanned platforms—e.g., physically transporting them, preprocessing data for them, and providing electric power via a tether. Second, USVs could be highly effective in overcoming challenging anti-access/area-denial (A2/AD) environments, particularly in military deception, information operations, electronic warfare, and cyberwarfare missions. USVs can help to counter A2/AD challenges by reducing risks to personnel and capital assets; dispersing capabilities into small, hard-to-target nodes; and expanding tactical choices by creating new concepts of employment. Third, we found that increased investment in USV research, development, and acquisition could facilitate technology transfers to other unmanned and manned R&D programs.

We found that advances in autonomy and assured communications are path-critical for USVs to conduct complex missions and/or operate in complex environments. Autonomy, assured communications, and mission or environmental complexity form a tradespace. As environments or missions grow more complex, increasingly advanced autonomy and/or assured communications are required. In essence, USVs are subject to a "control triangle" comparable to the well-known naval architects' "iron triangle" of speed, payload, and endurance. Figure S.2 illustrates the three elements of the control triangle in a three-dimensional graph.

While some aspects of autonomy R&D can leverage advances made for UAVs and UUVs, USV autonomy requirements for seakeeping on the surface and maritime traffic avoidance require USV-specific R&D that is unlikely to emerge from other programs. Advances in these capabilities will be critical to the continued development of USVs for virtually all Navy missions and functions. Finally, we note that advances in these areas, particularly the ability to adhere to regulations to prevent collisions at sea, could benefit future manned platforms.

Figure S.2
The Control Triangle



SOURCE: RAND analysis.
NOTE: The above diagram should be viewed as three-dimensional, with the middle arrow projecting off the page.
RAND *RR384-S.2*

Such advances, for example, could reduce watchstanding requirements on manned platforms with limited crews, such as the Littoral Combat Ship (LCS). Autonomous USV operations also present operational and policy-related challenges, since autonomous USVs would need to be integrated into the Navy's command and control (C2) structures.

Approaches and Considerations for USV Development

There are several approaches that could be undertaken in concert to improve the suitability of USVs for naval missions and functions:

- developing standard platforms with modular payloads, which could lower costs through economies of scale (one model for a parent vehicle), as well as improve the flexibility of the relatively small number of USVs that could be hosted on a ship
- enabling optional manning for maintenance support and situational awareness in transit or other benign environments, as well as for missions in which personnel are desirable
- leveraging the long potential endurance of USVs by
  - designing for reliability
  - developing optionally manned refueling, data-transfer, and maintenance vessels to support them
  - enabling "energy scavenging" (collecting energy from the environment) when power requirements are low.

There are also a number of programmatic challenges that need to be taken into consideration as USV programs evolve:

- USVs will exacerbate manpower and manning challenges. A widely accepted lesson learned from UAV and UUV operations is that unmanned systems are not really "unmanned"—they are, more accurately, "uninhabited." In many instances, the number of personnel required to operate and support a single unmanned system exceeds that for a manned platform with a similar concept of employment.
- USVs are likely to augment, not replace, other U.S. Navy manned programs, at least initially; thus, investments in USVs are likely to increase, rather than decrease, U.S. Navy costs for some time. USVs cannot wholly replace any existing capabilities; this is due in part to the multi-mission role of most Navy programs. For example, even if a USV can perform a particular mission as well as or better than a larger manned warship, that does not mean the USV can perform *all* of the manned warship's missions, and it certainly cannot perform them at the same time. Moreover, USVs that cannot self-deploy over long distances will need to be hosted by larger warships. While they can potentially enable fewer large warships to fulfill a given mission than would oth-

erwise be required, they are unlikely to supplant large, manned warships altogether. We also expect USVs to impose additional requirements on the supply chain, logistics, and maintenance infrastructures.
- The U.S. Navy will need to establish what warfare and/or platform communities will "own and operate" USVs once introduced and how those professional communities will be acquired and sustained.
- USVs will pose community sponsorship and management challenges. These relate to the Navy's planning, programming, budgeting, and execution and acquisition decision support systems and the challenges of starting and sustaining a USV program of record. These challenges include deciding which organizations will be responsible for shaping a USV's operational and programmatic requirements, which organization will sponsor the program's resources, and how the development or acquisition program will be organized.

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- Meggitt Training Systems Canada
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- The National Aeronautics and Space Administration (NASA)
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- Naval Special Warfare Command (NAVSOC)
- The Naval Mine and Anti-Submarine Warfare Command (NMAWC)
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Any errors are the sole responsibility of the authors.

Abbreviations

A2/AD	anti-access/area-denial
ACTUV	Anti-Submarine Warfare Continuous Trail Unmanned Vessel
AIS	Automatic Identification System
AMD	air and missile defense
ASW	anti-submarine warfare
C2	command and control
C^4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CARACaS	Control Architecture for Robotic Agent Command and Sensing
COLREGs	International Regulations for Preventing Collisions at Sea
CONEX	container express
CSG	carrier strike group
CZ	convergence zone
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
FAC	fast attack craft

FRTP	Fleet Response Training Plan
HM&E	hull, mechanical, and electrical
HSMST	High Speed Maneuvering Sea Target
HVU	high-value unit
IMINT	imagery intelligence
IPB	intelligence preparation of the battlespace
ISR	intelligence, surveillance, and reconnaissance
JHU/APL	Johns Hopkins University Applied Physics Laboratory
JPL	Jet Propulsion Laboratory
LCAC	Landing Craft Air Cushion
LCS	Littoral Combat Ship
LCU	Landing Craft Utility
MASINT	measurement and signature intelligence
MCM	mine countermeasures
MESF	Maritime Expeditionary Security Forces
MPA	maritime patrol aircraft
MS	maritime security
NASA	National Aeronautics and Space Administration
NSWC	Naval Surface Warfare Center
ONR	Office of Naval Research
OPAREA	operating area
OPFOR	Opposition Force
OPNAV N81	Office of the Chief of Naval Operations, Assessment Division

OTH	over-the-horizon
OTHT	over-the-horizon targeting
PC	patrol craft
PEO	Program Executive Officer
PIM	position of intended movement
PMS 406	Unmanned Maritime Systems Program Office
R&D	research and development
RHIB	rigid-hull inflatable boat
RMMV	Remote Multi-Mission Vehicle
ROE	rules of engagement
ROV	remotely operated vehicle
SAR	search and rescue
SIGINT	signals intelligence
SOF	special operations forces
SSN	nuclear submarine
SUW	surface warfare
TRL	technology readiness levels
UAV	unmanned aerial vehicle
USV	unmanned surface vehicle
UUV	unmanned undersea vehicle

CHAPTER ONE

Introduction

> "Tell me your land, your neighborhood, and your city, so that our ships, straining with their own purpose, can carry you there. For there are no steersmen among the Phaiakians, neither are there any steering oars for them, such as other ships have, but the ships themselves understand men's thoughts and purposes, and they know all the cities of men."—King Alkinoös of the Phaiakians, *The Odyssey*[1]

Although unmanned surface vehicles (USVs) have not developed as rapidly as other types of unmanned systems or received as much media attention, they are by no means new. Primitive unmanned vessels, such as fireships (vessels filled with combustibles, set on fire, and allowed to drift into enemy ships), have been used for millennia.

In modern history, the development of USVs precedes that of other unmanned systems: the first remotely controlled vehicle of any kind was the "Teleautomata" USV developed and tested by Nikola Tesla in 1898. The first operational use of a USV was in 1944, when Germany used a remotely controlled USV filled with explosives to target Allied shipping. USV development proceeded relatively slowly from the post–World War II period until the 1990s, though there was some usage by the U.S. Navy and others for testing, training, and mine countermeasures (MCM).

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1 Lattimore, Richard, trans., *The Odyssey of Homer*, New York: HarperCollins, 2007, book VIII, lines 555–560.

The past two decades have witnessed considerable developments with respect to all unmanned systems, leveraging advances in information technology, remote-control capabilities, the Global Positioning System for navigation, materials science, and other areas. In recent years, military use of unmanned systems—in the air, on the ground, on the waterline, and under the waterline—has increased dramatically, a trend that military leaders and experts expect to continue. For example, in a July 2012 article, the U.S. Chief of Naval Operations, Admiral Greenert, called for a future U.S. Navy in which ships would deliver modular payloads. He particularly emphasized unmanned systems, mentioning them ten times within the eight-page article.

While unmanned systems as a whole have received a great deal of attention in recent years, USVs—uninhabited maritime vehicles that maintain continuous, substantial contact with the surface—have received less attention and investment than unmanned systems in other domains. At the time of this writing (2013), the U.S. Navy has no USVs in operational use, though a handful of friendly nations employ USVs in their navies.[2] This anomaly has raised questions within the U.S. Navy, contributing to the motivating objective behind this research: to ascertain to what extent and in what ways USVs are suitable for contributing to the fulfillment of U.S. Navy missions and supporting functions.

Scope of This Report

This is a qualitative study that aims to link U.S. Navy needs and considerations with the capabilities that USVs can provide.

In delineating the scope of this report, it is important to emphasize that it is not intended to be an update to or replacement for *The Navy Unmanned Surface Vehicle Master Plan* (2007) or the USV portions of *The Unmanned Systems Integrated Roadmap FY2011–2036* (2011). In

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[2] The U.S. Navy has several USV programs at varying levels of technical development, such as the Remote Multi-Mission Vehicle (RMMV), the Modular Unmanned Surface Craft Littoral (MUSCL), and the Unmanned Influence Sweep System (UISS).

fact, one of our key recommendations is that a new USV master plan, roadmap, or both be pursued. Rather, this report is intended to provide insights to those seeking to understand how USVs can be employed in U.S. Navy operations, to lay a foundation for future roadmaps or master plans, and to offer a starting point for stakeholder community discussion of how best to proceed with USV development.

Research Objectives and Approach

To better understand the potential utility of current and future USV capabilities for the U.S. Navy, the Assessment Division, Office of the Chief of Naval Operations (OPNAV N81), asked the RAND Corporation to answer the following questions:

1. What is the state of the current and emerging marketplaces for USV systems and technology? For whom and how are they being employed?
2. Are there missions and functions within the U.S. Navy for which USVs are highly suitable? If so, how can USVs be employed in support of these missions?
3. To what degree are USV capabilities to support specific missions or functions available in the current and emerging marketplaces?
4. What technological, operational, programmatic, and other developments are needed to enable USVs to fulfill valuable roles in the U.S. Navy? How should such advances be brought to fruition?

The first three research questions amount to an analysis of USV supply and demand. We examined the supply side of the USV market by identifying manufacturers worldwide; the types of naval and civilian missions they are focused on; and the characteristics of current platforms and emerging technologies, including their level of technological advancement, length, speed, endurance, autonomy, payload mass, and power output. Next, we examined the demand side of the market, reviewing diverse naval missions and functions to identify how manned vessels currently conduct them. To determine how USVs might be employed in these missions, we developed USV concepts of employment and evaluated their impact on mission effectiveness, operational risks, costs, and capital asset requirements, among other considerations. To address the fourth research question, we analyzed prospective issues and impediments related to the development and integration of USVs into the U.S. Navy.

This research involved detailed analysis of key documents, as well as extensive consultation with subject-matter experts from diverse organizations. While a complete list of our documentary sources appears in the bibliography, a few of the important documents we consulted were

- Amit Motwani, *A Survey of Uninhabited Surface Vehicles*, Marine and Industrial Dynamic Analysis, School of Marine Science and Engineering, Plymouth University, April 22, 2012.
- Ronald O'Rourke, *Unmanned Vehicles for U.S. Naval Forces: Background and Issues for Congress*, Congressional Research Service Report to Congress, May 31, 2006.
- U.S. Department of the Navy, U.S. Marine Corps, and the U.S. Coast Guard, "The Universal Naval Task List, Version 3.0," January 30, 2007.
- U.S. Department of the Navy, *The Navy Unmanned Surface Vehicle (USV) Master Plan*, July 23, 2007.
- U.S. Department of the Navy, Naval Sea Systems Command (NAVSEA), PMS 406, Unmanned Maritime Systems, "USV Community of Interest Reference Booklet," April 13, 2011.
- James A. Winnefeld, Jr., and Frank Kendall, *The Unmanned Systems Integrated Roadmap, FY2011–2036*, reference number 11-S-3613, 2011.

We engaged with subject-matter experts from the following organizations:

- Commander, Naval Surface Forces (COMNAVSURFOR)
- Commander, Third Fleet (COMTHIRDFLT)

- The Defense Advanced Research Projects Agency (DARPA)
- General Dynamics
- LiquidRobotics
- Lockheed Martin
- Maersk
- Meggitt Training Systems Canada
- Naval Surface Forces San Diego
- The National Aeronautics and Space Administration (NASA)
- Naval Sea Systems Command (NAVSEA), including NAVSEA/Carderock
- Naval Special Warfare Command (NAVSOC)
- The Naval Mine and Anti-Submarine Warfare Command (NMAWC)
- The National Oceanographic and Atmospheric Agency (NOAA)
- The Naval Postgraduate School (NPS)
- The Naval Research Laboratory (NRL)
- Naval Special Warfare (NSW) Group 4 N3
- The Naval Surface Warfare Center (NSWC), including NSWC Panama City, NSWC Carderock, and the NSWC Combatant Craft Division
- The Office of Naval Intelligence
- The Office of Naval Research (ONR)
- The Office of the Chief of Naval Operations (OPNAV): N2/N6, N81, N95, N96, N97, and N9i
- Orca Maritime
- Program Executive Officer (PEO) Littoral Combat Ship (LCS) ONR Code 01
- PEO LCS Unmanned Maritime Systems Program Office, PMS 406
- PEO LCS Unmanned Surface Vehicle Systems
- PEO Ships Unmanned Maritime Systems Program Office, PMS 406
- SAIC
- SeaRobotics
- SeeByte
- SIS, Inc.

- Special Warfare Command (SPECWAR)
- The U.S. Coast Guard Research and Development Center (USCG RDC)
- Zyvex.

We leveraged insights from these sources, as well as in-house RAND expertise, to analytically address the questions listed above.

Organization of This Report

Chapter Two discusses the current and emerging marketplaces for USVs. In Chapter Three, we describe how we developed concepts of employment for USVs for naval missions and functions, as well as the criteria we applied to evaluate the suitability of USVs for those missions and functions. In Chapter Four, we present and discuss the results of this evaluation, as well as several mission-transcendent USV capabilities that emerged during the course of our research. Chapter Five examines several means of enabling USVs to fulfill their potential, focusing on advanced autonomy, modularity, optional manning, and endurance. Chapter Six explores the programmatic challenges of introducing USVs into the U.S. Navy. Finally, Chapter Seven presents our conclusions and recommendations.

CHAPTER TWO

The USV Marketplace Is Vigorous but Narrow

To better understand available and emerging USV capabilities, we conducted a brief review of the USV marketplace, fulfilling the first objective of our research: characterizing the state of the current and emerging USV marketplaces. The intent was not to catalog all USVs but to broadly characterize key aspects of the market, such as the purposes for which USVs have been developed; the operational capabilities of those USVs; the countries where they are manufactured; and the distribution of attributes that enable or limit their performance, such as payload capacity, range, or size. We evaluated these data sets to better understand the availability of platforms and capabilities that could fulfill U.S. Navy needs.

In our analysis, we differentiated between those USVs that are commercially available or nearly so, which we viewed as comprising the current market, and those USVs in less-advanced stages of development, which we termed the emerging market. We assigned individual USVs to one of these markets based on their technology readiness levels (TRLs), using the following TRL scale presented in the *USV Master Plan*:[1]

- TRL 9: actual system "flight proven" through successful application operations
- TRL 8: actual system completed and "flight qualified" through test and demonstration

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[1] U.S. Department of the Navy, *The Navy Unmanned Surface Vehicle (USV) Master Plan*, July 23, 2007. The TRL system was originally developed by NASA.

- TRL 7: system prototype demonstration in an actual operational environment
- TRL 6: prototype or system/subsystem validation model demonstration in a relevant environment
- TRL 5: component and/or breadboard demonstration in a relevant environment
- TRL 4: component and/or breadboard demonstration in a laboratory environment
- TRL 3: analytical and experimental proof-of-concept of critical function or characteristic
- TRL 2: technology concept and/or application formulated
- TRL 1: basic principles observed and reported.

We deemed systems at TRL 8, TRL 9, or in actual use to be part of the current market, while we deemed systems at TRL 7 or below to be part of the emerging market. Below, we discuss each of these markets in turn.

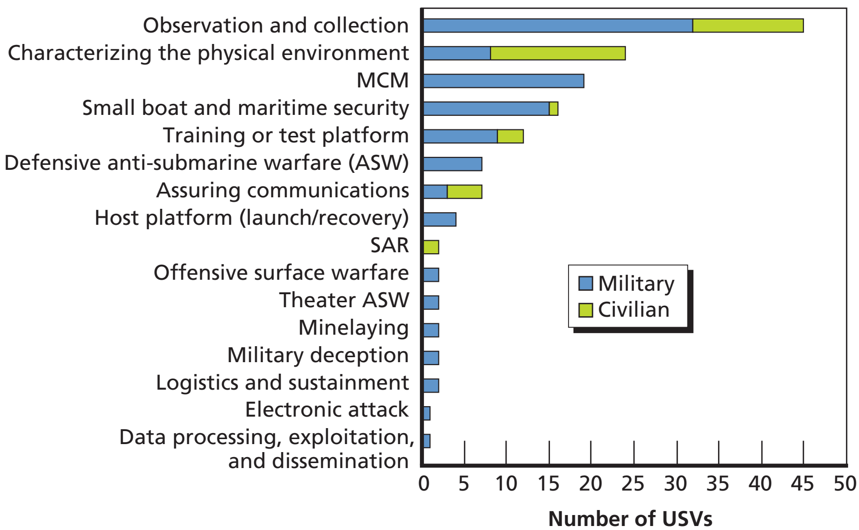
The Current USV Market

We identified 63 USVs in the current market. We obtained publicly available data on size, speed, endurance, level of autonomy, payload mass, and power provided to payloads. Where exact values were not available, we estimated based on vehicle and concept descriptions, comparisons with similar vehicles, and rough-order-of-magnitude technology-based assessments.

The Current USV Marketplace Focuses on Relatively Few Categories of Applications

While current USVs perform a range of missions and functions, the majority of activity in the USV marketplace tends to coalesce around a relatively small set of mission categories. Collectively, the 63 USVs in the current market perform 16 distinct types of missions, listed on the vertical axis of Figure 2.1.[2] As most of these USVs are designed to perform more than one type of application and many are modular (allowing a range of missions through tailored payloads), the set of 63 USVs collectively demonstrates 148 individual missions. Nearly 80 percent of the applications fall into just five categories.[3] The "observation and collection" application category is the most common; this partly reflects the fact that most USVs need to have some ability to observe their environment, enabling a remote operator or algorithm to respond to that environment. The large number of USV applications under the "characterizing the physical environment" category is accounted for by

Figure 2.1
Distribution of USV Applications in the Current Marketplace



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2 We used a mission taxonomy developed by OPNAV N81 and added a few supporting functions, such as search and rescue (SAR).

3 It should be noted, however, that a higher level of market activity does not necessarily reflect a high level of market maturity. SAR, for example, receives only four percent of the current share of applications, but several mature and functioning systems are available. While maritime security (MS) reflects only 8 percent of the market's activity, several mature platforms are being employed by multiple navies.

the large number of civilian-sector USVs that perform environmental survey work, while the number of USV applications under the MCM category reflects both a large number of legacy European drones conducting influence sweeping, as well as a few modern systems.

The high concentration of USVs focused on MS and intelligence, surveillance, and reconnaissance (ISR), MCM, and environmental survey leaves several gaps in the current market that may be worthy of U.S. Navy attention. For example, there have been relatively few market developments in such areas as electronic warfare, military deception, ISR in hostile environments, sensor deployment in hostile environments, relay of communications, minelaying, surface warfare, and ground strike capabilities. Our research and interviews suggest that firms are responsive to demand signals from potential clients, with the U.S. Navy having particular market power as the largest potential consumer.

Current Civilian USVs Tend to Have More Diverse Missions Than Current Naval USVs

The current USV market consists of an older and more developed naval sector that accounts for nearly 70 percent of currently available systems, as well as a smaller, more diverse civilian sector centered on commercial firms (chiefly oil and gas), universities, and laboratories.[4] Many of the naval USVs are relatively simple line-of-sight remote-control drones similar to those developed in the mid-20th century. Some naval and most civilian USVs are more modern platforms capable of a wider range of missions. Such platforms feature increased autonomy, over-the-horizon (OTH) capabilities, and, often, modular payloads. The civilian sector encompasses diverse applications, including environmental survey, SAR, and testing platforms. The civilian sector is a strong source of research in autonomy and networked operations, many of which may ultimately have military applications.

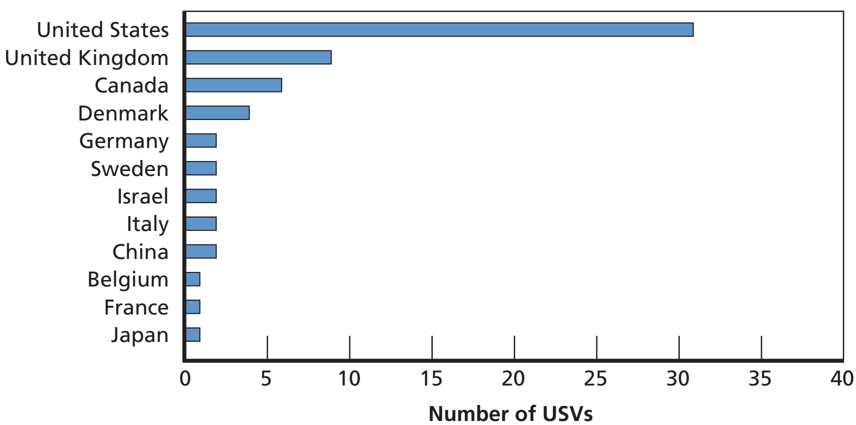
4 Some universities have received Department of Defense (DoD) funding, and some private firms making civilian USVs may hope to enter the military market, but we designated USV development that was not inherently DoD-specific as civilian.

USVs Are Primarily Manufactured in the United States and in Friendly Nations

As demonstrated in Figure 2.2, the overwhelming majority of USVs are manufactured in the United States or friendly countries. Over the past decade, non-U.S. producers have narrowed the U.S. market share. In terms of both production and employment, the majority of international naval systems fall into two categories reflecting a country's specific naval security interests. The first category includes advanced MS and ISR USVs. Firms in Israel, Sweden, Singapore, Italy, and the UK are developing USVs for these missions, and the Nigerian, Israeli, and Singaporean navies already employ USVs operationally for these missions. These USVs, which can feature lethal and non-lethal weapons, as well as advanced sensors and two-way communications, can contribute to a host of coastal applications: harbor and port security, maritime domain awareness, counterterrorism, counternarcotics, and protection of oil and gas infrastructure.

In the second category of foreign USV production and employment are the influence-minesweeping drones in longstanding use by European navies. They have been particularly prevalent in the Danish,

Figure 2.2
Numbers of USVs at TRL 8 or Above, by Countries of Manufacture



Swedish, German, and British navies, with some advancement in the past decade toward more advanced and automated sweep platforms.[5]

Current USVs Are Relatively Small

Most of the USVs at TRL 8 and above are relatively small—nearly 60 percent of them are 7 meters or less in length (see Table 2.1). This partly reflects the lower costs and greater ease of experimentation associated with smaller platforms. These small platform sizes also reflect mission requirements. Smaller vehicles are generally employed for observation and collection, as well as characterization of the physical environment. MS vehicles tend to be in the 7- to 11-meter range, while some of the larger USVs are used for missions that require large payloads, such as influence minesweeping.

Table 2.1
Length Distribution of USVs at TRL 8 and Above

Length (meters)	Similar to	Number of USVs
< 3	–	14
7	7-meter rigid-hull inflatable boat (RHIB)	24
7	Semi-submersible	6
11	11-meter RHIB	12
26	Mark V	4
26	Landing Craft Air Cushion (LCAC)	1
41	Landing Craft Utility (LCU)	2
Total		**63**

5 For example, Sweden's SAM-3 USV, in use by the Swedish, Finnish, and Japanese navies, is transportable by container, capable of semiautonomous operations, and features advanced mine-influence sweep payloads.

The Emerging USV Marketplace Primarily Consists of Small USVs with Limited Endurance, Payloads, and Power Output

In addition to our review of the current USV marketplace (comprised of USVs at TRL 8 or above), we also reviewed the emerging USV marketplace, which we defined as consisting of USVs from TRL 3 to TRL 7.[6] In addition to engaging with experts, we examined research documents, as well as IHS Jane's Defense and Security Intelligence and Analysis Database, the Defense Technical Information Center (DTIC), news sources, and manufacturers' websites.

The results of our research are summarized in Figure 2.3. As noted at the outset of this chapter, our intent was to broadly characterize the market rather than catalog all USVs. We included only those USVs about which we were able to find enough information as to characterize them. In Figure 2.3, each numbered circle represents an individual USV; blue circles represent those USVs being developed in the United States, and gray circles represent those developed in other nations. The first column in the figure shows where each vehicle or concept falls along a continuum that starts with TRL 7 at the top of the column and ends with TRL 2 at the bottom; the subsequent columns represent continuums for length, speed, endurance, autonomy, payload mass, and payload power output, respectively. For example, we can follow vehicle Y—the X-3 Trimaran—through the figure from left to right. The X-3 Trimaran has a TRL of 4, is 15 meters long, can achieve speeds of 25 knots, can endure in the environment for 100 days, and is expected to have high autonomy. Its payload capacity and payload power output are relatively small.

Several patterns are apparent from Figure 2.3. Beginning in the first column, the concentration of USVs toward the top of the TRL scale reflects the fact that relatively few low-TRL USVs are well publicized. Most of the USVs in the emerging marketplace, like those in the current marketplace, tend to be relatively small. In our discussions

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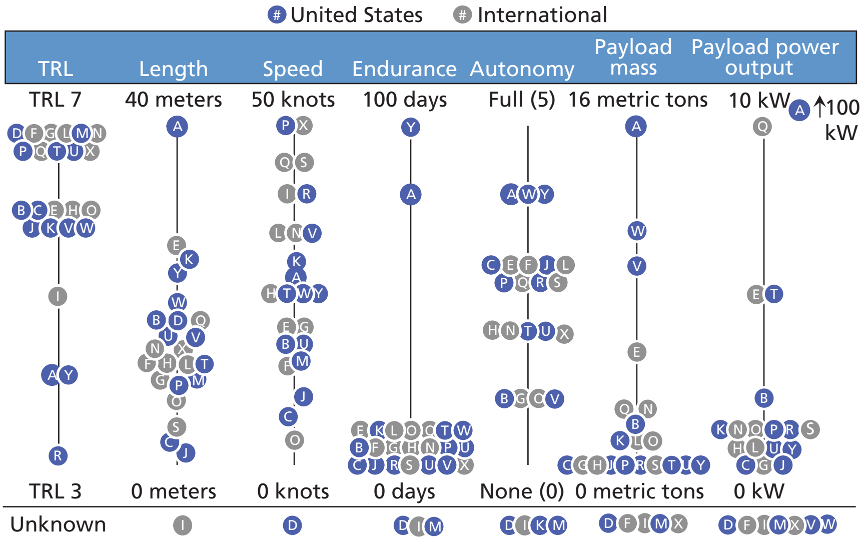
6 As noted above, we used the TRL scale from the 2007 *USV Master Plan*. The TRL for each system was estimated according to this scale based on the latest available information regarding system demonstrations, testing, and operational use.

Figure 2.3
Graphical Representation of Emerging USV Specifications



Letter	Vehicle name	Manufacturer name	Country of manufacture
A	ACTUV	DARPA	United States
B	ASW-USV	Willard Marine	United States
C	AutoCat	MIT AUV Labs	United States
D	Common USV	AAI Textron	United States
E	Espadon/Swordfish	DCNS	France
F	FAST	Atlas Elektronik UK	United Kingdom
G	Inspector Mk1	ECA	France
H	Inspector Mk2	ECA	France
I	Mako	Meggitt Training Systems	Canada
J	MUSCL	NSWC	United States
K	Piranha	Zyvex	United States
L	Rheinmetall USV	Rheinmetall	Germany
M	RMMV	Lockheed Martin	United States
N	Rodeur	Sirenha	France
O	SARPAL	International Submarine Engineering	Canada
P	Sentinel	AAC/Brunswick	United States
Q	Silver Marlin	Elbit	Israel
R	SPICE	NAVSEA	United States
S	Stingray	Elbit	Israel
T	UISS	Oregon Iron Works	United States
U	U-Ranger	Calzoni/L3	United States
V	USSV-HS	Maritime Applied Physics Corporation	United States
W	USSV-HTF	Maritime Applied Physics Corporation	United States
X	Venus	ST Electronics	Singapore
Y	X-3 Trimaran	Harbor Wing	United States

NOTE: To indicate the level of autonomy at which a USV can perform, we used the following scale:

- Level 0: No autonomy (fully remote-controlled)
- Level 1: Rudimentary semiautonomy (waypoint navigation without collision avoidance)
- Level 2: Semiautonomous (waypoint navigation including collision avoidance)
- Level 3: Advanced semiautonomy (generates best course to target)
- Level 4: Autonomous under most conditions (application-driven)
- Level 5: Fully autonomous under all conditions (application-driven)

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with experts, we found that this reflected the lower costs and greater ease of experimentation associated with small platforms rather than inherent limitations related to USVs; some experts indicated that these vehicles were being viewed as prototypes that could readily be scaled up. The small sizes of these current vehicles constrain payload capacity, endurance (due to limited space for fuel tanks), and power (since generator space is limited).

The vehicles that deviate most from the patterns mentioned above tend to have low TRLs. This suggests that, compared with higher-TRL USVs, they may take longer to become available and their specifications are more uncertain.

The Nature of the Current and Emerging USV Marketplaces Influences U.S. Navy Acquisition Options

To reiterate, both the current and the emerging USV marketplaces consist predominantly of small platforms developed in the United States and friendly nations. Most of their applications relate to ISR, MCM, countering small boats, training, or testing. The U.S. Navy could procure such USVs relatively easily, although it would likely need to work with developers to shape the specifications of USVs to precisely meet its needs. However, for the U.S. Navy to procure either larger USVs or USVs that support other missions, longer-term research and development (R&D) would be required.

CHAPTER THREE

Developing and Evaluating USV Concepts of Employment

In Chapter Two, we examined the prospective supply of USVs for consideration by the U.S. Navy. In this chapter, we begin to consider the demand signal—the ways in which the U.S. Navy could employ USVs in support of its missions and supporting functions. To that end, we analyzed 62 different naval missions and functions to understand how they are currently being performed or have been performed in the past. We then developed concepts of employment to ascertain how USVs could contribute to these missions and functions. Subsequently, we evaluated the suitability of using these USV concepts of employment to fulfill these missions and functions. The remainder of this chapter discusses the missions and functions we considered, how we developed the associated concepts of employment, and the evaluation criteria we applied. Chapter Four presents the results of our analysis.

Categories of Naval Missions

OPNAV N81 groups U.S. Navy missions into three broad categories: (1) command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) missions; (2) offensive missions; and (3) defensive missions. Below, we briefly describe these mission categories and, in broad terms, potential ways in which USVs could contribute to them.

C^4ISR Missions

C^4ISR missions encompass a wide spectrum of missions related to decisionmaking, as well as the gathering, transmission, and relay of data. Many of these missions must be performed covertly, particularly those related to intelligence collection. The Navy's C^4ISR missions include assuring communications; characterizing the physical environment; conducting operational command; counter electronic attack; cyberattack; cyberspace security; developing and maintaining the operational picture; electronic attack; observing and collecting data; and processing, exploiting, and disseminating data. Typically, USVs would be employed as part of an overall network in support of these missions.

Offensive Missions

Offensive missions involve the use of controlled force or support for the use of controlled force. These missions can include conventional strike, forcible entry, long-range strike, mining, and wide-area ASW. Under current doctrine, a person is required to be in the decision loop for each of these missions, which necessitates some degree of assured communications. USVs could be a component in a system devoted to one of these missions (e.g., by serving as a platform hosting the sensors for a conventional strike weapons system). A few of the offensive missions for which we developed concepts of employment are not currently part of the U.S. Navy's repertoire. These include using a USV as a "surface torpedo" that rams a target and explosively detonates[1] or as a blockship that detonates and sinks in a narrow waterway, preventing other vessels from transiting it.[2]

Defensive Missions

Defensive missions serve to protect the fleet or other key assets from opposing forces. They include air defense, anti-ship cruise missile defense, ballistic missile defense, defensive ASW, mine countermea-

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[1] This would be an explosive, remotely controlled version of a fireship. It would also be similar to the manned explosive boat attack on the USS *Cole* in 2000.

[2] British forces conducted a blockship attack in occupied Belgium during World War I and another in occupied France during World War II.

sures, military deception, surface warfare, and small boat defense. In some cases, we examined whether a mission, such as small boat defense, could be performed almost entirely by a USV. In other cases, such as anti-ship cruise missile defense, we explored whether a USV could serve as part of a network, hosting sensors or an interceptor system.

Non-Mission Functions

We also considered non-mission functions to which USVs could contribute, such as SAR, logistics and sustainment, testing, training, and screening. For example, we explored whether USVs could serve as "steerable life rafts" for swimmers in distress (as they are already being used in civilian contexts) or could resupply personnel during a contested landing.

To reiterate, we analyzed 62 different naval missions and functions, spanning all of the above categories. These missions and functions, which we regrouped into ten categories, are presented in Table 3.1.

Concepts of Employment

For each of the missions and functions listed above, we developed concepts of USV employment. We drew on subject-matter expertise to devise ways in which USVs could complement or supplant existing platforms or even perform missions or functions in wholly novel ways. Once we had developed one or more concepts of employment for a particular mission or function, we had panels of subject-matter experts analyze and refine them, modifying and extrapolating from the original concepts.

We discuss many of these concepts of employment at length in Appendixes A, B, and C. These appendixes describe specific missions and functions, the corresponding USV concepts of employment, the environments in which each mission is conducted, the advantages and disadvantages of employing USVs for the mission, autonomy and communications requirements, the desirable classes of USVs for the mission, and the development of USV capabilities for the mission.

Table 3.1
Potential Naval Missions and Functions for USV Employment

C^4ISR	Military Deception / Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	ASW	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
Persistent ISR in permissive environments	Disposition/ intentions deception	Armed escort	MCM intelligence preparation of the battlespace (IPB)	Unarmed ASW area sanitization	Unmanned vehicle support	Short/ medium-range ground attack	Sensing and warning—unit level	SAR of conscious victims	Blockship operations/ port detonations
Environmental collection in permissive environments	Communic-ations/ signals deception	Counter FAC (fully autonomous)	Reacquisition minehunting and neutralization	Act as an ASW sensor node	Autonomous ship-to-shore connector	Long-range ground attack (arsenal ship, optionally manned)	Sensing and warning—force level	Complex SAR	Deliberately allowing capture
ISR in hostile environments	Radar/ signals deception	Counter FAC (remote control)	Autonomous in-stride minehunting and neutralization	Cued overt ASW tracking	Opposed amphibious landing resupply		Non-kinetic unit defense	Test platform	Impairing adversary sensors

Table 3.1—Continued

C^{4}ISR	Military Deception / Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	ASW	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
USV with tethered unmanned undersea vehicle (UUV) to deploy sensors or networks	Acoustic/ signals deception	Presence patrol	Mechanical mine-sweeping and mine harvesting	Armed wartime ASW area sanitization	Covert/ clandestine special operations forces (SOF) cargo delivery		AMD kinetic force defense (using projectiles or directed energy)	Training support	Provocative, high-risk presence
Environmental collection in hostile environments	Decoy/ counter-measures	Open-water ship-vs.-ship conflict	Influence mine-sweeping	Uncued covert ASW tracking	Unmanned vehicle refueling				Vehicle as surface weapon
Processing, exploitation, and dissemination	Military information support operations	Countering swarms	Minefield proofing	Cued covert ASW tracking	Resupply for manned ships				
Communic-ations relay	Tactical jamming		Minelaying	Cued/ uncued ASW engagement	Military interdiction operations support				

Table 3.1—Continued

C^4ISR	Military Deception / Information Operations/ Electronic Warfare	Surface Warfare	Mine Warfare	ASW	Logistics	Ground Attack	Air and Missile Defense (AMD)	Functions	Missions Not Currently Being Performed
Deploy individual sensors	Disguised mission								
Deploy independent sensor network	Info systems (cyber/tech)								
	Computer network attack								
	Diversion								

Evaluation Criteria

We assessed the suitability of the USV concepts of employment for these missions using the following criteria:

- the potential ability of the USV concept of employment to redress gaps
- the potential impact of the USV concept of employment on mission effectiveness
- the potential impact of the USV concept of employment on operational and tactical risks
- the potential impact of the USV concept of employment on operational time lines
- the potential impact of the USV concept of employment on capital asset requirements
- the projected costs associated with developing and employing USVs for this purpose
- the degree to which the USV concept of employment would impose costs on the enemy to counter it
- the appropriateness of a USV for the mission relative to unmanned aerial vehicles (UAVs), UUVs, or manned vessels
- the types of interactions USVs would have with the operating environment
- the transportation, hosting, and support requirements associated with the USV concept of employment
- the types of institutional issues associated with the USV concept of employment.

These evaluation criteria are presented (with some abridgement) in Table 3.2.

The overall suitability characterization is necessarily qualitative and involves some subjectivity. However, we aimed to minimize the degree of subjectivity involved by using a thorough and traceable methodology. Specifically, we developed a spreadsheet in which we characterized the following regarding USV usage for each of the 62 missions:

- prospective benefits or disadvantages of employing USVs relative to current approaches
  - mission effectiveness
  - mission time lines
  - risk to people and/or capital assets
  - requirement for capital assets
  - degree to which USVs could counter emerging adversary capabilities
  - potential to cause an adversary to expend resources to counter USVs
  - reliability considerations
  - redundancy considerations

Table 3.2
Criteria for Evaluating the Suitability of USV Concepts of Employment for Particular Missions or Functions

Degree of Suitability	Criteria
Highly suitable	• Significantly increases effectiveness or addresses capability gaps • Reduces risks, costs, need for capital assets, and/or time lines • More appropriate than alternative unmanned or manned platforms • Acceptable transportation, hosting, and support requirements • Programmatic compatibility
Possibly suitable	• Moderately increases effectiveness • Little/no reduction in risks, costs, need for capital assets, and/or time lines • Alternative unmanned or manned platforms potentially more appropriate • Challenges relating to transportation, hosting, and support • Limited programmatic compatibility
Less suitable	• Very limited benefits (or net negative impact) in terms of effectiveness • Increased risks, costs, requirements for capital assets, and/or time lines • Less appropriate than alternative unmanned or manned platforms • Serious impediments relating to transportation, hosting, and support • Programmatic incompatibility

  - ability to achieve the desired degree of stealth or overtness
  - secondary missions and ancillary benefits
- any specific USV attributes that are relevant to the mission
- the degree to which the mission is conducted in particular environments
  - open waters
  - confined waters
  - hostile waters
  - friendly waters
  - high-traffic conditions
  - low-traffic conditions
  - high sea states
  - low sea states
- technological development of USVs for the mission
  - TRL
  - qualitative characterization of technology needs
  - technological development risks
  - ability to leverage technological developments also required for USVs to fulfill other missions
  - ability to leverage technological developments also required for other emerging platforms (notably unmanned systems) to fulfill other missions
- programmatic issues associated with using USVs for the mission
  - tactical integration
  - organizational acceptance
  - training requirements
  - qualitative cost considerations
- autonomy, communications, and preprocessing requirements
  - navigational autonomy requirements
  - assured communications requirements
    - specifically for employment of weapons
  - preprocessing requirements
  - networking with other unmanned vehicles
  - ability to trade off between autonomy and assured communications

- relative desirability of other platforms for the mission and relevant attributes for consideration
  - UAVs
  - UUVs
  - manned platforms
- prospective impact of having an optional manning capability while conducting the mission
- prospective utility of replenishment at sea for the mission
- prospective impact of payload modularity on mission capabilities
- prospective utility of an energy scavenging capability
- classes of USVs that might be desirable for the mission.

We then used material in this spreadsheet as a basis for qualitatively characterizing both the suitability of USVs for the mission (highly suitable, possibly suitable, or less suitable), as well as the degree of technological maturity associated with USV development for the mission.

USV Comparisons with Competing Platforms

One criterion—the appropriateness of USVs relative to other platforms—deserves special attention. USVs are always in competition for missions with manned and other unmanned platforms. To help determine the degree to which USVs are more or less appropriate than other platforms for any given mission, it is important to compare the performance attributes of USVs with those of other platforms. To that end, we compared USVs with UAVs and UUVs across eight key performance attributes, as shown in Figure 3.1.

As Figure 3.1 indicates, USVs have greater payload capacity and endurance than other unmanned systems. They are able to use higher-density energy sources than UUVs (hydrocarbons instead of batteries or fuel cells), and unlike UAVs, they do not need to burn fuel merely to maintain their vertical position; if desired, they can move relatively slowly for days or weeks without refueling. A comparison of the relative sizes of some aircraft and vessels, together with their payloads, is illustrated in Table 3.3.

Figure 3.1
USV Attributes Compared with Other Similarly Sized Unmanned Vehicles

● Clear advantage for USV ◐ Near parity ○ Clear disadvantage for USV

	USV Comparison with UAV		USV Comparison with UUV	
Attribute	Relative Advantage	Comment	Relative Advantage	Comment
Endurance	●	Advantage most pronounced when USVs can operate at low speed	●	Hydrocarbon fuels with unlimited oxidizers versus batteries and/or fuel cells
Power				
Propulsion	◐		●	UUVs are more volume-limited for propulsion systems; heat dissipation can be an issue
Mission packages	◐		◐	USVs have more power; UUV packages have lower power requirements
Speed	○		●	UUVs are speed-limited to a few knots
Range	○		●	
Payload capacity	●	UAV space, weight, and power for payloads are limited	●	Low energy density reduces UUV internal volume for payloads
Sensors				
Above the surface	○		●	
Subsurface	●		○	UUVs have more types of sensors and can position them better
Communications	◐	UAVs have better vantage points, but USVs have cross-domain capabilities	●	
Stealth	◐	Both USVs and UAVs have potential to be stealthy	○	
Autonomy requirements	○	UAVs have fewer traffic-avoidance problems and no seakeeping issues	◐	UUVs have limited seakeeping issues and fewer traffic-avoidance problems, although they need to avoid undersea hazards; USV autonomy demands are mitigated by better reachback capability

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Table 3.3
Comparison of Vessel and Aircraft Sizes and Payload Capacities

Platform	Domain	Dimensions (m)	Payload Capacity (kg)	Payload Divided by Length x (Beam or Wingspan) (kg/m^2)
7-meter RHIB	Surface	7 (length) 3 (beam)	700	100
Predator UAV	Air	8 (length) 11 (wingspan)	500	63
11-meter RHIB	Surface	11 (length) 3 (beam)	1,500	136
X-47B	Air	12 (length) 19 (wingspan)	14,000	61
Hercules C-130J-30	Air	35 (length) 40 (wingspan)	20,000	14
LCAC	Surface	26 (length) 14 (beam)	68,000	187
LCU	Surface	41 (length) 9 (beam)	113,000	306
C-17	Air	53 (length) 52 (wingspan)	137,000	50

NOTE: Aircraft are shown in brown, while vessels are shown in black.

While UAVs can operate above-the-surface sensors and UUVs can operate undersea sensors, USVs can do both. However, UAVs and UUVs can better adjust their proximity and altitude or depth with respect to particular objects. UAVs have a clear advantage over USVs in terms of speed, reflecting the fact that UAVs are not subject to hydrodynamic drag. Their higher speeds may give UAVs an advantage over USVs in terms of maximum range, although this depends on how much space on a USV can be set aside for fuel storage. Stealth is one of the greatest strengths of UUVs; the inability of electromagnetic waves to penetrate the sea makes them largely invisible in this domain. Also, the low speeds at which UUVs operate inherently reduce their radiated noise, making them difficult to detect acoustically. The degree to which USVs can achieve stealth depends heavily on their design and the environmental context of the mission. The stealthiest USVs are typically semi-submersible, meaning that only a small portion of their hulls breaches the surface. The emerging RMMV is an example of such a semi-submersible USV.

UAVs can take advantage of their altitude to communicate with few obstructions, whereas USV communications can be impeded by surface clutter, waves, humidity, and other phenomena. However, the greater mission-package power output of USVs can enable them to emit more powerful signals than a comparably sized UAV.

USV autonomy requirements include a couple of elements that are absent from UAV requirements: seakeeping and maritime traffic avoidance. While autonomous UAVs need to be able to avoid collisions or crashes and handle weather conditions, doing so is less complex than operating on the air-water interface or dealing with the greater density of traffic in two dimensions. Although UUVs have a lower risk of collisions with surface ships than do USVs and are largely indifferent to sea states, they do need to deal with undersea hazards such as entangling kelp or fishing nets. Moreover, given that UUVs typically have very limited communication capabilities, they need to be capable of autonomy in situations in which a USV could often rely on communication systems.

USVs compete for missions and resources (such as physical space) not only with unmanned platforms in other domains but also with manned surface vessels and sometimes manned helicopters. Again, a review of some typical attributes of manned and unmanned surface vessels helps to clarify the relative advantages of each. Because they can operate in environments that would be unacceptable for manned platforms due to the threat to onboard personnel, USVs can be put at greater risk than comparably sized manned vessels or helicopters. USVs not intended to be optionally manned could be designed with fewer safety features and more space for payloads. However, USVs also have some disadvantages in comparison to manned platforms. For example, USVs can be more dependent than manned vessels on communications, and, as autonomous systems, they can err in ways that their designers may not have anticipated. Until assured communications and advanced autonomy have been thoroughly tested and found to be highly robust, USV usage may be circumscribed for safety and security reasons.

Broadly speaking, missions in which payload weight, endurance, and multi-domain capabilities are important—and risk, cost, or other considerations make unmanned platforms preferable to manned ones—are likely to be more appropriate for USV employment. Likewise, missions in which speed is critical are likely to be more appropriate for UAVs, and UUVs will be favored for those missions in which stealth is paramount.

The above comparison between USVs and other platforms can help to shape decisions about whether USVs are the most appropriate vehicle for a particular mission. Among other criteria, we considered how these attributes related to specific mission requirements. In Chapter Four, we will provide the results of our analysis of USV employment for diverse missions and functions using this larger set of criteria.

Technological Maturity of USV Capabilities for Specific Concepts of Employment

We also characterized the degree of technological maturity of the USV capabilities required to fulfill the concepts of employment for specific missions and functions. This leveraged our earlier review of the current and emerging USV marketplaces. We characterized USV technological maturity for each mission or function as belonging to one of three categories:

- in or near market (TRL 8 or above)—the required technologies are available in the current USV marketplace
- emerging (TRL 4–7)—the required technologies are available in the emerging USV marketplace
- incipient (TRL 3 or below)—the required technologies are not yet available in the emerging USV marketplace.

CHAPTER FOUR

USVs Are Highly Suitable for Diverse Naval Missions

This chapter presents the results of our evaluation, determining the degree to which USVs are suitable for naval missions and functions. It also identifies the degree to which the U.S. Navy can leverage the current and emerging USV marketplaces by presenting the level of maturity of USV technologies for each mission and function we considered. In addition to presenting overarching findings relative to our evaluation criteria, this chapter also discusses additional benefits of USV development and employment that emerged during our analysis.

Nearly Half of the Missions and Functions Evaluated Are Highly Suitable for USV Employment

Of the 62 missions and functions we evaluated, 27 are highly suitable for USV employment. Table 4.1 divides the full list of missions and functions into three levels of suitability for USV employment (highly suitable, possibly suitable, and less suitable) and three levels of USV technological development (in or near market, emerging, and incipient).

As the left-hand cell of the top row shows, USV applications that are already in or near the combined civilian/military market are almost all highly suitable for U.S. Navy missions and functions. For example, USVs for the SAR of conscious victims have already been employed on beaches, particularly for the rescue aspect of this mission, in which the USV is directed to the victim, who grabs it and rides it to safety. Using a USV rather than a manned asset for this mission can

Table 4.1
Naval Missions and Functions by Level of Suitability for USV Employment and Level of USV Technological Maturity

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Highly suitable	C^4ISR: • Persistent ISR in permissive environments • Environmental collection in permissive environments Mine warfare: • Influence minesweeping • Mechanical mine-sweeping and mine harvesting Functions: • Test platform • Training support • SAR of conscious victims	Mine warfare: • MCM IPB • Reacquisition minehunting and neutralization Surface warfare: • Armed escort Military deception/information operations/ electronic warfare: • Disposition/intentions deception • Comms/signals deception • Radar/signals deception • Acoustic/signals deception • Decoy/countermeasures • Military information support operations ASW: • Unarmed ASW area sanitization Functions: • Unmanned vehicle support • Processing, exploitation, and dissemination	C^4ISR: • ISR in hostile environments • Environmental collection in hostile environments Mine warfare: • Autonomous in-stride minehunting and neutralization • Minelaying Surface warfare • Counter-FAC (fully autonomous) Functions: • Autonomous ship-to-shore connector • Complex SAR Missions not currently performed: • Impairing adversary sensors
Possibly suitable	Surface warfare: • Counter-FAC (remote control)	C^4ISR: • Communications relay among manned assets • Deploy individual sensors • Deploy independent sensor network Surface warfare: • Presence patrol	Ground attack: • Short/medium-range ground attack • Long-range ground attack (arsenal ship, optionally manned) AMD: • AMD kinetic force defense

Table 4.1—Continued

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Possibly suitable (cont.)		Missions not currently performed: • Provocative, high-risk presence • Vehicle as surface weapon AMD: • Sensing and warning (unit level) • Sensing and warning (force level) • Non-kinetic unit defense Military deception/information operations/ electronic warfare: • Tactical jamming • Disguised mission • Info systems (cyber/tech) • Computer network attack • Diversion Functions: • Opposed amphibious landing resupply	Functions: • Covert/clandestine SOF cargo delivery Missions not currently performed: • Blockship operations • Deliberately allowing capture
Less suitable		ASW: • Act as an ASW sensor node • Cued overt ASW tracking Functions: • Maritime interdiction operations support	ASW: • Armed wartime ASW area sanitization • Uncued ASW tracking • Cued covert ASW tracking • Cued/uncued ASW engagement Surface warfare: • Surface warfare (open water, ship vs. ship) Functions: • Resupply for manned ships

reduce risk to additional personnel. USVs are already capable of persistent ISR and environmental collection in permissive environments and have long been used for both testing and training; for all of these applications, USVs can reduce costs and the requirement for capital assets. Other nations' navies already employ USVs for influence minesweeping. Mechanical minesweeping and "mine harvesting" (collecting detached, floating mines in a net) require only the use of simple towing capabilities. Employing USVs for these mine warfare missions would reduce the risk posed to personnel and capital assets by exposure to minefields. The U.S. Navy could acquire USVs to fulfill these concepts of employment within the next several years.

The concepts of employment listed in the center and right-hand cells of the top row are also highly suitable for naval missions, but they depend on technological capabilities that are less developed. The military deception, information operations, and electronic warfare missions could be conducted at lower risk to personnel and capital assets, as well as at potentially lower cost. In addition, the relative expendability of USVs could enable these missions to be conducted in new, bolder ways, including in anti-access/area-denial (A2/AD) environments. USVs could play a role in diminishing the effectiveness of an adversary's A2/AD systems not only by deceiving adversary sensors but also by jamming or targeting them to impair overall network performance.

Using USVs to conduct mine warfare missions would reduce the risk mines pose to personnel and capital assets. Minelaying by USVs could enable this mission, now performed exclusively by aircraft, to be conducted more clandestinely in more dangerous A2/AD environments without imposing further demand and risk on high-value assets. In those same environments, and for the same reasons, it would be advantageous to conduct ISR and environmental collection using unmanned systems; USVs could be employed when their cross-domain capabilities, payload capacity, endurance, or other attributes make them preferable to other unmanned systems. Moreover, even when UAVs or UUVs are preferred, USVs could play an important supporting role by providing them with resources, cross-domain links, and services such as data processing. USVs could also provide such support in more benign environments, as well as shuttle goods between ships and shore locations without requiring the use of additional personnel.

USVs would also be highly suitable for protecting other platforms, performing missions that are often dull but occasionally dangerous. For example, they could serve as armed escorts for ships, keeping personnel out of harm's way and freeing up resources for other missions. Protecting port infrastructure and ships in port from FAC using USVs would be advantageous if the USVs in question could be fully autonomous. This would reduce the risk to personnel (and potentially reduce costs) compared with having manned vessels conduct the mission. Unarmed ASW area sanitization—a painstaking mission to detect and classify any enemy submarines—could be performed by USVs at lower risk and with less demand on capital assets than with manned platforms.

To reiterate, USVs are highly suitable for all of the missions and functions listed in the first row of Table 4.1. The U.S. Navy could consider investing in R&D to bring these capabilities to fruition. A key consideration for resource allocation in this context is the degree of technological advancement required, which is not perfectly correlated with the TRL. Some prospective missions, such as minelaying, may be relatively easy from a technical standpoint; USV capabilities have yet to be developed for this purpose due to a lack of interest, not technical challenges. However, developing fully autonomous USVs to counter FAC would require dramatic advances in autonomy for threat identification and use of force.

The U.S. Navy could also consider investing in USV technologies to support naval missions for which these technologies are possibly suitable (listed in the middle row of Table 4.1). Employing USVs for these missions and functions provides less benefits and/or entails greater liabilities than for the missions in the "highly suitable" category. However, the U.S. Navy may want to invest in USV technologies for possibly suitable missions if circumstances or priorities change—e.g., if an emerging adversary capability required the U.S. Navy to develop a USV-based countermeasure.

We found that USVs were possibly suitable for a number of missions spanning different categories. One of these missions merits special attention, given that the capabilities to fulfill it are already in the marketplace. We determined that remotely controlled (as opposed to fully autonomous) USVs were only possibly suitable for countering FAC in the context of the U.S. Navy's needs, although other nations are already employing remotely controlled USVs for this purpose. Our determination was based on the fact that personnel are still required to closely monitor and assess prospective threats just as though they were on the vessel itself, so any cost savings are likely to be very limited. However, despite having access to copious cameras and other sensors, controllers who were physically removed from the boat would inevitably have less situational awareness than if they were actually aboard. Although having personnel aboard the vessels obviously puts them at greater risk, we deemed the increase in situational awareness to be important enough to relegate this mission to the "possibly suitable" category.

Missions for which USV systems or concepts are less suitable (listed in the bottom row of Table 4.1) are not ready for U.S. Navy investment. They offer either limited benefits or a net negative impact in terms of effectiveness; increased risks, costs, requirements for capital assets, and/or time lines; may be less appropriate than alternative unmanned or manned platforms; may have serious transportation, hosting, and support impediments; and may be incompatible with related U.S. Navy programs. For example, USV concepts of employment were generally less suitable for ASW missions (in which an adversary uses diverse tactics to avoid being successfully tracked). This reflects the high degree of judgment required for ASW decisions, as well as other considerations, as described in Appendix B.[1] Another example of a mission for which

1 The need for expert judgment is driven by the fact that a human opponent is attempting to exploit a highly complex environment to break contact and prevent further tracking. Understanding a target's behavior—including its seeming disappearance—requires insight not only into complex environmental conditions but also enemy tactics, intelligence, and even human psychology. Ascertaining whether or how to respond to target submarine behaviors, as well as which combinations of sensors to employ in a given context, is highly judgment-dependent. Many sensor capabilities are degraded by the refractive nature of the ocean, a medium with multiple boundary effects involving the surface, the bottom, and distinct layers of water. Moreover, since the use of novel sensor systems or tactics can reveal something about them, decisions need to be made with regard to trade-offs between the prospective intelligence collected and the information that the enemy can thereby garner.

USVs are less suitable is surface warfare in an open-water environment. While USVs could be used in this capacity, alternative means of fighting ship-versus-ship actions or eliminating swarming attack craft are likely to be more effective and efficient.

Overall, we found that USVs could often improve the effectiveness with which a number of missions were performed. This stems in part from their potential for long endurance, which is advantageous in persistent ISR, MCM, and other missions. As expected, we found that one of the foremost ways USV concepts of employment can improve current practices is by reducing tactical and operational risks. In dangerous environments, such as minefields, the immediate vicinity of enemy assets, or chemically contaminated areas, employing unmanned platforms could avert risk to personnel. Moreover, this reduction in operational risk could allow a more aggressive posture, opening doors to innovative concepts of employment in a number of mission areas.[2] For some concepts of employment (e.g., USV minelaying, swarming attack USVs, using USVs as "surface torpedoes"), the use of USVs may force an adversary to expend considerable resources to counter them, diverting their efforts away from other activities.

In addition to dangerous missions and those in contaminated environments, USVs could also contribute to mundane, monotonous missions (reflecting the desirability of using unmanned vehicles for "dangerous, dirty, or dull" missions). Serving as an autonomous ship-to-shore connector and testing support could fall into this category, as could certain ISR missions, ASW area sanitization, and other missions.

In addition to technological barriers, our findings showed that institutional hurdles could prevent USVs from suitably performing specific missions. These could arise because the U.S. Navy does not have a natural constituency for a particular mission, such as the previously mentioned "surface torpedo" and blockship missions. There are

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Algorithms for making these decisions would appear to be a very distant prospect.

2 For example, having the option to approach potentially hostile vessels without endangering U.S. personnel or more valuable assets could enhance mission effectiveness in several respects. It could clarify, deter, or shape adversary intentions; increase decision confidence; reduce response times; and free more valuable assets for other high-priority missions.

also cultural and legal impediments to using unmanned platforms in particular situations, such as releasing weapons. Where USVs would require novel training regimes or logistical pipelines, they could conflict with existing U.S. Navy institutions.

USVs are likely to augment, not replace, other U.S. Navy manned programs, at least initially. Thus, investments in USVs are likely to be *in addition* to the rest of the U.S. Navy's program for some time. USVs cannot wholly replace any existing capabilities, in part due to the multi-mission role of most U.S. Navy programs. For example, even if a USV can perform a particular mission significantly better than, say, a coastal patrol craft (PC), that does not mean the USV can perform *all* PC missions. However, USVs may displace other required systems and capabilities on host vessels; this should incentivize a look at options for commonality and modularity, both for cost avoidance and as a way to preserve existing capabilities on host vessels. We also expect USVs to impose additional requirements on the supply chain, logistics, and maintenance infrastructures. An important consideration here will be how to bring USVs into theater and the added burden they may impose on inter- and intra-theater lift. Forward basing could mitigate this, depending on how USVs are integrated into the U.S. Navy's force structure.[3] If hosted USVs became modular adaptations of commonly available manned small craft, such as 7-meter and 11-meter RHIBs, then deploying USVs may not displace existing capabilities but only impose additional storage and training requirements.

If USVs employ familiar hull forms and sizes, then their addition to the fleet will likely just increase competition for existing physical infrastructure capacity rather than require new infrastructure.[4] If USV solutions employ "exotic" hull forms or uncommonly large sizes, however, this may impose significant additional costs.[5] FRTP may be

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[3] For example, USVs (both large and small) might be held operationally as theater assets and integrated into strike groups on arrival, with dedicated training assets in fleet concentration areas to support the Fleet Response Training Plan (FRTP) requirements.

[4] Such as existing berths, piers, maintenance facilities, etc.

[5] New handling and berthing systems and possibly even channel dredging, if larger, semi-submersible hull forms are introduced.

able to leverage or adapt existing simulator or synthetic training environments for both unit-level and integrated training, and again, more common hull forms and sizes may reduce requirements for training infrastructure and ranges.

USVs Could Enhance Cross-Domain Integration, Overcome Anti-Access and Area Denial Threats, and Facilitate Technology Transfer Across Manned and Unmanned Systems

Several additional benefits from USV employment emerged during the course of our analyses, which we will describe below.

USVs appear to uniquely enable cross-domain integration, making other unmanned vehicles or networks more capable. USVs can leverage their relatively large payloads, large reserves of power, and long endurance to provide services for other platforms, including physically transporting other unmanned systems, preprocessing data for them, or providing electric power via a tether. For example, USVs could communicate with UUVs over limited ranges via sonar or physical tethers, enabling UUVs to improve their navigational accuracy. They could also coordinate with other platforms using the USV as a relay. Through their unique ability to bridge the air-sea interface, USVs can sense and communicate to the ocean depths and into space, which could enable them to send and receive actionable information from other unmanned platforms as part of an integrated, coordinated network.

USVs could be highly effective in overcoming challenging A2/AD environments, particularly in C^4ISR, military deception, information operations, electronic warfare, and cyberwarfare missions. A2/AD strategies seek to deter, delay, or prevent effective U.S. military operations in regions of interest by imposing excessive threats to U.S. assets or interfering with systems needed for power projection. USVs can help to counter A2/AD challenges by reducing risks to personnel and capital assets; dispersing capabilities into small, hard-to-target nodes; and expanding tactical choices by creating new concepts of employment and even missions. USVs' potential for long endurance, high payloads, and available power, along with their cross-domain capabilities, make them attractive candidates for use as hubs, portals, storage, or relay components in maritime communications networks. Like UAVs, they can also collect information in environments that are too dangerous for manned platforms, but their lower radar signatures and ability to collect sub-surface information could lead to their being preferred over UAVs for specific missions. USVs can also provide deceptive targets, leading an adversary to misallocate resources and launch weapons at USVs instead of valuable manned assets. They can also jam or spoof networks, introduce false information, and conduct cyberattacks.

A2/AD environments pose considerable risks to assured communications and bandwidth, which means that concepts of USV employment for these missions in C^4ISR-denied or C^4ISR-diminished environments will need to be developed, and high degrees of autonomy will be required.

Increased investment in USV research, development, and acquisition could facilitate technology transfers in several directions. USVs will require autonomy, multifunctional sensors, communications and networks, vessel and payload control, and other technologies of similar functionality to other unmanned and manned air, surface, and subsurface platforms. For example, recent initiatives to explore common vehicle, sensor, and payload control stations between the Fire Scout UAV program and small USVs in support of Maritime Expeditionary Security Forces (MESF) could be leveraged in future USV development (for both smaller and larger vessels). We likewise expect that advances in smaller USV autonomy technologies would be immediately applicable for larger platforms because larger vessels present simpler sensing and control challenges and because of the maturity of modern, parameterized maritime autopilot technologies.

Autonomy, vessel control, and sensing technologies should also be readily applicable to manned platforms. For example, if the U.S. Navy decides it can trust autonomy and control solutions for the employment of larger USVs in blue-water and littoral operations, it could also apply them as support tools for bridge teams to increase safety and efficiency in complex maneuvering or restricted navigation situations.

Likewise, sensing and control improvements in small, autonomous USVs operating alongside manned vessels in deploy and recovery operations could translate into improvements in USV support for maritime intercept and counterproliferation operations and for USV-USV and USV-UUV mating evolutions. Sensor stabilization improvements needed for small USV autonomy and engagement could similarly be applicable to UAVs and UUVs.

CHAPTER FIVE

Capitalizing on the Potential of USVs: Key Enablers

Despite extensive growth in USV capability over the past two decades, many of the most promising technological advances remain in the realm of research and experimentation. Autonomy and assured communications are force multipliers in USV operations, but these capabilities will be limited in the near term. Our analyses suggest that USV desirability could also be enhanced by developing a common USV platform with modular payloads that would enable optional manning, as well as by investing in technologies to increase USV endurance. In this chapter, we describe these key enablers and highlight technological, operational, doctrinal, and programmatic issues associated with them.

Advances in Autonomy and Assured Communications Are Path-Critical for Complex Missions and Environments

Many missions and functions for which USVs may be highly suitable will require significant levels of autonomy. The simplest missions and functions for USVs (such as deploying objects at predesignated locations) require only autopilot-level autonomy and basic collision avoidance with little or no assured communication capability. However, highly complex missions, such as those involving weapon release, and highly complex environments, such as high sea states, require more advanced autonomy; this would entail a high level of onboard processing to interpret sensor outputs and assured communications to report the results of search and engagement. Significant levels of autonomy and high-level onboard processing are required even when no external limits are imposed on communications since communication bandwidth is a finite resource. Advancements in autonomy are seen as critical to reducing competition for limited bandwidth, as well as to operating in electronic warfare environments, decreasing USV reaction times, and potentially reducing personnel costs.

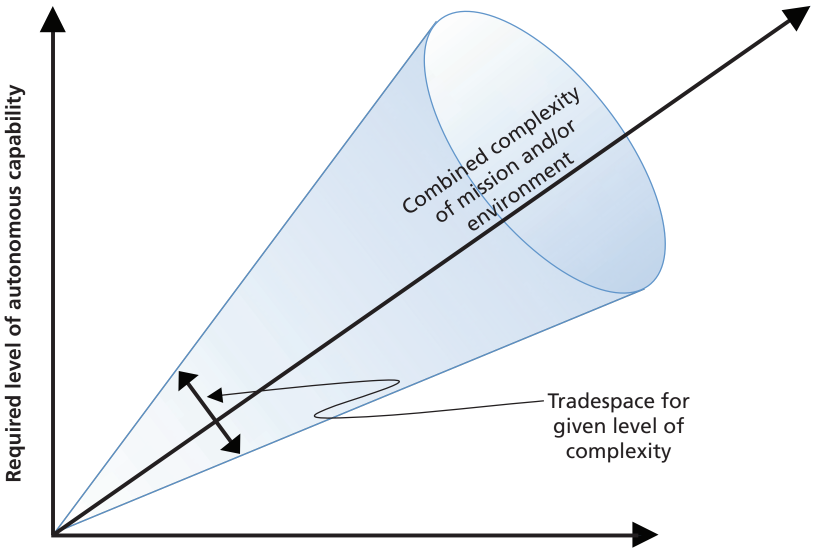
Autonomy and assured communications form a tradespace, with the need for some combination of autonomy and assured communications increasing with the complexity of missions and/or environments. In essence, USVs are subject to a "control triangle" comparable to the well-known naval architects' "iron triangle" of speed, payload, and endurance. Figure 5.1 illustrates the three elements of the control triangle in a three-dimensional graph.

While some aspects of autonomy R&D can leverage advances made for UAVs and UUVs, USV autonomy requirements for seakeeping on the surface and maritime traffic avoidance require USV-specific R&D that is unlikely to emerge solely from other programs. Advances in these capabilities will be critical to the continued development of USVs for virtually all U.S. Navy missions and functions.

A number of research entities are pursuing R&D on USV autonomy. For example, ONR is funding NASA's Jet Propulsion Laboratory (JPL) to develop the Control Architecture for Robotic Agent Command and Sensing (CARACaS), which accomplishes USV maneuvering and navigation with minimal human intervention. CARACaS' Perception Engine consists of a 360 electro-optical system with an automated target recognition system called the Contact Detection and Analysis System (CDAS), a stereo electro-optical infrared (EOIR) system, a radar and automatic identification system (AIS), and a sensor data fusion engine developed by Daniel Wagner Associates.[1] CARA-

1 Michael Wolf, Christopher Assad, Yoshiaki Kuwata, Andrew Howard, Hrand Aghazarian, David Zhu, Thomas Lu, Ashitey Trebi-Ollennu, and Terry Huntsberger, "360-Degree Visual Detection and Target Tracking on an Autonomous Surface Vehicle," *Journal of Field Robotics*, Vol. 27, No. 6, November/December 2010, pp. 819–833; and Terry Huntsberger, Hrand Aghazarian, Andrew Howard, and David C. Trotz, "Stereovision Based Navigation for Autonomous Surface Vessels," *Journal of Field Robotics*, Vol. 28, No. 1, January/February 2011, pp. 3–18.

Figure 5.1
The Control Triangle



SOURCE: RAND analysis.
NOTE: The above diagram should be viewed as three-dimensional, with the middle arrow projecting off the page.
RAND *RR384-5.1*

CaS' decisionmaking is a hybrid reactive-deliberative system composed of a behavior-based system for avoidance of static and moving hazards, which obeys a subset of the International Regulations for Preventing Collisions at Sea (COLREGs) and follows dynamic targets, and the "CASPER" deliberative planner, which plans activities based on mission goals and constraints.[2] Spatial Integrated Systems, Inc., and NSWC, Carderock Division, are also members of this team. The Naval Sea Systems Command (NAVSEA) has funded the use of CARACaS for autonomous operation of individual USVs and autonomous behaviors between two USVs in several fleet exercises.[3]

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2 Wolf et al., 2010.

3 Les Elkins, Drew Sellers, and W. Reynolds Monach, "The Autonomous Maritime Navi-

ONR has been using three complementary approaches to pursue navigational and mission autonomy for USVs. The first is to employ the existing Common Geospatial Navigational Toolkit (COGENT) by SPAWAR Charleston and the Tactical Control System (TCS) by Naval Air Systems Command for waypoint navigation and static object avoidance. The second approach, which enables a USV to respond more actively to its environment, draws upon work by JPL to leverage the autonomous systems from Mars Rover. The third, which allows for still greater responsiveness to a complex environment, involves work by Johns Hopkins University's Applied Physics Laboratory (JHU/APL), building on its earlier experience with UAVs and unmanned ground vehicles. JHU/APL's system assigns several values to each object in the environment and then employs algorithms to analyze the prospective impact of these objects on the USV's mission, enabling it to adjust accordingly.[4]

Autonomous operations represent not just significant technical challenges but also operational, resource, and policy-related challenges. A chief operational challenge is the U.S. Navy's historical preference for *decentralized* command and control (C2). A number of the suitable missions highlighted in this report will require substantial levels of autonomy and may involve USVs capable of inflicting damage on other systems. The U.S. Navy will also need to determine how USVs will fit into its unit-, force-, and theater-level C2 structures before significant investments are committed: How will operational control, tactical control, and administrative control relationships apply to USVs? How will the conditions for *unity of command* be met? How will USVs fit within the Combined Warfare Commander concept? Some concepts of employment proposed in this study involve USVs hosting or directly supporting other unmanned or manned systems (either air, surface, or subsurface), thus command and reporting relationships for the host/

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gation (AMN) Project: Field Tests, Autonomous and Cooperative Behaviors, Data Fusion, Sensors, and Vehicles," *Journal of Field Robotics*, Vol. 27, No. 6, November/December 2010, pp. 790–818.

[4] Robert A. Brizzolara, Will Sokol, Scott G. Littlefield, and Joseph A. Corrado, "Unmanned Sea Surface Vehicle Technology Development," proceedings of the ASNE Ships and Ship Systems Symposium, American Society of Naval Engineers, Alexandria, Va., 2006.

supporting and hosted/supported units or systems will likewise need to be worked out. How USVs would fit within or perturb the U.S. Navy's Composite Warfare Commander and Maritime Operations Center concepts will also need to be understood. Concerns include the nature of supporting and supported relationships with respect to USVs, as well as where within the organization USV controllers and watchstanders will work.

A widely accepted lesson learned from UAV and UUV operations is that unmanned systems are not really "unmanned"—they are, more accurately, "uninhabited."[5] In many instances, the number of personnel required to operate and support a single unmanned system exceeds that for a manned platform with a similar concept of employment. It may seem intuitive to expect that, as autonomy increases, the number of operating personnel required per unmanned system will decrease. However, there may be technical, maintenance, or cultural limitations that require a given number of USV control and support personnel, particularly to the degree that USVs are operating within a mixed naval force of manned and unmanned vessels. We foresee concepts of employment in which autonomy may actually complicate the C2 challenge and increase the number of decisionmakers relative to manned alternatives. Consider, for example, the case of an autonomous USV providing counter-FAC capabilities to an expeditionary force in the littorals. If a manned vessel were in the USV's place, the other supported vessels would be relying on the leadership, decisionmaking, and reporting of the vessel commander and watchstanders to do what trained people are expected to do in those positions. On other vessels, some of these responsibilities will inevitably be performed by human watchstanders and decisionmakers in addition to their normally expected responsibilities and workload, regardless of the sophistication of the USV's autonomy. In other words, USVs will likely change, shift, and/or impose additional human functions on personnel in supported ves-

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5 The use of the term "uninhabited" as an alternative to "unmanned" is becoming more commonplace and has gained considerable traction in Europe as a more appropriate characterization of these vehicles. The U.S. Air Force has begun referring to UAVs as remotely piloted aircraft (RPAs) for similar reasons. An additional benefit of the term "uninhabited" is that it is gender neutral.

sels or command nodes, and these new functions will need to be reconciled with existing mission responsibilities.

Advanced autonomy may also require the following changes to or reinterpretation of policies:

- The applicable rules of engagement (ROE) will need to be reviewed to determine whether an autonomous USV would be permitted to fill a particular role in an effects chain. ROE can be difficult to satisfy even when only manned systems are in an effects chain. When concepts of employment and capabilities cannot be practically reconciled with the ROE, the consequences can be damaging and/or expensive.[6]
- The fact that USVs operate on the surface means that USVs represent a trust and confidence challenge to surrounding vessels, as they have a higher probability of colliding with manned vessels than do UAVs or UUVs. The fact that a number of USV missions seem to call for large USVs exacerbates this problem due to the increased consequences of potential collisions.
- The COLREGs were written on the presumption that all vessels have a master. They also have specific rules for visual and audible signaling, call for all vessels to have visual and aural lookouts, and apply in all weather and visibility conditions. Employment of autonomous USVs and the minimum equipment they need onboard to safely operate will at least require reinterpretation of how these rules apply to unmanned systems and could also affect where USVs are allowed to operate.[7]

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[6] For example, the AIM-45 (Phoenix) air-to-air missile was rarely applied in the concept of employment for which it was designed (long-range, beyond line-of-sight engagement) mainly because of the Navy's inability to establish a practical effects chain that could satisfy extant ROE.

[7] Some nations, for example, may prohibit autonomous USVs from operating in their territorial waters.

Launch, Recovery, and Underway Refueling Capabilities Need to Be Further Advanced

USVs, except for those that self-deploy, need to be launched and recovered by larger vessels at sea. Many USVs could dramatically expand their ranges and endurance if they had the ability to be refueled at sea without recovery and relaunch. This would also save time and resources, avoid the need for a host ship to dramatically slow down (with attendant operational risks and costs), and reduce the risk of damage to the USV. Conducting launch, recovery, and refueling tasks is challenging at higher sea states, though it may be necessary, or at high speeds, which may be operationally desirable.

ONR has made progress on automated launch, recovery, and underway refueling of USVs. ONR is also pursuing systems that would allow USVs themselves to launch and recover other unmanned vehicles, as well as onboard diagnostic and self-maintenance systems.[8]

Modular Payloads and Common USV Platforms Could Enhance USV Suitability

Standard USV platforms with modular payloads would enable a single USV platform to perform multiple missions, as well as allow multiple USV platforms with different levels of capability and different hosting, transportation, and support requirements to perform the same mission. The 2007 *USV Master Plan* suggested four USV classes, all 11 meters or smaller. For the sake of considering the potential utility of larger USVs, we have proposed three classes that would be longer than 11 meters—the E, F, and G classes. All seven classes (presented in Table 5.1) are intended as concepts from which to deviate, rather than rigid templates for future systems.

A few of these conceptual classes share the same lengths but differ from one another in terms of other salient features. The Harbor USV would be an overt, visible platform, whereas the Snorkeler, though of

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8 Brizzolara et al., 2006.

Table 5.1
Proposed Classes of USVs

Class	Similar to	Length (m)
X	–	< 3
Harbor	7-meter RHIB	7
Snorkeler	Semi-submersible	7
Fleet	11-meter RHIB	11
E	Mark V	26
F	LCAC	26
G	LCU	41

equal length, would scarcely protrude above the surface. Though the Snorkeler would be stealthier (and, in rough seas, more stable), it would encounter greater drag, potentially limiting its range and endurance. The E and F classes would both be 26 meters in length but have different beam measurements: 5 meters and 14 meters, respectively. The E class could be transported via C-5 aircraft, while the wider beam of the F class would preclude its transportation by air. The E class, like the Mark V it resembles, could be studded with weapon systems, while the air-cushioned F class, like the LCAC, could deliver large-scale payloads (including to locations on land).

There is likely to be utility in having more than one class of USV that can contribute to certain missions, depending on the circumstances. For example, it may be desirable to have a semi-submersible USV for a given mission that can achieve considerable stealth, as well as a larger, more capable USV for that same mission that is also more overt. In many instances, it may be advantageous to have two classes of USVs with different sizes for a given mission. One would be a limited-capability USV with a length of 11 meters or less. Such a small USV could be transported in a container express (CONEX) box or on an LCS and could generally take full advantage of the logistical infrastructure associated with 11-meter RHIBs. The disadvantage of such a USV would be that it would likely have a limited tradespace with respect to endurance, speed, seakeeping capability, and payload/towing capacity. However, a larger, more capable USV for the same mission could either self-deploy or be deployed from the well deck of a larger ship, when available.

In the case of USVs whose missions may involve the introduction of new or higher-risk technologies, commonality may reduce risk in sea frame and hull, mechanical, and electrical (HM&E) components. Military small craft providers,[9] for example, have already begun to employ some degree of standardization to reduce the time, risk, and cost to capability ratios by starting with common hull forms or common hull sections[10] and applying different bow or stern shapes suited to specific mission profiles, as well as common HM&E components. We would expect smaller USVs to benefit from these techniques, but they could also apply to larger USVs.

Common USV platforms with modular payloads could reduce development costs and limit hosting requirements. Common hull forms or components also reduce development, training, and personnel costs, as well as development time lines. Commonality also involves common components and standardization, such as common HM&E components, which could simplify maintenance and repair. Common vehicle and/or payload control stations, sensor suits, and mission payloads could reduce costs across unmanned system programs, mitigate some operator training costs, and even improve safety through standardization.

In some cases, a particular mission may require that a USV have highly unique attributes, precluding the use of a standard, modular platform. Just as MCM ships have traditionally been highly unique platforms, given the highly unusual low-signature requirements of their mission, there are likely to be mission-specific USVs when requirements are stringent. However, when this is not the case, modularity and commonality should be pursued.

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9 These providers routinely supply solutions for ships' boats, Special Operations, Riverine and Maritime Expeditionary Security Forces, etc.

10 These can also be readily combined to facilitate construction of craft of different lengths.

Optional Manning Could Enhance USV Capabilities and Mitigate Autonomy Challenges

Optional manning is a common technique during prototyping and early development, but our analysis indicates that it would be valuable as a permanent capability of USVs. Optional manning could mitigate autonomy requirements, increase situational awareness in benign environments, and allow USVs to be used for missions in which personnel are desirable. For example, a larger, self-deploying USV intended to operate in support of a strike group in A2/AD or high-end warfare environments could have sufficient autonomy for its primary mission profiles, including basic traffic avoidance and station-keeping, but could also be equipped with crew stations that could be temporarily manned for navigation in restricted waters, entering and leaving port, and for more complex evolutions such as underway replenishment. The crew of an optionally manned USV could also provide maintenance support for the USV throughout the voyage, as well as deal with any complex or unexpected situations.

Another advantage of an optional manning capability is that it may make USVs more useful to the ships that host them. Host ships that require select missions to be manned may be reluctant to give up the manned platforms they support in order to accommodate USVs. Having USVs that can be optionally manned enables these host ships to maintain their current capabilities while also gaining the tactical option of using USVs.

Advances in parameterized marine autopilot technologies mean that the principal challenges of adapting a vessel for unmanned use relate to its autonomy and sensing technologies and the level or automation required for the ship's systems. These considerations imply that a vessel designed primarily as an optionally manned USV would reflect very different design choices than a manned platform adapted for unmanned missions. Moreover, these considerations also have an impact with respect to maintenance. Despite redundancy, systems aboard a manned vessel are expected to require some degree of troubleshooting, repairs, and routine maintenance. To accommodate such needs, some optional manning capability should likely be incorporated into all larger USV designs.

Key human factors in optional manning include how to get the crew safely on and off of the vessel and how long a crew would need to be sustained on board the USV. The design trade-offs necessary to permit even simple human accommodations could be significant, and the impact of these trade-offs would increase the longer humans are intended to remain onboard. Boarding and debarkation may involve design considerations for going alongside (at least with small craft, if not larger vessels), as well as support for helicopter operations (for embarkation and debarkation by sling or, if the vessel is large enough, a small landing platform).

A final consideration relates to community sponsorship. The question of who owns, operates, and mans an optionally crewed USV is straightforward for the smaller 7-meter and 11-meter modular USVs designed to be hosted on specific ship classes. The question becomes more challenging, however, for larger and self-deploying USVs intended to support a range of missions.

Long Endurance Is Singularly Important for USVs

Several requirements must be met for USVs to capitalize on their potential for long-endurance missions such as ISR, MCM, ASW, and AMD missions; the same requirements are also important for other missions in large theaters with long transit times. USVs and their payloads must have reliability commensurate with their planned endurance. Survivability features such as damage tolerance and multilayered redundancy will also be needed. In some instances, scavenging energy may be used to extend endurance. Energy scavenging is most appropriate for missions with low power requirements, such as select ISR and oceanography missions.[11]

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[11] Energy scavenging for USVs has been demonstrated using both wave and solar energy by such vehicles as the Wave Glider by Liquid Robotics. A Wave Glider recently completed a year-long, 9,000–nautical mile journey from San Francisco to Bundaberg, Australia. It survived storms and a shark attack and successfully negotiated currents. It successfully collected

Beyond these engineering options, additional steps could be taken to enable USVs to achieve long endurance in their operating environments. One possible step would be to employ optionally manned vessel stations where USVs could refuel, exchange data, and potentially receive light maintenance support. Such vessel stations—"USV tenders"—could be stationed in permissive environments near where USVs are operating. These tenders could preclude the need for USVs to return to more distant host ships or ports for recovery and relaunch, providing greater on-station time.

Another possible step applicable to self-deploying USVs would be to man them while they are operating in permissive environments *en route* to their operating areas. The crew could help the USV to deal with any unexpected situations that arise in transit and provide ongoing maintenance to ensure that the USV is in very good condition when it arrives on station. The crew could disembark onto one of the previously mentioned optionally manned vessel stations as the USV approached its operating area.

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and transmitted oceanographic and atmospheric data throughout the trip. As of this writing, two additional Wave Gliders are making their way from San Francisco to Japan (Joe Rosato, Jr., "Surfboard-Sized Robot Vessel Makes Journey Across the Pacific," NBC Los Angeles, December 5, 2012).

CHAPTER SIX

Program Sponsorship and Acquisition Management Challenges

In this chapter, we summarize some of the programmatic implications of introducing USVs into U.S. Navy programs of record.

The U.S. Navy will need to decide which organization will be responsible for developing a USV's operational and programmatic requirements, which organization will sponsor the program's resources, and how the development or acquisition program will be organized. For missions in which a USV's requirements are closely coupled to specific host platforms or involve closely related concepts of employment (e.g., mine warfare), these concerns are probably minimal. In the mine warfare case, for example, the resources and requirements sponsor will likely be OPNAV N96, and the program will likely be aligned under the PEO for the LCS, as in other related programs. The same logic could apply for other 7-meter and 11-meter USV solutions intended to be hosted on specific classes of ship, as the requirements and resources sponsorship and program may best be aligned with those of the mission host.

However, for USV solutions *not* intended to be hosted on specific classes of ship, for larger or self-deploying USVs, and especially for USVs intended to support multiple missions that cross communities, the sponsorship and acquisition alignment becomes more complicated. For example, consider the following USV solution concepts intended to support a range of missions, including mine warfare, ASW, C^4ISR, military deception, and information operations:

- a USV solution larger than 11 meters intended to host or support various types of smaller unmanned air, surface, and/or subsurface vehicles
- a very large long-endurance, self-deploying USV solution intended to support both strike groups and independent operations.

The sponsorship and acquisition management arrangements for such solutions may be more complicated because of the number of different mission concepts of employment and effects chains they may need to support and, consequently, the number of communities of interest that have some stake in the USV's and/or payload's performance. In cases where multiple sponsors and/or PEOs are involved, how the "seams" in the program responsibilities and authorities are laid out will have an impact on risk and the program's potential for success.

Once the U.S. Navy determines which warfare and/or platform communities[1] will "own and operate" USVs once they are introduced, it will need to determine how those professional communities will be developed and sustained. This decision will be complicated by several factors:

- There may be strong fiscal and practical incentives for designing USVs to support multiple missions, some of which may involve supporting or hosting unmanned air or subsurface vehicles or cut across easily defined community boundaries.
- USVs will compete for training, operating, and maintenance resources with existing force elements in the assigned community.
- If assigned to more than one community, training, operating, and maintenance procedures and associated costs may be more difficult to align or manage.
- Cultural issues leading to manpower and manning challenges are likely to accompany the introduction of USVs, mirroring the experience of other unmanned systems.

[1] For example, surface warfare, aviation, submarine, cruiser/destroyer, amphibious, tactical aviation, helicopter, intelligence.

- For some missions, the skills and training needed to get the desired level of utility from USVs will challenge the U.S. Navy's ability to sustain a professional community and meet its readiness requirements.

Mitigating such concerns will likely involve convincing stakeholders of the importance of any new mission responsibilities and the value of USVs in achieving those missions or filling critical mission capability/capacity gaps. It may also require establishing practical roles for each USV solution in both combat and steady-state operations to ensure sufficient training and operating opportunities.

CHAPTER SEVEN

Conclusions and Recommendations

To reiterate, we found that USVs are highly suitable for a number of U.S. Navy missions and functions. These missions and functions are listed along the top row of Table 7.1.

As the column distinctions in Table 7.1 indicate, the levels of technological advancement of USVs to fulfill specific missions within these categories vary. USV capabilities to support some missions are in or near the market and could be considered for acquisition, whereas USV capabilities to support other missions are less technologically advanced and require R&D to bring them to fruition.

These missions and functions leverage many of the particular strengths that differentiate USVs from other unmanned and manned systems. USVs typically have long potential endurance relative to comparably sized UAVs and UUVs, as they require little energy to remain in place and can burn liquid fuels. Other USV attributes include larger payloads and higher payload-related power outputs than UAVs or UUVs of comparable size. They also have unique cross-domain capabilities, such as collecting and exchanging information both above and below the waterline. These attributes enable them to serve as critical nodes for cross-domain networks in which they can collect, process, and relay information. USVs can also assume risks that would be unacceptable for manned systems, enabling them to aid in overcoming an adversary's A2/AD efforts. We recommend that, as the degree of concern about A2/AD grows, the U.S. Navy consider how USVs and other unmanned vehicles could be used to bypass, saturate, or distract adversaries' defenses.

Table 7.1
Naval Missions and Functions by Level of Suitability for USV Employment and Level of USV Technological Maturity

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Highly suitable	C^4ISR: • Persistent ISR in permissive environments • Environmental collection in permissive environments Mine warfare: • Influence minesweeping • Mechanical mine-sweeping and mine harvesting Functions: • Test platform • Training support • SAR of conscious victims	Mine warfare: • MCM IPB • Reacquisition minehunting and neutralization Surface warfare: • Armed escort Military deception/information operations/ electronic warfare: • Disposition/intentions deception • Comms/signals deception • Radar/signals deception • Acoustic/signals deception • Decoy/countermeasures • Military information support operations ASW: • Unarmed ASW area sanitization Functions: • Unmanned vehicle support • Processing, exploitation, and dissemination	C^4ISR: • ISR in hostile environments • Environmental collection in hostile environments Mine warfare: • Autonomous in-stride minehunting and neutralization • Minelaying Surface warfare • Counter-FAC (fully autonomous) Functions: • Autonomous ship-to-shore connector • Complex SAR Missions not currently performed: • Impairing adversary sensors
Possibly suitable	Surface warfare: • Counter-FAC (remote control)	C^4ISR: • Communications relay among manned assets • Deploy individual sensors • Deploy independent sensor network Surface warfare: • Presence patrol	Ground attack: • Short/medium-range ground attack • Long-range ground attack (arsenal ship, optionally manned) AMD: • AMD kinetic force defense

Table 7.1—Continued

	In or Near Market (≥ TRL 8)	Emerging (TRL 4–7)	Incipient (≤ TRL 3)
Possibly suitable (cont.)		Missions not currently performed: • Provocative, high-risk presence • Vehicle as surface weapon AMD: • Sensing and warning (unit level) • Sensing and warning (force level) • Non-kinetic unit defense Military deception/information operations/ electronic warfare: • Tactical jamming • Disguised mission • Info systems (cyber/tech) • Computer network attack • Diversion Functions: • Opposed amphibious landing resupply	Functions: • Covert/clandestine SOF cargo delivery Missions not currently performed: • Blockship operations • Deliberately allowing capture
Less suitable		ASW: • Act as an ASW sensor node • Cued overt ASW tracking Functions: • Maritime interdiction operations support	ASW: • Armed wartime ASW area sanitization • Uncued ASW tracking • Cued covert ASW tracking • Cued/uncued ASW engagement Surface warfare: • Surface warfare (open water, ship vs. ship) Functions: • Resupply for manned ships

Advanced autonomy and assured communications are critical enablers for many USV missions and functions. Fortunately, USVs can benefit from advances that are being pursued in these areas in support of other unmanned vehicles. However, autonomous seakeeping and maritime traffic avoidance capabilities are both unique to USVs and critical to their performance. While other navies and civilian entities developing USVs will make some progress in these areas, the requirements of these other entities will not necessarily reflect those of the U.S. Navy. Moreover, U.S. Navy involvement would likely accelerate progress in these areas.

The process of integrating unmanned vehicles into the fleet will require considerable adjustment, just as the advent of aircraft and more capable submarines did in the early 20th century. USVs and other unmanned vehicles will need to shape themselves to the fleet to gain programmatic traction, even as portions of the fleet adjust to acquiring, hosting, transporting, controlling, and otherwise supporting USVs. One way to alleviate programmatic tensions is to design USVs for optional manning so that, if a USV displaces a manned platform being hosted on a ship, it does not preclude manned missions. Optional manning, of course, has costs: for example, providing facilities for personnel may entail reducing the space available for payloads. Another way of enabling USVs to better integrate into the fleet is to develop a set of standard USV platforms with modular payloads when possible. USVs that can support multiple missions are naturally more attractive than those that are more limited, though there may be instances in which a highly unique mission requires a specialized platform.

To the degree that USVs can perform missions that would otherwise require larger, more expensive manned warships, they can help to control costs. However, the extent to which USVs can reduce costs is limited, and they should by no means be viewed as a panacea. USVs are more apt to complement manned warships than to wholly supplant them. Using USVs may decrease the number of manned warships required to conduct a mission, but large manned warships would still be needed to provide hosting, C2, and other functions. Moreover, given the small size of USVs compared to manned warships, they are unlikely to be able to perform as diverse a set of missions at any given time.

Recommendations

To realize the potential of USVs, we recommend that the U.S. Navy

- pursue R&D on employing USVs for those missions and functions for which they are highly suitable, as listed on the top row of Table 7.1. This could include standing-up concept development efforts and developing more detailed concepts of employment.
- consider R&D on employing USVs for those missions and functions for which they are possibly suitable, as listed on the middle row of Table 7.1.
- develop a technology roadmap and/or an updated master plan for USV development, partly to inform the community about further required advances for USVs to fulfill particular missions or functions.
- conduct cost-benefit analyses regarding the use of USVs for particular missions or functions. These may be embedded in larger analyses of alternatives to select between USVs and other systems, as well as among different classes of USVs.
- consider how USVs and other unmanned vehicles could be used to bypass, saturate, or distract adversaries' A2/AD capabilities.
- pursue further R&D on autonomous systems for seakeeping and maritime traffic avoidance, as well as other aspects of autonomy.
- consider how USVs can support and work in concert with both UAVs and UUVs. USVs can be envisioned as critical cross-domain elements of unmanned networks, enabling communication and coordination among vehicles operating above, on, and below the waterline.
- design near-term USV programs to be as compatible as possible with existing programs (e.g., design USVs to be similar to platforms that are currently hosted on ships and supported by exist-

ing logistics and training pipelines). This would accelerate the acceptance and integration of USVs.

- consider compatibility with the complete spectrum of doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF) considerations.
- make leveraging USVs' potential for long endurance and large payloads a focal point of USV programs, taking advantage of their strengths in these areas. To this end, USV design should emphasize fuel efficiency, fuel storage capacity, underway refueling capabilities, and reliability in the absence of human maintenance.
- conduct a more detailed analysis of optional manning to better understand its costs and advantages.
- explore the development of USV "vessel stations" to refuel other USVs and exchange data with them. If designed to be optionally manned, these vessel stations could also provide low-level maintenance.
- develop a set of standard USV platforms with modular payloads when possible.
  - It may be helpful to have at least two classes of USVs for performing some missions or functions. One platform would be 11 meters or smaller, enabling it to be hosted aboard an LCS or transported in a CONEX box and allowing the mission to generally take advantage of the logistical infrastructure associated with 11-meter RHIBs. A second USV for the same or a similar mission would be larger and provide greater capability but would either self-deploy or require a larger ship to host and transport it.
- pursue further analysis regarding the impact of employing USVs on capital asset requirements and costs. Detailed mission and logistical analyses are needed to ascertain the degree to which USVs could enable fewer capital assets to be devoted to a particular mission. More extensive cost calculations regarding USVs would enable higher-fidelity analysis of the prospective financial impact of developing and employing USVs for particular missions.

APPENDIX A

Concepts of Employment for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance

As noted in the body of the document, we developed and evaluated USV concepts of employment for the missions and functions we considered.

We considered five mission categories under the rubric of C^4ISR missions, specifically

- persistent ISR in permissive environments
- ISR in hostile environments
- environmental collection in permissive environments
- environmental collection in hostile environments
- communications relay.

For each of these missions, this appendix describes the corresponding concept of employment for USVs. It then discusses several other key considerations: the environments in which each mission is conducted, the advantages and disadvantages of employing USVs for these missions, the autonomy and communications requirements for these missions, desirable classes of USVs for these missions, and the level of development of USV capabilities for these missions.

Persistent Intelligence, Surveillance, and Reconnaissance (ISR) in Permissive Environments

Description of the Mission and the Concept of Employment

The reasons for conducting persistent ISR in permissive environments range from improving safety and security to improving operational capabilities by leveraging data. Manned platforms are often used for this mission, hosting or towing sensor packages that collect and sometimes analyze information about their surroundings. In this concept of operations, USVs would either host or tow sensor packages, much like their manned counterparts.

USVs could be used for many different types of ISR, including signals intelligence (SIGINT), imagery intelligence (IMINT), and measurement and signature intelligence (MASINT). The types of SIGINT gathered using a USV platform could include the detection of radio signals from vessels in the area for the purposes of locating the source or analyzing the content of the signals in the case of communications. IMINT could include images of vessels, facilities, geographic features, etc. MASINT is a broad category that includes the detection and measurement of electromagnetic emissions beyond just those used for communications, measurements of geophysical characteristics such as seismic activity or the weather, and other intelligence indicators. Once collected, the data go through processing to extract information that can support a broader mission.

The type of intelligence being sought and the time lines required for the processing will dictate the size and shape of the USV, the sensors the USV should be equipped with, and the communications equipment used. Likewise, different collection methods may require different operational behaviors. If the collection activity requires the sensor to be very close to a target, the USV will need a different set of autonomy guidelines than if the measurements could be taken from farther away from the targets (or if the target was stationary).

Environments in Which the Mission Is Conducted

This mission is performed in uncontested waters with varying physical layouts and traffic densities. More specifically, the nature of the targets dictates the operational environment. If the targets are vessels, the mission may be done in higher-traffic environments. Alternatively, if the targets are geographical features, weather, or other natural phenomena, the environment could have very low traffic.

Advantages and Disadvantages of Employing USVs for This Mission

A USV's potential persistence is one of its most valuable attributes, giving it a significant advantage over comparably sized manned platforms, as well as UUVs and UAVs. The longer the platform can stay on station, the more data can be collected. Thus, the USV's persistence can make it more effective at this mission. Additionally, unlike UAVs and UUVs, it can collect data both above and below the waterline.

The primary disadvantage of USVs compared with manned platforms would be the ability to process the material collected. A manned platform might have personnel who are able to process the data immediately, whereas an unmanned platform would need to relay information to a second site for analysis. If the volume of data collected is too much for communications equipment to handle in a timely fashion, processing activities could be delayed substantially, and the value of the intelligence may diminish over time.

Autonomy and Communications Requirements

The ability to autonomously navigate waypoints and avoid collisions will be required. The USV will need sufficient communications capabilities to relay information for processing and exploitation; alternatively, it will require enough data-storage capacity for data to be recovered along with the vehicle. If the collection activities require the USV to operate very close to its target, an additional degree of seakeeping autonomy may be required to rapidly adjust the vessel's position relative to its target.

Desirable Classes of USV for This Mission

USVs performing this mission could be of any size. Though the size of the sensor package and the mission duration may dictate the size of USV required.

Development of USV Capabilities for This Mission

This mission has received considerable market attention: 32 platforms at TRL 8 or above are designed to perform an ISR role.

ISR in Hostile Environments

Description of the Mission and the Concept of Employment

This mission is identical to the ISR in permissive environments mission, except that it is performed in contested waters. Threat avoidance and threat management will be the key components of a USV for this mission. Because the platform may be under threat, a USV used in this role may need to be stealthier, faster, or more disposable than one operating in a permissive environment.

Environments in Which the Mission Is Conducted

This activity would be performed in contested waters with variable physical environments and traffic densities. More specifically, the nature of the targets would dictate the operational environment. If the targets are vessels, the mission may be done in higher-traffic environments. Alternatively, if the targets are geographical features, weather, or other natural phenomena, the environment could have very low traffic.

Advantages and Disadvantages of Employing USVs for This Mission

USVs would present the same advantages and disadvantages as in the persistent ISR in permissive environments mission but would have the additional advantage of keeping personnel and valuable manned platforms out of harm's way. USVs are also likely to be stealthier than UAVs, though they are less stealthy than UUVs. Alternatively, a USV will be slower than a UAV but likely faster than a UUV.

One key advantage of a manned platform over a USV in this case is the risk of communication interception. An adversary could use electronic means to gain control over an unmanned platform, but it would be much more difficult to do so to a manned platform.

Autonomy and Communications Requirements

The ability to autonomously navigate waypoints and avoid collisions will be required. Depending on the time-sensitivity of the data and the desired degree of stealthiness, the USV may need to have assured communications. The ability to detect threats will require additional autonomy and may also require advanced avoidance behavior.

The more the platform relies on communications rather than autonomy, the greater its vulnerability to being hacked. If the platform is reliant on communications for navigation and control, spoofing the USV's communication could allow a hostile takeover of the vessel. For a USV that primarily uses communications to relay collected data, spoofing would not have as severe consequences.

Desirable Classes of USV for This Mission

Given the desirability of stealth when operating in nonpermissive environments, smaller USVs (X class, Harbor class, or Snorkeler class) would likely be advantageous. Likewise, the risk of capture sometimes makes smaller USVs more desirable for this mission.

Development of USV Capabilities for This Mission

Many of the ISR platforms for permissive environments could be employed in hostile environments, depending on the level of risk accepted. Developments in autonomy and stealth technologies would make USVs more effective for this mission.

Environmental Collection in Permissive Environments

Description of the Mission and the Concept of Employment

All naval operations require knowledge of environmental conditions and their variability; the efficacy of some naval operations, notably submarine warfare, ASW, and mine warfare, are particularly dependent on environmental conditions. USVs can be deployed to prospective operational environments to collect physical data, which they can then relay to a host platform or physically deliver upon recovery. This type of collection generally falls into the MASINT category and the platforms used will have similar characteristics to those of the more general ISR platforms. More specifically, this includes weather measurements, bathometric surveys, and other types of hydrological analysis.

Environments in Which the Mission Is Conducted

This mission would be performed in uncontested waters with variable physical layouts and traffic densities. Because the focus of this mission would be environmental collection, there would not inherently be high traffic density as with more general ISR mission environments.

Advantages and Disadvantages of Employing USVs for This Mission

A USV's persistence gives it a significant advantage for this mission over manned platforms, as well as UUVs and UAVs. The ability to operate on the air-water interface provides the USV unique capabilities relative to other unmanned platforms.

Autonomy and Communications Requirements

The USV will need sufficient communications to relay information for processing and exploitation. The ability to autonomously navigate waypoints and avoid collisions will be required. Additional communications capabilities may be required if the raw data is to be transmitted for processing. Some sensors will produce too much information to be transmitted, so either the information will need to be processed on board or the data will need to be pulled from hard drives by physically removing them.

Desirable Classes of USV for This Mission

USVs performing this mission could be of various sizes depending on the sensor package and the required endurance. Smaller USVs (such as the X class) that may lack space for power generation can take advantage of energy scavenging technologies that can increase endurance.

Development of USV Capabilities for This Mission

This mission has received considerable market attention, although much of this market activity is focused on only a few areas: characterizing pollution levels, marine life, and hydrography in inland waterways or littorals.

Environmental Collection in Hostile Environments

Description of the Mission and the Concept of Employment

This mission is identical to environmental collection in permissive environments except that it is performed in contested waters. As with ISR missions in hostile environments, operating in a hostile environment means that the platform will need to have some kind of threat avoidance or threat management capability that will likely take the form of stealth, speed, or disposability.

Environments in Which the Mission Is Conducted

This activity would be performed in contested waters with variable physical layouts and traffic densities.

Advantages and Disadvantages of Employing USVs for This Mission

USVs would present the same advantages and disadvantages as they would in ISR missions or environmental collection in permissive environments, but they would have the additional advantage of taking humans out of harm's way.

Autonomy and Communications Requirements

The ability to autonomously navigate waypoints and avoid collisions will be required, and higher autonomy will be required for stealthy missions. Additional communications capabilities may be required if the raw data is to be transmitted for processing, though there may be trade-offs between the ability to transmit data and the stealth of the USV. Thus, having additional processing capabilities beyond those used for environmental collection in permissive environments would be extremely useful.

Desirable Classes of USV for This Mission

USVs of any size could be employed for this mission, although smaller USVs (11 meters or less in length) would be desirable if stealth is important. The types of threats to be faced will determine the value of trade-offs between stealth, size, and capability. For threats with lower capability, the same platform as that used in a permissive environment may be sufficient. Against higher-capability threats, specially designed platforms may be needed.

Development of USV Capabilities for This Mission

While there has been no visible market attention to this mission, USVs designed for other ISR missions could likely be modified to fulfill it.

Communications Relay

Description of the Mission and the Concept of Employment

When two communications nodes cannot communicate directly, a third is sometimes interposed between them to enable communication. USVs hosting appropriate communications equipment could serve as this third node.

In this role, a USV could pass communications between manned platforms, UAVs, UUVs, and other USVs. The USV can also serve as a satellite communications link for smaller platforms that do not have such capabilities. This function could allow manned platforms to operate farther away from the unmanned vehicles they are hosting.

Environments in Which the Mission Is Conducted

Communications relay would be performed in diverse environments. Because areas with high traffic would likely present other means of transmitting communications, a USV would prove less useful in this environment.

Advantages and Disadvantages of Employing USVs for This Mission

USVs have the advantage of operating on the air-water interface, which allows them to exchange information with platforms above, below, and on the waterline. Relative to other unmanned systems of comparable size, USVs can typically host heavier communications equipment and use more energy for this mission. However, USVs lack the ability of UAVs to achieve a high altitude that enables line-of-sight communications over long distances.

Autonomy and Communications Requirements

This mission will be, by definition, highly dependent on access to assured communications.

Desirable Classes of USV for This Mission

USVs of any size could be used for this mission. Larger USVs could have additional support capabilities for other unmanned vessels.

Development of USV Capabilities for This Mission

This mission has received very limited attention in the current market. Payload modularity would be useful for swapping out the communications equipment.

APPENDIX B

Concepts of Employment for Antisubmarine Warfare

We examined the following ASW missions:

- unarmed ASW area sanitization
- overt cued ASW tracking
- acting as an ASW sensor node
- armed wartime ASW area sanitization
- uncued ASW tracking
- cued covert ASW tracking
- cued ASW engagement
- uncued ASW engagement.

For each of these missions, this appendix describes the corresponding concept of employment for USVs. It then discusses several other key considerations: the environments in which each mission is conducted, the advantages and disadvantages of employing USVs for these missions, the autonomy and communications requirements for these missions, desirable classes of USVs for these missions, and the level of development of USV capabilities for these missions.

Unarmed ASW Area Sanitization

Description of the Mission and the Concept of Employment

The objective of unarmed ASW area sanitization is to assure that no enemy submarine is operating in a designated area or to warn when an enemy submarine is operating in that area. Such designated areas include planned operating areas for carrier strike groups (CSGs) and areas along a position of intended movement (PIM). Sanitizing a PIM is a recognized USV application referred to as "Protected Passage" in the 2007 *USV Master Plan*.

The concept of employment for unarmed ASW area sanitization entails one or more USVs self-deploying or being transported to an operating area ahead of a high-value unit (HVU) with sufficient time to search the area to a specified level of confidence before the HVU arrives. If no enemy submarine is detected and classified, this information is reported at the end of search. If an enemy submarine is detected and classified, this information is reported at the time of detection and classification. USVs conducting unarmed ASW area sanitization might return or be recovered. Alternatively, USVs considered expendable might be operated to failure or scuttled.

Unarmed ASW area sanitization could be conducted overtly or covertly. Overt operations would be conducted using relatively short-range active sonars and other possible sensors (the use of such active sonars could reduce the onboard processing requirements for target classification). The USV might use electro-optical systems to search the contact area for a surface contact; absent a surface contact, it could be inferred that the active sonar contact is a submarine. Covert operations, which would use passive sonars operated from relatively stealthy USVs, would clearly be preferable.

The problem of unintentionally alerting enemy submarines is not the only challenge of the unarmed ASW area sanitization mission. As mentioned previously, contact classification will be an issue. The option of using off-board processing to classify passive sonar contacts is unattractive because it would burden communication links. However, onboard classification with high confidence could be challenging. Reliability and dependability issues with vehicles and communications could also pose challenges.

The use of multiple USVs would be desirable for this mission as it would increase the effectiveness of search by placing additional sensors in an area of interest and would reduce the need for high reliability. The use of multiple USVs would also reduce the consequences of having a USV detected.

Environments in Which the Mission Is Conducted

Unarmed ASW area sanitization could be conducted in all environments and in all sea states. It could be conducted in peacetime or wartime.

Advantages and Disadvantages of Employing USVs for This Mission

When conducted by manned platforms (surface ships, submarines, or aircraft), unarmed ASW area sanitization requires the dedicated use of otherwise multi-mission platforms, thus it is expensive (both monetarily and in terms of valuable resources). Cost savings and freeing multi-mission manned platforms to perform other missions are, then, the main advantages of using USVs for this mission.

In wartime, USVs performing unarmed ASW area sanitization have multiple disadvantages. The use of USVs to fulfill this mission in wartime could be unacceptable because the survival of personnel and HVUs would depend critically on the onboard processing and autonomy capabilities of USVs to detect and classify elusive targets without saturating communications links with processing demands or false alarms. The use of USVs would also demand trust in the reliability and dependability of USVs and their communications systems, as well as require significant doctrinal and organizational changes. Unarmed ASW area sanitization operations in peacetime or pre-hostilities are judged more acceptable, as they would present a pure benefit.

Autonomy and Communications Environments

In peacetime, USVs would be expected to operate in a benign communications environment, so they would have somewhat reduced autonomy requirements. Autonomy requirements would be higher in communications-limited wartime environments.

Desirable Classes of USVs for This Mission

The USVs best suited to this mission have long endurance and high reliability. The ability to avoid alerting target submarines would be advantageous. The ability to operate a towed array sonar to take advantage of acoustic propagation conditions and (possibly) separate acoustic sensors from noisy USV platforms would also be advantageous. The advantages of using multiple USVs that can operate for long periods favors low-cost, long-endurance USVs, particularly USVs that can be considered expendable. The ability to self-deploy and self-recover would also be advantageous.

Development of USV Capabilities for This Mission

PEO LCS Unmanned Maritime Systems Program Office (PMS 406) has sponsored the development of two USVs that could contribute to this mission: the ASW USV Engineering Development Model (EDM), built by General Dynamics Robotic Systems, and the ASW USV Advanced Development Model (ADM), built by Willard Marine. PMS 406 has also explored the use of different sonar payloads on these vessels.

The Wave Glider, developed by Liquid Robotics, appears to have some of the capabilities required for this mission, notably long endurance, high reliability, and low acoustic emissions.

Overt Cued ASW Tracking

Description of the Mission and the Concept of Employment

The overt cued ASW tracking mission calls for a USV to maintain continuous autonomous tracking of an enemy submarine over much of its deployment without regard for covertness. The concept of employment calls for the USV to deploy to an area of interest where it will be cued by another system—such as a set of sonobuoys, a maritime patrol aircraft, a wide-area surveillance system, a U.S. submarine, or a surface ship using a towed sonar array—that has detected, classified, and localized an enemy submarine. The overt cued ASW tracking mission has been championed by DARPA, which is funding the development of the ASW Continuous Trail Unmanned Vessel (ACTUV) program. This program has the goal of sending out an unmanned vessel for long-term submarine tracking on its own (the concept design has a 30-day loiter followed by a 30-day maximum energy trail application). The USV would overtly track the enemy submarine, defeat efforts by the submarine to "delouse" itself, and periodically report the enemy submarine's position, course, and speed. It should be noted that the overt cued ASW tracking mission is applicable only to diesel-electric enemy submarines; nuclear-powered submarines have greater high-speed endurance than any USV and could simply use that speed to exhaust the endurance of a USV attempting to track it overtly.

Environments in Which the Mission Is Conducted

Overt cued ASW tracking is a peacetime-only mission. It would be conducted in a combination of littoral and open-ocean environments.

Advantages and Disadvantages of Employing USVs for This Mission

Using USVs in place of manned platforms to track enemy submarines has two potential advantages. First, it could free manned platforms, such as U.S. nuclear submarines (SSNs) and maritime patrol aircraft (MPA), to perform other missions. Second, it would increase the number of enemy submarines that could be tracked simultaneously prior to hostilities. Since the total ownership cost of a USV would likely be a small fraction of that of an SSN or MPA, USVs for this mission could be acquired in much greater numbers than additional SSNs. Whereas an adversary could rapidly launch a large number of submarines to overwhelm the ability of SSNs and MPA to track them, the availability of USVs could help limit the success of such a tactic. Also, a USV could persist in conducting the mission long after an MPA would have to return home; employing a USV would thus obviate the need to repeatedly transfer the mission from one aircraft to another.

We found several key disadvantages with respect to employing USVs for this mission:

- **Possible provocation.** Overtly operating one or more USVs in regions such as the approaches to enemy submarine bases could be provocative. Attacks on USVs loitering outside military ports might even precipitate a conflict. This issue has not been wargamed.[1] Moreover, overtly and vocally following another

[1] Study discussion with the ACTUV program manager, Scott Littlefield, November 21, 2012.

nation's submarines—including, potentially, those with strategic nuclear weapons—could lead that nation to fear that some of its nuclear deterrent power is being attenuated, with unpredictable consequences.

- **Lost intelligence collection opportunities.** There are two objectives to tracking enemy submarines in peacetime: (1) locating them and (2) generating intelligence about them. Unlike SSNs or MPA, USVs would be unable to gather acoustic intelligence regarding the radiated noise characteristics of enemy submarines. Also, in overtly tracking enemy submarines, the opportunity to gain insights into their normal operations (how and where they operate) would be lost.
- **Vulnerability of the USV.** It is unclear how the USV could defend itself and continue to operate in the face of possible air strikes, deliberate ramming by another vessel, electronic warfare, or other forms of attack. DARPA has countered this criticism with the observation that the USV could be "the canary in the coal mine" that warns of impending hostilities.

Collectively, these disadvantages lead to our assessment that the overt cued ASW tracking mission is less suitable for USV employment. Our concerns are further exacerbated if the cuing platform is either an SSN or an MPA. The search portion of this ASW (needed to generate a cue for the tracking USV) can be prolonged relative to the tracking portion of the mission. Thus, if the cueing system is an SSN or MPA, the USV may not free up much of the cueing platform's time by assuming its tracking responsibilities. Rather, there would likely be considerable resistance to this concept of employment within the SSN and MPA communities. Having spent weeks or months searching for an enemy submarine, personnel would be reluctant to hand off the contact to a USV. Members of these communities might also argue that skills acquired in tracking enemy submarines during peacetime are valuable in wartime. (These disadvantages do not apply if another cueing platform is used.) The handoff from an SSN or MPA to a USV presents opportunities for a contact to be lost, whereas the process of having the same platform detect and track the submarine is more seamless.

Moreover, if the cueing asset happens to be an SSN, using a USV for overt tracking can present a further disadvantage. An enemy submarine that realizes it is being tracked by a USV can easily infer the presence of a cueing platform. The SSN's rough location might be inferred from knowledge of the enemy submarine's track and a time estimate of when cueing occurred based on USV movement. Such a compromise could jeopardize the cueing SSN.

Despite these reservations about the overt cued ASW tracking mission, the ACTUV program could have considerable value. Significant advances in USV autonomy (especially autonomy in adhering to regulations for collision avoidance) are expected to come out of the ACTUV program. Those advances could benefit other USVs, as well as manned vessels. If successful, the ACTUV program will also produce a uniquely capable USV with higher speed, wider range, and more payload capacity than any existing USV. Beyond the benefits of an expanded iron triangle, the ACTUV vehicle is expected to have excellent seakeeping capability. It is expected to be adaptable to multiple USV missions.

Autonomy and Communications Environments

Overt cued ASW tracking is a peacetime-only mission. Operations would be conducted only in permissive or semi-permissive environments without limits to communications.

Desirable Classes of USVs for This Mission

The overt cued ASW tracking mission places extraordinary demands on USV endurance and speed and requires a USV larger than any existing USV (with at least 100 long ton [LT] displacement). The ACTUV is the only practical USV alternative for this mission.

Development of USV Capabilities for This Mission

The USV capability most in need of development for the overt cued ASW tracking mission is autonomy for COLREGs. The error rate for interpreting COLREGs situations is now several orders of magnitude higher than for human operators. Achieving an error rate in complex situations that approaches that of humans will be challenging.

ACTUV represents the only visible market attention to this mission; no other USV's design appears suitable to perform it.

Other ASW Missions

Other ASW missions were considered in this study but all were found less suitable. As a rule, concepts of employment calling for autonomous weapon release appear to overtax USVs' autonomy capabilities—particularly in environments with denied communication (all known USVs capable of releasing weapons do so only under remote control). Uncued ASW missions demand large USVs with sophisticated sensors and are expected to overtax autonomy for target classification. Covert operations require a combination of sophisticated ASW sensors and a modicum of USV stealth. We briefly discuss the other ASW missions considered for this study below.

Acting as an ASW Sensor Node

The only advantage USVs have over deployable ASW sensor nodes is their ability to relocate. This is a very limited advantage, however. Perceived disadvantages include difficulty integrating USVs into the existing force architecture and the relatively high cost of USVs in comparison to existing deployable systems.

Armed Wartime ASW Area Sanitization

The objective of armed wartime ASW area sanitization is to assure that no enemy submarine is present in a designated area, such as an operating area for an HVU. The concept of employment for armed ASW area sanitization entails one or more USVs entering an operating area ahead of an HVU with sufficient time to search the area to a specified level of confidence before the HVU arrives. If no enemy submarine is detected and classified, that information is reported at the end of search. If an enemy submarine is detected and classified, the enemy submarine is engaged by the USV. The main advantage of this mission would be freeing manned vehicles to perform other missions. The main disadvantage is the high level of onboard processing and autonomy required for the mission—far higher than that required for unarmed ASW area sanitization. Autonomous classification requires a low false-alarm rate (to avoid possible fratricide or attacks against neutral ships and wasting weapons). Also, high confidence would need to be quickly achieved for valid contacts in order to attack before losing contact. A high level of autonomy would also be required to set weapons appropriately. Large USVs' lack of stealth and the need to equip them with sophisticated sensors are further disadvantages of USVs for this mission. It would be difficult to integrate USVs conducting armed wartime ASW area sanitization into the existing force architecture. On these grounds, armed wartime ASW area sanitization is more appropriate for manned vehicles for the foreseeable future.

Uncued ASW Tracking

The objective of the uncued ASW tracking mission is to provide long-term tracking against enemy submarines without requiring cueing. The concept of employment for uncued ASW tracking would place a USV in a region where it would be apt to encounter enemy submarines—perhaps outside a submarine base or in a regional chokepoint. The USV would then autonomously detect, classify, localize, and track enemy submarines. The advantages of USVs for this mission expand on those for cued ASW tracking: freeing multi-mission platforms to perform other missions and potentially increasing the number of enemy submarines that could be tracked simultaneously, particularly prior to hostilities. The main issue with using USVs for the mission is the high reliance it requires on onboard sensors and processing to autonomously detect, classify, localize, and track contacts. This reliance is higher for uncued ASW tracking than for cued ASW tracking because the USV cannot be vectored into contact. Unlike the overt cued ASW tracking mission, this mission would not present lost intelligence collection opportunities or the potential compromises of cueing submarines. Also unlike the overt cued ASW tracking mission, this mission does not appear to have acceptance issues. However, as with the overt cued ASW tracking mission, this mission might be provocative. This mission appears to be more suitable for manned platforms.

Cued Covert ASW Tracking

The objectives and concept of employment for cued covert ASW tracking are similar to those for cued overt ASW tracking, except that the USV would be required to remain undetected during the long-term tracking operation. Using USVs for cued covert ASW tracking would offer the same advantages as with cued overt ASW tracking: it would free manned platforms to perform other missions and increase the number of enemy submarines that could be tracked simultaneously, particularly prior to hostilities. It would also provide the opportunity to gain insights into the normal operations of enemy submarines. However, as with cued overt ASW tracking, the advantage of freeing an SSN would be limited. USV use for cued covert ASW tracking also shares some of the same disadvantages with cued overt ASW tracking: lost intelligence collection opportunities, the potential loss of contacts during handoffs, and possible provocation. It would present the same acceptance issues as cued overt ASW tracking. Extraordinary challenges are possible for onboard sensors, reducing the USV's acoustic signature and autonomy. Once in contact, the USV would perpetually balance on a knife-edge between maintaining contact and remaining covert—an extremely difficult autonomy challenge. Cued covert ASW tracking appears better suited to manned platforms.

Cued ASW Engagement

Cued ASW engagement has been suggested by DARPA as a second possible mission for the ACTUV USV.[2] In the cued ASW engagement concept of employment, one or more USVs armed with lightweight torpedoes would deploy ahead of a CSG. Cues would be generated using surface ship active sonars (with contacts expected to occur in convergence zones [CZs], which typically occur at ranges of 20–30 nautical miles from the sonar).[3] ACTUV-like USVs operating one CZ ahead

[2] Study discussion with the ACTUV program manager, Scott Littlefield, November 21, 2012.

[3] CZs occur in deep water when temperature conditions in the water column cause downward propagating sound to refract away from the ocean bottom without reaching it. Sound is then concentrated in an annulus roughly 3–5 nautical miles wide.

of an escort with an active sonar appear more responsive than ASW helicopters launched from carrier flight decks. The potential benefits resulting from such a reduced response time appear limited, particularly in cyclic carrier flight operations, which require extensive maneuvering that would make it extremely difficult for a USV to remain in a screen position ahead of the carrier. As with the armed area ASW sanitization mission, the cued ASW engagement mission would place an extraordinary burden on the USV's sensors, onboard processing, and autonomy (particularly in communications-denied environments). This burden would amplify the problem of allowing autonomous vehicles in proximity to CSGs to release weapons. Finally, this mission appears difficult to integrate into the existing force architecture. Cued ASW engagement appears better suited to manned platforms.

Uncued ASW Engagement

The objectives and concept of employment for uncued ASW engagement are the same as those for uncued ASW tracking, except that kill chains would be carried to completion. The concept of employment for uncued ASW engagement would place a USV in a region where it would be apt to encounter enemy submarines, perhaps outside a submarine base or in a regional chokepoint. The USV would then autonomously detect, classify, localize, and engage enemy submarines. The advantages of this mission expand on those for cued ASW tracking: freeing multi-mission platforms to perform other missions and potentially increasing the number of enemy submarines that could be engaged early in a conflict. The main issue with using USVs for the mission is the extreme reliance it requires on onboard sensors and processing to autonomously detect, classify, localize, and engage contacts. The demand for reliability is also high, and this mission might prove provocative. Acceptance for this mission could be hard to achieve, as unmanned vehicles, possibly operating in communications-denied environments, would be releasing weapons. Manned platforms are more suitable for this mission.

APPENDIX C

Concepts of Employment for Mine Warfare

We developed seven USV concepts of employment to support mine warfare missions, specifically

- MCM IPB
- reacquisition minehunting and neutralization
- autonomous in-stride minehunting and neutralization
- mechanical minesweeping and mine harvesting
- influence minesweeping
- minefield proofing
- minelaying.

For each of the above missions, this appendix describes the corresponding concept of employment for USVs. It then discusses several other key considerations: the environments in which each mission is conducted, the advantages and disadvantages of employing USVs for the mission, the autonomy and communications requirements of the mission, desirable classes of USVs for the mission, and the level of development of USV capabilities for the mission.

Mine Countermeasures Intelligence Preparation of the Battlespace

Description of the Mission and the Concept of Employment

MCM IPB entails conducting a sonar survey in a body of water during peacetime to characterize the floor and document any sonar contacts.

Having such data available prior to a conflict can enable MCM forces to rapidly and accurately differentiate preexisting sonar contacts from novel ones, which may be mines. MCM IPB may also provide data that can aid the planning of MCM operations during a conflict.

The concept of USV employment for this application is simple. The USV is launched from a ship or pier, towing a sonar system behind it. As it moves throughout the waterspace of interest, the USV uses its sonar to capture imagery. The USV then returns to its point of origin for recovery of the sonar system and the newly acquired data.

Environments in Which the Mission Is Conducted

MCM IPB can be conducted either openly in a permissive environment or stealthily in a nonpermissive one. In most cases, it will be conducted in relatively confined waters, where the mine threat is greater than in open environments. Typically, this mission is not time-sensitive and, therefore, can be scheduled for times when sea states and traffic densities are relatively low.

Advantages and Disadvantages of Employing USVs for This Mission

The greatest advantage of employing USVs for MCM IPB is that they are more risk-tolerant than manned platforms in nonpermissive environments; if designed as semi-submersibles, they are also stealthier. USVs can be used to conduct MCM IPB in areas where manned platforms would not be permitted to operate, since the destruction or capture of USVs would have more limited consequences. On the other hand, USVs have a higher probability of damage or capture than manned platforms, whose occupants can rely on human judgment to avoid threats and collisions.

In both permissive and nonpermissive environments, the costs and capital asset requirements associated with having a USV conduct this mission could be lower than those for sonar-towing manned vessels or helicopters.

USVs are more suitable for this mission than other unmanned systems. UAVs are far less stealthy than USVs in nonpermissive environments. Moreover, any UAV large enough to tow sonar for MCM IPB would consume a great deal of fuel, increasing costs and reducing endurance relative to USVs. USVs also have greater endurance than UUVs of comparable size due to the higher energy density of liquid fuels. It is true that UUVs could be stealthier than even semi-submersible USVs; however, the more attenuated communications capabilities and limited navigational accuracy of UUVs degrade their performance relative to USVs.[1]

Autonomy and Communications Requirements

To perform this mission, USVs require a combination of autonomy and assured communications sufficient to enable them to avoid collisions. They also need waypoint navigation and the ability to return to a ship that may have moved during their deployment.

Desirable Classes of USV for This Mission

USVs performing MCM IPB need to be capable of towing a sonar system, which requires a size exceeding that of the X class. A semi-submersible design is desirable for operations in nonpermissive environments, although lower-cost hull designs can be used for operations in permissive waterspace. USVs in the Harbor, Snorkeler, Fleet, E, or G classes could all be considered. Only the Snorkeler class would provide stealth, but larger classes could provide greater endurance. The F class's air cushion would make it a poor sonar-towing platform.

Development of USV Capabilities for This Mission

The U.S. Navy has a program of record for a minehunting USV that can conduct MCM IPB: the RMMV; when combined with the AN/AQS-20A sonar system it tows, it is called the Remote Minehunting System (RMS). The RMMV is a 7-meter, semi-submersible vehicle with only a combined snorkel and mast visible above the waterline,

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[1] UUVs can use surface-breaching antennae to compensate for their limited communication and navigational capabilities. However, such antennae are unlikely to have as high a vantage point or as consistent contact with the air as antennae aboard USVs, making them less capable.

making it a member of the Snorkeler class.[2] In 2012, it was launched from and recovered by an LCS.

Reacquisition Minehunting and Neutralization

Description of the Mission and the Concept of Employment

This mission entails two distinct phases: minehunting and neutralization. In the hunting phase, a platform conducts a sonar survey of the waterspace, going back and forth in a "mowing the lawn" pattern. The imagery from this survey is analyzed to detect sonar contacts, as well as to characterize those contacts as "minelike" or "non-minelike." In the neutralization phase, another platform (or sometimes the same platform) returns to the contact's location and reacquires the contact. If the object is visually identified as a mine, an explosive charge is used to neutralize it.

The concept of USV employment for this mission is as follows. The "hunter" USV is launched from a ship or pier, towing a sonar system behind it. It moves through the waterspace to collect data and then returns to its point of origin for recovery. The sonar data is analyzed ashore or aboard the ship, then the "neutralizer" USV (which may be the same as the hunter) is launched to reacquire contacts of interest. It deploys a UUV or remotely operated vehicle (ROV) to identify and neutralize the mine. While this concept of employment uses USVs for both phases, other platforms could conceivably be substituted for use in either phase.

Environments in Which the Mission Is Conducted

Reacquisition minehunting and neutralization is conducted when there is a known or potential mine threat (usually after hostilities have commenced). As with MCM IPB, it can be conducted either openly in a permissive environment or stealthily in a nonpermissive one. It is usually conducted in relatively confined waters, where mines are most effective; however, due to the mine threat, traffic densities are typically

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2 U.S. Navy Fact File, "Remote Multi-Mission Vehicle – (RMMV)," October 31, 2012.

low. Given the application's time-sensitivity—it is a prelude to other operations using the waterspace—it may be conducted during high sea states or other adverse environmental conditions.

Advantages and Disadvantages of Employing USVs for This Mission

The most important reason to employ unmanned systems for this mission is to avoid subjecting personnel and valuable platforms to the risk of damage from the minefield. A secondary consideration is that moving carefully and predictably through a minefield can subject a mine clearance platform to actively launched attacks; USVs can be both stealthier and more expendable than manned platforms. Using USVs would also reduce the requirement for high-value manned assets and their associated costs.

USVs are more suitable for this mission than other unmanned systems. UAVs would have lower endurance, greater fuel costs, and less stealth in conducting both the hunting and neutralization phase. USVs have greater endurance and payload capacity than UUVs of comparable size, as well as better communications and navigational accuracy.

Autonomy and Communications Requirements

Both hunter and neutralizer USVs require waypoint navigation and the ability to be recovered by a ship that may have moved during their deployments. Assuming that current rules of engagement apply, neutralizer USVs will also require assured communications to enable personnel to visually identify mines and approve the use of ordnance to neutralize them. Alternatively, if a high degree of autonomy can be achieved and organizational trust engendered, it could obviate the need for neutralizer USVs to seek human approval for employing ordnance.

Desirable Classes of USV for This Mission

Hunter and neutralizer USVs would likely be selected from the same classes as those used for MCM IPB: the Harbor, Snorkeler, Fleet, E, or G classes. Larger classes of neutralizers, such as the E or G, could accommodate more ordnance for neutralization than their smaller counterparts. This consideration would need to be weighed against other issues, such as cost and hosting requirements, and the degree to which larger platforms could cause mines to detonate. The X class would be too small for this mission, while the air cushion associated with the F class would be too disruptive.

Development of USV Capabilities for This Mission

As indicated in the section regarding MCM IPB, the U.S. Navy's program of record for the hunting aspect of this mission is the RMMV.

In-Stride Autonomous Minehunting and Neutralization

Description of the Mission and the Concept of Employment

This mission, like the reacquisition minehunting and neutralization mission, entails distinct hunting and neutralization phases. Like the mine warfare applications discussed earlier, the minehunting phase involves a "hunter" conducting a sonar survey of the waterspace. However, in-stride autonomous minehunting is unique in that a computer aboard the hunter uses sophisticated algorithms to analyze the sonar imagery in seconds or less, detecting sonar contacts and characterizing some of them as mine-like. The hunter relays mine-like contact locations to the nearby neutralizer, and the neutralizer deploys a UUV or ROV to visually identify and neutralize the mine while the hunter continues its sonar survey. In a densely mined area, multiple neutralizers per hunter may be necessary.

In the concept of USV employment for this mission, both the hunter and neutralizer USVs are deployed from a ship or pier. The hunter tows a sonar system and the neutralizer follows shortly behind. As described earlier, when the hunter detects a contact and classifies it as mine-like, it forwards this information to the neutralizer for identification and neutralization with a UUV or ROV.

It might seem that combining the hunter and neutralizer into a single vehicle would be advantageous, but continually interrupting the hunter's sonar search to identify and neutralize mines would be very inefficient, given the time required to move the towed sonar system back into a continuous, smooth motion profile to survey the waterspace.

Environments in Which the Mission Is Conducted

In-stride minehunting and neutralization is conducted under the same environmental conditions as reacquisition minehunting and neutralization.

Advantages and Disadvantages of Employing USVs for This Mission

USVs are more expendable, less expensive, and potentially stealthier than the manned platforms that could perform this mission. USVs are more suitable than UAVs and UUVs for this mission because of their greater endurance and payload capacity, as well as their stealth advantage relative to UAVs.

Autonomy and Communications Requirements

USVs performing in-stride autonomous minehunting and neutralization have the same requirements as those employed in reacquisition minehunting and neutralization (i.e., waypoint navigation, recovery capabilities, assured communications with personnel), with the addition of two requirements: (1) The hunter must have advanced software that can enable it to analyze sonar data to detect and classify sonar contacts and (2) the hunter and neutralizer must have assured communications with one another.

Desirable Classes of USV for This Mission

The classes of USVs used as hunters and neutralizers would likely be the same as those used for reacquisition minehunting and neutralization: the Harbor, Snorkeler, Fleet, E, or G classes.

Development of USV Capabilities for This Mission

The U.S. Navy's RMMV could be used for the hunting aspect of in-stride autonomous minehunting and neutralization.

Mechanical Minesweeping and Mine Harvesting

Description of the Mission and the Concept of Employment

This mission is intended to counter moored mines—that is, buoyant mines that are tethered to an anchor. Like its immediate predecessors, this mission has two phases. In the first phase, mechanical minesweeping, a platform drags cables behind it; each cable is studded with devices that catch onto and sever the tethers of any moored mines the cable encounters. The second phase, mine harvesting, requires a surface-level net to be dragged through the water to collect the newly severed mines for subsequent disposal. Of the two phases, only mechanical minesweeping is current U.S. Navy practice, though mine harvesting was practiced during the Vietnam War. Under current protocol, mechanically swept mines are neutralized by helicopter-deployed assets. However, mine harvesting could counter not only mines that have been mechanically swept but also mines that have been deliberately set adrift and those whose tethers have broken accidentally.

The concept of employment for USVs would be to use one USV (the "sweeper") to tow cables severing the tethered mines. Two "harvester" USVs with a net strung between them would immediately follow the sweeper and catch the severed mines in the net.

Environments in Which the Mission Is Conducted

Mechanical minesweeping and harvesting would be conducted if there were a potential or known threat from moored mines. This mission could be performed either openly in a permissive environment or stealthily in a nonpermissive one. Like the previously described minehunting and neutralization missions, it would usually be conducted in relatively confined waters with low traffic densities and might need to be conducted during high sea states.

Advantages and Disadvantages of Employing USVs for This Mission

As with minehunting and neutralization, USVs that perform mechanical minesweeping and mine harvesting would dramatically reduce the risk to personnel and key assets by keeping them out of the minefield and, potentially, farther away from other types of enemy weapons. It would also reduce capital asset requirements and costs.

USVs are more suitable for this mission than UAVs or UUVs, given that both sweepers and harvesters would need considerable power and endurance.

Autonomy and Communications Requirements

Both sweeper and harvester USVs would have minimal requirements in these areas—namely, waypoint navigation capabilities and the ability to coordinate their recovery with host platforms.

Desirable Classes of USV for This Mission

Sweepers' and harvesters' power requirements suggest that larger classes of USVs, such as the Fleet, E, F, or G classes, would be best. If sensitive influence mines were expected to be interspersed among the moored mines, the relative acoustic and magnetic signatures of different USV classes would need to be taken into account; this may give some advantage to smaller classes.

Development of USV Capabilities for This Mission

There are no USVs currently being developed for mechanical minesweeping and mine harvesting. However, any USV with substantial towing capabilities could be readily adapted for this purpose.

Influence Minesweeping

Description of the Mission and the Concept of Employment

The purpose of influence minesweeping is to generate a signal that causes an influence mine (i.e., a non-contact mine) to incorrectly perceive that a ship is overhead and detonate. Influence minesweeping gear can emit acoustic, magnetic, and other ship signatures for this purpose. Such gear is typically towed by a ship, helicopter, or other platform via a long towing cable.

The concept of employment for this mission would simply be to use a USV as the towing platform. The USV would traverse potentially mined waterspace in a “mowing the lawn” pattern, towing the minesweeping gear behind it.

Environments in Which the Mission Is Conducted

Influence minesweeping would be conducted in the context of a threat from influence mines. As with other MCM missions, it could be performed either openly in a permissive environment or stealthily in a nonpermissive one. It would usually be conducted in relatively confined waters with low traffic densities, and it might be need to be performed during high sea states.

Advantages and Disadvantages of Employing USVs for This Mission

Influence minesweeping platforms, like those performing other MCM missions, are at inherent risk from minefields and/or hostile fire. Having USVs perform influence minesweeping would reduce the risk to personnel and more valuable assets. Moreover, it would reduce the requirement for capital assets and reduce costs.

USVs are more suitable for this mission than UAVs or UUVs since towing minesweeping gear would require sustained, large-scale power output.

Autonomy and Communications Requirements

Influence minesweepers, like mechanical minesweepers and mine harvesters, require only waypoint navigation capabilities and the ability to coordinate with recovery platforms.

Desirable Classes of USV for This Mission

Given influence minesweepers’ power requirements, larger classes of USVs, such as the Fleet, E, F, or G classes, would be best in this role.

Development of USV Capabilities for This Mission

The Navy has a program of record for this mission, the Unmanned Influence Sweep System (UISS), an 11-meter (Fleet class) USV.

Minefield Proofing

Description of the Mission and the Concept of Employment

Minefield proofing, also called "check sweeping," entails sending a platform into potentially mined waterspace for two complementary reasons: (1) to help determine if the mine risk is acceptably low for subsequent usage of the waterspace and (2) to reduce the residual risk by detonating any remaining mines. Minefield proofing is typically conducted under one of two conditions. The first is following extensive MCM operations, when there is a desire to perform one last check to validate their effectiveness and/or reduce the risk from any residual mines. The U.S. Navy conducted minefield proofing for this purpose in 1973 as part of Operation End Sweep, sending the foam-filled USS *Washtenaw County* through the minefields in North Vietnam that the Navy had cleared in compliance with the Paris Peace Accords. The second condition under which minefield proofing is conducted is when there is an urgent need to determine whether a waterspace has been mined. One example of this took place during the 1982 Falklands War, when the British Royal Navy sent HMS *Alacrity* to proof for possible mining in Falkland Sound.

The USV concept of employment for this mission entails a USV with an ample draft, high magnetic signature, and loud acoustic signature to move through the waterspace to be proofed. If desired, the USV's draft and signatures could be enhanced by attachments (e.g., a large rake to increase effective draft, wire coils to increase magnetic signature, a very loud speaker system). The USV might also be made more capable of surviving a mine blast by filling it with buoyant materials, such as foam or ping-pong balls.

Environments in Which the Mission Is Conducted

Minefield proofing would typically be performed in relatively confined waters; due to the prospective mine risk, there would be little ambient traffic. Depending on the urgency of the mission, it might be conducted during high sea states.

Advantages and Disadvantages of Employing USVs for This Mission

Having a USV assume the risk of deliberately detonating any residual mines greatly reduces risk relative to having manned platforms perform this mission. There are also potential benefits in terms of costs and asset requirements.

USVs are far more suitable than UAVs or UUVs for this mission because they can more accurately replicate the signatures associated with a ship.

Autonomy and Communications Requirements

The USV would require only waypoint navigation capabilities and the ability to move out of key shipping channels if it were in danger of sinking.

Desirable Classes of USV for This Mission

This mission requires larger size: a G-class vessel (41 meters) or a large civilian ship that has been converted into a USV would be best.

Development of USV Capabilities for This Mission

USVs are not currently being developed for this purpose.

Minelaying

Description of the Mission and the Concept of Employment

Naval minelaying is simply the process of dropping mines into the waterspace in designated locations. The United States currently does this exclusively by dropping mines from aircraft, although it previously conducted minelaying from submarines and surface ships. Such minefields could be operationally useful for several reasons. A hostile state's submarines and surface vessels could face the invidious choice of being trapped in (or outside of) their homeports or subjecting themselves to mine damage. Clearing the mines would be time-consuming, resource-intensive, and risky. In other cases, mines could be used to protect particular waterspace from submarine incursions.

Mines could also be used to apply strategic pressure on a state, with the condition that the United States would clear the minefield once the state's offending behavior had ceased. The most recent minelaying operation by DoD was during the Vietnam War, when the United States aerially laid mines in Haiphong Harbor to coerce North Vietnam during negotiations.

The existence of a robust mining capability could have value even if the mines are never employed. To the degree that an adversary fears naval mining by the United States, it needs to invest in costly MCM capabilities. Moreover, the possibility that waters could have been stealthily mined could lead to trepidation and protract time lines at critical moments.

The USV concept of employment for minelaying would be simple: a USV would depart from a host ship or pier, follow preprogrammed tracks, and release mines at designated locations. If feasible, it would be desirable to be able to release the mines from beneath the hull. In environments where the USV might be subject to enemy surveillance, this ability would frustrate adversary attempts to observe where the mines were laid. If the mines had some mobility—as the recently retired Submarine-Launched Mobile Mine (SLMM) did—they could further obfuscate attempts to ascertain their final locations.

An alternate concept of employment would be to have a UUV attached by a long tether (e.g., multiple miles) to a USV to deliver the mines. This arrangement could enhance stealth but would require added complexity.

Environments in Which the Mission Is Conducted

Minelaying would mostly be performed in hostile, confined waterspace, although (as noted previously) it might be conducted in permissive waters to counter the submarine threat. It could be conducted at various levels of maritime traffic and during a variety of sea states.

Advantages and Disadvantages of Employing USVs for This Mission

Large USVs would be able to deliver more mines than combat aircraft and without putting those aircraft at risk. Moreover, the use of USVs would prevent valuable combat aircraft from being pulled away from alternate tasking and would likely be less expensive.

USVs are far more suitable than UAVs for this mission. UAVs have smaller minelaying capacities than would USVs, and an adversary could observe the mines' splash points to aid in its MCM efforts. The chief advantage UUVs would have over USVs for minelaying would be their ability to be stealthier in hostile environments. However, the limited payloads, ranges, and endurances of UUVs compared with similarly sized USVs would put them at a disadvantage. This is a principal reason why having a UUV tethered to a USV to conduct minelaying could be advantageous: the USV would provide power, payload, and endurance, while the UUV could provide a modicum of stealth.

Autonomy and Communications Requirements

A minelaying USV would require waypoint navigation capabilities and the ability to release mines at specified locations. It would also need to be able to avoid traffic and, in some cases, maneuver evasively or sink itself to avoid capture. If it had a tethered UUV, it would need to control it as well.

Desirable Classes of USV for This Mission

For minelaying, large size is paramount: E-, F-, or G-class vessels would be required to lay appreciable numbers of mines.

Development of USV Capabilities for This Mission

USVs are not currently being developed for minelaying. In principal, the ACTUV seaframe could be modified for this mission.

APPENDIX D

Concept of Employment for a USV Training Platform

USVs as Training Platform

This appendix describes the use of USVs as training platforms, together with several other key considerations: the environments in which the training mission is conducted, the advantages and disadvantages of employing USVs for the mission, autonomy and communications requirements of the mission, desirable classes of USVs for the mission, and the level of development of USV capabilities for the mission.

Description of the Mission and the Concept of Employment

U.S. Navy surface force training is based on service policy and doctrine to prepare individuals, teams, and ships to become interoperable units. U.S. Navy training is sequenced through several phases: basic-, intermediate-, and advanced-phase training. In the basic phase of training, ships train and demonstrate their proficiency and obtain certification in the mission areas they are designed to perform. Intermediate training focuses on teaching naval units (e.g., ships) to operate in unison with one another. In advanced-phase training, units are trained and tested in a joint environment—e.g., with U.S. Marine Corps assets and/or Air Force aviation units.

USVs could support the U.S. Navy in each of these phases of training. A primary mission area for surface ships—frigates, destroyers, and cruisers—is surface warfare (SUW). USVs provide a realistic and maneuverable target designed to simulate the actions and responses of small boats. USVs could simulate piracy operations by acting as small boats or fast attack units and could be used as platforms to support over-the-horizon-targeting (OTHT) exercises. The threat of small (and large) surface craft is significant, especially in restricted waterways and choke points. For example, the U.S. Navy operates in the Persian Gulf, where shipping traffic is dense and includes small boat traffic. The challenge is that small, high-speed boats or FAC can saturate defenses and present a real threat to U.S. Navy ships. A ship at anchor or in port can be an easy target if crews are not trained to counter this threat.[1] USVs can serve as a realistic opposition force asset to train units for deployment on the tactics, procedures, and rules of engagement for SUW missions, small boat tactics, and other missions. Surface ships (and some USVs) currently perform the role of Opposition Force (OPFOR) units. Using USVs as OPFOR units provides a realistic training opportunity to prepare units for this threat. USVs used as training support assets could also fulfill the secondary mission of serving as test platforms.

Sensor packages that could be installed on USVs to assist training include active/passive acoustics, passive/active radar augmentation, AISs,[2] flares, electro-optical/infrared cameras, full-motion video, and strobe lights (to simulate firing). A USV could be outfitted with some or all of these packages, depending on the scenario and training demands. For example, an active radar augmentation could be installed on a USV to support an OTHT engagement by surface/air platforms.

USVs could also be optionally manned in support of training. A manned platform offers the command, control, and communication (and maintenance) role that may be needed in an OPFOR environment. USVs performing the training support mission would need direct C2 links with an OPFOR commander. They must be controllable and be ready to respond to course, speed, and track changes relative to the forces they are operating against. The actions of USVs used as training support assets must be integrated by an OPFOR commander—that is, "a man in the loop." USV actions must be planned,

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1 The USS *Cole* bombing in Yemen in 2000 demonstrates the devastating damage posed by small boats. Seventeen USS *Cole* sailors were killed and 39 were injured in the attack. The ship required extensive repairs and was out of service for an extended period.

2 AIS is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels.

as well as dynamic. Controllers of USVs will need training to use them as intended in support of training events. That the OPFOR units are unmanned (or optionally manned) platforms may be transparent to units that are being trained.

The USV concept of employment for an OPFOR USV would be as follows: USV(s) would depart from a pier, follow a preprogrammed route out of the harbor, and proceed to a designated location(s) for the FAC, antipiracy, or OTHT exercise. Some autonomy is needed, such as waypoint travel and traffic avoidance. The OPFOR commander will direct the USVs to present an attack to a ship, closing the ship or ships at high speed and stressing the crew to communicate and follow ROE and detect-to-engage procedures. USVs can provide a realistic representation of what could occur in the operational environments in which our deployed forces operate today and support training for engagement with these potential threats.

Environments in Which the Mission Is Conducted

The training environments in which USVs would primarily operate would be fleet operating areas (OPAREAs), such as the Hampton Roads Operating Areas off of Norfolk, Virginia, and the Southern California Operating Area (SOCAL) off of San Diego. Training support with USVs would mostly be performed in friendly, open water. The mission could be conducted at various levels of maritime traffic and at a variety of sea states.

Advantages and Disadvantages of Employing USVs for This Mission

The advantage of employing USVs as OPFOR units is that USVs provide realistic platforms in numbers that can replicate a threat to naval forces. Ships must be prepared to defend against the tactics employed to saturate a ship's defenses, as this type of asymmetric warfare has been used in the past and is a threat to ships and units. USVs employed as training OPFOR units can assist deploying ships in preparing for this threat. The disadvantage of employing USVs in this role is that they may pose additional cost if a complementary role for their services is not available. However, surface ships do act as OPFOR units today, and USVs could perform this role at a lower cost relative to manned surface platforms that consume fuel and/or other consumables. Another disadvantage could be the loss of the training benefit manned OPFOR units derive from performing the OPFOR role.

Autonomy and Communications Requirements

USVs performing OPFOR roles would require waypoint navigation capabilities and, based on certain training scenarios, would be augmented with radar and/or other sensors. These USVs would preferably have the ability to avoid shipping traffic and, in some cases, conduct evasive maneuvers to evade engagement with U.S. Navy ships' weapon systems.

Desirable Classes of USV for This Mission

For training support, the speed of the platform is important, as well as the sensors or augmenting packages that could be installed onboard in support of training requirements. A 7-meter RHIB-sized vessel could support this role (and a smaller vessel could do so as well).[3] An 11-meter RHIB may also be appropriate for the training requirements. The training role supported is as an FAC, piracy craft, and OTHT target.

Development of USV Capabilities for This Mission

USVs are currently being used for training support and have assisted the U.S. Navy with the counter-FAC mission, most notably the High Speed Maneuvering Sea Target (HSMST) developed by the Naval Air Warfare Center Weapons Division at Point Mugu. HSMSTs are the workhorses of the surface target fleet and can be operated manned or unmanned and remotely controlled. A Canadian company has also manufactured USVs to support this role and has conducted training exercises with allies using USVs.

The traffic avoidance technology requirement, if developed in other areas, would be a very useful and necessary feature. The technol-

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[3] The Canadian Navy has employed a small (5-meter) OTH-capable USV that functions as an expendable "kill target" (warfighters can fire live ammunition at the USV). The manufacturer claims that the USV provides a more realistic and maneuverable target designed to simulate the responses and maneuvers of small boats.

ogy needed for training support (for unmanned USVs), such as waypoint travel and traffic avoidance, would be useful to the test platform mission also. If optionally manned, the need for autonomy is reduced, but the need for assured communications increases. USVs can and do perform this training role, but they would need to be under direct control of an OPFOR commander. An optionally manned training support USV would benefit units being trained by assisting and responding to dynamic training support tasking by the OPFOR commander. Moreover, the manning on the USVs could provide direct feedback to the OPFOR commander on the performance of the units being trained. It could and should be transparent to units being trained that the OPFOR units are unmanned (or optionally manned) platforms.

There should be few organizational acceptance issues for USVs operating as OPFOR units. The OPFOR commander, USV training support operators, and manned operators (if deemed appropriate) will require C2, communication, and maneuvering requirements training to integrate the OPFOR and meet the training demands of the ships. The U.S. Navy will also need trained personnel to perform maintenance on the USVs used for training support, as well as facilities and/or a cradle on the pier to perform installation and/or maintenance.

APPENDIX E

Concept of Employment for a USV Test Platform

USVs as Test Platforms

This appendix describes the use of USVs as test platforms, including discussion of the mission environment, the advantages and disadvantages of employing USVs for this mission, the autonomy and communications requirements of the mission, desirable classes of USV for this mission, and the level of development of USV capabilities for this mission.

Description of the Mission and the Concept of Employment

USVs can perform the role of a test platform in two ways: (1) as a test platform for equipment that will eventually be installed on surface ships and (2) as a test platform for testing USV equipment and systems and examining the suitability of USVs to effectively and efficiently perform different missions.

There are numerous demands placed on the U.S. Navy surface force to support the development and testing of new systems and equipment that will eventually make its way to the fleet. While manned surface ships are normally used for testing new systems, ships are in high demand for operational missions and are less available to perform as test platforms. USVs could suit this role. There are extensive testing requirements normally used to provide a proof of concept and operational functioning of systems and equipment before adoption by the fleet. This extensive installation, training, and testing puts significant demands on the surface ships that are used as test platforms. Often, the tests require significant underway time to measure and gauge the system or equipment's performance during underway operations in an operational and maritime environment.

USVs are in the developmental stage, and USV test platforms are used to examine new concepts for their use, as well as assess their practicality and suitability for different missions. The U.S. Navy and private industry have built USVs for this role, and continued investment is needed for USVs to be used as test beds and expand their role. The use of USVs should be pursued in areas or missions where they can decrease risk to personnel, equipment, and ships and increase capability at a potentially lower cost.

In the early phases of testing, systems or equipment can be installed on USVs to support an operational evaluation. Moreover, USVs could remain underway for extended periods to operate the systems, test their functionality, and provide an initial gauge of their performance before they are installed on Navy ships. USVs have the advantage of being relatively low-cost assets (compared to manned ships) with the ability to remain underway for extended periods of time. The capability of autonomous operation would greatly add to the benefits of USVs as test platforms. C2 for maneuvering could be performed pierside, and a remote equipment/system monitoring station could also be established at a shore station. In addition to serving as test platforms, USVs could fulfill the secondary mission of providing training support.

The concept of employment for a USV test platform would be as follows: The system or equipment to be tested on the USV would be installed pierside. Remote monitoring capability of the system or equipment, if needed, could also be installed pierside. The USV would depart from the pier, follow a preprogrammed route out of the harbor, and proceed to a designated location where the testing can be completed. A USV performing a testing mission would be under the direct command of a shore facility directing the test. The USV must be either autonomous or controllable and responsive to course, speed, and track changes. The testing coordinator or designated shore-based commander will direct the USV to course and speed changes and/or maneuvers to complete the operational testing demands. USVs can provide a realistic representation of the operational environment and may save valuable underway days for manned surface platforms in addition to potentially saving money.

A USV can be a test bed for evaluating systems that may be employed on other USVs. ONR has used the Unmanned Sea Surface Vehicle-High Tow Force (USSV-HTF) to aid in platform design, develop CARACaS, develop recovery and underway refueling technologies, and test a USV-hosted mine influence sweep. Similarly, ONR and DARPA fund work using the Powervent USV, developed by NSWC-Carderock, to test advanced autonomy systems and collaborative algorithms. The Seadoo Challenger 2000 is used by the Space and Naval Warfare Systems Center as a test bed to assess and leverage unmanned ground vehicle (UGV) technology for use on USVs.[1]

The U.S. Navy has designed and built USVs, and continued development is needed to employ them as test platforms for improved USV capabilities, such as navigation, autonomous operations, and obstacle avoidance systems. Increasing the capabilities of these systems through testing will help leverage USVs to support mission demands, potentially at reduced risk and cost.

Environments in Which the Mission Is Conducted

USVs would operate as test platforms in fleet OPAREAs, such as the Hampton Roads Operating Area off of Norfolk, Virginia, and the Southern California Operating Area (SOCAL) off of San Diego, California. The mission could be conducted at various levels of maritime traffic and at a variety of sea states. Testing support with USVs would mostly be performed in friendly, open water.

Advantages and Disadvantages of Employing USVs for This Mission

One advantage of employing USVs as test platforms is that it allows new systems and equipment to be tested in their intended operational environment. Also, the use of USVs as test platforms could reduce the burden placed on the surface ships that currently act as test platforms. At the very least, USVs could be configured to perform this role during

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[1] Amit Motwani, *A Survey of Uninhabited Surface Vehicles*, Marine and Industrial Dynamic Analysis, School of Marine Science and Engineering, Plymouth University, April 22, 2012.

the initial stage of testing that occurs afloat in a maritime environment. New systems and equipment do not always perform well when first installed. An operational evaluation in a USV would provide a relatively low-cost opportunity to test the system or equipment in the maritime environment in which it was designed to operate. USVs employed as test platforms can assist program offices in the testing and development of their systems and equipment. This platform offers the opportunity to test the equipment in a benign environment without imposition on a ship's crew and/or equipment to "get the bugs out." The disadvantage of employing USVs as test platforms is the additional time and cost that may be required to conduct an operational evaluation on a USV. Moreover, a USV may not be the appropriate test platform for all systems and equipment. However, surface ships act as test platforms for U.S. Navy systems and equipment today, often requiring extensive underway periods for testing and operational evaluations. USVs could perform this role at a lower cost than manned surface platforms that consume fuel and/or other consumables.

Autonomy and Communications Requirements

A USV performing the role of a test platform would require waypoint navigation capabilities and, depending on the testing scenario, would be augmented with radar and/or other sensors in addition to the systems and equipment being tested. The USV would preferably have the ability to avoid shipping traffic and, as needed, conduct maneuvers in support of the testing demands.

The need for autonomous operations may be high. The USV will need to transmit and receive communications and data with a shore station. While a manned platform would be more suitable as a test platform, it is much more costly. A "man in the loop" would be helpful for troubleshooting, resetting, and communicating the performance of the equipment or system being tested. Designing modularity into USV test platforms would be greatly beneficial, allowing them to accommodate different systems and equipment. The need for power on the USVs would likely outweigh any energy scavenging demands for a testing platform mission.

Desirable Classes of USV for This Mission

The USV must be functionally aligned with the requirements of the equipment being tested. For example, the systems being tested may require specific power supplies. For testing support, the power of the platform is important, as well as the sensors or augmenting package that is installed onboard in support of the training requirements. Either a 7-meter or 11-meter RHIB could function in this role. An 11-meter RHIB may offer the appropriate size and power needed to support testing requirements.

Development of USV Capabilities for This Mission

As noted above, USVs could perform both as test platforms for equipment that may eventually be installed on surface ships and as a test platforms for testing USV equipment and systems. For the latter role, there are numerous USVs undergoing testing and evaluation to determine their suitability for performing maritime missions, including the Seadoo Challenger 2000. However, there is no known U.S. Navy development in the area of using USVs as test platforms for systems/equipment intended to be installed on surface ships.

The technologies needed for a USV to perform as a test platform depend on the system or equipment being tested. Therefore, the capabilities requirements for simply testing communications gear in a maritime environment could be minimal, while more advanced capabilities may be needed to test systems with sophisticated energy demands.

The technology needed for a USV test platform, such as waypoint travel and traffic avoidance, would also be useful to the training platform mission. If optionally manned, the need for autonomy is reduced, but, as is the case in the training platform role (and all roles), the need for assured communications is increased for manned platforms. USVs could perform this role, but they would need to be under direct control of a shore-based controller (if unmanned) for the duration of the at-sea testing. An optionally manned test support USV could provide additional benefits if it served a complementary role while underway.

When a USV is not being used in a testing role, it could be used in support of surface force training. Additionally, the USV could provide logistics support to remote bases—e.g., San Clemente Island—

shuttling supplies and equipment to units and personnel based in these facilities. An optionally manned USV test platform could also perform this role.

As with training platform USVs, there should be few organizational acceptance issues with USVs operating as test platforms. While systems and equipment sponsors may offer resistance to testing their equipment on a USV instead of a manned platform, fleet demands and limited ship assets may necessitate a satisfactory operational test on a USV (and any necessary troubleshooting) before tasking manned platforms with supporting an operational evaluation of a system or equipment.

Training will be needed for the systems test personnel, USV test support operators, and manned operators (if deemed appropriate), as well as those who design systems to be tested on a USV platform. The required training will consist of C2, communication, and maneuvering requirements to integrate the OPFOR and meet the testing demands of the ships.

The U.S. Navy will also need trained personnel to perform system or equipment installation and maintenance on USVs for testing support. Facilities and/or a cradle on the pier in which to perform installation and/or maintenance will be necessary as well.

APPENDIX F

Concept of Employment for Armed Escort and to Counter Fast Attack Craft

This appendix describes the use of USVs for armed escort and to counter FAC, including discussion of the mission environments, the advantages and disadvantages of employing USVs for these missions, the autonomy and communications requirements of these missions, desirable classes of USV for these missions, and the level of development of USV capabilities for these missions.

Armed Escort

Description of the Mission and the Concept of Employment

For this mission, USVs would escort warships and/or important civilian vessels (such as ferries or liquefied natural gas tankers) when they were in confined waters. Multiple USVs would form a security screen around the vessel, interposing themselves between the vessel and prospective attackers. The USVs would try to characterize the intent of small boats, differentiating curious onlookers and other nonhostile boaters from those aiming to launch an attack. They would employ a continuum of force against potential threats, including warnings, nonlethal weapons, blocking, ramming, swamping, and lethal force.

Environments in Which the Mission Is Conducted

This mission would typically be conducted in confined waters with moderate to high traffic conditions, such as inland waterways, the approaches to ports, maritime chokepoints, and occasionally narrow seas. It would exclusively be conducted in friendly environments. Sea states would vary.

Advantages and Disadvantages of Employing USVs for This Mission

A prime reason for using USVs for this mission would be to reduce risk to personnel compared with employing manned boats. This may contribute to deterrent effects, as a suicide attacker who is intercepted would damage a device rather than a person. A secondary consideration would be that if the USVs can operate autonomously, they may be less costly than having manned boats perform the mission.

USVs would be preferable to UAVs or UUVs for this mission. The visibility and proximity of the USVs would aid in communicating with prospective threats, helping to differentiate actual threats from curious boaters. Also, their ability to physically interpose themselves between prospective threats and the high-value target could aid in deterring prospective attackers.

There are two key disadvantages of using USVs for this mission. First, they would need to operate weapons in close proximity to high-value targets and neutral traffic, and misfired weapons could have dire consequences. Second, they would need to be highly agile to avoid collision with neutral traffic, as well as the vessel they were protecting and one another.

Autonomy and Communications Requirements

The USVs' close proximity to the ship being protected would facilitate remote control from it. The controllers would have situational awareness both from their own ship and from the sensors aboard the USVs. The main disadvantage of the USVs being primarily remote controlled rather than autonomous is that it would require the attention of multiple personnel and raise costs. However, given that most transit through narrow, densely trafficked waterways would be relatively brief, this may not be an insuperable obstacle. Moreover, even if USVs are technologically capable of autonomously operating and using force in these environments, there may be legal and institutional resistance to allowing them to do so.

Desirable Classes of USV for This Mission

Agility, speed, the ability to launch weapons, and sheer momentum would all be useful attributes for USVs conducting this mission. As such, the Fleet or E classes would likely be good choices.

Development of USV Capabilities for This Mission

The most important development requirement for this mission would be a well-honed remote-control network that instilled sufficient confidence to allow an armed USV to operate in well-trafficked waters.

Countering Fast Attack Craft

Description of the Mission and the Concept of Employment

This mission would be similar to armed escort, but it would be conducted within a port facility to protect anchored ships, as well as port infrastructure. As such, the mission would likely be of longer duration than the transits during which armed escorts would be conducted. An adversary would have the advantage of being able to stalk a stationary target, observing it closely and striking at the most opportune moment.

Depending on the geometry of the port, a group of USVs could protect a single ship or could protect multiple ships in close proximity to one another. The USVs would form a security screen between the vessel and potential attack craft. Again, a continuum of force would be used, ranging from warnings to deadly weapons.

Environments in Which the Mission Is Conducted

As noted above, this mission would be conducted in friendly (i.e., non-hostile) port facilities and their approaches. Sea states would vary.

Advantages and Disadvantages of Employing USVs for This Mission

Employing USVs for this mission rather than manned boats would diminish the risk to personnel. However, if the boat is remotely controlled, there may be the disadvantage of a loss of situational awareness. Regardless of how many cameras and sensors a USV has, a human-machine interface remains: a person controlling a USV from afar is likely to have less situational awareness and slower reaction times than one who is aboard a manned boat.

However, if a USV can operate fully autonomously with institutional confidence in its ability to avoid collisions and use force only when warranted, it could actually respond more quickly and deftly than a manned boat. Moreover, its relative expendability would be an asset: it could ram another vessel under circumstances in which a manned boat could justifiably be more hesitant to do so. If human controllers were only marginally involved in the USV control loop, there could be considerable cost savings in terms of personnel. An autonomous USV that could be trusted with this mission is still a long way off, but it is a desirable outcome.

USVs would be preferable to UAVs or UUVs for this mission for the same reasons they would be preferable for armed escort—their visibility and ability to physically block attacks.

As in the armed escort mission, principal concerns include the need to avoid collisions with neutral traffic or static objects, as well as avoid using lethal force inappropriately.

Autonomy and Communications Requirements

As noted above, this mission could be conducted either via remote control or autonomously.

Desirable Classes of USV for This Mission

As with the armed escort mission, agility, speed, the ability to launch weapons, and momentum would all be important. As such, the Fleet or E classes would likely be good choices.

Development of USV Capabilities for This Mission

As with the armed escort mission, the most important aspect of USV development for countering FAC is ensuring that armed USVs have the C2 capability (preferably autonomously) to operate safely and perform the mission in a high-traffic environment.

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This report assesses in what ways and to what degree unmanned surface vehicles (USVs) are suitable for supporting U.S. Navy missions and functions. It briefly characterizes the current and emerging USV marketplaces to provide a baseline for near-term capabilities, describes USV concepts of employment to support diverse U.S. Navy missions and functions, and evaluates these concepts of employment to identify specific missions and functions for which they are highly suitable. USVs offer several particular strengths relative to other platforms, including the ability to interact both above and below the waterline, enabling them to serve as critical nodes for cross-domain networks. They also have potentially longer endurance, larger payloads, and higher power outputs than comparably sized unmanned air or undersea vehicles. Additionally, their greater risk tolerance compared with manned systems makes them desirable platforms for overcoming adversaries' anti-access and area-denial measures. These strengths make USVs particularly suitable for missions such as characterizing the physical environment, observation and collection regarding adversaries, mine warfare, military deception/information operations/electronic warfare, defense against small boats, testing and training, search and rescue, and the support of other unmanned vehicles. However, USVs need advanced autonomy and assured communications to complete complex missions, as well as any missions in complex environments. Autonomous seakeeping and maritime traffic avoidance are USV-specific capabilities that likely need to be developed with U.S. Navy involvement. Also, optional manning and payload modularity can enhance the desirability of USV programs.

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