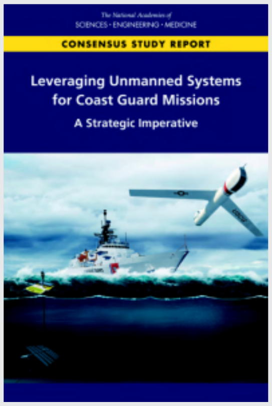

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Leveraging Unmanned Systems for Coast Guard Missions

A Strategic Imperative

Committee on Coast Guard Maritime Domain Awareness

A Consensus Study Report of

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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Preface

Section 812 of the Frank LoBiondo Coast Guard Authorization Act of 2018 calls on the National Academies of Sciences, Engineering, and Medicine (the National Academies) to "prepare an assessment of available unmanned, autonomous, or remotely controlled maritime domain awareness technologies for use by the U.S. Coast Guard." The full legislative request for the study is provided in Appendix A.

To conduct the study, which was undertaken under the auspices of the Transportation Research Board (TRB) and its Marine Board, the National Academies appointed a committee of 10 experts in the fields of automation and control; systems research, acquisitions, and integration; Coast Guard operations and mission support; naval engineering and architecture, cybersecurity, field applications of unmanned systems; and relevant legal, regulatory, and policy issues. This report represents the consensus efforts of these 10 individuals, who served uncompensated in the public interest. Their biographical information is provided in Appendix B.

ACKNOWLEDGMENTS

The committee met six times from September 2019 to June 2020 to gather information relevant to the study and to deliberate on the report contents, findings, and recommendations. Four of the meetings included briefings and discussions with experts from industry, academia, and numerous government agencies on existing and planned uses of unmanned systems, operational issues, cybersecurity and mission support requirements, and requisite institutional and organizational structures.

The committee wishes to thank the following individuals for participating in these briefings and making other contributions to the committee's work.

From the U.S. Coast Guard: LCDR Steven Arnwine, Operations Officer, USCGC Munro; Eric Downes, Deputy Chief Information Officer for Intelligence; CDR Maria Richardson, UAS Joint Program Office Supervisor; RADM Matthew Sibley, Assistant Commandant for Capability; CDR Chad Thompson, Chief, Unmanned Aircraft Systems; and CDR Sara Wallace, Deputy, Office of Requirements and Analysis. The committee also wishes to thank Scott Craig, who served as the principal contact between the Coast Guard and the committee and coordinated information requests from the committee to offices within the Coast Guard, and William Carter, who provided valuable information regarding the Coast Guard response operations for oil spills of national significance.

From the U.S. Department of Homeland Security: Timothy Bennett, Science and Technology Directorate, and Joseph Wawro, Joint Requirements Council.

From the U.S. Navy: Donald McCormack, Naval Surface Warfare Center and Naval Undersea Warfare Center; Anthony Schmidt, Naval Air Warfare Center; CAPT Pete Small, Navy Unmanned Maritime Systems Program Office; and Jason Stack, Office of Naval Research.

From other federal agencies: Francisco Castillo and Michael Romanowski, Federal Aviation Administration; RADM Tim Gallaudet, National Oceanic and Atmospheric Administration; Michael Ilmanen and Scott Millerand, Federal Bureau of Investigation; Bradley Koeckeritz, U.S. Department of the Interior; and John Sherman, Director of National Intelligence.

From academia, research institutions, and industry: Peter Beling, University of Virginia; James Bellingham and Glen Gawarkiewicz, Woods Hole Oceanographic Institution; Joseph Bondaryk, Apollo Autonomy; Steve Brodet, Hydroid; VADM Michael Connor, ThayerMahan Inc.; Francesca D'Arcangelo, MIT Lincoln Laboratory; Donald Siebers and Namrata Kolla, Vulcan Inc.; and Michael Smitsky, Association for Unmanned Vehicle Systems International.

Monica A. Starnes directed the study and assisted the study committee in the preparation of this report under the guidance of Thomas R. Menzies Jr. Anusha Jayasinghe provided support to the committee in arranging meetings.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The National Academies thanks the following individuals for their review of this report: Craig Allen, University of Washington School of Law, Seattle, Washington; Michael Connor, ThayerMahan, Inc., Groton, Connecticut; Mary Landry, U.S. Coast Guard (retired), Boston, Massachusetts; Thomas McNamara, Raytheon Missiles & Defense, Tewksbury, Massachusetts; John Montgomery, Center for Naval Analysis, Granite Falls, North Carolina; Alan Weigel, Blank Rome LLP, Lisbon, Connecticut; and Steven Wiker, ErgoTek, Inc., Nine Mile Falls, Washington.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the committee's conclusions and recommendations, nor did they see the final version of the report before its release. The review of the report was overseen by National Academy of Engineering members Chris T. Hendrickson, Carnegie Mellon University, Pittsburgh, Pennsylvania, and Chris G. Whipple, Consultant, Lafayette, California. Appointed by the National Academies, they were responsible for making certain that an independent review of the report was conducted in accordance with institutional procedures and that all review comments were carefully considered by the committee. Responsibility for the final content of the report rests solely with the authoring committee and the institution. Karen Febey, Senior Report Review Officer, TRB, managed the report review process.

Contents

Acronyms and Abbreviations

AECA	Arms Export Control Act
AEGIS	Advanced, Efficient and Green Intermodal Systems
AIS	Automatic Identification System
ASR	air search radar
ATON	Aids to Navigation
AUTOSHIP	Autonomous Shipping Initiative for European Waters
AUV	autonomous underwater vehicle
AUVSI	Association of Unmanned Vehicle Systems International
BSEE	Bureau of Safety and Environmental Enforcement
C4&IT	Command, Control, Communications, Computers, and Information Technology
CBP	U.S. Customs and Border Protection
CG	Coast Guard
CMI	Comité Maritime International
COA	Certificate of Waiver or Authorization
CONOPS	concept of operations
CRADA	Cooperative Research and Development Agreement
CRREL	Cold Regions Research and Engineering Laboratory
cUAS	Counter-Unmanned Air System
cUUV	Counter-Unmanned Underwater Vehicle
DARPA	Defense Advanced Research Projects Agency

DASN (UxS)	Deputy Assistant Secretary of the Navy for Unmanned Systems
DCMS	Deputy Commandant for Mission Support
DCO	Deputy Commandant for Operations
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOI	U.S. Department of the Interior
DOJ	U.S. Department of Justice
DOL	Director of Operations Logistics
EEZ	Exclusive Economic Zone
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FBI	Federal Bureau of Investigation
FORCECOM	Force Readiness Command
FY	Fiscal Year
GPS	global positioning system
HQ	Headquarters
ICAO	International Civil Aviation Organization
ICE	U.S. Immigration and Customs Enforcement
IMO	International Maritime Organization
IOC	Interagency Operations Center
ISO	International Organization for Standardization
ISR	Intelligence, Surveillance, and Reconnaissance
ITAR	International Traffic in Arms Regulations
IWG	International Working Group
JIATF-S	Joint Interagency Task Force South
LIDAR	Light Detection and Ranging
LR	Lloyd's Register
MARAD	Maritime Administration
MASS	Maritime Autonomous Surface Ship
MDA	maritime domain awareness
MER	Marine Environmental Response
MOTR	Maritime Operational Threat Response
MSC	Maritime Safety Committee

MSRO	Maritime Security and Response Operations
MTS	Marine Transportation System
MUST	Maritime Unmanned System Technology
NAS	National Airspace System
NAVSAC	Navigation and Safety Advisory Council
NAVSEA	Naval Sea Systems Command
NCC	National Command Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSC	National Security Cutter
OAS	Office of Aviation Services
OSD	Office of the Secretary of Defense
OTA	Other Transaction Authority
PAO	public aircraft operations
PATFORSWA	Patrol Forces Southwest Asia
PC&I	procurement, construction, and improvements
PWCS	Port, Waterways and Coastal Security
R&D	research and development
RAM	reliability, availability, and maintainability
RDC	Research and Development Center
RDT&E	Research, Development, Test, and Evaluation
RF	radio frequency
ROS2	next generation Robot Operating Systems
ROV	remotely operated vehicle
RSE	Regulatory Scoping Exercise
S&T	Science and Technology
SAR	Search and Rescue
SAROPS	Search and Rescue Optimal Planning System
SIGINT	Tactical Signals Intelligence
sUAS	small unmanned aerial system
SVIP	Silicon Valley Innovation Program
TRB	Transportation Research Board
UAS	Unmanned Aerial (or Aircraft) System
UAV	unmanned aerial vehicle
UMS	Unmanned System (as per NIST)
UMV	Unmanned Maritime Vessel (or Vehicle)

UNCLOS	United Nations Convention for the Law of the Sea
USAF	U.S. Air Force
USN	U.S. Navy
USV	unmanned surface vessel (or unmanned surface vehicle)
UUV	unmanned underwater vehicle (or unmanned undersea vehicle)
UxS	unmanned system
UxV	unmanned vehicle
VHF	very high frequency
ViDAR	video detection and ranging
VLOS	visual line-of-sight
VTOL	Vertical Takeoff and Landing

Executive Summary

The Frank LoBiondo Coast Guard Authorization Act of 2018 called for this study of the U.S. Coast Guard's existing and prospective use of unmanned systems (UxSs) to fulfill its many critical and often unique missions. The act implies an interest in a range of technology-based concepts, from aerial, surface, and underwater vehicles that have no human occupants or controllers to vehicles that may have a crew but have some level of remote, automated, or autonomous control, as well as systems that are not vehicles such as intelligent decision aids. The request for this study calls for a review of the current and emerging capabilities of these systems; their affordability, reliability, and versatility; and any realignments in Coast Guard policies, procedures, and protocols that may be necessary to exploit them more fully and effectively.

As one of the country's six military services, the Coast Guard also serves as a first responder, law enforcement agency, maritime regulator, and member of the intelligence community. The Service is currently sponsoring multiple initiatives to assess the applicability of UxSs to these mission areas and to introduce their capabilities into the fleet and force structure. To date, however, the initiatives have been characterized by limited funding spread over many years and the absence of a formal means, or a pacing mechanism, for proactively identifying, investigating, and integrating promising systems. In the meantime, technological advancements in UxSs continue to accelerate, driven by commercial and military demands and interests.

A major realignment of the Coast Guard's UxS approach is warranted. After reviewing the Coast Guard's many important, complex, varied, and demanding missions; observing that its fleet and operational forces are being increasingly taxed; finding that a variety of UxSs are being used today with high utility across the public and private sectors; and knowing that the technologies that enable and underpin these systems are rapidly advancing, the committee is struck by the magnitude and breadth of opportunity that lies ahead for the Coast Guard to pursue UxSs across its multiple operational domains and missions. As other military services and other operational agencies of the U.S. Department of Homeland Security (DHS) integrate UxSs into their force structures, the Coast Guard will be impelled to do the same, because it engages in joint and combined operations and missions with these partners.

Abundant evidence in this report points to both a compelling need and burgeoning opportunities for the Coast Guard to proceed more aggressively, albeit strategically and deliberately, in leveraging UxS advancements. Indeed, **the study committee concludes that to remain responsive and fully relevant to its many missions, it is imperative that the Coast Guard take a more strategic and accelerated approach to exploit the capabilities of existing and future unmanned systems.**

The Coast Guard has expressed a keen interest in exploiting UxSs for a range of missions and with growing levels of sophistication and scale. That interest, however, is not matched by a funding commitment, including critical funding for research and development (R&D). The Coast Guard's R&D spending is modest when compared to R&D spending by other military and DHS operational agencies, and is negligible in the context of the UxS imperative. **The committee concludes that the Coast Guard's small current budget for UxS R&D and incremental applications is not sufficient to meet the UxS imperative and therefore will need augmentation by Congress and DHS to enable more and larger-scale investigations and investments.** In the committee's view, the Coast Guard's investments in UxS should be made with the explicit aim of introducing new and improved capabilities to fulfill the Service's missions, and not simply as cost-saving substitutes for traditional manned assets and operations.

How best to proceed in realigning plans, operations, budgets, and policies to prompt and enable the Coast Guard to embrace and capitalize on UxSs is a question that faces its leadership, DHS, and Congress. Similar to the experiences of other military services, DHS operational units, and several other federal agencies, the Coast Guard has reached a point where purposeful and strategic actions are needed. Informed by these experiences, the committee recommends the following five steps.

ISSUE A HIGH-LEVEL UxS STRATEGY

The Commandant should issue a high-level UxS strategy that articulates a compelling rationale for UxSs, sets forth agency-critical goals that these

systems should further, and outlines the Coast Guard's approach for achieving them. The Commandant has issued several other strategic documents to bring service-wide attention to critical needs and interests. The strategies are intended to convey urgency to senior leadership and to galvanize changes needed across the organization, from shifting budget priorities and adjusting acquisition policies to investing in supportive R&D and personnel recruitment and training. It is time, in the committee's view, for Coast Guard leadership to do the same for UxSs by articulating a vision for the use of these systems across mission areas, setting strategic goals and objectives for achieving that vision, and establishing appropriate organizational structures and lines of authority to introduce and integrate UxSs across the force structure.

DESIGNATE A SENIOR UxS CHAMPION

The Coast Guard is small when compared to other military services, but it is nevertheless a large organization with a complex—and in places stove-piped—bureaucratic structure. Although the Commandant's strategic commitment to UxSs can go a long way to spurring the institutional responsiveness required to carry the strategy out, the scope and scale of the responses that will be required should not be underestimated. Accordingly, the **Commandant should designate a top Coast Guard official, at the Flag Officer or Senior Executive Service levels, to advocate for and advance the Service's UxS strategy.** This top official should be responsible for identifying, promoting, pushing for, coordinating, and facilitating the changes that will be needed across the organization to further the Commandant's strategic goals and objectives for UxSs.

STAND UP A UxS PROGRAM OFFICE

Given the many changes in Coast Guard priorities, practices, and procedures that will be required to more fully exploit UxSs—from systems acquisition to personnel hiring and training—no single directorate or subunit could be expected to initiate and implement them all. However, a dedicated program office, in concert with a high-level UxS advocate, could play a vital leadership and coordinating role in sustaining and expanding the use of UxSs across Coast Guard operational forces. Such a program office would be charged with fostering an organizational environment—administratively, culturally, and operationally—in which the Coast Guard is not only ready, willing, and able to leverage UxS technologies, but also enterprising and opportunistic in exploiting their promise.

Underscoring the importance of such an environment for the future Coast Guard, the **Commandant should establish a UxS program office**

that will work in concert with the top official charged with advancing the Service's UxS strategy to plan out, coordinate, assess, and promote UxS activities across the Service and to leverage relevant activities and capabilities from outside the Service. An early initiative of the program office should be to develop a "roadmap" that translates the high-level UxS strategic goals and objectives into an actionable plan to accomplish them, which should specify tasks needing priority attention, time frames for completion, and performance metrics and milestones.

EXPAND AND NORMALIZE UxS EXPERIMENTATION

As documented in this report, the Coast Guard is experimenting with UxS capabilities on a limited basis, often in partnership with other military services and DHS agencies. In the committee's view, such experimentation is vital to expanding and transitioning UxSs across the Coast Guard and is highly compatible with the Coast Guard's well known "can do" attitude and spirit of innovation to meet its diverse and demanding missions in the face of resource constraints. Budgetary limits are an important factor in the Coast Guard's need to be a "fast follower" that leverages and adapts technologies developed by others. Therefore, the Coast Guard must be attuned to, and experiment with, technology developments elsewhere in the military and government and in the commercial sector.

To build on and reinforce its naturally innovative culture, **the Coast Guard should expand and normalize efforts to ensure ample and systematic operations-related experimentation with low-cost UxSs, including potentially designating field units specifically for experimentation and rapid transitioning of systems into operations.** Encouraging experimentation with low-cost UxS technologies will not only help to identify beneficial uses, but also nurture a technology-curious and -proficient workforce across the ranks. The Coast Guard should aim to spur interest in, and create opportunities for, experimentation across operational units with an aggressiveness that is at least commensurate with the general pace of development and proliferation of UxS technologies.

GET A FIX ON UxS FUNDING NEEDS

The committee's recommendations are intended to expand and accelerate Coast Guard investigation and implementation of UxSs that can lead to new concepts of operation. Acting on these recommendations, however, will require ample and sustained funding, and a commitment to continually increasing funding over time. While the committee is not in a position to estimate and advise on how much additional funding will be required, a detailed assessment of investment needs is not required to conclude that a $5 million per year R&D program and budget line items of a few million dollars more per year for acquisitions and deployments of off-the-shelf UxS technologies is clearly insufficient.

As it identifies UxSs for incorporation into the fleet and force structure, the Coast Guard will need to invest in R&D, acquisitions, field experimentation, strategic planning, systems integration, evaluation, cybersecurity, legal analyses, personnel recruitment and training, and many other field and mission support functions and requirements. The sooner the Coast Guard estimates the magnitude of required investments, the sooner it can press for additional resources to meet them. Thus, to get a fix on the magnitude of investments that will be required, **the Commandant should commission an internal study of the multi-year spending that will be required for research, assets, integration, personnel, and the like that will enable full and sustained implementation of a UxS strategy.** Given the Coast Guard's need to be opportunistic and enterprising in leveraging other organizations' technologies, the study should consider the likely advances in UxS capabilities and affordability, as well as strategic partnerships with other services and federal agencies, to enable cost-saving economies of scale. The study should also recognize that investments in UxSs may not be accompanied by opportunities to significantly reduce spending on manned assets and operations, but will nevertheless be vital to supporting efficient and capable hybrid operations to fulfill the Coast Guard's critical missions.

CONCLUDING COMMENTS

The recommendations in this report are directed to the Coast Guard and its leadership. The committee is fully aware, of course, that the request for this study originated in legislation and that Congress has a keen interest in the Coast Guard's ability to effectively and efficiently perform its many missions critical to the nation. DHS has the same interest. Funding needs for UxSs, as established in the recommended Coast Guard study, will unlikely be met through reallocations of traditional Coast Guard appropriations and budget items. Although it is incumbent on the Coast Guard to build a compelling case for substantial additional funding, the committee believes its findings and recommendations warrant the attention of Congress and DHS, whose support will be vital to the advent of a future Coast Guard that fully embraces and delivers on the promise of UxSs.

1

Introduction

The U.S. Coast Guard is a relatively small military service with a broad scope of responsibilities spanning 11 statutory missions to ensure the country's maritime security, safety, and economic and environmental stewardship. The Coast Guard fulfills these diverse missions in a maritime domain that encompasses more than 100,000 miles of coastline and inland waterways and the largest Exclusive Economic Zone in the world, covering some 4.5 million square miles of sea from Puerto Rico to Guam and from the Arctic Circle to American Samoa, south of the equator.[1]

The Coast Guard deploys about 120 cutters,[2] 200 aircraft,[3] and several hundred smaller vessels and special purpose craft[4] and a force of about 41,000 active duty personnel, 7,000 reservists, 31,000 auxiliary members, and 8,500 full-time civilian employees.[5] Except for a small number of aerial systems—further described in Chapter 4—that expand the surveillance range of some cutters, all Coast Guard vessels and aircraft are manned. In contrast, during the past two decades and more, the U.S. Navy and other branches of the U.S military have significantly increased their use of unmanned aerial, surface, and underwater systems for surveillance,

[1] See U.S. Coast Guard at https://www.work.uscg.mil.

[2] A cutter is a Coast Guard vessel that is at least 65 ft. in length and has accommodations for a crew to live aboard.

[3] These 200 aircraft include fixed wing airplanes and helicopters.

[4] Among these assets are icebreakers, buoy tenders, small patrol boats, harbor tugs, and rescue and lifeboats.

[5] See https://www.uscg.mil/Portals/0/documents/CG_Cutters-Boats-Aircraft_2015-2016_edition.pdf?ver=2018-06-14-092150-230.

reconnaissance, and other warfare applications that have added new capabilities and are transforming military operational concepts. Although on a less sophisticated and smaller scale, other federal agencies, including the U.S. Customs and Border Protection, Federal Bureau of Investigation, National Oceanic and Atmospheric Administration, and U.S. Department of the Interior, are deploying unmanned systems (UxSs) for a range of civilian missions and purposes. Furthermore, a variety of public agencies and private industries are using unmanned technologies in emergency response, infrastructure inspection, nature conservation, undersea exploration, agriculture, and mining. All of these organizations have expanded use of these systems as their capabilities, commercial availability, reliability, and affordability have grown.

In comparison to the other military services, and even some civilian agencies and private industries, the Coast Guard's adoption of UxSs has been slow and ad hoc, but the opportunity remains to deploy them in a more concerted and strategic manner to add new capabilities and strengthen existing ones with less risk to personnel and traditional assets. It is inconceivable that a Service with many military and civilian missions spanning a vast maritime domain would not make greater use of UxSs, but how, when, and where to deploy them remain open questions.

Even without an operator or crew on board, these systems will require trained and skilled personnel to test, deploy, maintain, direct, monitor, and control them. Also necessary are ongoing research and development (R&D), changes in operational procedures and policies, data management and analytics support, and system maintenance and technology upgrades. Furthermore, there is no guarantee that deployments of these systems will reduce the need for investments in traditional manned vessels and aircraft; indeed, effective use of their capabilities—including many new ones that cannot be provided by manned systems—may necessitate even greater investments in assets. Federal and international regulatory and legal requirements—from those governing the use of airspace and the open seas and therefore may restrict where and how UxSs are deployed, and therefore require considerable Coast Guard attention.

The promise of UxSs for the Coast Guard is alluring and, at the most fundamental level, driven by rapid advances in technology. However, navigating a course to realize this promise will require a great deal of planning, experimentation, preparation, and sound investment.

STUDY CHARGE

On December 4, 2018, the Frank LoBiondo Coast Guard Authorization Act of 2018 was enacted. Section 812 of the act requests that the National Academies of Sciences, Engineering, and Medicine (the National Academies) "prepare an assessment of available unmanned, autonomous, or remotely controlled maritime domain awareness technologies for use by the Coast Guard."[6] It asks for a description of the potential limitations of current and emerging UxSs if used by the Coast Guard for its missions; how factors such as affordability, reliability, and versatility should be considered when prioritizing investments in UxSs; and how the Coast Guard can use UxSs to carry out its missions at lower costs, expand the scope and range of its maritime domain awareness, and more efficiently and effectively allocate vessels, aircraft, and personnel. It further calls for the identification of any changes in Coast Guard policies, procedures, and protocols that may be necessary to incorporate UxSs.

In commissioning this study to respond to this legislative request, the Coast Guard and the National Academies negotiated the following more detailed Statement of Task:

> An ad hoc committee will identify, examine, and make recommendations on key considerations to guide the Coast Guard's priorities for developing, testing, and deploying unmanned technologies for maritime domain awareness applications. Specific known or anticipated considerations for these new technologies are:
>
> - acquisition, operations, and maintenance costs;
> - service life, reliability, and versatility;
> - readiness for testing and/or deployment;
> - infrastructure requirements for beyond line of sight control of remotely controlled systems and autonomous system data transmission/collection/analysis/storage;
> - ability to aid the Coast Guard in pursuing its missions at lower cost and deploying its vessels, aircraft, equipment, and personnel more efficiently and effectively;
> - ability to create new mission related capabilities, such as by increasing persistence of effort and expanding the scope and range of maritime domain awareness; and,
> - operational and regulatory challenges when used in domestic and international airspace and waters.
>
> The study committee shall take into account all Coast Guard missions that require maritime domain awareness, but give particular attention to the application of unmanned technologies for asset intensive missions—such as for intelligence gathering, surveillance, and reconnaissance to support law enforcement (e.g., drug-interdiction, fisheries enforcement, and migrant-interdiction), search and rescue, and oil spill response—where

[6] See Section 812 of the Frank LoBiondo Coast Guard Authorization Act of 2018 at https://www.congress.gov/bill/115th-congress/senate-bill/140/text.

> unmanned technologies can increase the persistence and scope of maritime domain awareness and aid in the efficient and effective use of current manned assets. The committee will consider, and make recommendations as appropriate, on adjustments that may be needed to Coast Guard policies, procedures, and protocols to incorporate unmanned technologies.

STUDY SCOPE AND APPROACH

To conduct the study, the National Academies appointed a committee of 10 experts in Coast Guard operations, naval engineering and architecture, automation and control, system integration, cybersecurity, and field application of automated systems. In reviewing the study charge, as articulated in the Statement of Task, and in considering the legislative origins, the committee made several decisions about the study scope that shaped the study approach.

First, it adopted the broad definition of maritime domain that was provided by the White House in its 2013 "National Maritime Domain Awareness Plan for the National Strategy for Maritime Security."[7] According to this definition, the maritime domain consists of "all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels, and other conveyances." The committee also employed the definition of maritime domain awareness (MDA) espoused by the International Maritime Organization (IMO).[8] According to this definition, when applied to the United States, MDA implies an understanding of the global maritime arena that could affect the safety, security, economy, and environment of the country. Together these definitions imply that the Coast Guard's interest in MDA encompasses all 11 of its missions and must include its operations on the water, underwater, and in the air. Thus, while recognizing that certain Coast Guard missions such as search and rescue, reconnaissance to support law enforcement, and oil spill response, can be asset intensive for maintaining necessary and persistent levels of maritime domain awareness, the committee decided that the potential for aerial, surface, and underwater UxSs must be considered in a broader context across all missions, particularly because the Coast Guard places a heavy emphasis on having assets that can be used efficiently and effectively in a diverse set of missions.

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[7] U.S. White House Office. 2013. "*National Maritime Domain Awareness Plan for the National Strategy for Maritime Security.*" https://www.hsdl.org/?abstract&did=747691.

[8] International Maritime Organization. 2010. "Amendments to the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual." http://www.imo.org/blast/blastDataHelper.asp?data_id=29093&filename=1367.pdf.

Second, given the fast pace of change in UxSs and their applications, the committee was reluctant to provide detailed technical assessments of specific existing or emerging technologies and systems,[9] including assessments of their specific benefits or cost and budgetary implications. The decision was made instead to consider these systems in a more generic way based on their key attributes and functions, rather than specific vehicles or data systems that could become obsolete or completely transformed in the near future. The committee also realized that any effort to quantify costs and benefits would have been hindered by limited access to restricted information on Coast Guard operations, assets, and expenses. Moreover, inasmuch as UxS technologies have the potential to be used across multiple Coast Guard mission areas, assignments of the costs and benefits associated with investments in any given system—including calculations of savings in traditional manner assets—would need to take into account numerous shared-use scenarios that would greatly complicate such assignments and limit their decision-making value.

Finally, as discussed above, the successful development and deployment of UxSs is more of an institutional than a technology issue for the Coast Guard. The Coast Guard is a user, not a developer, of technologies. The UxS technologies that the Coast Guard deploys in the near and longer terms will almost certainly be leveraged from the commercial domain and other military services that invest heavily in basic and applied R&D. Committee members observed from their own experiences that many agencies and organizations that successfully leveraged UxSs into their operations were guided by a strategic vision and deliberate plan for making the necessary changes in culture, processes, and investments in resources such as personnel. Therefore, the committee sought to understand how the Coast Guard's pursuit of UxSs may be affected by its institutional, procedural, cultural, and legal contexts, all of which will bear on its ability to exploit the promise of UxSs.

To obtain a better understanding these contexts, as well as the kinds of unmanned technologies and systems that are being deployed by the Coast Guard and that are candidates for use, the committee scheduled numerous briefings with speakers from industry, academia, and numerous government agencies to gather information on existing and planned uses of different kinds of unmanned technologies, cybersecurity issues, accommodating organizational structures, and system operational and scalability

[9] The Association of Unmanned Vehicle Systems International (AUVSI) created and maintains the Unmanned Systems and Robotics Database, which is the most comprehensive database of all unmanned vehicles and robotic products operating in the air, land, and maritime domains. The database includes more than 4,700 UxS platforms from across the globe. See http://roboticsdatabase.auvsi.org/home?CLK=05da284f-5498-49d9-a548-91169efa9d65&_ga=2.13374910.825991843.1600711525-1811913171.1595438235.

issues. Speakers included Flag Officers and other top officials, senior program managers, and center directors from the Coast Guard, Navy, and other military and civilian agencies listed in the Preface and in Appendix C. They also included technology experts from academia and industry, including the MIT Lincoln Laboratory, Woods Hole Oceanographic Institution, ThayerMahan Inc., University of Virginia, Apollo Autonomy, Hydroid, and the Association for Unmanned Vehicle Systems International. The information from these briefings was invaluable to the committee in informing its deliberations that led to this report.

REPORT ORGANIZATION

The remainder of this report is organized into five chapters as follows:

- Chapter 2 summarizes key aspects about the Coast Guard, including its missions and how they are pursued; the maritime domain under its responsibility; its organizational structure; its joint, interagency, and international operations; and its budget. As such, Chapter 2 provides important context for the remainder of the report.
- Chapter 3 provides context about UxSs innovation by describing the state of practice, what is on the horizon, and what technologies might change current practice. Specifically, the chapter describes vehicle and payload technology—with a 5-year horizon—revolutionary technology, evolutionary technology, the pace of change, platform versus payload approaches, architectural constructs to allow for change, and other issues such as cybersecurity and dependability.
- Chapter 4 explores the current state of unmanned technologies within the Coast Guard and other services and government agencies. The chapter reviews the research and acquisition of UxSs within the Coast Guard and the budget resources allocated to these activities. The chapter then summarizes UxS activities and programs in other government agencies.
- Chapter 5 assesses the UxS capabilities that could deliver the most impact across Coast Guard missions. The chapter describes the importance of a framework for return on investment and proposes a potential approach to such a framework.
- Chapter 6 brings to a close the study findings and presents the committee's overarching conclusions and the recommendations to move forward in the systematic deployment of UxSs within the Coast Guard. The chapter presents the study committee's recommendations on strategy, organizational structure, experimentation, and budgetary allocation.

2

U.S. Coast Guard and Its Vital Missions

The United States is a maritime nation. The country's maritime domain is varied and immense. It consists of thousands of miles of navigable river channels; nearly 400 harbor and port complexes on rivers, lakes, and oceans; more than 95,000 miles of coastline; and about 4.5 million square miles of the Exclusive Economic Zone (EEZ) in the Pacific, Atlantic, and Artic Oceans, Gulf of Mexico, and Great Lakes.[1] Responsibility for ensuring the safety, security, and economic and environmental stewardship of this vast maritime domain rests largely with the U.S. Coast Guard.

Founded in 1790, the Coast Guard's first mission, as part of the U.S. Department of the Treasury, was to enforce compliance with the nation's customs duties.[2] Over the next century its revenue functions were supplemented by many new responsibilities, including safeguarding the U.S. coasts and maritime community from piracy and providing steamship inspection (vessel safety), lighthouse (navigation), and life-saving (search and rescue) services. Its missions continued to expand during its next 100 years, as it was called on to protect other U.S. interests, including fisheries and other marine resources, the marine environment, the integrity of the EEZ, and the nation's defense in concert with the U.S. Navy and other military services. These varied missions have led to a modern Coast Guard with a unique

[1] U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[2] U.S. Coast Guard Historian's Office. "Timeline 1700's-1800's." https://www.history.uscg.mil/Complete-Time-Line/Time-Line-1700-1800.

blend of military, law enforcement, environmental stewardship, and humanitarian assistance capabilities and cultures.

This chapter begins with background on the Coast Guard's statutory missions, which now total 11. An appreciation of the sheer number, complexity, and diversity of these missions is essential for understanding (1) the ways in which unmanned systems (UxSs) could be deployed by the Coast Guard; (2) where their use could present operational and other practical challenges; and (3) why interest in UxS could be Service-wide, such as to augment a uniformed force and traditional assets stretched thin by so many varied mission responsibilities.

Following the description of the 11 statutory missions, the chapter describes the Coast Guard's organizational structure. The regionally-based command structure is designed to provide the Coast Guard with an ability to operate effectively and efficiently both domestically and globally. Most of the Coast Guard's operations, and thus most of its forces and assets, are deployed by these regional commands. Accompanying these commands are several other Coast Guard units that provide mission support functions such as acquisitions, engineering and logistics, force readiness, cyberspace capability, and communications and information technology. Therefore, the chapter provides background information on several units that would play an important role in any expanded use of UxS.

The chapter ends by noting the Coast Guard's Fiscal Year (FY) 2020 budget and how it is allocated across statutory missions and how it compares to the budgets of the other military branches. The budget is an important consideration because spending on UxSs usually constitutes a new expenditure and UxSs are sometimes viewed as a means for the Coast Guard to accomplish more with a limited budget.

STATUTORY MISSIONS

A unique instrument of national power, the Coast Guard is one of the six armed forces of the United States. The Coast Guard also serves as a first responder, law enforcement agency, maritime regulator, and member of the intelligence community. Located within the U.S. Department of Homeland Security, most of the Coast Guard's missions are unique and distinct from those of the U.S. Department of Defense (DOD). The Coast Guard's 11 statutory missions are as follows:[3]

1. Port, Waterways and Coastal Security
2. Drug Interdiction

[3] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions.

3. Aids to Navigation (ATON)
4. Search and Rescue (SAR)
5. Living Marine Resources
6. Marine Safety
7. Defense Readiness
8. Migrant Interdiction
9. Marine Environmental Protection
10. Ice Operations
11. Other Law Enforcement

Port, Waterways and Coastal Security[4]

The Port, Waterways and Coastal Security mission seeks to prevent and disrupt terrorist attacks, sabotage, espionage, and other subversive acts on population centers, vessels, and critical infrastructure in the maritime domain. Activities in fulfillment of this mission include performing vulnerability assessments and preparedness planning and exercises, establishing and enforcing security zones, approving and enforcing compliance with area-wide and vessel- and facility-specific security plans, escorting vessels that carry dangerous cargos or high numbers of passengers, and conducting harbor patrols and boardings of high-interest vessels, which imply vessels, cargos, and/or crews that might pose security risks to the United States.[5] This mission requires intelligence support to identify these higher-risk vessels.

Drug Interdiction[6]

The Coast Guard is the lead federal agency for drug interdiction on the high seas. In pursuit of this mission, the Coast Guard seeks to deter and disrupt the smuggling of illegal drugs into the United States through at-sea interdiction and seizure of smuggling vessels, typically in the offshore area. These operations involve Coast Guard cutters and aircraft patrolling the high seas to provide a persistent presence for detection and monitoring, as well as vessel boardings by deployable specialized forces for interdiction,

[4] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/ports-waterway-security.

[5] Examples of high-interest vessels are barges or ships carrying liquefied petroleum gas, liquefied natural gas, or any other cargo deemed to be of high risk by the Captain of the Port. Any high-interest vessel entering or departing the United States is subject to Coast Guard security boardings.

[6] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/drug-interdiction.

apprehension, and evidence retrieval.[7] The operations also depend on intelligence support, given the need to target the deployment of resources within the vast 6 million square-mile region of concern.

Aids to Navigation[8]

The Coast Guard is responsible for ensuring that the country's aids to navigation network is current and functioning properly to mitigate transit risks and to promote the safe, economic, and efficient movement of military, commercial, and other vessels. To do so, the Coast Guard installs, maintains, and operates more than 45,000 lighted and unlighted buoys and beacons that mark 25,000 miles of U.S. coastal, intracoastal, and inland waters. As part of this mission crews verify the position and condition of the devices; repair or replace devices that are lost or damaged by wind, waves, and storms; and place new devices, such as when channels are relocated and new channels are dredged. This mission also involves monitoring and coordinating marine traffic in key ports and waterways through the Vessel Traffic Service. The Vessel Traffic Service provides active monitoring and navigational advice for vessels in particularly confined and busy waterways. Vessels traveling in these waterways make position reports to a vessel traffic center and are in turn provided with accurate, complete, and timely navigational safety information. The use of surveillance technology and computer-assisted tracking, similar to that used in air traffic control, also allow the Vessel Traffic Service to manage marine traffic and therefore decrease vessel congestion and dangerous encounter situations. To fulfill this service, the Coast Guard operates 12 Vessel Traffic Centers across the country.[9]

Search and Rescue[10]

The Coast Guard is the lead agency for maritime SAR in U.S. waters. It executes this mission by planning, coordinating, and conducting SAR efforts using its own surface and airborne units, as well as those of other federal, state, and local responders. These efforts involve not only searching for, locating, and rescuing mariners in distress, but also rescuing people in distress during floods from natural disasters such as hurricanes. The Coast

[7] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[8] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/aids-to-navigation.

[9] U.S. Coast Guard. Vessel Traffic Services. https://www.navcen.uscg.gov/?pageName=vtsMain.

[10] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/search-and-rescue.

Guard's SAR response involves multi-mission stations, cutters, aircraft, and boats that are linked by communications networks.

Living Marine Resources[11]

The Coast Guard is the lead federal agency for at-sea enforcement of U.S. and international fisheries laws as well as for maintenance of international fisheries agreements. This responsibility is part of its Living Marine Resources mission, which seeks to support conservation and management of living marine resources and their environment, including protected species, protected areas, and critical habitats. In carrying out this mission, Coast Guard personnel observe and board commercial fishing vessels suspected of violating laws that govern fisheries and that protect marine species and habits, and they provide assistance for stranded and entangled marine animals.

Marine Safety[12]

The Marine Safety mission promotes safety at sea and the prevention of maritime accidents, personnel casualties, and property losses. To fulfill this mission, the Coast Guard investigates maritime accidents and inspects vessels and marine facilities. In addition, the Coast Guard credentials mariners, documents U.S. flagged vessels, and implements a variety of boating safety education and awareness programs. It also establishes safety standards and policies for vessel design and construction, safety equipment, and vessel safety checks. The Coast Guard is the lead U.S. representative to the International Maritime Organization (IMO), a specialized agency of the United Nations responsible for establishing international legal regimes for maritime safety.[13]

Defense Readiness[14]

The Coast Guard is one of the six services of the U.S. Armed Forces, providing several key defense missions, including maritime intercept operations; deployed port operations, security, and defense; peacetime engagement; and

[11] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/living-marine-resources.

[12] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/marine-safety.

[13] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[14] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/defense-readiness.

environmental defense operations. The Coast Guard maintains readiness to carry out these responsibilities by ensuring that its forces and assets are capable, equipped, and well matched to deploy and conduct joint operations with combatant commanders from the U.S. Navy and other military services. These joint missions with other armed forces require extensive interservice integration in logistics and operations. As such, consistent technology capabilities and equipment interoperability are indispensable.

Migrant Interdiction[15]

As the country's chief maritime law enforcement agency, the Coast Guard also enforces U.S. immigration laws at sea. It does so by detecting and interdicting undocumented migrants and smugglers as far as possible from the U.S. border, and by denying entry via maritime routes to the United States and its territories. In addition to enforcing U.S. immigration laws, the Coast Guard enforces international conventions against human smuggling through at-sea interdiction. Operations in support of this mission include carrying out patrols—by boat, cutter, or air—in conjunction with other federal agencies, including the U.S. Immigration and Customs Enforcement, the U.S. Customs and Border Protection, and the U.S. Department of State.[16]

Marine Environmental Protection[17]

One of the Coast Guard's environmental stewardship missions is to protect the marine ecosystem by developing and enforcing regulations to prevent and respond to oil and hazardous substance spills in the marine environment, the introduction of invasive species into the maritime environment, and unauthorized ocean dumping. In accordance with the National Oil and Hazardous Substances Pollution Contingency Plan, the Coast Guard is responsible for pre-designating the Federal On-Scene Coordinator for maritime pollution incidents. The Coast Guard responds to oil and hazardous substance incidents in the inland, coastal, and offshore operational areas, including by overseeing, directing, and conducting response operations.[18]

[15] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/migrant-interdiction.

[16] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[17] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/marine-environmental-protection.

[18] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

Ice Operations[19]

The Coast Guard is responsible for ice breaking operations in the Great Lakes and Northeast regions to ensure safe maritime commerce, prevent and respond to ice cover that causes flooding, and protect coastal communities in emergencies. This responsibility extends to the polar regions in support of U.S. national security, economic, and scientific interests. The Coast Guard also conducts International Ice Patrol operations in the offshore operational area to monitor and warn mariners of iceberg danger near the Grand Banks of Newfoundland in the Atlantic Ocean. The ice breaking and monitoring mission is conducted using icebreakers, and some other cutters depending on ice thickness, as well as aircraft.

Other Law Enforcement[20]

Other law enforcement missions of the Coast Guard include deterrence, detection, and interdiction of any illegal foreign fishing vessel making incursions into U.S. waters, including the EEZ.

JOINT, INTERAGENCY, AND INTERNATIONAL OPERATIONS

The scope of the Coast Guard's 11 missions is extensive, and to conduct their associated operations, the Coast Guard benefits from partnerships with hundreds of federal, state, tribal, and local government organizations.[21] These partnerships involve joint (with other military services), interagency, and international collaborations. A noteworthy partnership that combines these three kinds of collaborations is the Joint Interagency Task Force South (JIATF-S)—a naval cooperation that combines personnel and assets from the Navy, the Coast Guard, and civilian law enforcement, working with multinational partners to reduce illicit drug trafficking throughout Central and South America.[22]

As one of the six branches of the U.S. military, the Coast Guard has the mandate to support DOD worldwide by deploying cutters, boats, aircraft, and deployable specialized forces in and around harbors to protect military mobilization operations in the United States and expeditionary operations overseas, including warfighting forces under combatant commander

[19] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/ice-operations.

[20] This section draws information from the Coast Guard website at https://www.gocoastguard.com/about-the-coast-guard/discover-our-roles-missions/other-law-enforcement.

[21] U.S. Coast Guard. Partnerships. https://www.work.uscg.mil/Partnerships.

[22] U.S. Navy. 2015. *A Cooperative Strategy for 21st Century Seapower.* https://www.work.uscg.mil/Portals/6/Documents/PDF/21_century_seapower.pdf?ver=2016-10-13-153830-287.

operational control. Carrying out these joint operations requires extensive interservice integration, and to that end, the Coast Guard maintains full interoperability to operate its personnel, assets, and equipment with the other military services at any time.[23] These operations also present special logistics needs, especially if deployed to carry out operations in foreign countries.

Interagency coordination with nonmilitary agencies is also a Coast Guard core competency, because many of its operations require close cooperation with other law enforcement and civilian agencies. Two examples illustrate this capability. First, the Security and Accountability for Every Port Act of 2006 mandated the establishment of Interagency Operations Centers (IOCs)[24] to plan, coordinate, and execute multi-agency maritime security operations at 37 high-priority U.S. ports.[25] The Secretary of Homeland Security delegated the authority to implement this requirement to the Commandant of the Coast Guard, who in 2008 established the program to design, develop, deploy, and operate an information management system to support the IOCs' functions. The *Deepwater Horizon* oil spill response in the Gulf of Mexico in 2010 provides another example of the Coast Guard's adeptness at interagency coordination. This vast spill impacted major portions of the coastal and inland areas along the coast of five states, and Coast Guard forces led the largest U.S. interagency response to a spill of national significance.

Other Coast Guard missions, such as Living Maritime Resources in which the Coast Guard enforces compliance with international agreements to deter illegal, unreported, and unregulated fishing activity, also benefit from strong collaborations with foreign governments and other international partners. To cultivate international partnerships for its multiple missions, the Coast Guard engages in more than 60 bilateral agreements with partner-nations, participates in the Arctic Coast Guard Forum[26] and the North Pacific Coast Guard Forum,[27] and assigns Coast Guard personnel at

[23] U.S. Coast Guard. 2012. Publication 3.0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[24] The IOC is a matrix organization conducting joint planning and assignment of resources to mission demands. https://www.dcms.uscg.mil/Our-Organization/Assistant-Commandant-for-Acquisitions-CG-9/Programs/C4ISR-Programs/IOC-Transitioned-to-Sustainment.

[25] Security and Accountability for Every Port Act of 2006. Section 108—Establishment of interagency operational centers for port security. https://www.congress.gov/109/plaws/publ347/PLAW-109publ347.pdf.

[26] A multi-lateral forum that includes Coast Guard–like agencies from Canada, Denmark, Finland, Iceland, Norway, Russia, and Sweden. https://www.uscg.mil/readings/Article/1548235/partnerships.

[27] A multi-lateral forum that includes Coast Guard–like agencies from Canada, China, Japan, Korea, and Russia, which coordinates maritime law enforcement, search and rescue, and environmental response activities. https://www.uscg.mil/readings/Article/1548235/partnerships.

foreign ports, leads U.S. participation in the IMO, and the Coast Guard's International Mobile Training Branch temporarily deploys to foreign countries under U.S. Department of State direction as requested.

ORGANIZATIONAL STRUCTURE

To perform and support its 11 missions, the Coast Guard assigns both uniformed and civilian personnel to different commands, directorates, and other offices, including the regional commands under which most forces and assets are used to fulfill the Service's statutory missions. Figure 2-1 illustrates the Coast Guard organizational chart.

The structure of the regional command is summarized next, followed by background on several other Coast Guard operational and mission support units that would have a role in UxS investments.

Regional Commands

Although the Coast Guard's headquarters is in Washington, DC, its operations are divided into two theater commands: the Atlantic Area and Pacific Area. The two Area Commanders allocate command and control to 9 District Commanders, who in turn assign command and control to 37 Sector Commanders. The number and types of Coast Guard units vary by sector but often include air stations, boat stations, aids to navigation teams, and other special-purpose detachments as discussed below. Figure 2-2 shows the geography of the nine districts, five in the Atlantic Area and four in the Pacific Area. Sector Commanders (holding the rank of Captain) serve in several important capacities, including Captain of the Port (with authority to enforce port safety, security, and marine environmental protection regulations), Officer in Charge of Marine Inspection, Federal On-Scene Coordinator for oil spills, and Search and Rescue Mission Coordinator.[28]

Other Relevant Operational and Mission Support Units

In addition to the regional commands, other operational and mission support directorates and units report directly to headquarters,[29] several of which could be expected to play an important role in supporting UxSs and

[28] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

[29] U.S. Coast Guard. "United States Coast Guard Organization Chart." https://www.uscg.mil/Units/Organization/#direct.

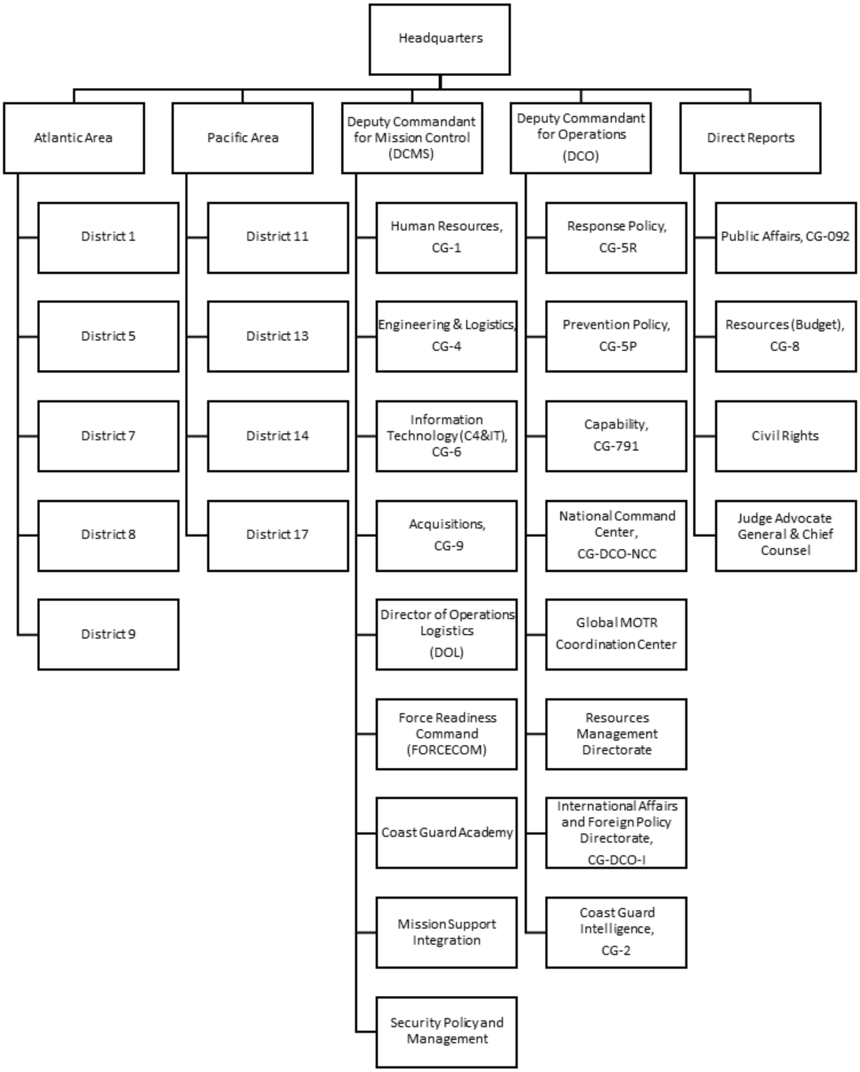

FIGURE 2-1 Coast Guard organizational chart.
SOURCE: U.S. Coast Guard.[30]

[30] See https://www.uscg.mil/Units/Organization.

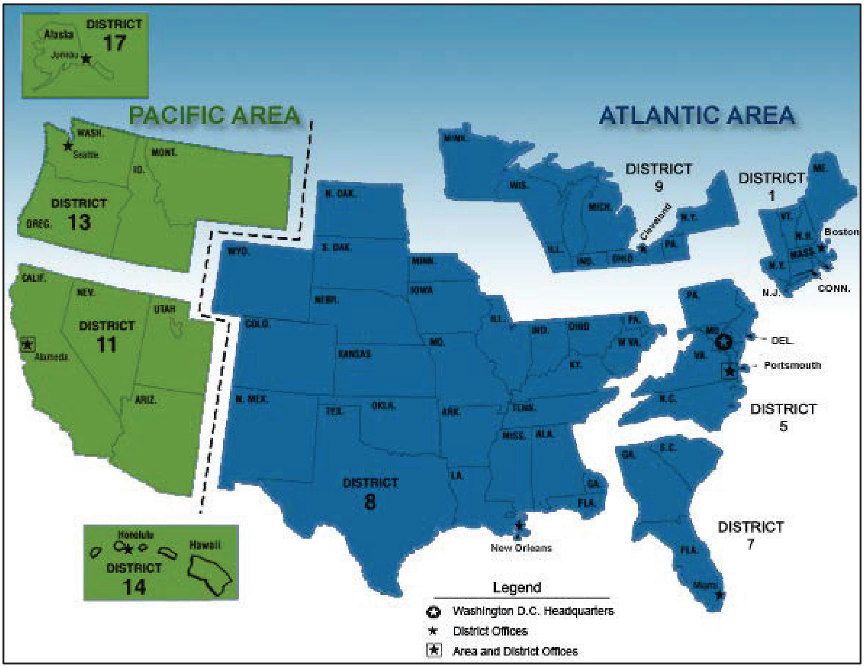

FIGURE 2-2 Coast Guard command and control organization.
SOURCE: U.S. Coast Guard.[31]

in using them for mission purposes. It is not possible to describe all potentially relevant units here, the following are pertinent examples.

- *Acquisition:* The Acquisition Directorate plans and executes the modernization and recapitalization of the Coast Guard's fleet of vessels and aircraft, other equipment and assets, systems for information technology (IT), communications, intelligence, surveillance, and reconnaissance systems. The Research and Development (R&D) Office is administered in this directorate.
- *Force Training and Capability:* The Assistant Commandant for Capability is responsible for identifying and providing capabilities, competencies, and capacity and for developing standards for staffing, training, equipping, and employing Coast Guard forces to meet mission requirements. The Force Readiness Command

[31] U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

develops and maintain plans and policies for training, education, and development programs for personnel.

- ***Command, Control, Communications, Computers, and Information Technology (C4&IT):*** The Assistant Commandant for C4&IT designs, develops, deploys, and maintains C4&IT solutions for the entire Coast Guard to enable mission execution.
- ***Response Policy:*** The Assistant Commandant for Response Policy develops policy guidance for Coast Guard forces to accomplish operational maritime missions, provides oversight to ensure successful operational execution, and ensures policy alignment throughout the Service and with other federal and international partners.
- ***Intelligence:*** The Assistant Commandant for Intelligence supports the Coast Guard Intelligence enterprise through planning, policy, programming, budgeting, training, security, and information systems support.
- ***Legal:*** The Judge Advocate General and Chief Counsel provide varied legal functions for the Coast Guard to ensure their missions, operations, and activities are consistent with and achieved under the law. These functions include ensuring that Coast Guard operations, policies, and activities comply with and conform to applicable federal regulations and international treaty standards.

DEPLOYMENT OF ASSETS AND FORCES

The Coast Guard performs all 11 or a subset of its missions in three basic geographic operational areas: inland waters, coastal zones, and offshore. Table 2-1 summarizes the geography of each operational area and the typical Coast Guard asset deployments and activities. These deployments and activities can differ substantially by operational area depending on the size and nature of the particular maritime domain and the missions relevant to that domain. Most of the Coast Guard's major cutters, for instance, are deployed in the offshore operational area for functions such as national security and law enforcement, while its smaller boats and special purpose vessels, such as tugs and ATON tenders, are stationed on the inland waterways and coastal zones.

Commensurate with these operational areas, Coast Guard forces are divided into three types of operational units: shore-based, maritime patrol, and deployable specialized forces.[32]

[32] This section draws information from U.S. Coast Guard. 2012. Publication 3-0. "Operations." https://www.work.uscg.mil/Portals/6/Documents/PDF/CGPub_3-0.pdf?ver=2016-10-20-091037-843.

TABLE 2-1 Coast Guard Operational Areas and Associated Assets[33]

	Inland and Coastal	**Offshore**	**Aviation Capability**
Geography	Navigable inland waterways and lakes, including major inland ports From shoreline to 50 nautical miles into the sea, including sea harbors and ports	Beyond 50 nautical miles from the shoreline, including polar regions (some areas cross international waters to the territorial seas of foreign nations where bilateral agreements)	Inland, coastal, and offshore
Assets	• Response and Pursuit Boats • Medium-Range Multi-Mission Boats • Surf Boats • Aids to Navigation Boats • Inland and Coastal Construction/Buoy Tenders • Icebreaking Tugs • Coastal Patrol Boats	• Patrol Boats • Sea Going Buoy Tenders and Great Lakes Icebreaker • High-Endurance Fleet • Polar Icebreaker Fleet	• Short-range recovery (375 nautical miles range, 3 hours endurance) • Medium-range recovery (700 nautical miles range, 6 hours endurance) • Medium-range surveillance (2,200 nautical miles range, 9 hours endurance) • Long-range surveillance (5,000 nautical miles range, 20 hours endurance)

Shore-Based Forces

Shore-based forces operate in inland waters and in coastal zones. Capable of conducting a varied set of operations, they are typically deployed in the following units:

- Boat Stations, which consist of motor lifeboats, rapid response boats, and special purpose craft.
- Aids to Navigation Teams, which operate navigation boats, such as river, construction, and inland buoy tenders. These teams also support flood recovery.
- Marine Safety Units and Marine Safety Detachments, which conduct a range of prevention activities, including inspections, casualty investigations, and waterways management.

[33] The information in this table draws from the first two columns in Figure 2 of the following white paper: U.S. Coast Guard. 2013. "America's 21st Century Coast Guard: Resourcing for Safety, Security and Stewardship." https://www.uscg.mil/Portals/0/Strategy/2013_USCG_WP.pdf. More information about the Coast Guard assets can be found in the report "The Cutters, Boats, and Aircraft of the U.S. Coast Guard." https://www.mycg.uscg.mil/Portals/6/Documents/PDF/CG_Cutters-Boats-Aircraft_2015-2016_edition.pdf?ver=2016-10-19-153700-540.

- Vessel Traffic Services, which facilitate the safe and efficient transit of commercial vessel traffic on high-volume navigation channels.
- Harbor and Icebreaking Tugs, which keep harbors and channels open for commerce. They also conduct SAR and maritime security patrols.

Maritime Patrol Forces

Although they can operate in inland areas as required (such as in response to a natural disaster), Maritime Patrols are primarily deployed in coastal and offshore areas. Their main function is to conduct prevention and response operations through patrol, presence, and at-sea operations, such as interdiction, boarding, enforcement, and SAR. They also conduct intelligence, surveillance, and reconnaissance activities and provide unique capabilities to DOD for joint operations. Marine Patrols may be deployed on the following:

- Major Cutters, whose high endurance and sea keeping capabilities provide the Coast Guard with an ability to maintain persistent presence in a wide range of extreme environmental conditions. These vessels will carry small boats and helicopters capable of medium- and long-range response operations, such as SAR, as well as logistics and transport flights. As described in more detail below, National Security Cutters also have small, unmanned aircraft systems.
- Patrol Boats, which are smaller cutters designed for rapid response, patrol, and interdiction. They conduct operations primarily in the coastal zone but are sometimes deployed overseas to support foreign interdiction operations.
- Polar and Great Lakes Icebreakers, which are cutters designed to ensure surface access to U.S. ports and navigational channels in the Great Lakes, Saint Lawrence Seaway, and polar regions.
- Oceangoing and Coastal Buoy Tenders, which are cutters designed to maintain ATONs and support reconstitution of ports after natural disasters or armed conflicts. Some of these vessels carry dive teams.
- Air Stations, where fixed-wing aircraft and helicopters support missions such as SAR and oil spill monitoring, as well as provide logistics and transport flights.

Deployable Specialized Forces

Able to deploy rapidly across the United States and globally, the Deployable Specialized Forces consist of the following:

- Maritime Safety and Security Teams, which were established to protect local maritime interests—for example, by patrolling the shore side and harbors to detect, and potentially stop and arrest, submerged divers suspected of terrorism.
- Maritime Security Response Teams, which conduct law enforcement and counterterrorism operations through boardings and advanced interdictions in all the operational areas. They also have particular capabilities to conduct security and response operations, including chemical, biological, radiological, nuclear, and high-yield explosive detection and response.
- Tactical Law Enforcement Teams, which consist of law enforcement detachments that are deployed aboard to conduct global offshore operations through interdiction, boarding, and enforcement activities. These teams operate from U.S. Navy or allied vessels.
- Port Security Units, which conduct expeditionary operations to ensure coastal and port security. They operate primarily in the offshore operational area.
- National Strike Force, which consists of experienced personnel and specialized equipment to facilitate preparedness for and response to oil and hazardous substance pollution incidents.
- Regional Dive Lockers, whose diver teams support multiple missions, such as ATON, and polar operations and underwater search and recovery.

COAST GUARD BUDGET

Table 2-2 shows a breakdown of the Coast Guard's FY 2020 budget by mission area. Although it has large and diverse set of missions, the Coast Guard is a small Service, especially when compared with other military branches.[34] Its net discretionary budget (which excludes spending on retirement and other mandated programs) in FY 2020 was $9.974 billion, or about one-twentieth the size of the other military services (see Table 2-3). Further consideration is given to the Coast Guard's budget in later chapters, particularly its budget allocations for R&D and UxS.

[34] The Coast Guard's active duty personnel is about one-twelfth the size of the Navy's. The personnel data as of June 2020 for all of the services can be found at the DOD website "DOD Personnel, Workforce Reports & Publications." https://www.dmdc.osd.mil/appj/dwp/rest/download?fileName=DMDC_Website_Location_Report_2006.xlsx&groupName=milRegionCountry.

TABLE 2-2 Coast Guard FY 2020 Discretionary Spending by Mission

Mission	Enacted Budget (millions)[35]
Aids to Navigation	1,309
Defense Readiness	554
Drug Interdiction	1,868
Ice Operations	460
Living Marine Resources	912
Marine Environmental Protection	222
Marine Safety	909
Migrant Interdiction	1,002
Other Law Enforcement	344
Ports, Waterways, and Coast Security	1,368
Search and Rescue	1,025

TABLE 2-3 FY 2020 Discretionary Budgets (enacted) of the U.S. Coast Guard and Other U.S. Military Services

Military Service	Enacted Budget (millions)
Coast Guard[36]	$9,974
Navy[37]	$209,000
Army[38]	$178,468
Air Force[39]	$205,406

[35] U.S. Coast Guard. "Posture Statement: 2021 Budget Overview." https://www.uscg.mil/portals/0/bib/BIB-booklet-FINAL-v3-web.pdf.

[36] U.S. Department of Homeland Security, U.S. Coast Guard. "Budget Overview. Fiscal Year 2021, Congressional Justification." https://www.dhs.gov/sites/default/files/publications/u.s._coast_guard.pdf.

[37] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer. 2020. "Defense Budget Overview." https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

[38] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer. 2020. "Defense Budget Overview." https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

[39] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer. 2020. "Defense Budget Overview." https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

3

Unmanned Systems Context

An examination of the U.S. Coast Guard's potential to make greater use of unmanned systems (UxSs) should address the broader context of technology development, introduction, and diffusion. The Coast Guard's research and development budget is small, extremely so when compared to that of the U.S. Navy. Budgetary constraints are an important factor in the Coast Guard's approach to being a "fast follower" that leverages and adapts the technologies developed and introduced by others. A reliance on this approach makes it incumbent on the Coast Guard to be attuned to relevant technology developments elsewhere in the military and the federal government and in the commercial sector.

In staying attuned to these technology developments from other domains, the Coast Guard must make important choices about which technologies to acquire with a number of considerations in mind, some that apply to all organizations that leverage or "fast follow" and some that have particular relevance to the Coast Guard, such as ensuring cybersecurity. This chapter discusses some of these considerations when leveraging unmanned technologies from other domains and sectors, leaving the more detailed discussion of Coast Guard–specific circumstances to later chapters. This chapter begins with an overview of the terminology and nomenclature of the report, such as the specific terms used to describe unmanned vehicles and systems and the meaning of "unmanned" with respect to human control and onboard presence. The chapter then describes the breadth of systems and technologies that can fall under the rubric of UxS when considering the Coast Guard's workflow. An important point is that the application of unmanned technologies is not limited to mobile assets such as the aircraft, ships, and underwater vessels that execute the Coast Guard's missions; it can also include capabilities onboard a vehicle (e.g., intelligent payload) and software systems that operate virtually to provide analytic and decision support.

Following this overview, the chapter discusses how the Coast Guard, like all fast followers that acquire technology from the other sectors, must consider how a candidate technology will integrate with its operations and systems. Systems engineering is especially important to the Coast Guard, which must be confident that UxS will be ready when needed, integrate with assets and personnel, and reliably perform as expected. An important element of that confidence is cybersecurity. When leveraging technologies from other sectors, including the commercial sector, the Coast Guard must be vigilant about cybersecurity risks given its many important missions, including those focused on law enforcement and national security.

Finally, when operating UxS in the air and on the water, the Coast Guard must consider a variety of legal and policy requirements intended to ensure the safety of the civil airspace and waterways, protect individual privacy, and further other interests such as adherence to federal and Coast Guard acquisition guidelines. These requirements are covered in detail in later chapters but are discussed briefly here because they are relevant to the Coast Guard's ability to acquire and fully exploit unmanned technologies.

UNMANNED SYSTEMS TERMINOLOGY AND CONCEPTS

As UxSs and their enabling technologies have proliferated, a common terminology has taken shape but with a considerable heterogeneity. This section explains the report's use of the term "unmanned" as opposed to other terms such as "unoccupied"; makes distinctions among remote, automated, and autonomous systems; and highlights the importance of considering a system's applicability in a context broader than how it is controlled.

"Unmanned" Nomenclature

The term "unmanned" is sometimes replaced by the terms "un-crewed" or "unoccupied." Although the reasons to use such gender-free terms are sound, the committee elected to use the term "unmanned" to remain consistent with the terminology in the study request and to avoid the implication that the study's focus is on only vehicles, and even more narrowly on only vehicles with no crew or passengers. The term "unmanned" applies to a range of concepts, from vehicles with no human occupants or human controllers to vehicles with a crew but also some level of remote, automated, or autonomous control. It can also apply to systems and components of systems that are not vehicles, such as intelligent decision aids and autonomous payloads.

To align with this terminology, the report uses the following nomenclature to distinguish between unmanned vehicles and unmanned systems:

- UxV: Unmanned Vehicle, where the "x" can be
  - A for Aerial (i.e., UAS is Unmanned Aerial System)
  - M for Maritime
  - U for Underwater
- UxS: Unmanned System, where the x takes the same values above but encompasses the vehicle as well as other system elements, such as off-board control and data processing, user interfaces, launch and recovery mechanisms, and communications links.

Remote, Automated, and Autonomous Control

The legislative request for this study seeks an assessment of current and emerging unmanned technologies, both autonomous and remotely controlled, for maritime domain awareness applications by the Coast Guard. A key difference between autonomous and remotely controlled systems is straightforward: the former implies a degree of independent action by the system, and the latter implies that a human operator exercises full control. The concept of autonomy, however, can be more difficult to pin down because of the varying degrees of independence from human intervention that a system can exhibit. Sometimes the term "autonomous" is applied to systems that are more appropriately characterized as "automated" because they are controlled by a programmed set of rules or instructions. Automation assumes an operator will make decisions when the automated sequence is not instructed to do through its programmed rules, such as algorithms or specific instructions that govern the course and speed of an automated vehicle. Autonomy, by comparison, implies that the system can independently formulate multiple courses of action and select one to pursue, albeit with human-prescribed objectives that it should conform to. As a practical matter, however, systems can depend on a combination of control mechanisms. Therefore, it can be difficult to draw a clear distinction between what constitutes an "automated" versus an "autonomous" system, or even a distinction between these systems and systems with some elements of remote operation.

Although numerous organizations and academic papers have proposed varying definitions of autonomy (see Appendix D for examples), it is not necessary for the purposes of this report to discuss these many distinctions, or levels of autonomy, in depth because the study charge seeks an assessment of the applicability to the Coast Guard of UxSs generally, presumably spanning the full spectrum of remote control to full autonomy.

Autonomy in Motion and Autonomy at Rest

As noted above, UxSs, and especially the more autonomous end of the spectrum, should be viewed as encompassing more than vehicle control systems (i.e., autonomy in motion) to include cyber systems and other technologies that provide intelligent data analysis and decision aids (i.e., autonomy at rest). Figure 3-1 illustrates why both autonomy in motion and autonomy at rest are important considerations. The schematic depicts the workflow involved in deciding whether and when to execute a tactical action—such as deploying a manned or unmanned vessel for an interdiction. The workflow entails data acquisition, analysis, decision making, and action, all connected in a feedback loop that should improve operational and mission performance. Although this workflow has traditionally been performed by humans, autonomous technologies—from artificial intelligence and machine learning to advanced sensor and control systems—can be applied across all three phases to create a faster, more efficient, and more effective feedback loop.

The ability to harness the power of unmanned technologies in all three phases of the workflow can be especially important in complex operations such as the pollution-response event depicted in Figure 3-2. In this example, in responding to the 2010 *Deepwater Horizon* platform explosion and well blowout in the Gulf of Mexico, the Coast Guard office in Louisiana was responsible for coordinating the deployment and actions of a workforce of 18,000 people and a fleet of 6,000 vessels involved in containment and remediation operations. The office had to align with national protocols for handling pollution-response operations and coordinate with numerous other federal agencies and state and local authorities. Decisive actions required significant quantities and types of data, from initial assessments of the situation to continual reassessments as conditions changed and mitigation activities ensued. Because this major incident occurred a decade ago, the workflow loop did not benefit from significant use of truly autonomous systems. However, its complexity would make it a candidate for the systems available today.

SYSTEMS ENGINEERING AND INTEGRATION

When one considers the applicability of a new technology or system, the desired functioning of that technology or system within larger systems into which it will be integrated must be assured. Indeed, one can point to many historical examples of unmanned technologies that were specifically designed to integrate well, largely because they do not present any special demands for integration. The Predator aircraft, for instance, was designed with enough range to perform reconnaissance missions over long

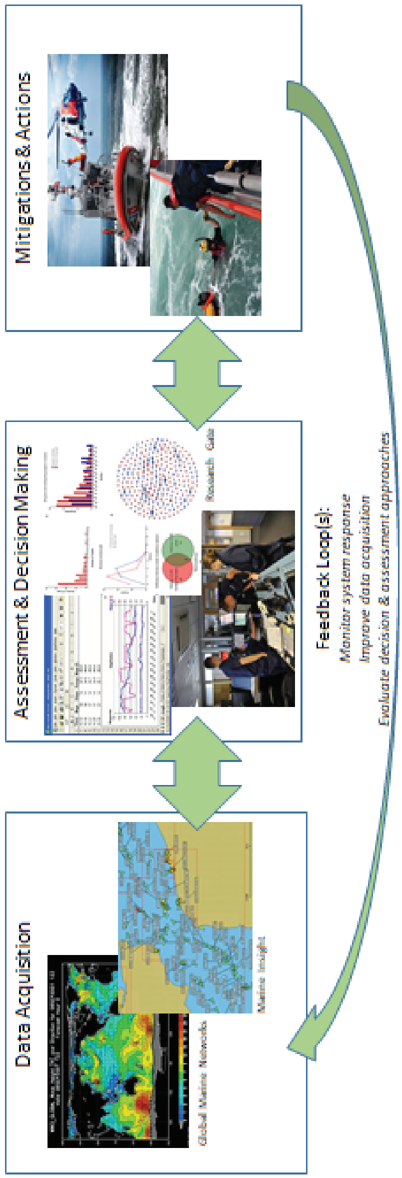

FIGURE 3-1 Depiction of the basic workflow for a Coast Guard action.

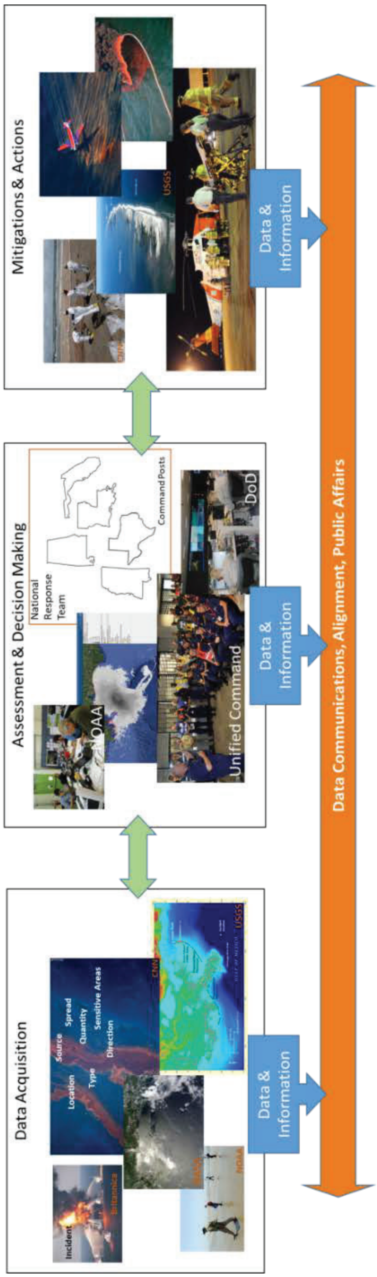

FIGURE 3-2 Depiction of the Coast Guard's workflow during a complex pollution response event.

distances, including at sea, while being operated remotely from land-based facilities rather than placing demands on vessels at sea. Likewise, the Navy has developed both unmanned underwater vehicles and unmanned surface vehicles that can operate for thousands of miles, and can be launched and serviced from a port rather than shipboard.

Increasingly, commercial, off-the-shelf technologies are becoming easier to integrate, mainly because they require minimal integration. For example, it is possible to purchase torpedo-shaped underwater vehicles that can be launched from a ship to complete multi-hour side-scan mapping missions without supervision.[1,2] Another example is the popular Roomba™ robot vacuum cleaner. A consumer takes a Roomba™ home, plugs it in, and lets it go. It is not integrated into a higher-level command and control system, lacks a complex user interface, and does not need high-accuracy global positioning system or even room maps. Users quickly learn what the Roomba™ can handle and which parts of the house (e.g., closed doors, stairs, steep thresholds) are barriers. The Roomba™ does enough work to be cost-effective without being perfect—indeed it serves as a good example of a system that is easy to integrate, fulfills a well-defined but limited "mission set," and is operated with sufficient frequency for users to obtain an intuitive sense of, and trust in, its capabilities.

The Coast Guard, like the other military services, emphasizes sound integration through systems engineering because of the high expectation, or trust, that a system will properly execute its critical functions. A variety of approaches can be pursued to achieve that level of trust and functionality when leveraging systems from the commercial sector or other domains. One example is to leverage systems that can be operated by the supplier's or contractor's experienced personnel. Indeed, as will be discussed below, the Coast Guard has successfully used this approach in its ScanEagle UAS program. No special Coast Guard training has been necessary. Another approach is to leverage systems that require only limited integration, as typified by the Coast Guard's procurement of small tethered underwater vehicles. In this case, a diver operates the vehicle from the shipdeck and generates pictures and verbal reports much in the same manner as during a dive. Here again, no new training or new interfaces are required to build trust in the system. When training is required to operate a leveraged system, its capabilities and integration could be ensured through test operations under a variety of conditions (e.g., sea states, day/night, meteorological).

Considering the premium that the Coast Guard places on shipboard space and crew time on board its ships, systems that integrate well with

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[1] General Dynamics. "*Bluefin Robotics Unmanned Underwater Vehicles*." https://gdmissionsystems.com/underwater-vehicles/bluefin-robotics.

[2] Hydroid. https://www.hydroid.com.

space and time demands can be major advantages. Examples of systems that might be attractive for these reasons are those that are

- Small enough to be launched from a vessel of opportunity, rather than dedicated space on a larger cutter;
- Autonomous enough for "fire and forget," which means the mission can be carried out without constant monitoring;
- Capable of long enough range so that launch and recovery can occur from the shore, without using ship time;
- Affordable enough to be launched on one-way missions, without the need to expend vessel and crew time for recovery at sea; and
- Smart enough to do onboard sensor processing and only call home—through robust and secure communications links—with snippets of information or windows of images.

Ensuring that a candidate system integrates well involves several other considerations. Notably, when the U.S. Department of Defense (DOD) considers acquiring off-the-shelf technology, it examines its reliability, availability, and maintainability (RAM) as indicators of the technology's suitability to be integrated into operations.[3] Reliability is the probability it will perform a required function under stated conditions for a specified period of time. Availability is the degree to which it can be expected to be in an operable state for use at the start of a mission when start time is random. Maintainability is the potential for the technology to be retained in, or restored to, a specified condition when maintenance is performed by personnel with specified skill levels. RAM integration problems are viewed as the failure of systems engineering.

Conformance with standards is another factor to assess a technology's potential for integration. Although very specialized high-performance systems may require all-custom development, most off-the-shelf systems will adhere to at least some government or industry standards intended to facilitate interchangeability and interoperability across various dimensions such as

- User interface
- Means of physically mounting payloads
- Communications links
- Power supplies and batteries and recharging connections
- Computing modules
- Sensor interfaces

[3] U.S. Department of Defense. 2005. "Guide for Achieving Reliability, Availability, and Maintainability." http://www.acqnotes.com/Attachments/DoD%20Reliability%20Availability%20and%20Maintainability%20(RAM)%20Guide.pdf.

The Coast Guard has already recognized the benefits of some of these standards. For example, the off-the-shelf ScanEagle (a small UAS discussed later) has multiple standardized sensor configurations for surveillance, including video detection and ranging (ViDAR) cameras for daylight use and alternative thermal (infrared spectrum) cameras for night sensing.

In addition, there is a growing family of military specifications for system architectures that may have relevance for the Coast Guard. For example, the Army is establishing system architecture standards for its Robots and Autonomous Systems thrust.[4] It has adopted Interoperability Profiles as a means to define a set of physical, electrical, and software interfaces for a specific ground robotic system. In its Unmanned Systems Integrated Roadmap 2017–2042, DOD cites interoperability first among the priorities for autonomous systems.[5] DOD has defined an Unmanned Systems Control Segment architecture for operator control stations that the Navy has been using extensively and the Army is starting to use. This architecture has transitioned to an SAE standard. Many other examples of DOD standard setting can be cited, such as the Army's plan to base all future autonomy software on standardized next generation Robot Operating System (ROS2) software libraries and tools.

CYBERSECURITY

UxS can present cybersecurity vulnerabilities from network-based and other perimeter attacks on information systems, as well as from attacks that directly affect the behavior of the vehicles and other physical assets. The source of the attacks—especially in the case of leveraged, off-the-shelf systems—can originate in the product supply chain, including individuals who create application software, as well as post-acquisition, during system life-cycle support. A system with cybersecurity vulnerabilities by definition lacks the qualities of RAM and sound systems engineering, but the Coast Guard must treat this possibility very seriously because of its many sensitive missions, such as in the domains of law enforcement and national security. When leveraging unmanned technologies developed by others, the Coast Guard must determine the criticality of ensuring cybersecurity in light of the intended application, the availability and cost of cybersecurity solutions, and the prospects of the solutions performing as required and not creating undesirable operational challenges.

[4] U.S. Army. 2017. "The U.S. Army Robotic and Autonomous Systems Strategy." https://www.tradoc.army.mil/Portals/14/Documents/RAS_Strategy.pdf.

[5] U.S. Department of Defense. "Unmanned Systems Integrated Roadmap 2017–2042." https://assets.documentcloud.org/documents/4801652/UAS-2018-Roadmap-1.pdf.

The Coast Guard must therefore weigh the advantages of leveraging UxS against the requirements to ensure their cybersecurity. Although considerable attention has been paid to protecting information systems from cyberattacks in recent years, the rapid advancements in physical systems, including unmanned vehicles, are presenting new cybersecurity challenges. DOD, in particular, has been focusing on achieving cyberattack resilient physical systems, including conducting risk analyses to prioritize potential resilience solutions. With a UxS, cyberattack resilience is the ability to detect when an attack is occurring and reconfiguring the system to permit continued operation, perhaps in a deteriorated but still acceptable mode. For example, a UAS might be equipped with multiple sensors—each procured through different supply chains—to validate navigation measurements in the event that one or more is attacked and provides corrupted measurements. The use of artificial intelligence approaches is also emerging as effective means for detecting, responding to, and continuing to operate under cyberattacks.

Although DOD, and the Navy in particular, can help identify potential cyberattack likelihoods and corresponding security solutions, the burden remains on the Coast Guard to assess the consequences of attacks and to identify operational issues related to employing potential solutions, including the need for operational doctrine and corresponding personnel training. DOD's experience suggests that systems must undergo considerable testing to assure proper implementation and effectiveness of security solutions. There may also be a need for data collection capabilities to support post-attack assessments and decisions related to protecting the attacked system. Addressing these technical and operational concerns may require development of an organizational structure that integrates people with cybersecurity and operational capabilities.

Certain Coast Guard missions pose less risk of adverse consequences from cyberattack, and these missions may be candidates for earlier applications of UxSs. The information needs of the Coast Guard's missions vary across a wide spectrum; some, as Search and Rescue (SAR), actively seek and use publicly available information and support, and others, such as Defense Readiness Operations, require the highest degree of cybersecurity. The type of mission is the main driver of the cyber requirement; hence, lower-risk missions allow for greater risk in the cyber domain without adversely impacting other Coast Guard, law enforcement, or national defense systems. Missions such as SAR, Marine Environmental Protection, Living Marine Resources, domestic Ice Operations, and Aids to Navigation and Marine Safety may derive great benefit from public interaction and collaboration through systems with a relatively lower degree of cybersecurity than other missions with a security or a defense nexus that would require a higher level of cybersecurity. The implementation of security solutions in these cases (e.g., SAR), while important, could be less technically and operationally challenging, and could provide the Coast Guard with opportunities to build its cybersecurity knowledge and capabilities related to UxSs.

LEGAL AND POLICY CONSIDERATIONS

To fulfill its missions and ensure consistency with its regulatory and maritime law enforcement roles, the Coast Guard has extensive legal authorities that accord with its functions as a regulator, law enforcement agency, and military service. Therefore, the Coast Guard's ability to use UxSs to execute one or more of its missions may depend on it having the applicable legal authority, jurisdiction, and basis in policy. For example, the Coast Guard must abide by relevant legal protections for safety, individual privacy, civil rights, and civil liberties. When it operates UxSs in international waters and airspace, the Coast Guard must comply with international law.

In addition to determining the lawful operation of UxSs, the Coast Guard must ensure their compliance with Federal Aviation Administration (FAA) regulations if intended for use in domestic air space. The Coast Guard also needs to ensure compliance with applicable data and privacy laws, specifically, as they relate to maritime law enforcement (e.g., search and seizure), privacy rights, and data collection. While in principle, UxSs should be allowed for all statutorily authorized Coast Guard missions that can be executed by manned assets, the legal regimes governing some unmanned operations are emerging and unsettled and therefore can present legal uncertainties.

Thus, as the Coast Guard explores candidate UxSs, it must carefully consider whether it can use them in a lawful manner under prevailing legal domestic and international frameworks (see Box 3-1). If a survey of applicable legal authorities leaves uncertainty or raises questions about its ability to operate certain UxS in compliance with laws, the Coast Guard may need to seek legal and policy determinations about their lawful use based on the type of operation, envisaged platform, and location of operations. In some cases, the Coast Guard may need to secure special authorizations or permissions from a cognizant authority, such as the FAA.

Finally, even if the Coast Guard confirms both its legal authority and jurisdiction to use UxSs, it will need to consult relevant policy guidance that govern technology procurements, at the federal and Coast Guard levels. Although a wide range of acquisition authorities may be applicable, newly emerging technologies can fall outside historical procurement processes and therefore may require innovative acquisition methods (see Box 3-2). To this end, the Coast Guard has started to explore new acquisition options—some of which emerged over the past year—and has, for example, assigned fulltime Cost Guard liaisons with the Defense Innovation Unit to accelerate the adoption of commercial technology.

BOX 3-1
Legal and Policy Considerations

Although the Coast Guard possesses extensive statutory authorities to execute its missions and can be expected to rely and build on these authorities to use unmanned systems (UxSs), continued technological capabilities are offering new use opportunities that may outpace existing legal frameworks. As fields of law related to UxS use emerge and become tested, new legal and policy frameworks for their use will need to be developed for the air, surface, and underwater operational domains. The pace of technology in this space is rapidly advancing, and the advent of emerging unmanned maritime vessel (UMV) technology has raised legal and operational questions as to whether some maritime regulations and conventions— such as those falling under the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), Inland Navigation Rules, and United Nations Convention for the Law of the Sea (UNCLOS)—were drafted with an expectation that vessels would be manned or at least have a "human in the loop" during operations. For example, such legal questions have served as the basis for the IMO MASS Regulatory Scoping Exercise and legal surveys promulgated by the Comité Maritime International (CMI) to several national maritime law associations, through which the IMO and the CMI sought assessments on the applicability of MASS to certain conventions and domestic laws, and more generally, whether the regulations can keep pace with the developing technology.

Therefore, the Coast Guard's legal and policy offices will need to determine whether existing laws, regulations, and policies allow for the safe and effective use of UxSs across the full range of envisaged operations. If they do not, the Coast Guard will need to identify the additional authorities and process that can fill the gaps, and if appropriate, work to bring them about. In the near term, this effort may require drafting of legal and policy memoranda for each type of UxS that the Coast Guard intends to acquire and deploy. Such memoranda would (1) account for the scope, purpose, and location of contemplated UxS operations; (2) fully assess the complex legal environment in which a UxS will operate and the relevant legal authorities on which the UxS will rely; (3) be vetted through the relevant field units and Coast Guard Headquarter Programs prior to acquisition and use of a UxS in the maritime domain; and (4) be used to support development of respective concept of operations. Appendix E provides further information on such legal and policy matters, including relevant resources and legal precedent.

BOX 3-2
Coast Guard Acquisition Authorities and Models

Once a promising UxS is identified, the challenge becomes selection of the most timely and cost-effective acquisition authority and model. The primary regulation that governs all federal agencies' acquisition of supplies and services is the Federal Acquisition Regulation. Other mechanisms include agreements such as the U.S. Department of Homeland Security Cooperative Research and Development Agreements (CRADAs), Silicon Valley Innovation Program, Unsolicited Proposals, and Other Transaction Authority (OTA). The Coast Guard is familiar with all of these mechanisms, whose use depends on needs and circumstances.

Although some acquisition authorities and models will be better suited to UxSs than others, the rapid pace of UxS advancements could require even more streamlined and nimble options to quickly respond to available opportunities and partnerships. Perhaps the most efficient way to acquire and accelerate the transition of UxS platforms and payloads to desired operations would be to identify and prioritize tested and proven technologies, and then adapt those systems for specific requirements. For example, mature technologies that are relatively inexpensive to operate, outfitted with operator-friendly control systems, and readily configured for multiple missions and payloads could be the primary focus of early transitions. Likewise, the contractor-owned and -operated model also provides valuable experience and exposure to systems, platforms, payloads, and concept of operations without long-term investments in short-term technology, as well as continual access to the latest system and sensor capabilities provided by the contractor. Another potential mechanism to maximize experience and exposure to a variety of technologies, while minimizing capital investments, is the use of "data buys" from UxS service providers as appropriate.

Partnerships and mutual support arrangements with other organizations offer another way to increase access to emerging technologies and to decrease acquisition and operating costs, such as through volume purchases or use of a UxS already purchased by a partner. Furthermore, partnerships with industry can be pursued through a variety of mechanisms including CRADAs, the National Oceanographic Partnership Program, Small Business Innovation Research, and standard grants and contracts.

4

Unmanned System Experience in the U.S. Coast Guard and Other Federal Agencies

Driven by the commercial and governmental sectors, technological advancements in unmanned systems (UxSs) have been accelerating, along with their reliability, capability, and affordability. The U.S. military, in particular, has demonstrated a keen interest in using UxSs to add and strengthen operational capabilities by making large and sustained investments over the past two decades. Other federal organizations—with law enforcement, national security, and other civilian missions—are also exploiting capabilities afforded by UxSs. The Coast Guard has also invested in research and development (R&D), acquisitions, and some limited deployments of these systems, as well as actively partnering on UxS projects sponsored by other military services and federal agencies.

The chapter begins by identifying and reviewing the status of 12 UxS projects and programs, active or planned at the time of this study, that the Coast Guard either sponsors or supports in partnership with other entities.[1] These descriptions are followed by an overview of the Coast Guard's programmed budgetary expenditures for UxSs, as well as relevant R&D expenditures by the U.S. Department of Homeland Security's (DHS's) Science and Technology (S&T) Directorate. This budgetary information is incomplete because much of the Coast Guard's work on UxSs, as evident from the 12 projects, is not pursued in programs of record but rather in unit-based initiatives and partnerships with other agencies. The Coast

[1] The committee was able to identify these 12 projects during the course of its work, but others may have escaped its effort to catalog activity. The status of all 12 projects at the completion of this report is not known.

Guard does not appear to have a commonly planned, coordinated, or resourced effort for furthering the development, acquisition, and use of UxSs across the organization.

After reviewing the Coast Guard's activity on UxSs, the chapter provides examples of systems and initiatives from several other military services and federal agencies that briefed the committee. Although far from a complete listing of UxSs across the agencies discussed, much less the federal government, the examples are helpful for identifying key features of initiatives and programs that can potentially inform the Coast Guard's efforts to expand its UxS activity and programs. The chapter concludes by highlighting some of those features.

COAST GUARD UxS ACTIVITIES

The Coast Guard has a range of UxS efforts that span fully funded programs to informal, and often lightly funded or unfunded, partnerships with other governmental, academic, and private-sector entities. Some efforts, including several Coast Guard R&D projects and an established program (ScanEagle) that deploys a small unmanned aerial system (sUAS), are well documented by the Coast Guard. More difficult to trace, however, are various unit-based initiatives and partnerships with other agencies and entities to investigate and utilize UxSs. In tracing these efforts, the committee realized that the Coast Guard is pursuing UxSs in more ways than formally cataloged. Indeed, the number and variety of initiatives that were identified suggest a keen operational-level interest in UxSs for an array of Coast Guard functions and missions.

The following sections contain brief descriptions of 12 Coast Guard UxS projects that the committee identified in programs of record, R&D, and partnerships with other organizations from the military, DHS, and elsewhere in the federal government. In addition to providing basic information on the technologies involved and the operational domain (air, surface, undersea, decision-support), the descriptions identify the sets of missions impacted, the sponsoring Coast Guard unit, and the other public- and private-sector entities involved.

When available, the descriptions include Coast Guard estimates of budgetary expenses and other resource requirements for procuring, deploying, and operating the system, as well as Coast Guard assessments about whether the system is conferring, or expected to confer, budgetary savings or other benefits such as improved safety and quality of the work environment for personnel. Several accompanying tables summarize the project descriptions across different dimensions.

Programs of Record

Small Unmanned Aerial System—National Security Cutter Augment

In 2016, the Coast Guard awarded Insitu, a Boeing subsidiary, a services contract to deploy its commercial, off-the-shelf ScanEagle UAS onboard the National Security Cutters. The UAS was deployed to provide augmented air surveillance for drug and migrant interdiction, other law enforcement activity, and Search and Rescue (SAR). Insitu is paid to install the UAS (three units) and their launch-and-recovery equipment and ground-control stations on board the ships, and to deploy a small team embedded in the ship's crew to operate the system.

The ScanEagle has a wingspan of 10.2 ft. and a length of 5.1 to 5.6 ft. Its empty structure weighs between 30.9 lb. and 39.68 lb., while its maximum takeoff weight is of 48.5 lb. This UAS is launched autonomously using a catapult launcher (see Figure 4-1). The systems also includes a no-net, runway-independent solution that catches the aircraft by its wing tip with a rope that hangs from a 50-ft.-high boom.[2]

The initial deployments on the Coast Guard cutter Stratton have been characterized as highly successful, because the ScanEagle—equipped with an electro-optical/infrared camera, a laser pointer, a communication relay, an Automatic Identification System interrogator and ViDAR (visual detection and ranging, a surface search capability)—has enabled scans of 75 miles on either side of the ship, effectively doubling the ship's surveillance area, and has enabled surveillance of as much as 1,000 square miles per flight hour.[3] As a result, the Coast Guard has expedited its schedule for installing the UAS on all of its Legend-class National Security Cutters (NSCs), including five to date and all by the end of 2020. Expansions beyond this cutter class are not planned because of cost.

Sponsored by the Office of Air Forces (CG-711), the program has cost $40.2 million through Fiscal Year (FY) 2020. Although some of the costs associated with single-event deployments may qualify for reimbursement from Treasury Forfeiture Fund (or similar sources), the program is fully funded by Coast Guard budget allocations from Headquarters (HQ). In providing augmented capabilities, rather than substituting for other personnel and assets in the provision of an existing capability, the system is not expected to provide well-defined budgetary savings. Nevertheless, in the absence of the UAS, to achieve that augmented surveillance, the Coast Guard

[2] In Situ. "ScanEagle Unmanned Aircraft Systems." http://www.boeing.com/farnborough2014/pdf/BDS/ScanEagle%20Backgrounder%200114.pdf.

[3] Burgess, R. 2020. "Coast Guard Expedites ScanEagle ISR Services for National Security Cutters." *Sea Power Magazine*, January 17, 2020. https://seapowermagazine.org/coast-guard-expedites-scaneagle-isr-services-for-national-security-cutters.

FIGURE 4-1 Launch of ScanEagle from U.S. Coast Guard cutter.
SOURCE: U.S. Coast Guard.

would have to commit time and money for additional manned flights and associated operations, such as deploying a crash safety and fire suppression crew for the duration of each manned flight.

Active Joint Programs

Long-Range Unmanned Aerial System Program

Since 2008, the Coast Guard has participated in the U.S. Customs and Border Protection (CBP)–U.S. Coast Guard UAS Joint Program Office. The UAS Joint Program Office is staffed by personnel from both agencies who operate CBP-owned systems, including the long-range MQ-9 Predator (separate land and maritime variants) and ground equipment. With a focus on law enforcement and anti-terrorism, the joint program generates surveillance data that serves not only CBP's Air and Marine Operations and the Coast Guard, but also the U.S. Border Patrol, the U.S. Immigration and Customs Enforcement (ICE), and the U.S. Citizenship and Immigration Services. Surveillance from the joint program is intended to benefit the

Law Enforcement, Drug Interdiction, Migrant Interdiction, and Marine Environmental Protection Coast Guard Missions.

Conducted from the National Air Security Operations Center in San Angelo, Texas, these joint operations have involved Coast Guard pilots, sensor operators, and trainers. The approximately 17 Coast Guard personnel that serve in the joint program every year are funded by Coast Guard HQ at a cost of $2.25 million annually (for personnel and travel).

From the technology perspective, the MQ-9 (see Figure 4-2) is long range with an endurance of up to 20 hours, making it an ideal candidate for persistent surveillance. With a maximum gross weight of 10,500 lb., the MQ-9 operates with a service ceiling of 50,000 ft. and can reach speeds of 240 knots.[4] The "Guardian" version of the MQ-9 is designed specifically for maritime domain missions, and it differs from the land domain Predator by its SeaVue marine search radar as well as the electro-optical infrared sensor optimized for maritime operations. The lack of both land and maritime surveillance sensors within the same aircraft hinder operational adaptability when unforeseen surveillance opportunities at sea suddenly occur while conducting a land domain awareness operation. This limitation, in addition to the scarce number of maritime domain flights under this program, reduces the potential gains for Coast Guard missions.

Briefings by the UAS Joint Program Office suggest that awareness of the Predator program is currently low among Coast Guard pilots, and it has proven difficult to attract pilots to the program. Accordingly, the Coast Guard is trying to encourage pilots to participate in the program after their first aviation tour. Training for experienced pilots lasts about 8 weeks. Unlike the U.S. Air Force, for example, the Coast Guard does not have an established career path for unmanned aircraft operators. Pilots who serve in the MQ-9 program fly unmanned aircraft during a limited tour and then return to the fleet.

Additional challenges are the lack of a strategic plan and supporting roadmaps and the high cost of operating the MQ-9. Because CBP covers most costs for this program, the Coast Guard's spending on this technology would be much higher if it had pursued this technology alone. However, this program has not shown a cost savings compared to the use of manned aircraft.[5]

[4] DHS. "Unmanned Aircraft System MQ-9 Predator B." https://www.cbp.gov/sites/default/files/assets/documents/2019-Feb/air-marine-fact-sheet-uas-predator-b-2015.pdf.

[5] DHS Office of Inspector General. 2014. "U.S. Customs and Border Protection's Unmanned Aircraft System Program Does Not Achieve Intended Results or Recognize All Costs of Operations." https://www.oig.dhs.gov/assets/Mgmt/2015/OIG_15-17_Dec14.pdf.

FIGURE 4-2 The MQ-9 Predator owned by the U.S. Customs and Border Protection.
SOURCE: U.S. Department of Homeland Security.

Research and Development

Robotic Aircraft for Maritime Public Safety

Initiated in FY 2013 and completed in FY 2019, this R&D project evaluated small quad copter (see the Yuneec Typhoon H being tested in Figure 4-3) and small fixed-wing UAS platforms (see the Puma AE in Figure 4-4) across a variety of geographic areas and every class of Coast Guard vessel as well as shore locations.

With a size of 20.5 in. × 18 in. × 12.2 in. and takeoff weight of 368.8 oz., the Yuneec Typhoon H has an endurance of up to 25 min., fly ceiling of 122 meters (restricted by the Federal Aviation Administration [FAA]) and maximum climbing speed of 5m/s. Its maximum rotation rate is 85 deg/s and maximum roll angle is 35 degrees.[6] It operates using a 4S 14.8V LiPo battery and has a ST16 Personal Station Ground transmitter. This UAS also has a small 9.0 oz. (with battery) camera with a 14 mm/F2.8

[6] See https://us.yuneec.com/typhoon-h-specs.

FIGURE 4-3 Yuneec Typhoon H small quad copter.
SOURCE: U.S. Coast Guard.

FIGURE 4-4 Puma AE (All-Endurance) UAS by AeroVironment.
SOURCE: U.S. Coast Guard.

lens and field of view of 98 degrees. It can transmit video in the 5.8 GHz Wi-Fi frequency band at a range of up to 1 mile in optimum conditions.

The Coast Guard also tested the Puma AE by AeroVironment.[7] Weighing 13.5 lb., the Puma AE operates for more than 210 min., usually at a range of up to 9 miles, and provides live-streaming color and infrared video, as well as laser illumination from its pan-tilt-zoom Mantis i25 AE gimbaled payload. The system is very portable; it is launched by hand and is capable of landing on the ground or in fresh or salt water.[8]

With the potential to benefit the SAR, Drug Interdiction, Migrant Interdiction, Living Marine Resources Enforcement, and Marine Environmental Response missions, the program evaluated realistic scenarios for maritime security to help guide the development of requirements, standards, and concept of operations (CONOPS). It also helped guide future platform and sensor development including payloads.

This research, sponsored by the Coast Guard Office of Aviation Forces (CG-711), was funded by DHS S&T at a cost of $1.42 million. By the time the R&D project was completed, funding and the limited capabilities of sUAS had emerged as primary challenges. Because these technologies could alleviate the need for manned aircraft for some surveillance operations, research continued in subsequent R&D programs.

Short-Range UAS Program

This program, sponsored by the Office of Aviation Forces (C-711) and initiated in FY 2018, focused on short-range (i.e., 1 mile, 30 min. endurance), low-cost, commercial off-the-shelf technology that requires minimal training and low endurance. This work, conducted in partnership with DHS, started as a test and demonstration to explore the capabilities of these systems. Seven prototypes were tested in FY 2018, and 11 more units were fielded in FY 2019, with the goal of expanding to fleet-wide deployment by the end of FY 2020.[9] The program, however, is currently on hold, pending compliance with congressional mandates about foreign supply sources. If implemented in the future, the use of short-range UASs could benefit several Coast Guard missions including SAR; Port, Waterways and Coastal Security (PWCS); Law Enforcement; Drug Interdiction; Marine Environmental Protection; Aids to Navigation; Ice Operations; and Migrant Interdiction.

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[7] Moncourtois, A. 2020. "U.S. Coast Guard Deploys Puma™ AE during Operation Deep Freeze." https://www.avinc.com/images/uploads/news/Operation_Deep_Freeze.pdf.

[8] AeroVironment. 2016. "Aerovironment's Puma AE UAS Supporting Coast Guard Ice Breaker for Operation Deep Freeze Resupply Mission through Treacherous Antarctic Seas." https://www.avinc.com/resources/press-releases/view/aerovironments-puma-ae-uas-supporting-coast-guard-ice-breaker-for-operation.

[9] Briefing from CDR Chad Thompson in September 2019.

The program, paid for by Coast Guard Field Units, involved an investment in technology of approximately $50,000 per year and produced an estimated cost savings of $513,000 in FY 2018. Thus, the potential for cost savings is high because the use of these UASs could result in fewer aircraft/boat launches, which would ultimately reduce maintenance and fuel costs. The use of seven short-range UAS units in 1 year can save more than $500,000, because the need to contract out cranes, survey crews, or manned aviation assets is eliminated. Fleet-wide implementation could realize very large potential savings. Likewise, the use of this technology could improve the quality of life for Coast Guard personnel, because short-range UASs could reduce the need for boat launches by providing greater situational awareness of the maritime domain and could be easily used for dull/dangerous missions such as tower or other infrastructure inspections.

Because this program is focused on future deployment to Coast Guard field units, additional benefits for routine Coast Guard operations may be discovered once the technology is in the hands of the workforce. For external partners, information gathered with short-range UASs could support law enforcement agencies and maritime entities located near Coast Guard units, and ultimately provide faster and better maritime domain awareness (MDA) that could increase the safety and security of the American public.

As with other programs, the lack of a Coast Guard strategic plan for UxS could challenge the success of this program and the effective integration of the technology into Coast Guard missions. From the technology perspective, the lack of affordable and cyber-hardened short-range UASs could limit the type of operations these systems can support.

Medium-Range UAS Program

In 2018 and 2019, the Coast Guard conducted proof-of-concept research in Texas, Puerto Rico, and California for medium-range UASs using the ScanEagle. Sponsored by the Office of Aviation Forces (CG-711), the program is currently developing requirements for fleet-wide, cutter-based UASs for tactical airborne surveillance and reconnaissance. At a cost of $180,000, this work is being funded through the Deputy Commandant for Operations (DCO) at HQ.

This program's goal is to augment or replace manned surveillance flights, both from ships and on land, which could potentially reduce costs in traditional equipment and personnel recognizing of course that the unmanned assets themselves have costs and require personnel to operate and maintain them. If successfully developed and deployed, medium-range UASs could benefit the Law Enforcement, Drug Interdiction, Migrant Interdiction, and Marine Environmental Response missions. When operated from Coast Guard cutters, this UAS could reduce the burden of manned flight operations, which involve significant time investments for a large portion of the crew.

Technical and regulatory impediments for the deployment of this UAS involve mainly airspace see-and-avoid regulations. In addition, successful development and deployment could be hindered by the lack of a Coast Guard strategic plan for UxSs and limited funding for R&D and acquisition.

Vertical Takeoff and Landing (VTOL) UAS Operations

This ongoing R&D project evaluates UAS that can takeoff vertically, transition to forward flight, and then land vertically, thus eliminating the need for specialized launch and recovery equipment. The Vertical Take-Off and Landing (VTOL) system being tested is the Martin unmanned aerial vehicle (UAV) V-BAT (see Figure 4-5).[10] Having a wing-span of 9 ft., length of 8 ft., and weight of 88 lbs., the V-BAT UAS has a range of 130 km and airspeed of 47 knots when flying for maximum endurance, and 90 knots when flying for maximum speed. The V-BAT is designed with enough capacity to carry a range of interchangeable payloads, such as electro-optical/infrared, Automatic Identification System (AIS), land and maritime surveillance, Tactical Signals Intelligence (SIGINT) and 4G/LTE, to serve mission-specific requirements.[11]

The project—sponsored by the Office of Aviation Forces (CG-711) and funded through the Deputy Commandant for Mission Support (DCMS)/ Research, Development, Test, and Evaluation (RDT&E) appropriation—was initiated in FY 2020 at a cost of $381,000 and is slated for completion in FY 2022. The project is being conducted in partnership with U.S. Southern Command.

Successful development and deployment of VTOL technology could benefit the SAR, Law Enforcement, Drug Interdiction, Marine Environmental Response, and Migrant Interdiction missions. The technology could potentially support the U.S. Navy through joint Coast Guard–Navy operations. With the potential to reduce manned flight operations, which require a significant time investment by a large portion of the crew, VTOL technology could relieve crew to focus on other key operations, and thus serve as a force multiplier. This technology could decrease the deck size required for flight operations, which could bring “flight deck” capability to a greater range of cutters. The main challenges to successful development and deployment are the requirements for see-and-avoid technology and flight endurance.

[10] UASWeekly.com. “Martin UAV V-BAT Selected as the First-Ever VTOL UAS to Be Evaluated During an Operational Coast Guard Patrol.” https://uasweekly.com/2020/09/03/martin-uav-v-bat-selected-as-the-first-ever-vtol-uas-to-be-evaluated-during-an-operational-coast-guard-patrol.

[11] Martin UAV V-BAT. https://martinuav.com/v-bat.

FIGURE 4-5 Martin AUV V-BAT by Northrop Grumman.
SOURCE: U.S. Coast Guard.

Low-Cost MDA Pilot

This pilot program, carried out in response to legislation and initiated in FY 2018, is studying the potential to improve MDA in remote areas using low-cost, commercially available, unmanned surface vessels, specifically vessels from Saildrone[12] and Spatial Integrated Systems,[13] and historic Automatic Identification System (AIS) data. The study is focused on a turn-key solution that would engage contractors to operate the entire system.

Saildrone is an unmanned surface vehicle (USV) designed to perform autonomous long-range data collection missions in ocean environments. The vehicle weighs 750 kg and has a narrow 7 meters long hull, 5 meters tall wing, and a keel with a 2.5 meters draft. The system combines wind-powered propulsion technology that enables mission durations of up to 12 months (sailing on average 100 km per day) and solar-powered meteorological and

[12] Saildrone. "Eyes and Ears at Sea: US Coast Guard to Test Saildrone Autonomous MDA Capabilities." https://www.saildrone.com/news/uscg-test-maritime-domain-awareness-solution.

[13] PRNewswire. "Spatial Integrated Systems (SIS) Wins US Coast Guard Maritime Domain Awareness Pilot Study Contract." https://www.prnewswire.com/news-releases/spatial-integrated-systems-sis-wins-us-coast-guard-maritime-domain-awareness-pilot-study-contract-301010569.html.

oceanographic sensors. This USV can be launched and recovered from a dock. It operates either under the constant supervision of a human pilot via satellite or can navigate autonomously from prescribed beginning and end points within a user-defined safety corridor. While traveling autonomously it accounts for wind and currents to stay on track. Its meteorological and oceanographic sensor are capable to measure in real time solar irradiance, long wave radiation, atmospheric pressure, air temperature and humidity, wind speed and direction, ocean skin temperature, bulk water temperature, chlorophyll and colored dissolved organic matter, among others.[14]

The Spatial Integrated Systems' Multi Agent Robotic Teams Autonomy System is a vehicle control system that can turn any platform into an unmanned system. The vehicle platform used for the project is the MetalCraft 7 meter Interceptor Boat by MetalCraft Marine, who teamed up with Spatial Integrated Systems for this Coast Guard award. A high speed patrol boat, which is also used by the Coast Guard Cutter Boat-Large Program, the MetalCraft 7 meter Interceptor was specifically chosen for this project because it can operate in extreme conditions, has been proven for launch and recovery from USCG Cutters and has a large space for future payloads.[15]

The pilot is sponsored by the Office of Intelligence, Surveillance, and Reconnaissance (ISR) Systems and Technology (CG-26), but it involves an extensive list of Coast Guard stakeholders, including the Office of Aviation Forces (CG-711), Office of Specialized Capabilities (CG-721), Office of C4 and Sensor Capabilities (CG-761), Office of Law Enforcement Policy (CG-MLE), Atlantic Area, Pacific Area, District 14 (D14), and District 17 (D17). The $3 million cost for the project has been funded by Coast Guard HQ, specifically the Deputy Commandant for Mission Support, Acquisition Directorate (CG-9), R&D.

The Coast Guard is conducting this project with no external partnerships. Successful development and deployment of the technology could support other government agencies, such as the Maritime Administration (MARAD), the National Oceanic and Atmospheric Administration (NOAA), the National Marine Fisheries Service, and the U.S. Department of State, and the states of Alaska and Hawaii. It could also benefit relevant nonprofit environmental groups, allied foreign governments located in the region where the Coast Guard operates (e.g., Australia, France, and New Zealand), and the Oceania region (consisting of small island nations—Melanesia, Micronesia, and Polynesia—that lack the resources or capability

[14] Saildrone. Wind-Powered Ocean Drones. https://www.saildrone.com/technology.

[15] Cision. "Spatial Integrated Systems (SIS) Wins US Coast Guard Maritime Domain Awareness Pilot Study Contract." February 25, 2020. https://www.prnewswire.com/news-releases/spatial-integrated-systems-sis-wins-us-coast-guard-maritime-domain-awareness-pilot-study-contract-301010569.html.

to monitor their Exclusive Economic Zones). Although somewhat speculative, Coast Guard deployment of this technology could urge other nations and U.S. government agencies to financially support a Coast Guard–capable system that could improve SAR, Fisheries Law Enforcement, Drug Interdiction, and Migrant Interdiction in vast and remote maritime regions.

The expansion of MDA in remote areas using autonomous systems could reduce patrol days and fuel costs, while improving the ability to monitor and combat illegal, unreported, and unregulated fishing. Fleet operations could also be freed up to support other missions that are not currently sourced.

As with other UxS projects within the Coast Guard, the lack of a strategic plan and budget considerations are the main challenges to future deployment of this technology.

Oil Spill Detection and Mapping

This R&D project is focused on the development of an autonomous underwater vehicle for mapping oil spills on the surface, subsurface, and under the ice. The Tethys Long Range Autonomous Underwater Vehicle is designed for under ice operations in the Arctic environment.[16] Designed for low-drag and low-power operation, this system has a 15-day endurance (with 6kWH rechargeable batteries) and the capability to travel hundreds of miles.[17] The Tethys is designed for dissolved hydrocarbon and environmental anomaly detection and mapping.

The technology could improve understanding of oil in water column, which would ultimately impact response strategies. Successful development and deployment would therefore benefit primarily the Coast Guard's Marine Environmental Response (MER) mission; therefore, the Office of Marine Environmental Response Policy (CG-MER) is sponsoring this R&D. Although the University of Alaska's Arctic Domain Awareness Center, Woods Hole Oceanographic Institute, and Monterey Bay Aquarium are partners, DHS S&T is funding the project at a total of $4.18 million.

The project will be completed in FY 2021. If adopted, some of the costs associated with single-event deployments may qualify for reimbursement

[16] See https://www.arcticdomainawarenesscenter.org/P10_LRAUV.

[17] Tethys is 2.7 meters long, 0.3 meters diameter, 110 kg dry weight. It is rated to 300-meters depth. It is propeller-driven with a 0.5–1.2 m/s speed. Its buoyancy engine enables neutral buoyancy and drift mode. It has the following sensors: CTD (or Sonde to measure the conductivity, temperature, and pressure of seawater), DO2 (to measure dissolved oxygen and temperature), SeaOWL (fluorometers), fluorescence/backscatter and hydrocarbon detection, up/down acoustic Doppler current profiler, umodem, USBL array (for underwater acoustic positioning), docking nose, and a photosynthetically active radiation sensor.

because the "responsible party" for a given oil spill is legally required to clean up or reimburse cleanup efforts to the National Pollution Funds Center.

Cost, complexity of these underwater unmanned vehicles, and their maintainability are the primary challenges to their deployment and use. However, their use could enable more rapid and accurate response to pollution spills in U.S. waters, thereby increasing the quality of life of all Americans.

Oil Spills in Ice Environments

This ongoing project is conducting lab and field tests of long-range autonomous underwater vehicles (AUVs), AUVs, and UASs in ice conditions to verify the accuracy of sensors and unmanned systems and is testing the timeliness of data transfer to responders. The technology under research involves multiple domains: air, surface, subsurface, and decisions support systems. The Coast Guard has partnered with NOAA, the Cold Regions Research and Engineering Laboratory (CRREL), the Woods Hole Oceanographic Institute, the Bureau of Safety and Environmental Enforcement (BSEE), and the U.S. Environmental Protection Agency (EPA) to carry out this project. Figure 4-6 depicts the recovery from icy waters of a Puma AE UAS during one of the tests conducted in collaboration with the Coast Guard's partners. The project's research results are expected in September 2021; its successful completion will result in a prototype.

The Coast Guard mission that will most benefit from these systems is MER; therefore, the program sponsor is the Office of Marine Environmental Response Policy (CG-MER). The project also has the support of other Coast Guards offices including the Acquisitions Directorate (CG-9) Research and Development Center (RDC); the Office of Incident Management & Preparedness (CG-5RI); and Districts 1, 9 and 17. At a total cost of $300,000, this project is funded through the National Pollution Funds Center, specifically the Oil Spill Liability Trust Fund.

The potential for the Coast Guard to be reimbursed for costs to use these systems during its operations is very high, because the spill's "responsible party" is legally required to clean up or reimburse cleanup efforts to the National Pollution Funds Center.

Proving the concept and allocating funds for future development and deployment will be essential to realizing these systems and their expected benefits. The Coast Guard responds to thousands of pollution events every year, and therefore improved data collection could significantly improve response times and provide better information about geographic location. Thus, the potential to realize benefits from deployment of these various UxSs is very high.

FIGURE 4-6 U.S. Coast Guard crew testing a Puma AE UAS to identify the extent of simulated spilled oil in the Beaufort Sea in 2013.
SOURCE: U.S. Coast Guard (photo by Petty Officer 3rd Class Grant DeVuyst).

These systems could improve the quality of life of Coast Guard personnel, because they can replace people as data collectors in very harsh environmental conditions. Moreover, environmental conditions in the Arctic sometimes preclude data collection altogether, so the benefits derived by the Coast Guard from the systems would be significant. Other beneficiaries would be NOAA, EPA, U.S. states and territories that regularly experience maritime ice conditions, neighboring countries (e.g., Canada), and nongovernmental organizations working on environmental issues.

Counter-Unmanned Air Systems (cUASs)

This project, initiated in October 2016 and slated for completion in November 2020, is examining air domain vehicles and decision support systems to detect, track, identify, and defeat illicit use of UASs in the maritime environment. Its deliverable will inform requirements for the PWCS and Defense Readiness missions. The project is conducting market research of government and commercial off-the-shelf technology and evaluating prototypes to support the development of requirements. It is also providing subject-matter expertise in Coast Guard–wide development of tactics, techniques, and procedures. Similar to other UxS under investigation by the Coast Guard, successful development and deployment could be hindered by the lack of a strategic plan and historic low levels of investment in these systems.

Given the anticipated proliferation of small UASs in the commercial market and the growing threats posed by these systems, ensuring cUAS capabilities will likely become increasingly important for the Coast Guard in order to protect the safety and security of the American public. This added capability could also benefit the U.S. Navy, the U.S. Department of Defense (DOD), and law enforcement agencies through their joint and cooperative activities with the Coast Guard.

The Office of Maritime Security Response Policy (CG-MSR) is the Coast Guard sponsor for this R&D project. Stakeholders include a wide range of organizations within the Coast Guard: Office of Aviation Forces (CG-711), Office of Specialized Capabilities (CG-721), Office of Boat Forces (CG-731), Office of Cutter Forces (CG-751), Office of Security Policy and Management (DCMS-34), Coast Guard Intelligence (CG-2), Assistant Commandant for Command, Control, Communications, Computers and Information Technology (CG-6), Command, Control, and Communications Engineering Center (C3CEN), Surface Forces Logistics Center, and Area-3. Funded at $1.39 million, the project is being paid for primarily by the Atlantic Area and, to lesser extent, the Deputy Commandant for Mission Support (DCMS) RDT&E. External partnerships include DHS S&T, U.S. Air Force (USAF) Research Lab, Defense Advanced Research Projects Agency (DARPA), Naval Surface Warfare Centers, and the Office of Naval Research.

Counter-Unmanned Underwater Vehicles (cUUVs) Including Anti-Swimmer

This ongoing research project, to be completed in 2021, builds on prior anti-swimmer work. The project is summarizing cUUV and anti-swimmer technologies with high technology readiness levels that can be demonstrated for Coast Guard use and conducting limited user evaluation to identify baseline and desired functional characteristics. The primary Coast Guard missions that would benefit from these systems are PWCS, Defense Readiness, and Law Enforcement. The primary challenges for full development and deployment are proof of technology and funding.

Although this technology is not expected to yield costs savings, field personnel would benefit because they would be better equipped to counter underwater threats including anti-swimmers. This technology could be useful for DOD, federal/state/local law enforcement agencies with maritime vessels or infrastructure, and even allied partner nations—and perhaps even cruise lines and other passenger vessels.

The project sponsor is the Office of Specialized Capabilities (CG-721). Stakeholders include the Office of Naval Engineering (CG-45), Office of Boat Forces (CG-731), Office of C4 & Sensors Capabilities (CG-761), and Area-3. The Coast Guard's DCMS RDT&E is funding this project at a total cost of $164,000.

Maritime Unmanned System Technology (MUST)

This project is evaluating autonomous underwater and surface vehicles—such as the Triton by Ocean Aero in Figure 4-7—and their potential for persistent MDA.

Ocean Aero's Triton is a wind- and solar-powered surface and subsurface ocean UxS, designed to be able to be out in the ocean for months a time. It is 4.14 meters long, 2.45 meters high, and has a weight of 127 kg. Its wind propulsion allows for speeds of 5 knots. For operations underwater, Triton's wingsail folds and retracts allowing the vehicle to quickly submerge to evade detection and severe weather conditions as well as perform subsurface data collection tasks. The platform also provides with stability ballast tanks, and solar rechargeable lithium batteries. It can collects a wide variety of ocean and environmental data using its set of sensors, such as weather sensors, acoustic Doppler current profiler, magnetometers, seismic survey sensors, and hydrocarbon detectors.[18]

If successful, deployment would certainly benefit the Law Enforcement, Drug Interdiction, Migrant Interdiction, and Marine Environmental Protection missions; research results could reveal benefits for other statutory Coast Guard missions, the Navy, and other maritime law enforcement agencies. Eventual deployment must overcome the challenges of sensor capability, equipment endurance, and funding. If those challenges are met, then use of the systems would intensify persistent maritime surveillance in U.S. waters and thus increase the safety and security of all Americans.

The project was initiated in October 2019 and is slated for completion in November 2023. DHS S&T is a sponsor and the sole funder, providing $16 million for FY 2019–2020. In addition to DHS S&T, external non-funding partners include the U.S. Naval Research Lab, the University of Southern Mississippi, the Naval Undersea Warfare Center, and the Naval Information Warfare Center. Internal to the Coast Guard, the project benefits from the sponsorship of Coast Guard Intelligence (CG-2) and numerous

[18] Ocean Aero. https://www.oceanaero.com/vehicles.

FIGURE 4-7 Example of maritime unmanned system technology under evaluation (Triton by Ocean Aero).
SOURCE: U.S. Coast Guard.

stakeholders including the Office of Intelligence, Surveillance, and Reconnaissance (ISR) Systems and Technology (CG-26), Office of Specialized Capabilities (CG-721), and Office of Law Enforcement Policy (CG-MLE).

The following tables summarize the details for the Coast Guard UxS projects that were identified by the committee:

- Table 4-1 lists the Coast Guard missions that could benefit from the capabilities of the specific UxSs activities and projects completed or under way.
- Table 4-2 summarizes the operational domain—air, surface water, subsurface, or decision-support platforms—relevant for each of those known projects.
- Table 4-3 identifies which organization(s) carries the primary and secondary cost burden for each UxSs activity.
- Table 4-4 provides an overview of the program sponsors for each UxS project.
- Table 4-5 shows the Coast Guard's U.S. government, foreign government, academic, and private-sector entities partners for the UxS projects/programs.

The tables reveal the Coast Guard's interest and ongoing efforts to realize the promise of these technologies across its missions and operational

TABLE 4-1 U.S. Coast Guard UxS Projects by Mission Area

	Mission										
	Search and Rescue	Ports, Waterways and Coastal Security	Law Enforcement	Defense Readiness	Drug Interdiction	Living Marine Resources	Marine Environmental Protection	Aids to Navigation	Marine Safety	Ice Operations	Migrant Interdiction
Long-Range UAS	L	Pt	H	Pt	H		Pt				H
Medium-Range UAS	L	Pt	H	Pt	H		Pt				H
Short-Range UAS	Pt	Pt	Pt				H	H	M	M	
sUAS—NSC Augment	L	Pt	H	Pt	H		Pt				H
VTOL UAS Operations	Pt		Pt	Pt	Pt		Pt				Pt
Robotic Aircraft for Public Safety	Pt	Pt	Pt				Pt	Pt	Pt	Pt	
Low-Cost MDA	Pt	Pt	Pt		Pt	Pt	Pt				Pt
Oil Spill Detection and Mapping							H				
Oil Spills in Ice Environments							H				
Counter-Unmanned Air Systems		H		Pt							
Counter-Unmanned Underwater Including Swimmers		H		Pt							
Maritime UxS Technology	Pt		Pt		Pt	Pt					Pt

NOTE: Mission Impact: H = high; L = low; M = medium; Pt = potential.

domains (air, surface, subsurface, and decision support). However, they also reveal the ad-hoc and decentralized nature of the Coast Guard UxSs programs to date. Table 4-4, in particular, highlights the fact that no single organization champions the Coast Guard's coordination of UxSs activities.

TABLE 4-2 U.S. Coast Guard UxS Activity by Modality or Operational Domain

	Modality or Operational Domain			
	Air	Surface	Subsurface	Decision Support
Long-Range UAS	P			
Medium-Range UAS	P			
Short-Range UAS	P			
sUAS—NSC Augment	P			
VTOL UAS Operations	P			
Robotic Aircraft for Public Safety	P			
Low-Cost MDA		P		P
Oil Spill Detection and Mapping			P	
Oil Spills in Ice Environments	S		P	
Counter-Unmanned Air Systems				P
Counter-Unmanned Underwater Including Swimmers			P	
Maritime UxS Technology		P	P	

NOTE: P = primary; S = secondary.

TABLE 4-3 Organizations That Carry Cost Burden for U.S. Coast Guard UxS Projects

	Cost Burden				
	USCG Headquarters	USCG Area	USCG District	USCG Field Units	DHS
Long-Range UAS	S				P
Medium-Range UAS	P				
Short-Range UAS				P	
sUAS—NSC Augment	P				
VTOL UAS Operations	P				
Robotic Aircraft for Public Safety					P
Low-Cost MDA	P				
Oil Spill Detection and Mapping					P
Oil Spills in Ice Environments	P				
Counter-Unmanned Air Systems	S	P			
Counter-Unmanned Underwater Including Swimmers	P				
Maritime UxS Technology					P

NOTE: P = primary; S = secondary.

TABLE 4-4 U.S. Coast Guard Program Sponsors for Each Listed UxS Project

Sponsors			Unmanned System Projects											
			Long-Range UAS	Medium-Range UAS	Short-Range UAS	sUAS—NSC Augment	VTOL UAS Operations	Robotic Aircraft for Public Safety	Low-Cost MDA	Oil Spill Detection and Mapping	Oil Spills in Ice Environments	Counter-Unmanned Air Systems	Counter-Unmanned Underwater and Anti-Swimmers	Maritime UxS Technology
Deputy Commandant for Operations (DCO)	CG-2					S						S		S
		CG-26							P					P
	CG-5R										S			
		CG-MLE				S			S					S
		CG-MER								P	P	P		
		CG-MSR										P		
	CG-5P													
	CG-7													
		CG-711	P	P	P	P	P	P	S			S		
		CG-721							S			S	P	S
		CG-731										S	S	
		CG-741												
		CG-751				S	S					S		
		CG-761							S				S	
		CG-771												

		DCMS-34									S		
	CG-1													
	CG-4													
		CG-45										S	
	CG-6										S		
	CG-9					S	S				S			
Atlantic Area						S			S			S	S	
	District 1										S			
	District 5													
	District 7													
	District 8													
	District 9										S			
Pacific Area						S			S			S	S	
	District 11													
	District 13													
	District 14								S					
	District 17								S		S			

NOTE: P = primary; S = secondary.

TABLE 4-5 Partnering Entities for the U.S. Coast Guard's UxS Projects

			UxS Projects/Programs											
			Long-Range UAS	Medium-Range UAS	Short-Range UAS	sUAS—NSC Augment	VTOL UAS Operations	Robotic Aircraft for Public Safety	Low-Cost MDA	Oil Spill Detection and Mapping	Oil Spills in Ice Environments	Counter-Unmanned Air Systems	Counter-Unmanned Underwater and Anti-Swimmers	Maritime UxS Technology
DHS					X									
	CPB	Air and Marine	X											
		Border Patrol												
	S&T							X		X		X		X
DOD	OSD													
	USN	Naval Surface Warfare Center										X		
		Naval Undersea Warfare Center												X
		Naval Air Systems Command										X		
		Office of Naval Research										X		X
		Naval Information Warfare Center												X
	USAF	Air Force Research Lab										X		

	USA	Army Research and Development Center (CRREL)									X			
	US SouthCom						X							
		JIATF - South					X							
	DARPA											X		
Other U.S. Government	NOAA	National Oceanographic and Atmospheric Administration					X				X			
	BSEE	Bureau of Safety and Environmental Enforcement									X			
	FAA	Federal Aviation Administration												
	EPA	U.S. Environmental Protection Agency					X				X			
Private Entity	Monterey Bay Aquarium									X				
Academia	University of Alaska									X	X			
	Woods Hole Oceanographic Institute									X	X			
	University of Southern Mississippi													

COAST GUARD BUDGET FOR UxSs

Only one of the Coast Guard's UxS activities described above is called out in its FY 2020 budget—the sUAS-NSC Augment (ScanEagle) program, which is funded at $9.4 million, up from $6.0 million in FY 2019. Inasmuch as the Coast Guard is involved in several UxS projects other than ScanEagle, the Service is certainly investing more than $9.4 million per year, which represents less than 5 percent of Coast Guard aviation-related procurement, construction, and improvements (PC&I) allocations, and less than 0.1 percent of the Coast Guard's total discretionary budget for FY 2020.

However, even if one assumes the Coast Guard is spending measurably more on these non-program projects, its UxS spending totals would undoubtedly be quite small in absolute and relative terms as a share of its discretionary budgets when compared to UxS investments by the other military services. For example, the U.S. Department of Navy (Navy and Marine Corps) allocates about 2 percent of its discretionary budget to UxS procurements, R&D, and associated installation and construction activity (see Table 4-6). Total DOD investments in UxSs have grown from less than $5 billion in FY 2017 to more than $8 billion in FY 2020.[19]

Although some of the Coast Guard's UxS projects are funded through the R&D program budget, this funding program does not offer a promising avenue for significantly expanded UxS activity as currently resourced. As shown in Table 4-7, the Coast Guard's R&D budget in FY 2020 was about $5 million, representing about 0.04 percent of its total discretionary budget. Other DHS agencies with operating responsibilities, such as CBP and the Transportation Security Administration, have R&D budgets that are 5 to 9 times higher than that of the Coast Guard as a percentage of total budgets (see Table 4-7).

By far the largest R&D sponsor in DHS is the S&T Directorate. As the primary research arm of DHS, it funds basic and applied R&D, demonstrations, and testing and evaluation activities in support of all DHS agencies. A review of the directorate's funding for UxS over the past 5 FYs, as summarized in Table 4-8, indicates that investments are growing, up from $5 million in FY 2015 to $8 million in FY 2020, after reaching nearly $12 million in FY 2019—or about 2 percent of the directorate's total R&D budget.

Indeed, the S&T Directorate does fund UxS project that apply to the Coast Guard. Four of the 12 projects described above are funded by the Directorate—projects on robotic aircraft for public safety, oil spill detection and mapping, counter-unmanned air systems, and maritime counter UxS technology.

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[19] See https://www.defensedaily.com/wp-content/uploads/post_attachment/206477.pdf (Table 1).

TABLE 4-6 FY 2020 Discretionary Budgets and Estimated Investments in UxSs by the U.S. Coast Guard and Other Military Services

		Enacted FY 2020 Budget[20,21] ($ million)	**President's Budget FY 2020[22] ($ million)**	**UxS Budget as Percentage of Discretionary Budget**
Coast Guard	Discretionary Budget	9,973		0.1%
	UxS Budget (sUAS-NSC Augment)	9.4		
Navy/Marine Corps	Discretionary Budget	209,000		2.2%
	UxS Budget		4,700	
Army	Discretionary Budget	178,468		0.8%
	UxS Budget		1,500	
Air Force	Discretionary Budget	205,406		1.1%
	UxS Budget		2,200	

NOTES: The UxS budgets for the U.S. Department of Navy, Army, and Air Force are based on the President's Budget 2020, not appropriated amounts. The proposed totals nevertheless indicate the scale of investment. NSC = National Security Cutter; sUAS = small unmanned aerial system; UxS = unmanned system.

[20] U.S. Department of Homeland Security, U.S. Coast Guard. "Budget Overview. Fiscal Year 2021, Congressional Justification." https://www.dhs.gov/sites/default/files/publications/u.s._coast_guard.pdf.

[21] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer. 2020. "Defense Budget Overview." https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

[22] Klein, D. 2019. https://www.auvsi.org/unmanned-systems-magazine-fiscal-2020-defense-budget-request-includes-billions-unmanned-systems.

TABLE 4-7 U.S. Department of Homeland Security (DHS) Agency Total Discretionary Budgets and Research and Development (R&D) Budgets, FY 2020

DHS Agencies	Total Budget (000)	R&D Budget (000)	R&D % of Total Budget
U.S. Customs and Border Protection	$14,721,867	$45,000[a]	0.31
Coast Guard	$11,966,124	$4,949	0.04
Immigration and Customs Enforcement	$8,080,071	$0	0.00
Transportation Security Administration	$5,233,567	$22,902	0.44
Federal Emergency Management Agency	$5,076,799	$0	0.00
U.S. Secret Service	$2,415,845	$12,455	0.52
Cybersecurity and Infrastructure Security Agency	$2,015,622	$14,431	0.72
Science and Technology Directorate	$737,275	$422,411	57.29
Countering Weapons of Mass Destruction Office	$432,299	$69,181	16.00
Citizen and Immigration Services	$132,395	$0	0.00
Federal Law Enforcement Training Center	$351,170	$0	0.00
Total DHS Funding	$51,163,034	$591,329	1.16

[a] CBP does not receive a direct R&D appropriation but funds R&D through its operations and acquisitions budget.

TABLE 4-8 U.S. Department of Homeland Security Directorate of Science and Technology Spending on UxS Research and Development, FY 2015–2020

Enacted Funding (000)				
FY 2016	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**
$5,303	$5,503	$3,420	$11,807	$8,000

SOURCE: Funding data estimated from the latest draft of DHS's National Defense Authorization Act report.

EXAMPLES OF UxS ELSEWHERE IN THE FEDERAL GOVERNMENT

During the course of this study, the committee was briefed by officials from several federal agencies of varying size and having a range of civilian, law enforcement, national security, and defense missions to learn more about their development and use of UxSs. The briefings not only provided numerous examples of the kinds of systems being pursued at the federal level but also insight into the organizational steps and commitment required to develop and field the systems. A short synopsis of what the committee learned is provided next.

U.S. Navy

The Navy has a long history of employing UxSs for defense missions including intelligence, surveillance, reconnaissance, and attack. Indeed, many modern weapons, including missiles and torpedoes, are sophisticated UxS capable of navigation, obstacle avoidance, data collection, communication, and planning and prioritization, often in full or semi-autonomous control. The Navy (and DOD generally) has expanded its use of UxSs for other purposes as advances in energy storage, communications, precision navigation, processing, and autonomy have enabled longer duration missions by relatively affordable vehicles. Today, the Navy operates unmanned vehicles in air, sea surface, and undersea environments for a wide range of other missions, including reconnaissance, vessel tracking and identification, minehunting and sweeping, installation and maintenance of underwater infrastructure, search and rescue, and oceanography.[23]

As reported above, the Coast Guard partners with the Navy on a couple of projects on cUASs and marine UxS technology. Figure 4-8 presents examples of the Navy's UAS program. The aircraft range from the large 32,000 lb., high-altitude, and long-endurance MQ-4C Triton (a successor to the RQ-4 Global Hawk) to mid-size aircraft such as the MQ-8B/8C Fire Scout and much smaller UAVs, such as the 44-lb. MQ-27A ScanEagle and a number of ultralights weighing less than 10 lb. Although a description of the full range of Navy UAVs is not possible in this report, a few examples illustrate the Navy's expanding use of these systems across a wide size and capability spectrum.

The Triton is a remotely piloted UAS designed to conduct surveillance over more than 1 million square miles of sea and littoral space from an altitude as high as 55,000 ft. on missions that can exceed 24 hours in duration.[24] Signifying this system's value, the Navy has established a dedicated ground control squadron (VUP-19) to operate it. Priced at more $100 million per aircraft (and requiring substantial ground support), the required investment to deploy the Triton, or a similarly large and capable UAS—for Coast Guard missions—would seem to be prohibitively high. However, in cases where the capabilities of a highly sophisticated UAS can

[23] For example, the Naval Meteorology and Oceanography Command deploys autonomous underwater vehicles on ships for surveying ocean bathymetry and a fleet of buoyancy gliders that measure ocean conditions such as temperature and salinity.

[24] Mark Darrah. "The Age of Unmanned Systems." *Proceedings*, September. 2015. U.S. Naval Institute.

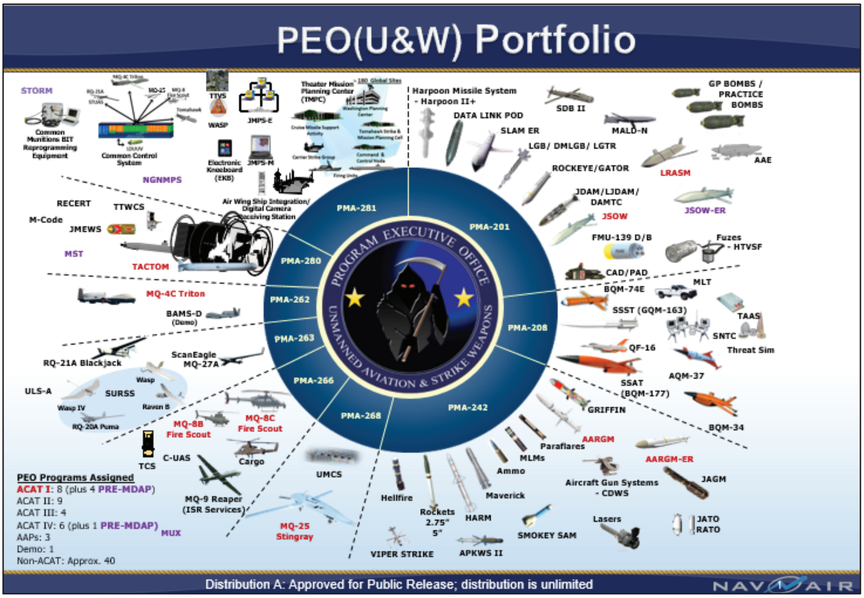

FIGURE 4-8 U.S. Navy's unmanned air systems.
SOURCE: U.S. Navy.

serve particular Coast Guard mission requirements for surveillance and intelligence gathering, partnering with the Navy and other potential users, such as the U.S. Immigration and Customs Enforcement and the Drug Enforcement Administration, may be an option.

An example of a Navy-developed mid-size UAS used for surveillance is the MQ-8B Fire Scout. This rotor-wing aircraft operates autonomously from either a ship or from shore with a 20,000-ft. ceiling and mission duration of about 6 hours.[25] An advantage of the Fire Scout is that it has a smaller shipboard footprint than manned helicopters and does not require active remote piloting. The Fire Scout's latest variant, the MQ-8C (see Figure 4-9) built on a Bell 407 helicopter frame, has the same autonomous capability as the MQ-B but can fly for longer (11-hour) periods and carry a larger payload. While this example of a Navy-developed rotor-wing UAS is provided simply to illustrate the Navy's pursuit of a range of UASs having different capabilities and sizes, the committee was informed that the Coast Guard has tested this particular aircraft for potential mission deployments.

[25] Brian Alkire, et al. "Applications for Navy Unmanned Aircraft Systems." RAND Report. 2010.

FIGURE 4-9 MQ-8C Fire Scout.
SOURCE: U.S. Navy.

Like the Coast Guard, the Navy employs sUASs, including the ScanEagle, which it has used for more than a decade. The Navy deploys even lighter UAVs as part of its Small Unit Remote Scouting System Program.[26] They include the RQ-12A Wasp IV, which has a length of 2.7 ft., wing-span of 3.3 ft., weighs less than 3 lb. and can operate for 50 min. for use by small tactical units (platoons and squads) for front-line reconnaissance and surveillance. Other examples of ultralights used for scouting are the 5 lb. Raven (with a length of 3 ft. and wing-span of 4.5 ft. and 50–90 min. endurance) and 14-lb. RQ-20B Puma (with a length of 4.7 ft. and wing-span of 9.2 ft. and 3.5 hour endurance).

Examples of the Navy's interest in unmanned surface vessels (USVs) and unmanned undersea vehicles (UUVs) are presented in Figure 4-10. The USV family, which consists of vessels that are mostly in the design, prototype, and demonstration stages, range from large- (>100 meters) and medium-size combatants (e.g., SEA HUNTER) to small coastal patrol

[26] See https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2159299/group-1-small-unmanned-aircraft-systems.

FIGURE 4-10 U.S. Navy's unmanned surface water and underwater systems.
SOURCE: U.S. Navy.

boats and minehunting and minesweeping vessels.[27,28] The Navy's interest in UUVs is likewise varied in terms of mission uses and vehicle scales and ranges. The UUV family ranges from small, highly portable vehicles (having platforms of less 12 meters in length) to extra-large vehicles weighing more than a highway truck and exceeding 50 meters in length.[29] As scale increases the Navy's emphasis is on multi-mission capability including armed conflict. At smaller scales the vehicles are often purpose-designed for missions such as minehunting and clearing.

By way of example, the unmanned Knifefish is a medium-class mine cUUV designed for deployment off littoral combat ships.[30] It is a derivative of the civilian Bluefin-21, which has a modular design that can be adapted

[27] See https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SNA2019/UnmannedMaritimeSys-Small.pdf?ver=2019-01-15-165105-297.
[28] See https://fas.org/sgp/crs/weapons/R45757.pdf.
[29] Presentation by CAPT Small to the committee on February 19, 2020.
[30] See https://www.dote.osd.mil/Portals/97/pub/reports/FY2019/navy/2019smcm_uuv.pdf?ver=2020-01-30-115519-923.

to carry a variety of sensors and payloads, which makes it suitable for many missions including offshore surveying, marine salvage detection, and oceanography. The Knifefish exemplifies how the Navy also deploys off-the-shelf unmanned technologies that can be adapted to specific mission sets, not unlike how the Coast Guard has effectively used the commercially developed UAV ScanEagle.

In embracing UxS, the Navy has created special units for testing, integrating, and fielding USVs and UUVs. UUVRON-1, which is housed in the developmental squadron DEVRON-5 in Keyport, Washington, was created in 2017 to eventually operate and maintain all UUV classes. In 2019, the Navy stood up an equivalent squadron for large- and medium-size USVs. The Surface Development Squadron 1, which is based in San Diego, California, is charged with experimenting with the operations and integration of USVs to accelerate their delivery for fleet warfighting capability. In essence, both squadrons are charged with putting UxSs in the hands of those who will deploy and operate them, both for early uses and to learn more about their operations, supply, maintenance, and integration into the force structure.

As a further indication of DOD's early embrace of UxS, in 2007 it issued the *UxS Roadmap 2007–2032* to guide the future development of military UxS and related technologies in ways that leverage and prioritize the funding and development of UxS technology across the military.[31] The roadmap, which has been updated multiple times,[32] was issued to ensure that UxS capabilities were being pursued in a cooperative and collaborative manner across the services and supported by joint standards and efforts to ensure interoperability of air, ground, and sea systems, both manned and unmanned. The roadmap not only identifies challenges to achieving a range of desired outcomes such as interoperability, integration, cybersecurity, affordability, technological progress, and conformance laws and policies, but also identifies a range of approaches for meeting these challenges.

In 2015, the Secretary of the Navy issued a department-wide memo titled "Treat Unmanned as Unmanned."[33] The memo emphasizes that UxS differ fundamentally from their manned counterparts, and therefore

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[31] U.S. DOD. 2007. *Unmanned Systems Roadmap, 2007–2032*. https://apps.dtic.mil/dtic/tr/fulltext/u2/a475002.pdf.

[32] U.S. DOD. 2011. *Unmanned Systems Integrated Roadmap, 2011–2036*. https://apps.dtic.mil/dtic/tr/fulltext/u2/a475002.pdfhttps://fas.org/irp/program/collect/usroadmap2011.pdf; U.S. DOD. 2017. *Unmanned Systems Integrated Roadmap, 2017–2042*. https://www.defensedaily.com/wp-content/uploads/post_attachment/206477.pdf.

[33] The Secretary of the Navy. 2015. "Memorandum for Assistant Secretary of the Navy (Research, Development and Acquisition) Chief of Naval Operations Commandant of the Marine Corps: Treat Unmanned as Unmanned." https://www.secnav.navy.mil/innovation/Documents/2015/11/TreatUnmannedAsUnmannedMemo.pdf.

the policies and procedures needed to field and sustain them should differ. In the memo, the Secretary established the position of Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN (UxS)) with responsibility for bringing together all UxS stakeholders to streamline their efforts toward successful development, employment, and sustainment of UxSs.[34] For instance, the DASN (UxS) would be responsible for identifying manned system requirements germane to the design, development, and evaluation of UxSs and for issuing a comprehensive, department-wide roadmap with aggressive actions for overcoming UxS development and deployment obstacles to both. The memo went further in establishing a Director for Unmanned Systems in the Office of the Chief of Naval Operations to support the DASN (UxS).

In 2018, the Navy issued the strategic roadmap for UxSs. Although the full version is not available for public release, the public summary cites the Service's goal of enabling the integration of UxSs into every aspect of naval operations and ensuring fully integrated manned and unmanned teaming.[35] The plan also emphasizes the importance of ensuring appropriate cybersecurity rigor, infrastructure and logistic support, acquisition processes, and legal and policy conformance. Accompanying this strategic plan are a series of master plans for aerial, surface, and undersea UxSs. These plans comport with the Service's broader vision of a future Navy that has migrated to a more heterogeneous and distributed operational concept in which multiple platform solutions—consisting of manned and unmanned systems—greatly enhance combat force effectiveness.[36]

Following nearly 3 years of consolidated strategic planning for UxSs across all naval warfighting domains and completion of the UxS roadmap, the DASN (UxS) office was disestablished in 2018. UxS activities were then distributed into two separate program executive offices—one for maritime systems and the other for aviation systems—where domain-specific UxS activities would be further developed.[37]

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[34] Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN (UxS)). https://www.secnav.navy.mil/rda/Pages/Unmanned-Systems.aspx#:~:text=DASN(UxS)%20brings%20together%20all,imbed%20unmanned%20systems%20of%20systems.

[35] U.S. Navy. 2018. *Department of the Navy Strategic Roadmap for Unmanned Systems—Short Version*. https://www.secnav.navy.mil/rda/Documents/DON-Strategic-Roadmap-for-Unmanned-Systems.docx#:~:text=The%20Department%20of%20the%20Navy,every%20aspect%20of%20Naval%20operation.

[36] See, for instance, the Naval R&D Framework at https://www.onr.navy.mil/en/our-research/naval-research-framework.

[37] Program Executive Office, Unmanned and Small Combatants. https://www.navsea.navy.mil/Home/PEO-Unmanned-and-Small-Combatants; Program Executive Office, Unmanned Aviation and Strike Weapons. https://www.navair.navy.mil/organization/peo-uw.

U.S. Department of the Interior

In managing and protecting federal lands, the U.S. Department of the Interior (DOI) faces some of the same challenges as the Coast Guard in that it must monitor vast areas and engage in personnel-intensive activities such as search and rescue, firefighting, and lifesaving in environments that can be harsh and hostile for operating personnel. Also like the Coast Guard, it has modest resourcing.

Officials from DOI's Office of Aviation Services (OAS) briefed the committee on its use over the past decade of sUAS for a variety of applications intended to reduce exposure of personnel and create new capabilities. One notable example is an instrumented sUAS that is used for wildfire surveillance and other purposes. The OAS briefers demonstrated how the system was used to visually and chemically monitor and chart lava flows from the Kilauea Volcano in conditions where manned aircraft could not operate due to low visibility and other hazards. During the course of this successful application, the system provided an additional unanticipated benefit by spotting a pedestrian who had become trapped between lava flows. With the aid of the UAS, emergency responders established communications with the individual and used the UAS to guide the escape pathway.[38]

Over the years, OAS has found increasing applications for its sUASs. Between 2016 and 2019, the number of flights rose from about 500 to more than 10,000 per year.[39] The increased flights covering more than 30 missions, and the accompanying experimentation, have led to many refinements in the program. In 2018, OAS published a primer on the use of optionally-piloted helicopters able to not only perform all the functions of a traditional helicopter in piloted mode, but also missions when unmanned, including operating in dark and hazardous environments without risking the safety of pilots.[40] In this case, OAS leveraged DOD's development of an optionally piloted helicopter for the Marine Corps to extend logistics support in environments too hostile to risk using an aircrew.

With most—if not all—of its UASs being foreign-made, in January 2020 DOI temporarily grounded all of its UASs out of concern that sensitive data could be transmitted to foreign organizations.[41]

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[38] U.S. Department of the Interior. 2018. "DOI UAS Teams Supporting Volcano Monitoring & Emergency Response/Rescue."

[39] "U.S. Department of the Interior Unmanned Aircraft Systems (UAS) 2018 Use Report."

[40] U.S. Department of the Interior. "Optionally-Piloted Helicopters." https://www.doi.gov/sites/doi.gov/files/uploads/doi_uas_background_info_paper_gamechanger_the_promise_of_optionally-piloted_helicopters_in_wildland_fire_08_2018.pdf.

[41] U.S. Department of the Interior. Order No. 3379. "Temporary Cessation of Non-Emergency Unmanned Aircraft Systems Fleet Operations." https://www.doi.gov/sites/doi.gov/files/elips/documents/signed-so-3379-uas-1.29.2020-508.pdf.

Federal Bureau of Investigation

With the U.S. Department of Justice (DOJ), the Federal Bureau of Investigation (FBI) has been an early adopter of UxSs, for example, by deploying robots for bomb disposal.[42] The FBI has also been active in deploying a fleet of sUAVs, consisting of a mix of fixed-wing and rotor-wing systems available commercially.[43] Having used UASs periodically for about a decade, the FBI had increased its UAV fleet to 17 units by 2014. According to briefings by the FBI's Aviation Office, the growing fleet is expecting to fly as many as 14,000 missions by 2023. Applications include surveillance, mission pre-planning, rural searches, crime-scene documentation, and evidence gathering, both indoor and outdoor, and frequently in confined spaces and low light.

In addition to being subject to all relevant FAA regulations governing UAVs and the safe use of airspace, the FBI must comply with DOJ-wide policies and guidelines intended to ensure that agencies carrying out their law enforcement and national security missions use these systems in a manner that respects individual privacy, civil rights, and civil liberties.

National Oceanic and Atmospheric Administration

For several years, NOAA has used UxSs for an assortment of missions, including seafloor and habitat mapping, ocean exploration, marine mammal and fishery stock assessments, emergency response, and at-sea observations of algal bloom and hypoxia events. The systems consist of purpose-built and modified off-the-shelf technologies, including the following sUASs and UUVs:

- REMUS 600 (UUV) deployed from ships for bathymetric mapping missions. Rated for 1,500-meter depths and 24-hour endurance, it is an off-the-shelf technology but highly modular to enable mission-specific payload variations;
- L3 Latitude hybrid quadrotor (a VTOL sUAS) deployed from the shipdeck or shore for climate and air quality studies, fishery and mammal surveys, weather observations, oil spill detection, and post severe weather damage assessments;

[42] Federal Bureau of Investigation. "Special Agent Bomb Technicians." https://archives.fbi.gov/archives/fun-games/tools_of_the_trade/tools-of-the-trade-bomb-technicians-text-version.

[43] "Audit of the Department of Justice's Use and Support of Unmanned Aircraft Systems." 2015.

- Deep Discoverer (UUV) deployed from ships to map and characterize deepwater areas. Remotely operated and tethered, the vehicle/robot can dive to depths of 6,000 meters;[44]
- Glider UUVs launched from ships for collecting ocean temperature, salinity, and other data in remote ocean locations, including deployments in partnership with the Navy and Shell Oil in the Gulf of Mexico to provide data for improving hurricane intensity forecasts; and,
- Hexacopter (a VTOL sUAS) deployed from the shipdeck or shore for marine mammal monitoring in difficult-to-traverse terrains, such as the remote Aleutian Islands.

In briefing the committee on the agency's longstanding and continuously expanding use of UxSs, NOAA officials explained how in 2018 Congress required the agency to coordinate research, assess, and acquire unmanned maritime systems in collaboration with the Navy, other federal agencies, industry, and academia. Congress further appropriated $12.7 million in FY 2020 for the creation of a centralized UxS Operations Program.[45] Consequently, NOAA (in February 2020) issued a UxS Strategic Implementation Plan that established five goals for expanded UxS operations across the agency.[46] The goals call for (a) a centrally coordinated and supported UxS operations at the enterprise level, (b) the purposeful expansion of UxS across all units of the agency, (c) accelerated transitions of UxS research to field application, (d) strong and expanded partnerships across NOAA and with other organizations, and (e) a workforce with a high level of proficiency in UxS operations.

Although not intended to be a detailed roadmap of UxS initiatives, NOAA's strategic plan contains a series of objectives aimed at furthering each of the five goals. For example, there are objectives for establishing an effective and adaptive organizational structure, partnering with universities and the private sector, training and certifying personnel, ensuring cybersecurity, introducing appropriate acquisition mechanisms, and building a thriving community of practice that is supportive of experimental and innovative UxS designs and uses. According to the strategic plan, NOAA is working on more detailed tactical plans (i.e., a roadmap) for each goal

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[44] National Oceanic and Atmospheric Administration. "Remotely Operated Vehicle *Deep Discoverer*." https://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/deep-discoverer.html.

[45] See the Commercial Engagement Through Ocean Technology Act of 2018 (CENOTE, P.L. 115-394), which requires NOAA to coordinate research, assess, and acquire unmanned maritime systems with the U.S. Navy, other federal agencies, industry, and academia.

[46] National Oceanic and Atmospheric Administration. 2020. *NOAA Unmanned Systems Strategy*. https://nrc.noaa.gov/LinkClick.aspx?fileticket=0tHu8Kl8DBs%3D&tabid=93&portalid=0.

and objective that will specify action items, deadlines, and assignments for organizational responsibilities.

UxS PROGRAM FEATURES RELEVANT TO THE COAST GUARD

As the Coast Guard expands its use of UxS, some of the key features of the UxS programs reviewed above merit consideration. Among the features that standout are (a) development of a comprehensive strategy for the use of UxS and actionable roadmaps for developing, acquiring, deploying, and integrating them; (b) creation of a central office responsible for advocating for UxSs, monitoring and coordinating UxS research, acquisitions, and deployments across the agency, and facilitating changes in policies and practices needed to further their use and integration; (c) recognition of the importance of programs dedicated to training personnel in UxS operations and support functions; (d) budgets dedicated for UxS R&D, acquisitions, and supportive investments; and (e) openness to, and indeed encouragement of, prototyping and field experimentation with a wide array of UxSs for different missions, including the creative use off-the-shelf technologies—with the establishment of dedicated squadrons or field units.

Having made large investments in UxSs for more than two decades, the Navy (and the entire DOD enterprise) intends for most, if not all, of these systems to accelerate the development and deployment of UxSs and ensure operational integration, appropriate cybersecurity rigor, infrastructure and logistics support, acquisition processes, and legal and policy conformance. The Navy's enormous investments in UxSs (both current and planned), imperative for seamless integration with manned forces, and vision of UxSs playing a central role in future operational concepts compel such a deliberate approach to planning, developing, integrating, and sustaining UxSs.

The need to be deliberate, however, is not scale-driven. For example, NOAA's varied and extensive use of UxSs has emerged in a largely organic manner, seemingly facilitated by its many science-oriented missions and an organizational culture that encourages and values experimentation. In this case, too, the agency has recognized that, in the absence of more purposeful, enterprise-level efforts to expand and accelerate the use of UxSs, a wealth of mission-enhancing applications for these technologies could go neglected. Accordingly—and with prompting and funding support from Congress—NOAA recently established a central office for UxSs, issued a strategic plan that articulates the goals and objectives of its UxS investments, and indicated its intention to create a more detailed roadmap of actions to further these goals and objectives through specific organizational, procedural, and funding steps.

Although their uses of UxS remain limited, DOI and the FBI have illustrated the value of encouraging field-level experimentation with commercial, off-the-shelf technologies. Over time, both agencies have gained familiarity with the systems, including workforces that have increased their technical and operational proficiency, and each has discovered a growing number of useful applications. In some respects, their experience resembles that of the Coast Guard, which has fostered unit-level experimentation with low-cost, commercial systems. Although the committee is not aware of any plans by DOI or the FBI to engage in more strategic planning for future UxS application or to establish a central office for furthering agency-wide use of these systems, NOAA's recognition of the need to take these additional steps to scale UxS activity is illuminating.

The committee observes that the Coast Guard has recognized the importance of proceeding strategically to advance agency-critical initiatives. Over the past several years, for example, the Coast Guard Commandant's office has issued several strategic-level documents intended to attract the attention of top leadership to a critical Coast Guard interest and to set in motion the organization-wide steps needed to advance the interest. The strategies not only compel the senior leadership of the Coast Guard to act purposefully and in concert, but also convey the urgency for doing so. Recent examples are the Commandant's arctic,[47] cyber,[48] and human capital[49] strategies. The Arctic Strategy was a catalyst for the Coast Guard's initiative to invest in a new fleet of polar icebreakers, deemed critical to the Service's mission to uphold the country's sovereignty and to respond to contingencies in the Arctic. The Cyber Strategy emphasizes how cybertechnology is inextricably linked with all aspects of Coast Guard mission performance and articulates strategic priorities for operating effectively within the cyber domain and countering and protecting against maritime cybersecurity threats. The Human Capital strategy lays out a 10-year plan to build and maintain a proficient, diverse, and adaptable workforce to respond to changing technology and an increasingly complex operating environment.

It is notable that both the Cyber Strategy and Human Capital Strategy point to the importance of senior leadership and organizational structures committed to advocating for the interest and pursuing implementation. For example, the Human Capital Strategy directs the Assistant Commandant for Human Resources and Force Readiness Command to spearhead the plan in coordination with other critical units such as the Civil Rights

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[47] U.S. Coast Guard. 2013. *United States Coast Guard Arctic Strategy*. https://www.uscg.mil/Portals/0/Strategy/cg_arctic_strategy.pdf.

[48] U.S. Coast Guard. 2015. *United States Coast Guard Cyber Strategy*. https://www.uscg.mil/Portals/0/Strategy/Cyber%20Strategy.pdf.

[49] U.S. Coast Guard. 2016. *United States Coast Guard Human Capital Strategy*. https://www.work.uscg.mil/Portals/6/Documents/PDF/CG_Human_Capital_Strategy.pdf.

Directorate and Rating Force Master Chiefs.[50] Although it does not call for a new organizational structure, the Cyber Strategy emphasizes the importance of the Coast Guard developing a command and control structure that ensures that the diverse cyber elements within the Service coordinate and cooperate with each other and align their activities with Coast Guard tactical and strategic priorities.[51] It calls for more centralization by creating policies and processes to facilitate requests for and approval of cyber support for operations, standards for planning and conducting cyber operations, and means of recording and learning from Coast Guard cyberspace operations.

[50] U.S. Coast Guard. 2016. *United States Coast Guard Human Capital Strategy*. https://www.work.uscg.mil/Portals/6/Documents/PDF/CG_Human_Capital_Strategy.pdf.

[51] U.S. Coast Guard. 2015. *United States Coast Guard Cyber Strategy*. https://www.uscg.mil/Portals/0/Strategy/Cyber%20Strategy.pdf.

5

A Vision and Framework for Exploiting Unmanned Systems

The U.S. Coast Guard's limited use of unmanned systems (UxSs) for select mission areas has been paying dividends in the form of improved mission execution, most notably in the case of its use of small unmanned aerial systems (sUASs) that augment the surveillance capabilities of National Security Cutters. Briefings by Coast Guard leaders revealed a strong desire to leverage UxS to enhance mission capabilities across the Service's air, surface, underwater, and shore-based domains.[1] The committee heard, for instance, about the Coast Guard's interest in leveraging unmanned aerial vehicles (UAVs) for surveillance, unmanned surface vehicles (USVs) to assist in aids-to-navigation maintenance and ice survey missions, and unmanned underwater vehicles (UUVs) for subsurface situation awareness. Table 5-1 gives these and other example applications, including systems that leverage artificial intelligence and machine learning technology to aid decision making. In many cases, however, uncertainty remains about the full range of mission areas suited to these systems—both functioning alone and in concert with one another and manned systems—and about the scale of effort that is justified and warranted for the Service to incorporate them effectively into current and future operations concepts.

The chapter starts with three vignettes envisioning how the future Coast Guard could exploit current and prospective capabilities of UxSs, including the pairing and integrating of capabilities provided by multiple systems. The vignettes offer insight into why the Coast Guard's interest in UxSs has been growing to encompass a wider spectrum of systems,

[1] ADM Matthew Sibley briefing to the committee in May 2020.

TABLE 5-1 Examples of Potential Future Coast Guard Applications of UxS

Domain	Platform/Technology	Mission Capability
Air/space	Tethered drones	Augmented surveillance
	UAS	Persistent surveillance
	Cube satellites	Enhanced communications
Surface	Autonomous boats	Aids-to-navigation maintenance
		Ice survey
Subsurface	UUV	Counter UUV/anti-swimmer
Shore	Decision aids	Vessel inspections
		Pollution response
	Artificial intelligence algorithms	Staff/administrative work reduction

domains, and mission areas. To assist the Coast Guard in making choices about where, how, and at what scale it should exploit UxS, the vignettes are followed by an example of a deliberate way to think about aligning UxS capabilities with mission areas while accounting for considerations such as operational efficiency benefits and costs and resource demands associated with different UxS application complexities and implementation scales. The chapter concludes by highlighting systems engineering considerations that the Coast Guard would need to address in leveraging and integrating UxS, particularly at a larger scale.

COAST GUARD UxS USE SCENARIOS

It has been said that robots are best suited for work that is "dull, dirty, and dangerous." In addition, to the 3 "Ds," potential applications for UxSs by the Coast Guard may be described as "distant and exhausting." Operating in all U.S. and territorial waters, the Coast Guard's fleets of cutters, boats, and aircraft can be stretched thin, along with the personnel responsible for operating them and carrying out missions. UxSs have reached cost and capability readiness to relieve some of these mission tasks, including many that can be characterized as dull, dirty, dangerous, distant, and exhausting. The following three vignettes, for scenarios involving Search and Rescue (SAR), Aids to Navigation (ATON), and Arctic and Oceania missions, illustrate the possibilities.

Search and Rescue

In Fiscal Year (FY) 2018, the Coast Guard responded to more than 15,000 maritime SAR cases, assisted more than 41,000 people, and saved 3,965 lives in imminent danger.[2] Many of the searches were handled by a single small boat station. Air support, when required, was usually provided by a single Coast Guard air station. Both small boat stations and air stations are constrained by the number of boats or aircraft (typically three aircraft and two or three boats) in addition to personnel limits. Thus, the longer and more complicated the search, the more difficult it is to maintain full response capability.

For SAR, timeliness is critical and made all the more challenging by harsh weather, distance, and scarcity of personnel and assets. Indeed, the Coast Guard's FY 2018 Performance Report, states

> the number of cases the Coast Guard is called to respond to are becoming increasingly complex, requiring greater levels of SAR planning proficiency. Therefore, the Office of Search and Rescue is developing innovative Service-wide training solutions to improve SAR planning across the Service in effort to retain and sharpen the skills necessary to execute complex maritime SAR.
>
> The time it takes to reach the scene of distress is a key performance factor that may influence the response outcome. The Coast Guard's performance benchmark is to arrive on scene within two hours of notification 100% of the time.
>
> Factors beyond the Coast Guard's control influence its ability to arrive within the benchmark timeframe, including adverse weather conditions, unfavorable geographical proximity, and limited asset availability. The Coast Guard is continually looking at ways to improve this performance, with focus on where search and rescue assets are strategically located.[3]

Although SAR depends on highly skilled, ready, and courageous personnel, UxS can relieve them of some of their more taxing responsibilities and augment their performance in several ways. Here we describe a hypothetical future Coast Guard where small boat stations have smart unmanned aviation support. This capability would enable the station to start a search by launching several sUAS, as the boat crew is getting ready. The sUAS could launch with search waypoints automatically uploaded from the sector's SAR Optimal Planning System (SAROPS). The sUAS would take a direct path to their assigned search area without regard to land mass or the need to utilize the marine transportation system. This would allow

[2] U.S. Coast Guard Fiscal Year 2018 Performance Report. https://www.uscg.mil/Portals/0/documents/budget/FY%202018%20USCG%20APR%20Signed%206-12-19.pdf.

[3] U.S. Coast Guard Fiscal Year 2018 Performance Report. Page 38.

them to quickly able to make on-scene weather reports. Carrying a small camera that sends live stream video, they could provide a priori situational awareness to rescue crews. SAROPS would be automatically updated, and the search area is continuously refined based on live environmental conditions. As information is rapidly disseminated across the entire search team, Coast Guard responses are faster and better focused on the correct search area. It is also conceivable that the sUAS could drop a flotation device, location beacon, or portable very high frequency (VHF) radio to facilitate the rescue. The dangers and difficulties of some of the Coast Guard's most challenging SAR operations, such as Bering Sea fishing boat rescues, are reduced, albeit not eliminated.

The most important performance result of this UxS scenario is more lives saved and fewer lives endangered. Secondary benefits could be fewer boat and aircraft sorties with associated reductions in crew stress and crew fatigue and ancillary benefits of reduced craft maintenance. While such a scenario is well within the capabilities of today's UxS readiness, it is easy to imagine a longer-term, but not distant, scenario in which experience with these systems grows and the capabilities evolve to impact the manning and number of stations and boats required across the entire Coast Guard.

Aids to Navigation

Coast Guard cutters, boats, aircraft, and personnel are in heavy demand for myriad critical functions during and after a major hurricane or other severe natural disaster that affects a coastal or inland waterway region. Large storms accentuate the relative lack of assets and equipment that can be surged to a particular location if a storm rakes a large geographic area (up the East Coast or a large swath of the coastal Gulf of Mexico).

One of the more important Coast Guard functions in the aftermath of a disaster is the reconstitution of ports critical to the health and safety of affected communities and for the economy of an entire region. Opening a port quickly can be crucial to the logistics of aiding devastated areas that may be hundreds of miles away.

Key to port reconstitution is ensuring that ATON are functioning and in their proper place. The Coast Guard establishes, maintains, and operates more than 45,000 buoys and beacons, both lighted and unlighted, and is responsible for administration of a nearly equivalent number of private navigation aids.[4] Following a storm, these assets need to be restored quickly to enable the clearing of channels and docks of debris to make them usable and for identifying and mitigating secondary disasters such as pollution spills. Yet, even working with federal, state, and local partners, a large

[4] U.S. Coast Guard Fiscal Year 2018 Performance Report.

storm will stress the Coast Guard's limited resources, which can only be in one place at a time. For example, after Hurricane Sandy passed through New York, the Coast Guard's Maritime Transportation System Recovery Unit had to wait for the arrival of Coast Guard cutters, National Oceanic and Atmospheric Administration (NOAA) vessels, and Army Corps of Engineers vessels to start a physical assessment of the port. In the After Action report, Coast Guard officials recounted the workload challenge.[5]

> New York Harbor was directly in the path of the most damaging part of the storm. There was significant impact on many of the terminal facilities of the Port of New York and New Jersey. The U.S. Coast Guard closed the entire Port to all traffic before the storm hit on October 28th, and it was not fully reopened to vessel traffic until November 4th. After the storm … they surveyed the damage to prepare to reopen the Port. Activities included conducting waterway surveys to ensure navigational aids were on station, locating and removing marine debris, locating floating shipping containers, and making sure that the channels were cleared for navigation.[6]

Although disasters of the magnitude and scale of Hurricane Sandy will stress Coast Guard assets and personnel to restore the functioning of the marine transportation system, UxS capabilities can be a force multiplier. It is conceivable that a future Coast Guard could equip Captains of the Port with UxSs tailored to their areas of responsibility. The systems could include sUASs and UUVs pre-programmed with vital port characteristics such as channel locations, depths, and the precise location of ATONs. When storms approach, these systems may be staged in locations so that they can be deployed immediately after the event to check the status of both fixed and floating ATONs. The sUASs and UUVs could be deployed to survey channels, report missing ATONs, and check for clearance near cargo piers. In a case like New York Harbor with Hurricane Sandy, the condition of the marine transportation system could be better understood much more quickly.

By commencing this surveillance and verification activity without having to wait for vessel support, such as Coast Guard buoy tenders or NOAA ships with side-scan sonar, the Captains of the Port could save hours or even days in opening the port. When support vessels do arrive, they could immediately get to work on damaged infrastructure without having to conduct laborious channel surveys.

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[5] LT Hillary Allegretti, CDR Linda Sturgis, and LCDR Anne Morrissey. *2012. Hurricane Sandy, Sector New York Marine Transportation System Recovery Unit, After Action Report*. https://homeport.uscg.mil/Lists/Content/Attachments/1901/SANDY%20AFTER%20ACTION%20REPORT%20MTSRU.pdf.

[6] U.S. Department of Transportation. UTC Spotlight., November 2016. "Lessons Learned from Super Storm Sandy." https://cms7.dot.gov/utc/lessons-learned-super-storm-sandy.

During normal times, these same autonomous systems are capable of carrying out the routine checks on the status of ATONs. ATON teams would no longer have to transit long distances by car or boat to perform these routine checks, allowing them to spend more time and resources addressing known discrepancies.

Remote Pacific and Artic Surveillance

As discussed in Chapter 1, the U.S. Exclusive Economic Zone (EEZ) consists of approximately 4.5 million square miles of sea spread across three oceans, the Gulf of Mexico, and the Caribbean Sea. Alaska's Pacific and Artic waters alone encompass some 1.5 million square miles, and the waters surrounding Hawaii and the Oceania territories of the Central and Western Pacific cover more than 2 million square miles. Together Alaska, Hawaii, and Oceania represent nearly 85 percent of the EEZ. Although the EEZ is of great importance to the country, ensuring safe, legal, secure, and environmentally responsible maritime activity across this vast domain presents an enormous challenge for the Coast Guard.

In FY 2018, the Coast Guard reported that it met its boarding and compliance performance standards less than 25 percent of the time due to constrained asset hours and ineffective targeting.[7] The reported interdiction rate was only 31 percent, while detected incursions grew by nearly 50 percent. Although these data are heavily influenced by illicit activity in the Gulf of Mexico, illegal fishing in the Central and Western Pacific is substantial, and a particularly challenging problem to monitor and interdict because of the difficulty of conducting persistent surveillance over such vast territory that includes waters off the Western Aleutians Islands to the far north, American Samoa to the far south, and Guam to the far west. By way of example, the Coast Guard's FY 2018 performance report noted that

> Tuna fisheries are among the most valuable pelagic fisheries in the world. In FY 2018, there was one incursion detected along the U.S.-Russia Maritime Boundary Line; and 15 incursions detected in the Western and Central Pacific where tuna are prevalent, a region that is extremely remote, hard to effectively patrol, and where it is difficult to detect incursions and even more difficult to respond in a timely manner.[8]

In the Arctic region, the challenges facing the Coast Guard have been growing as climate change invites increased maritime activity. In FY 2018, the Coast Guard conducted 15 SARs and forward deployed two HH-60

[7] U.S. Coast Guard Fiscal Year 2018 Performance Report.

[8] U.S. Coast Guard Fiscal Year 2018 Performance Report. Page 36. https://www.uscg.mil/Portals/0/documents/budget/FY%202018%20USCG%20APR%20Signed%206-12-19.pdf.

helicopters to Kotzebue, Alaska, on the Chukchi Sea above the Arctic Circle. Other years have seen deployments even farther north on the Beaufort Sea. The Coast Guard missions in Alaska are varied, as noted in the FY 2018 Performance Report:

> The U.S. has significant equities in the [Arctic] region, and the Coast Guard is responsible for them. This includes exercising maritime sovereignty and maintaining persistent maritime domain awareness in the Arctic; providing effective maritime border control; overseeing and ensuring the safety of maritime activities; protecting natural resources; providing governance regimes; and supporting collaborative engagement that safeguards U.S. Arctic interests.[9]

The distances in the Arctic are vast. The Coast Guard Air Station in Kodiak in the Gulf of Alaska is nearly 1,000 miles to Barrow on the Beaufort Sea and 700 miles to Kotzebue. By superimposing the map of Alaska over the map of the contiguous 48 states, Figure 5-1 shows the relative size of Alaska's vast distances. Sorties to northern points in Alaska may cross several mountain ranges. The combination of rugged terrain, harsh weather, and mountain ranges combine to make Coast Guard flights more difficult, dangerous, and expensive than normal.

Although maritime domain awareness across such a vast and arduous region will always be challenging, with broader-based use of UAS capabilities a future Coast Guard could project its presence farther by a fleet of all-weather, long-range UAS aircraft based in Kodiak. The UAS could be routinely deployed into the Gulf of Alaska, Bering Sea, Chukchi Sea, and Beaufort Sea with the understanding that visibility in the Arctic is often limited by cloud cover—ranging from 50–70 percent most of the year and varying seasonally up to 70–85 percent during June–October—which may compel future UAS to operate below cloud cover much of the time. In Guam, the Coast Guard sector might be augmented not only by UAS but also by a fleet of USVs and UUVs.

Equipped with live stream cameras and video recording capability, these systems would eliminate random sea patrols and boardings of opportunity. In their place, the Coast Guard conducts targeted boardings of vessels in locations known for illicit activity such as illegal fishing. In some domestic cases, video provided by UxS could eliminate the need for a boarding, as violators would be met at the pier when the fishing vessel returns and the high-definition video could be used as evidence. Fisheries law enforcement is transformed, because the information gained from the

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[9] U.S. Coast Guard Fiscal Year 2018 Performance Report. Page 21. https://www.uscg.mil/Portals/0/documents/budget/FY%202018%20USCG%20APR%20Signed%206-12-19.pdf.

FIGURE 5-1 Map of Alaska and some of its main towns overlaid over the map of the contiguous United States to illustrate the scale of the distances between Kodiak, Barrow, and Kotzebue.[10]

UxSs would be shared with partner nations to ensure the protection of each nation's natural resources.

The Coast Guard's use of UxS has the potential to expand maritime domain awareness exponentially above the Arctic Circle, as UAS could routinely fly pre-designated areas with a host of sensors that can detect electronic emissions and vessels. The UAS fly day or night regardless of weather, eliminating the dangers to manned flight of high-latitude operations. They could be operated by a ground-based workforce charged with conducting surveillance over a large swath of the Arctic regions.

A FRAMEWORK FOR MISSION ANALYSIS AND SYSTEMS TRADES

The three vignettes are helpful for visualizing how various UxS capabilities can support some of the Coast Guard's 11 statutory missions. Based on information received from the Coast Guard, briefings by technology

[10] DHS website. Written testimony of U.S. Coast Guard Commandant Admiral Robert Papp, Jr., for a Senate Committee on Appropriations, Subcommittee on Homeland Security field hearing titled "U.S. Coast Guard Operations in Alaska." August 6, 2012. https://www.dhs.gov/news/2012/08/06/written-testimony-us-coast-guard-commandant-admiral-robert-papp-jr-senate-committee.

developers, and documented experience with UxSs in other domains, Table 5-2 provides a more complete alignment of UxS capabilities with Coast Guard missions. Although a first-cut assessment and by no means exhaustive of all possibilities, the matrix reveals the following interesting points:

- All missions have multiple potential uses for UxS capabilities;
- Persistent surveillance would be the most widely useful capability, applicable to 6 of the 11 missions;
- Advanced tracking capability would support select missions in which detection, identification, and tracking of unique signatures are critical to mission success; and
- Survey and inspection tasks enabled by UxSs, could allow for devotion of more Coast Guard resources to missions requiring direct human intervention such as rescues and drug interdictions.

The exercise of creating such mission/capability matrices would presumably be of value to the Coast Guard as it prioritizes its pursuit of UxS and considers their full potential for in-fleet and force operations. Persistent surveillance is one area where UxS can have a positive impact, but there are potentially many more. Although this first-order mission matrix suggests many potentially beneficial applications for UxSs across mission areas, decisions about where, when, and at what scale (e.g., unit, district, area) to implement these systems will require consideration of various system-level issues such as implications on user tasking, training, data management, and requisite regulatory and policy changes.

Like the Coast Guard's manned assets, one should expect that unmanned systems will also be shared across missions and used in circumstances where Coast Guard personnel and assets are engaged in, or must be ready to engage in, multiple missions or facets of missions. Hence, even if a UxS can substitute for a manned asset for a given function, an expectation of cost or budgetary savings from such a substitution may be misplaced because the manned asset and personnel will continue to be needed for other purposes not suited to the capabilities of a UxS. For example, although a ScanEagle UAV deployed on a National Security Cutter may enhance persistent surveillance in support of SAR or the interdiction of vessels moving illicit drugs, the cutter's crew as well as manned helicopters will still be necessary for rescuing survivors, boarding vessels, and apprehending suspects. Assessments of the cost-effectiveness—or "business case"—of individual investments in UxS technologies may be impractical given the shared nature of both the new UxS investments and existing personnel and assets. The Coast Guard will need to find the right balance of UxS and manned systems in the context of its full array of missions and considering different concept

TABLE 5-2 Unmanned Systems Capabilities That Could Benefit Coast Guard Missions

	Statutory Missions											
Capabilities	Port, Waterways and Coastal Security	Drug Interdiction	Aids to Navigation	Search and Rescue	Living Marine Resources	Marine Safety	Defense Readiness	Migrant Interdiction	Marine Environmental Protection	Ice Operations	Other Law Enforcement	Totals (how many missions would benefit from this capability)
Persistent surveillance	x	x			x		x	x			x	**6**
Persistent search				x								1
Expansion of search area				x								1
Persistent presence (for deterrence or other)	x							x		x	x	4
Persistent tracking					x					x		2
Semi-submersible tracking		x										1
Tracking (fish populations, whales, etc.)					x							1
Counter-unmanned systems (C-CUAS, C-UUV, etc.)	x						x					2
Detection	x							x		x		3
Identify targets of interest		x						x				1
Search and locate aids to navigation (ATON)			x									1
Disabling capability—non-lethal		x										1
Delivery of equipment or supplies				x				x				2
LIDAR to make 3D images of target (mapping interior/exterior of ships)		x										1
ATON survey			x									1
Post storm survey			x									1

TABLE 5-2 Continued

	Statutory Missions											
Capabilities	Port, Waterways and Coastal Security	Drug Interdiction	Aids to Navigation	Search and Rescue	Living Marine Resources	Marine Safety	Defense Readiness	Migrant Interdiction	Marine Environmental Protection	Ice Operations	Other Law Enforcement	Totals (how many missions would benefit from this capability)
Ice survey										x		1
Annual required inspections (hull, buoy chafe)			x									1
Inspections: vessels (tank bottoms, shell plating thickness, confined spaces)						x						1
Inspections: stack gas emissions						x						1
Visual pre-screen prior boarding						x						1
Boom deployment									x			1
Fishing gear inspection while deployed					x						x	2
Fishing vessel speed tracking capability					x						x	2
Mapping oil/hazardous substances above and below surface									x			1
Sample collection									x			1
Dispersant delivery									x			1
Directional electromagnetic pulse							x					1

of operations (CONOPS). It is reasonable to expect that over time and as this balance is achieved, the Coast Guard's investments in UxS will yield budgetary savings; for instance, by deploying manned assets and personnel more efficiently in accordance with the new CONOPS made possible by the UxS investments.

In the meantime, system-level analyses are helpful for considering the relationship between capability benefits and costs (in terms of asset procurements, requisite personnel training, data management, and regulatory and policy development) for UxS deployments at different scales. To illustrate, Figure 5-2 depicts the trade-off considerations for systems showing how operational capability benefits but also budgetary impacts would be expected to increase as the scale of UxS implementation increases from single-user, mission-specific applications to district- and area-level implementations for multiple missions in new operational concepts. For example, the use of remotely operated vehicles (ROVs) and unmanned vehicles (UxVs) that already offer high readiness levels of sensing capabilities can make existing field unit operational concepts more efficient with relatively low-cost implications even when accounting for acquisition costs and considerations for personnel training (see Box 5-1), logistics, support infrastructure, and the like. A good example is a small UAV that increases the efficiency of current field unit operations through expanded surveillance capability. The upfront development and enduring operational cost implications in this case are

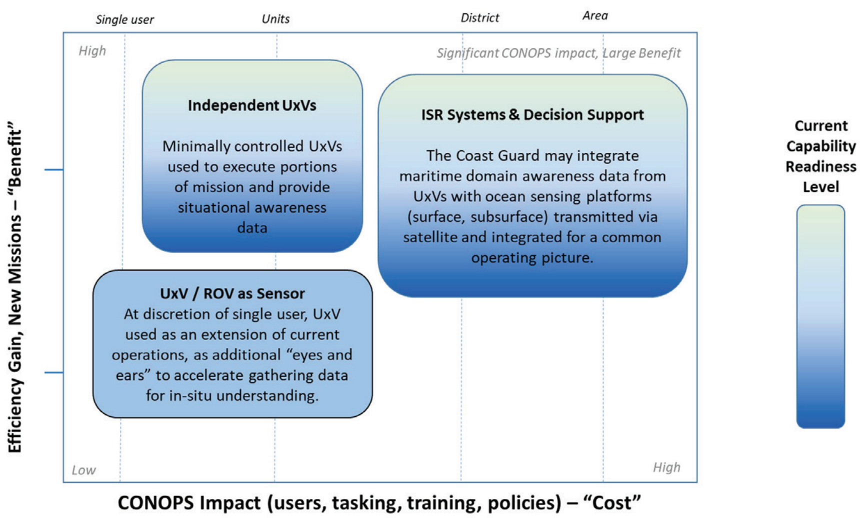

FIGURE 5-2 Coast Guard UxS concept trade space.
NOTE: ISR = intelligence, surveillance, and reconnaissance.

BOX 5-1
Personnel Training and Career Paths in UxS

Greatly expanded use of UxSs, if found to be highly desirable for Coast Guard operations, will require specialized personnel and a civilian workforce and uniformed force with varying skills for adept operations, automation technology evaluation, systems engineering, and associated management processes. To ensure this capacity, the Coast Guard will need to provide means for career development, training, and education of its uniformed and civilian personnel. Formal training programs are emerging and are proving to be resources to other agencies; the Unmanned Maritime Systems Certificate Program at the University of Southern Mississippi has served as training for both Navy and NOAA personnel.[a] Designated career paths for UxSs may be necessary at some point to recruit and retain personnel with the needed skills. For example, the U.S. Air Force has created career paths for unmanned aircraft pilots[b] and sensor operators.[c]

Predictions of growth in commercial and government adoption of UxS suggests increasing need for skilled personnel, not only for mission operations but also for system engineering, cybersecurity policies, data management implications, and the like. Therefore, Coast Guard training and career paths may be needed to attract and develop personnel with the necessary knowledge and skills—for example, starting with Officer Candidate School with required classes and offerings of academic majors at the U.S. Coast Guard Academy. For example, in support of the Commandant's Cyber Strategy, the Coast Guard Academy has created a Cyber Systems major, with the first class graduating in 2022.[d]

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[a] University of Southern Mississippi. Unmanned Maritime Systems (UMS) Certificate Program. https://www.usm.edu/ocean-science-engineering/unmanned-maritime-systems-ums-certification.php; https://www.dvidshub.net/image/6295824/usms-unmanned-maritime-systems-certification-program-graduates-april-2019.

[b] U.S. Air Force. "Remotely Piloted Aircraft Pilot." https://www.airforce.com/careers/detail/remotely-piloted-aircraft-pilot.

[c] U.S. Air Force. "Remotely Piloted Aircraft Sensor Operator." https://www.airforce.com/careers/detail/remotely-piloted-aircraft-rpa-sensor-operator.

[d] U.S. Coast Guard Academy. "Academic Majors: Cyber Systems." https://www.uscga.edu/cyber-systems.

relatively small because the system has already been developed, is widely available through commercial industry providers, and because operations can be provided by contractors whose role can be temporary if the system does not achieve its goals. The contractor-owned and contractor-operated model provides the means for experience and exposures to these systems without long-term investments on technology that is rapidly changing.

Advancing the capabilities of UxS to the point where they can be used by field units to execute partial missions with autonomy could substantially increase operational benefits, potentially without proportional increases in costs for personnel training because of the systems' capacity to act independently. For example, a minimally controlled UxV could offer the advantage of a forward deployment capability for situation awareness and partial mission execution with limited demands on the ship's crew or shoreside personnel engaged in other tasks. The benefit here lies in the use of autonomy to broaden geographic reach and extend endurance beyond human capability, with relatively minimal impact to current Coast Guard operations.

By comparison, a UxS that is implemented at larger scale to potentially benefit multiple missions performed by units across a Coast Guard district or area offers the potential for larger efficiency benefits but also large cost impacts associated with new operational concepts and an increasingly complex operating environment. In this case, the advanced UxS concept might include multiple unmanned vehicles and strategically positioned sensing platforms to provide maritime awareness data and other services via satellite to form an integrated common operating picture. Through the use of artificial intelligence technology, visualization software, and secure communications, the Coast Guard may be able to leverage emerging autonomy technology even further to expand operational efficiency gains.

This trade space framework, which is depicted in Figure 5-3 with several more examples, offers a way for the Coast Guard to begin to assess leveraging different types of UxS at different scales. Indeed, the Coast Guard has started to evaluate the use of UxVs in various mission scenarios and has experienced efficiency gains within these use cases, primarily in the "UxS/ROV as a Sensor System Concept" space. Future operational concepts that include the use of independent unmanned vehicles could see more efficiency gains as assets are deployed to perform some of the more "distant" and "exhausting" tasks. As enabling communications and artificial intelligence technology becomes more widely available, a fully integrated decision support capability could be provided through port security systems or manned-unmanned "system of systems" for maritime domain awareness of larger areas.

A fully implemented manned-unmanned system of systems could involve fleets of gliders checking port security and navigation aids, integrated decision systems that pull data from maritime surface buoys, coastline radars, undersea sensor arrays and open source information, all fused for a common operating picture by Coast Guard area. The Navy's Oceanography glider fleet operates this way and provides data from around the globe.[11] If the Naval Meteorology and Oceanography Command were gathering that data by manned operations, it would be cost prohibitive. Instead, the glider fleet provides situation awareness under watch by operators at the

[11] J. Ervin. 2016. "CNMOC Updates Defense, Industry Leaders at Unmanned Systems Defense 2016." https://www.navy.mil/submit/display.asp?story_id=97410.

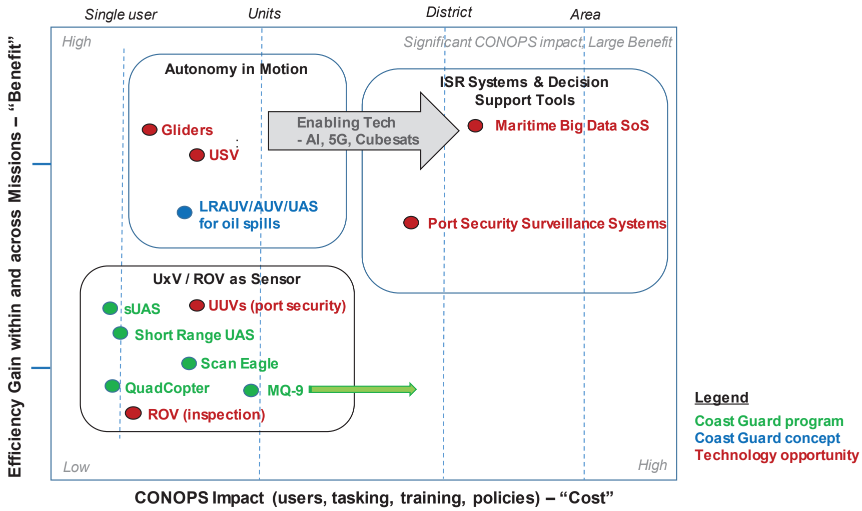

FIGURE 5-3 System considerations for persistent surveillance capabilities using unmanned systems.

Stennis Space Center in Mississippi. This example illustrates the potential advantage to shifting the balance of manned to unmanned systems from a return-on-investment perspective.

SYSTEMS ENGINGEERING UxS AT LARGER SCALE

As has been noted, the Coast Guard's use of UxSs to this point has focused largely on systems that perform well-defined tasks and present minimal challenges to integration with current manned operations—a focus that we refer to as the "UxV/ROV as a Sensor System" or "Roomba™" concept. As the Coast Guard seeks to increase and broaden the impact of UxS applications (i.e., move toward the upper right quadrant of the "trade space" in Figures 5-2 and 5-3), integration and systems engineering requirements will multiply and become more challenging. Although not intended to be an exhaustive accounting of these requirements, some examples are presented next.

Life-Cycle Learning, Adjustment, and Management

As the Coast Guard introduces more UxSs, at larger scales, and with increasing system integration it must do so with a well-developed understanding of the workflow design to continuously add operational efficiencies, as discussed in Chapter 3. This understanding, however, must be accompanied by decision makers and implementers in the civilian and uniformed ranks who are increasingly conversant in the technical details of application designs and implementations, the cost and lead-time requirement associated with implementations, and both the technical and policy/legal issues that can arise concerning collection, storage, dissemination, and security of information gathered and analyzed by the systems. For example, systems must be designed with an understanding of legal controls on the use of unmanned vehicles, such as the authorized deployments of UAVs in regulated airspace.

Although the development of this knowledge will require time and experience working with UxS technologies and related applications, the Coast Guard can develop operational productivity models to support effectiveness and efficiency assessments associated with the employment of new UxS applications. Importantly, the Coast Guard can tap the experience and expertise of operational partners to develop reusable system workflow and technical designs along with processes and procedures. Indeed, working with partners that bring their systems to bear will require cooperation on many fronts, such in the development of compatible cybersecurity protections—because no partner will want to be the weak link in a system-of-systems configuration.

System-of-Systems Issues

Orders prohibiting federal agencies from buying and using foreign-made UAVs out of concern over cybersecurity[12] exemplify the importance of building UxS engineering capacity within the federal government. Concerns about cybersecurity could presumably be extended to prohibit or limit the use of other foreign-manufactured unmanned technologies and their components. Rapid compliance would require the Coast Guard to have detailed, systems-level information about the suite of systems and their components across integrations. The Service would also need the systems engineering and technical skills to make requisite changes to systems and their components to ensure that vital mission capabilities are sustained. Even if the federal government permits foreign-made systems or components, the Coast Guard would need to understand the supply chains for multiple systems to prevent cyberattack avenues.

As a general matter, a systems engineering capability will be needed to institute life-cycle changes to systems and their designs that are motivated by the desire to add new features to UxSs. It is reasonable to expect that

[12] See for instance, the Secretary of the Interior's ban in January 2020. https://www.doi.gov/sites/doi.gov/files/elips/documents/signed-so-3379-uas-1.29.2020-508.pdf.

advances in technology will continue to provide—and probably rapidly—significant new opportunities for increasing the effectiveness and efficiency of existing implementations. These opportunities will require operational and technical analyses of options, potentially across multiple or even all Coast Guard missions. The Coast Guard will need the necessary knowledge and readiness to fulfill these needed, systems-level analytic capabilities.

Overall System Design Considerations

Given the potential benefits that would be conferred by the ready and seamless integration of newly available UxS capabilities, the Coast Guard could explore new approaches for fielding advanced systems and new automation components for existing systems. This effort may require strategic planning with the acceptance of some trade-offs, such as

- Designing systems that are less complex so that they can be more rapidly modified;
- Developing a strategy for sequential addition of more complex design features to a system so that implementation of earlier available automation capabilities can occur;
- Delaying selected system testing requirements to occur after operational deployment in order to gain earlier values achieved through new automation;
- Developing systems in a manner that continuously provides incremental additional capabilities on a short-term basis, funded on a level-of-effort basis;
- Developing systems that can incrementally exploit artificial intelligence and machine learning methods in order to enhance their performance; and
- Designing systems that can be more resilient to successful cyberattacks in order to reduce complex cyberattack defense requirements that would need to be added to commercially available automation products.

The U.S. Department of Defense has recognized the importance of taking advantage of rapidly emerging commercial UxS technologies, and has therefore adapted procurement practices to reduce the time required to acquire new capabilities and offers an example of the importance of not only designing systems that can be adapted to benefit from continual advances in UxS technology, but also creating adaptable processes and policies.

6

Moving Forward

The Coast Guard is sponsoring multiple initiatives to assess the applicability of unmanned systems (UxSs) to introduce their capabilities into the fleet and force structure. Many of these efforts have been highlighted in this report. According to Coast Guard briefings, the Service has considered the return on UxS investments primarily by examining its ability to carry out missions more effectively, enable more efficient use of manned assets, and expand the scope of maritime domain awareness. However, to date the Coast Guard's applications of UxSs have been characterized by limited funding spread over several years and the absence of a formal means, or a pacing mechanism, to proactively investigate and integrate promising systems. In the meantime, technological change and advancements in UxSs have accelerated, driven by commercial and military demands and interests.

A major realignment of the Coast Guard's UxS approach is warranted. After reviewing the Coast Guard's many important, complex, varied, and demanding missions; observing that its fleet and operational forces are being increasingly taxed; finding that unmanned systems are being used today with high utility across the public and private sectors; and knowing that the technologies that enable and underpin these systems are advancing rapidly, the committee is struck by the magnitude and breadth of opportunity that lies ahead for the Coast Guard to pursue UxS in its multiple operational domains and across its many missions. As other military services and U.S. Department of Homeland Security (DHS) operational units integrate UxS into their own force structures, the Coast Guard will be impelled to do the same, as it engages in joint and combined operations and missions with these partners.

The evidence in this report points to both compelling reasons and burgeoning opportunities for the Coast Guard to proceed more aggressively, albeit strategically and deliberately, in leveraging UxS. Indeed, **the committee concludes that to remain responsive and fully relevant to its many missions, it is imperative that the Coast Guard take a more strategic and accelerated approach to exploit the capabilities of existing and future unmanned systems.**

The Coast Guard has shown interest in exploiting UxS for more missions. That interest, however, is not matched by a funding commitment, including critical funding for research and development (R&D). The Coast Guard's R&D spending is modest when compared to R&D spending by other military and DHS operational agencies, and negligible in the context of the UxS imperative. **The committee concludes that the Coast Guard's small current budget for UxS R&D and incremental applications is not sufficient to meet the UxS imperative and therefore will need augmentation by Congress and DHS to enable more and larger-scale investigations and investments.**

How best to proceed in aligning plans, operations, budgets, and policies to prompt and enable the Coast Guard to embrace and capitalize on UxSs is a question that faces the its leadership, DHS, and Congress. Similar to the experiences of other military services, DHS operational units, and several other federal agencies, the Coast Guard has reached a point where purposeful and strategic steps are needed to exploit UxS more effectively and efficiently. Informed by these experiences, the committee recommends the following five steps.

ISSUE A HIGH-LEVEL UxS STRATEGY

The Coast Guard's Strategic Plan for 2018–2022 is intended to provide a "framework for a Ready, Relevant, and Responsive Coast Guard to address America's most complex maritime challenges across the full spectrum of maritime operations."[1] The plan explicitly points to the opportunities, complexities, and challenges of a maritime domain that is being transformed by advanced technologies, including UxS, by observing that

> rapid technological advancements are changing the character of maritime operations. The accelerating pace of innovation manifests itself through increasingly complex vessels, high traffic volumes, and greater demands on the Marine Transportation System (MTS). Advanced technologies, such as

[1] U.S. Coast Guard. 2018. *Coast Guard Strategic Plan 2018–2022*. Page 2. https://www.uscg.mil/Portals/0/seniorleadership/alwaysready/USCG_Strategic%20Plan__LoResReaderSpreads_20181115_vFinal.pdf?ver=2018-11-14-150015-323.

> autonomous and robotic systems and new propulsion methods usher in an era of new regulatory, legal, and operational challenges. While these technologies increase the complexity of our operating environment, they also present great opportunities for improved safety and efficiency. Our ability to set and enforce effective standards that advance maritime safety and environmental stewardship must keep pace with rapid technology application in the afloat, ashore, and cyber elements of the MTS.[2]

The plan recognizes the tremendous promise of advanced technologies to transform the maritime domain, but it also highlights the significant regulatory, policy, and operational challenges and complexities that accompany that promise. Furthermore, it says little about how these same advancements can transform the Coast Guard itself and present similar technical, regulatory, policy, and operational challenges.[3] Indeed, this report documents how the Coast Guard has made progress in investigating and introducing UxSs, but finds no evidence of these efforts being guided by a strategic vision of a future Coast Guard that is transformed by UxSs or a set of strategic goals and objectives for pursuing that transformation.

It is time, in the committee's view, for the Coast Guard leadership to offer that future vision, articulate strategies and objectives aimed at achieving it, and establish the appropriate organizational structures and lines of authority to deliver and integrate UxSs across the force structure. Other military services, including the Navy, and other federal agencies, most recently the National Oceanic and Atmospheric Administration (NOAA), have taken this important step in recognition that ad hoc and piecemeal efforts to investigate and introduce UxSs risk fragmented and unrealized benefits. Developed and issued by top leadership, their plans reveal the importance of a high-level commitment to UxSs because of the need for deliberate and coordinated implementation and support efforts across the organization, from headquarters to the field. The Coast Guard could benefit by leveraging the work by other military services and agencies that have established UxS programs.

To ensure this commitment and coordination, **the Commandant should issue a high-level UxS strategy that articulates a compelling rationale for**

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[2] U.S. Coast Guard. 2018. *Coast Guard Strategic Plan 2018–2022*. Page 4. https://www.uscg.mil/Portals/0/seniorleadership/alwaysready/USCG_Strategic%20Plan__LoResReaderSpreads_20181115_vFinal.pdf?ver=2018-11-14-150015-323.

[3] There are only two specific references to unmanned systems in the 2018–2022 Strategic Plan. Section 1.2.2 calls for investments in shore- and cutter-based unmanned aerial systems and Section 1.2.4 calls for the evaluation of emerging technologies, such as unmanned platforms, data analytics, block chain encryption, artificial intelligence, machine learning, network protocols, information storage, and human–machine collaboration for possible use in mission execution.

UxS, sets forth agency-critical goals these systems should further, and outlines the Coast Guard's approach for achieving them.

There is ample precedent for strategic planning in the Coast Guard, and clear evidence that strategies issued at the highest level command Service-wide attention and action. As discussed in Chapter 4, the Commandant has issued several strategic documents to call attention to critical needs and interests. Some of these documents provide concise statements of strategic goals and intentions, while others offer more details on the specific strategies and objectives to be pursued. In either form, the documents are intended to convey urgency to senior leadership and to galvanize the need for change across the Service—from shifting budget priorities and adjusting acquisition policies to making investments in supportive R&D and personnel recruitment and training.

DESIGNATE A SENIOR UxS CHAMPION

While the Coast Guard is small when compared to the Navy and other military services, it is nevertheless a large organization with a complex—and in places stove-piped—bureaucratic structure. Decisions and their execution can involve multiple command, operational, and mission support units. Rules, policies, procedures, and business practices—which are sometimes rigid and ingrained—must be followed for logistics, financial management, human resources, acquisitions, and information technology. Although reforms during the past decade have led to many improvements in organizational agility and efficiency,[4] the Coast Guard, like many large organizations, cannot assume that its day-to-day decision making, operational, and administrative processes will suffice when pursuing bold new initiatives that require innovation and adaptability.

A strategic commitment to UxSs from the Office of the Commandant can go a long way to spurring the organizational responsiveness required to carry it out. However, the scope and scale of the responsiveness, should not be underestimated. For example, the Coast Guard has multiple acquisition authorities and mechanisms that can be applied to UxS investments, but the most streamlined and adaptable ones will be needed to keep pace with advancements in technological capabilities. Some longstanding design, development, and evaluation standards that were instituted to ensure the safety of manned systems will need to be culled or eliminated, and risk-appropriate standards will need to be adopted in their place to exploit the capabilities of UxS and their integration with operational forces. New policy guidance, interpretations, and applications will be required to maximize

[4] See https://www.gao.gov/products/GAO-09-530R and https://www.gao.gov/assets/710/704873.pdf.

the beneficial use of these systems. For example, legal and policy assessments will be required to ensure that existing laws, regulations, and Coast Guard authorities will allow the safe and legally compliant uses of UxSs across a range of envisaged, and sometimes novel, applications.

As discussed in Chapter 4, in 2015 the Secretary of the Navy, in a memo titled “Treat Unmanned as Unmanned,” created the position of Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN (UxS)), whose core responsibility would be to accelerate the development and fielding of UxSs through coordinated and efficient efforts across the U.S. Department of the Navy. In essence, the DASN (UxS) was charged with being a powerful advocate for UxSs across the Navy and Marine Corps, as well as external interests. Although both the U.S. Department of Defense (DOD) and the U.S. Department of the Navy had issued multiple UxS strategic plans and action-oriented “roadmaps” over the years, the decision by Navy leadership to create this new office in the Secretariat signaled the importance of high-level and sustained prompting, persuasion, facilitation, and coordination to further these strategies and the many interdependent steps needed to execute them in a vast and complex organization with many competing demands and priorities.

While the intra- and inter-organizational challenges the Coast Guard faces in furthering a UxS strategy differ in magnitude from those faced by the much larger Navy, they are comparable in nature and seem to warrant comparable solutions. Thus, learning from the experience of the Navy, **the Commandant should designate a top Coast Guard official, at the Flag Officer or Senior Executive Service levels, to advocate for and advance the Commandant’s UxS strategy.** This top official should be responsible for identifying, promoting, pushing for, coordinating, and facilitating the changes that will be needed across the board to further the UxS strategy, including ensuring

- Innovative uses of all available and relevant acquisition authorities, including fast-track procurement, partnering, and contract services.
- Statutory and regulatory assessments of existing Coast Guard authorities to ensure that planned operations and uses of UxSs will be legally compliant and to identify gaps in authorities that may need to be filled to enable some beneficial envisaged uses.
- Introduction and promotion of a desirable career path or component that specializes in UxSs, including the requisite education and training programs to support UxS operations across mission areas.
- Co-development with mission area partners of cybersecurity policies for system-of-systems configurations that ensure that cybersecurity risk assessments are routinely conducted to guarantee the secured use of unmanned technologies and to safeguard the Coast Guard’s critical data and systems.

The official serving in this capacity would have a large remit, but also a high-level mandate and prominent platform from which to pursue it. Although this remit would involve a great deal of coordination and facilitation, as opposed to program execution and management, it would need to be pursued with the purpose and resolve of committing the entire multimission Coast Guard enterprise to realizing the Commandant's strategic vision for UxS.

STAND UP A UxS PROGRAM OFFICE

As noted above, the Coast Guard has made a series of organizational realignments over the past decade to improve operational effectiveness and to deliver mission support services more efficiently. Critical to this effort has been the establishment of new headquarters organizations, including a Deputy Commandant for Operations, Deputy Commandant for Mission Support, and Force Readiness Command (FORCECOM).[5] The Deputy Commandant for Operations was created to strategically manage the Coast Guard's mission programs—consolidating under a single umbrella numerous functions that had been dispersed across the organization such as managing intelligence activities, coordinating interaction with external stakeholders, and identifying new and emerging issues that threaten operations. The Deputy Commandant for Mission Support was created to consolidate and manage support policy, strategy, planning, and resourcing to meet mission needs for human resources, engineering and logistics, information systems, and acquisitions. FORCECOM was created to ensure that each mission has the necessary equipment and personnel skills to ensure operational readiness to support mission delivery and business processes. The Coast Guard established these offices in recognition of the importance of centralizing responsibility for furthering interests and initiatives that would otherwise languish because of a lack of direct ownership and singularity of focus.

Although the Coast Guard does not have an office dedicated to UxSs—or even a clearinghouse-like unit responsible for inventorying and tracking the results of existing UxS activities—other federal agencies have been moving in this direction. In its recently released UxS Strategic Plan, NOAA stated its intention to create a centralized office for UxSs to enable a more effective transition of the systems into operational platforms across its line agencies. Housed in the Office of Marine and Aviation Operations, NOAA's new UxS Operations Program Office is charged with coordinating and

[5] U.S. Government Accountability Office. 2020. "COAST GUARD: Actions Needed to Evaluate the Effectiveness of Organizational Changes and Determine Workforce Needs." https://www.gao.gov/assets/710/704873.pdf.

providing support for UxS activities, including training, cybersecurity, and acquisition, as well as serving as a trusted source of UxS expertise across the agency. The new office will also help the agency to meet the mandates of the Commercial Engagement Through Ocean Technology Act of 2018, which requires NOAA to coordinate research, assessment, and acquisition of UxS with the Navy, other federal agencies, industry, and academia.

Given the many changes in Coast Guard priorities, practices, and procedures that will be required to exploit UxSs more fully—from systems acquisition to personnel hiring and training—no single office or subunit could be expected to initiate and implement them all. Such an office, in the committee's view, would require an unrealistic number of new and reassigned authorities and potentially hinder the Coast Guard's mainstreaming of UxS. At the other extreme, however, a unit charged with simply tracking and monitoring Coast Guard UxS activities would be too passive for furthering this important strategic initiative. The creation of a UxS program office whose main functions are to coordinate and leverages will provide more value than one that authorizes and directs, and should have the advantage of not requiring complicated and controversial internal reorganizations.

Much like NOAA's nascent UxS Operational Office, a dedicated Coast Guard UxS program office could play a leadership and coordinating role in sustaining and expanding the use of UxS capabilities across Coast Guard operational forces. More importantly, a UxS program office would be charged with fostering an organizational environment—administratively, culturally, and operationally—in which the Coast Guard is not only ready, willing, and able to leverage UxS technologies, but also increasingly enterprising and opportunistic in exploiting their capabilities. Underscoring the importance of such an environment for the future Coast Guard, **the Commandant should establish a UxS program office that will work with the top official charged with advancing the Services's UxS strategy to plan out, coordinate, assess, and promote UxS activities across the Service and to leverage relevant activities and capabilities from outside the Service.**

In keeping with its role as both facilitator and champion of UxSs, the program office's responsibilities and functions should include the following:

- Creating an actionable roadmap (i.e., tactical plan) that identifies desired outcomes from UxS and major initiatives, indicators (including annual performance metrics), and milestones needed to bring about these outcomess.
- Assessing activities across the Coast Guard mission areas to identify capability needs and opportunities for using UxSs.
- Developing processes and practices to facilitate UxS initiatives, where warranted and practical, to enable rapid nomination, evaluation, and transition of UxSs systems into Coast Guard operations.

- Monitoring UxS capabilities development and technology availability in other military services, federal agencies, national laboratories, and the commercial sector, and identifying affordable leveraging opportunities that align with Coast Guard mission needs.
- Creating economies-of-scale opportunities by coordinating and partnering with other military services, federal agencies, private companies, and academia to further the initiatives and outcomes defined in the roadmap, including through joint efforts to develop, test, acquire, and utilize UxSs.
- Supporting UxS acquisition decisions by considering not only cost, schedule, and performance evidence, but also technical readiness, prospects for incremental capabilities, complexity of design, and system resilience to failures (including those due to cyberattacks).

To fulfill these responsibilities, the program office will need to work with the top official charged with advocating for UxS and to maintain strong ties to the Coast Guard's operational leadership and field units, that is, the principal users of UxSs. Because close ties with mission support units will also be vital, it would be advantageous for the program office should be situated organizationally so that its reach is broad. Prominence in the organization chart would also be appropriate for a strategic priority.

An early initiative of the program office should be to develop a "roadmap" that translates the high-level UxS strategic goals and objectives into an actionable plan to accomplish them, which should specify tasks needing priority attention, time frames for completion, and performance milestones and measures. A roadmap "connects the dots" by showing how various actions across the Service fit together to further the UxS strategic goals and objectives. For example, the roadmap could show how investments in, and investigations of, a specific UxSs are expected to inform follow-on decisions about UxS deployments. The roadmap should also lay out steps to overcome barriers to obtaining or using a UxS, such as legal or acquisition policy constraints. Given the importance of integrating UxSs with manned systems and with other UxSs into a system of systems, the roadmap should identify the activities needed to facilitate integration and transition of technology across the Service. As such, the roadmap should also incorporate steps for developing workforce training on UxS and for leveraging other agencies work in this field.

Roadmap development requires an understanding of the Coast Guard's starting point with UxSs. The inventory of recent, ongoing, and planned UxS programs and activities presented in Chapter 4 makes clear that the Coast Guard is not a UxS novice, but its efforts are largely ad hoc and fragmented—lacking a common evaluation framework, a means to disseminate results and experiences across the Service, and definitive plans for follow-on activities to build on promising results. The UxS program office should not only be responsible for filling these voids, but also function as a "one-stop" place for operational and mission support units to obtain information about the current status and planning of UxSs in the Coast Guard. These interactions should be bi-directional, because the program office should regularly consult with operational units to identify and understand their desired capabilities, consider how those capabilities correspond with those desired by other operational units, and explore ways in which UxSs could satisfy them.

The program office should be keenly aware that the Coast Guard, as a "fast follower," must leverage technologies that are being developed and introduced elsewhere. The program office must therefore have a vigorous outward-facing presence, not simply a liaison-like interface. In this regard, the program office should actively monitor UxS developments from outside the Coast Guard, including elsewhere in DHS, the Navy and other military services, other federal agencies, national laboratories, the private sector, and academia. As the Coast Guard's primary connection to potential external partners, the UxS program office would broker such partnerships by canvassing interest among Coast Guard operational units and coordinating the steps needed to pursue the promising partnership opportunities. In this regard, the UxS program office should look for economies-of-scale opportunities to jointly develop, test, acquire, and utilize UxSs.

To facilitate these external partnerships and the Coast Guard's own internal deployments of UxSs, the program office should work on an ongoing basis with mission support units responsible for functions such as acquisitions, legal compliance, personnel hiring and training, and information technology to ensure that their practices, processes, and investments are increasingly suited to the expeditious introduction and use of UxS technologies. In some cases—as discussed in Chapter 3—the rapid introduction of UxS may be accomplished through the creative or innovative use of existing legal, regulatory, and policy frameworks, but in some cases, they may not. If the latter, the program office should be prepared to work with the relevant Coast Guard authorities to pursue changes to these frameworks inasmuch as such additional effort is warranted by the benefits expected and likely to prove fruitful.

As UxS capabilities grow and are embraced by the Coast Guard, so too will the complexities of ensuring that UxSs are integrated with manned systems and with one another across the air, surface, and multiple domains. At the level of the technologies being deployed, integration may require standards for interoperability, user interfaces, communications, sensor interfaces, and the like. Integration will also need to extend to launch and recovery means, operator consoles, logistics for fuels and spare parts, and communications links and command and control. When operating with mission partners, system-of-systems configurations will increase integration needs and challenges.

Accordingly, the Coast Guard needs a systems engineering capacity devoted to UxSs. Although this capacity need not reside in the UxS program office, the office should be responsible for ensuring that it exists and is sustained and accessible. Advances in automation-related technology to exploit UxS opportunities require a knowledge base of workflow design, the technical details of system design and implementation of applications, and the costs and lead times associated with project implementations. Furthermore, this knowledge base must include understanding of the policy issues and corresponding technical issues that stem from the collection, storage, dissemination, and security of information gathered and analyzed by the UxSs. Such a knowledge base requires time and experience to develop. Therefore, the Coast Guard should commence efforts to build a systems engineering capacity as soon as possible to ensure successful UxS investments and implementations.

EXPAND AND NORMALIZE UxS EXPERIMENTATION

As discussed in Chapter 4, the Navy created two operational units dedicated to UxS experimentation, one focused on unmanned underwater vehicles (UUVs) and one on unmanned surface vessels (USVs). This decision was intended to facilitate transition of the technology into the fleet through a "test and learn" process, whereby field units employ prototypes to learn how system designs should be adapted before investing in a system at scale. Indeed, the importance of involving operators to understand how UxS technologies can be utilized was an oft-repeated theme in the agency presentations. Encouraging experimentation with low-cost systems was seen as critical for not only identifying beneficial uses, but also nurturing a technology-curious and -proficient workforce.

Some of the experimental strategies employed by the Navy and others are as follows:

- Involve operators in as many experimental situations as feasible and affordable, such as in exercises, simulations, demonstrations, and tests and evaluations;
- Employ technologies that are commercially available and inexpensive to accelerate the acquisition process and more freely explore possible applications without excessive worry about system damage or losses; and
- Test UxSs owned by partners before committing to investment.

The military services have long embraced experimentation as foundational to force development. The importance of experimentation for the Navy has been known for some time. In particular, the Warfare Centers of the Naval Sea Systems Command (NAVSEA) and Naval Air Systems Command have been developing UxS for years. In briefings, NAVSEA leadership explained that it either builds prototypes for the field to test or it provides commercially available technology to the field to test.[6] The Navy leverages its substantial infrastructure for testing and experimentation including simulation, war games, and test ranges. As an example, the objective of the Advanced Naval Technology Exercises program is to expose UxSs to a larger operational community to assess readiness levels, possible applications, and even manpower implications.

Although at a much smaller scale, experimental uses of UxSs have occurred at agencies as diverse at the U.S. Department of the Interior (DOI), NOAA, and the Federal Bureau of Investigation (FBI). The DOI Strategy document for UAS acknowledges the importance of operational tests to determine the readiness of UASs to expand applications and the use of UAS equipment from partners as a "try before you buy" approach.[7] Indeed, DOI developed a set of easy-to-follow processes to facilitate investigations of potential candidates for UAS applications, from determining requirements to executing the program. After experimenting with small UAVs for more than a decade, the FBI identified more than 30 applications for the technology, even though initially expecting only a handful of uses. Likewise, in its Unmanned Systems Strategy, NOAA describes its intention to expand the use of UxSs through experiments across its line agencies.[8] NOAA emphasizes the importance of building communities-of-practice for UxSs and leveraging partnership opportunities with the Navy, Coast Guard, and other agencies as a means to test UxSs readiness for integration into operations.[9]

As documented in Chapter 4, the Coast Guard is experimenting with UxSs, with the notable example the ScanEagle sUAS as well as about a dozen other projects and partnerships. In the committee's view such experimentation is vital to expanding and transitioning UxSs across the Coast

[6] Briefing and committee discussion with Mr. McCormack, Executive Director for Naval Surface Warfare Center and Naval Undersea Warfare Center, in February 2020.

[7] U.S. Department of the Interior. 2015. *Department of the Interior Unmanned Aircraft Systems (UAS) Integration Strategy (2015–2020)*. https://www.doi.gov/sites/doi.gov/files/uploads/DOI_UAS_Integration_Strategy_2015-2020.pdf.

[8] NOAA. 2020. *NOAA Unmanned Systems Strategy*. https://nrc.noaa.gov/LinkClick.aspx?fileticket=0tHu8Kl8DBs%3D&tabid=93&portalid=0.

[9] NOAA. "NOAA, U.S. Navy will increase nation's unmanned maritime systems operations." August 4, 2020. https://www.noaa.gov/media-release/noaa-us-navy-will-increase-nation-s-unmanned-maritime-systems-operations.

Guard and is compatible with the Coast Guard's "can do" culture and spirit of innovation to fulfill diverse and demanding mission in the face of resource constraints. To build on and reinforce its naturally innovative culture, **the Coast Guard should expand and normalize efforts to ensure ample and systematic operations-related experimentation with low-cost UxSs, including potentially designating field units specifically for experimentation and rapid transitioning of unmanned systems to operations.**

With its diverse set of missions, the Coast Guard is well positioned to experiment with a range of capable and inexpensive technologies that are becoming increasingly available commercially. Moreover, the Coast Guard should encourage such experimentation both organically and through more deliberate and planned efforts. Expanding activities in UxSs requires that the Coast Guard increase investigations of these systems to determine which technologies are best suited and more effective for its missions. This requires a systematic approach to making decisions about UxSs investments systems that includes the use of experimentation, prototypes, and capability demonstrations. For example, investigations of prototypes should test their functionality with mature UxS technologies to understand their potential contribution to the mission, and if beneficial, to determine the changes needed to transition the prototype to a fielded capability. In short, such investigations should be designed so that their results can inform decisions about what capabilities to incorporate in the force structure.

The committee's use of "systematic" refers to robust experimentation campaigns that are designed to test concepts over a range of operational scenarios and with applications directed at near-, mid-, and long-term objectives. A body of literature exists on the use of such experimental methods, including the *DOD Prototyping Guidebook*,[10] *DOD Experimentation Guidebook*,[11] *The Role of Experimentation in Building Future Naval Forces*,[12] and *The Role of Experimentation Campaigns in the Air Force Innovation Life Cycle*.[13] Recognizing the important role that operational evaluation plays in moving systems into field use, the DHS Science & Technology (S&T) Directorate has likewise established processes for understanding UxS commercial readiness levels in operational settings, such

[10] U.S. Department of Defense. 2018. *Department of Defense Prototyping Guidebook*. https://www.afwerx.af.mil/resources/DoD-Prototyping-Guidebook.pdf.

[11] U.S. Department of Defense 2019. *Department of Defense Experimentation Guidebook*. https://www.dau.edu/tools/Lists/DAUTools/Attachments/381/DoD%20Experimentation%20Guidebook,%20v1.0.pdf.

[12] National Academies for Sciences, Engineering, and Medicine. 2004. *The Role of Experimentation in Building Future Naval Forces*. https://www.nap.edu/catalog/11125.

[13] National Academies for Sciences, Engineering, and Medicine. 2016. *The Role of Experimentation Campaigns in the Air Force Innovation Life Cycle*. https://www.nap.edu/catalog/23676.

as through the use capability demonstrations. The Coast Guard can tap this in-house expertise to design and carry out its own UxS experiments, and the UxS program office could play an important role in providing these connections with partner agencies and experimental guides and tools.

Experimentation with low-cost UxS will not only lead to the identification of beneficial uses, but also nurture a technology curious and proficient workforce across the ranks. In the committee's view, the Coast Guard should aim to spur interest in, and create opportunities for, experimentation across operational units with an aggressiveness that is at least commensurate with the general pace of development and proliferation of UxSs technologies.

GET A FIX ON UxS FUNDING NEEDS

The Coast Guard's application of UxS technologies to date appear to be paying off and will likely continue to yield incremental benefits even if pursued in a limited and highly targeted manner as the technologies leveraged from the commercial sector and spun off from Navy and other military investments become more reliable, capable, and affordable. In foregoing the fuller range of potential benefits, however, the Coast Guard risks the foreclosing of potential opportunities to capitalize on UxS capabilities as it makes investments in long-lived assets and the recruitment, training, and deployment of personnel with only nominal or partial regard for the potentially transformative technological developments on the horizon.

The committee's recommendations are intended to expand and accelerate Coast Guard investigation and implementation of UxSs that can lead to new concepts of operation. However, the recommendations assume intent; that is, they are offered with the premise that the Coast Guard wants to capitalize on the growing and expanding capabilities of UxSs—and indeed that the Coast Guard concurs with the committee's conclusion about the imperative of doing so if the Service is to remain responsive and fully relevant to its many missions. The interest expressed by Coast Guard leadership in committee briefings and the Service's apparent satisfaction with its experimental and limited uses of UxS technologies to date suggest this assumption is well founded. Acting on these recommendations, however, will require ample and sustained funding, and a commitment to continually increasing funding over time.

While the committee is not in a position to estimate and advise on how much funding will be required, a detailed assessment of investment needs is not required to conclude that a $5 million per year R&D program and budget line items of a few million dollars more per year for acquisitions and deployment of off-the-shelf technologies is clearly insufficient. As it identifies UxS capabilities for incorporation into the fleet and force structure, the Coast Guard will need to invest in R&D, acquisitions, field experimentation, strategic planning, systems integration, evaluation, cybersecurity, legal analyses, personnel recruitment and training, and many other field and mission support functions and requirements. The sooner the Coast Guard estimates the magnitude of required investments, the sooner it can press for additional resources to meet them. Without dedicated funding for UxSs, the Coast Guard is almost certain to lose out on many of these benefits.

Thus, to get a fix on the magnitude of investments that will be required, **the Commandant should commission an internal study of the multi-year spending that will be required for research, assets, integration, personnel, and the like that will enable full and sustained implementation of a UxS strategy.** Given the Coast Guard's need to be opportunistic and enterprising in leveraging other organizations' technologies, the study should consider the likely advances in UxS capabilities and affordability, as well strategic partnerships with other services and federal agencies, to enable cost-saving economies of scale. The study should also recognize that investment in UxS may not be accompanied by opportunities to significantly reduce spending on manned assets and operations, but will nevertheless be vital to supporting efficient and capable hybrid operations to fulfill the Coast Guard's critical missions. The Coast Guard has a range of spending needs and priorities that it must balance with investments in UxS. The recommended study should help the Coast Guard make more informed decisions to maintain that balance.

CONCLUDING COMMENTS

The recommendations in this report are directed to the Coast Guard and its leadership. The committee is fully aware, of course, that the request for this study originated in legislation and that Congress has a keen interest in the Coast Guard's ability to effectively and efficiently perform its many missions critical to the nation. DHS has the same interest. Funding needs for UxSs, as established in the recommended Coast Guard study, will unlikely be met through reallocations of traditional Coast Guard appropriations and budget items. Although it is incumbent on the Coast Guard to build a compelling case for substantial additional funding, the committee believes its findings and recommendations warrant the attention of Congress and DHS, whose support will be vital to the advent of a future Coast Guard that fully embraces and delivers on the promise of UxSs.

Appendix A

Legislative Request

COAST GUARD AUTHORIZATION ACT 2018, SECTION 812

(a) IN GENERAL.—The Secretary of the department in which the Coast Guard is operating shall seek to enter into an arrangement with the National Academy of Sciences not later than 60 days after the date of the enactment of this Act under which the Academy shall prepare an assessment of available unmanned, autonomous, or remotely controlled maritime domain awareness technologies for use by the Coast Guard.

(b) ASSESSMENT.—The assessment shall—
- (1) describe the potential limitations of current and emerging unmanned technologies used in the maritime domain for—
  - (A) ocean observation;
  - (B) vessel monitoring and identification;
  - (C) weather observation;
  - (D) to the extent practicable for consideration by the Academy, intelligence gathering, surveillance, and reconnaissance; and
  - (E) communications;
- (2) examine how technologies described in paragraph (1) can help prioritize Federal investment by examining;
  - (A) affordability, including acquisition, operations, and maintenance;
  - (B) reliability;
  - (C) versatility;

(D) efficiency; and
(E) estimated service life and persistence of effort; and

(3) analyze whether the use of new and emerging maritime domain awareness technologies can be used to—
(A) carry out Coast Guard missions at lower costs;
(B) expand the scope and range of Coast Guard maritime domain awareness;
(C) allow the Coast Guard to more efficiently and effectively allocate Coast Guard vessels, aircraft, and personnel; and
(D) identify adjustments that would be necessary in Coast Guard policies, procedures, and protocols to incorporate unmanned technologies to enhance efficiency.

(c) REPORT TO CONGRESS.—Not later than 1 year after entering into an arrangement with the Secretary under subsection (a), the National Academy of Sciences shall submit the assessment prepared under this section to the Committees on Transportation and Infrastructure and Homeland Security of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.

(d) USE OF INFORMATION.—In formulating costs pursuant to subsection (b), the National Academy of Sciences may utilize information from other Coast Guard reports, assessments, or analyses regarding existing Coast Guard manpower requirements or other reports, assessments, or analyses for the acquisition of unmanned, autonomous, or remotely controlled technologies by the Federal Government.

Appendix B

Study Committee Biographical Information

Heidi C. Perry, *Chair*, is currently the Assistant Division Head for the Division Office for Air, Missile & Maritime Defense Technology at the MIT Lincoln Laboratory. In her role, she leads strategic initiatives for undersea systems, including the development of new approaches in autonomy technology and artificial intelligence. She also serves as the Chief Innovation Officer for the division. Previously, Ms. Perry was the Director, System Engineering, at the Charles S. Draper Laboratory, Inc. She also served in other senior leadership roles, including the Director, Algorithms & Software and the Director, Internal R&D Portfolio. Her expertise includes guidance, navigation, and control; global position system anti-jam and ground control; autonomous systems; mission-critical software; and command, control, communications, computers, intelligence, surveillance, and reconnaissance systems. Ms. Perry began her career with General Electric as a systems engineer working on the AN/BSY-2 Sonar System before moving to IBM to work as a systems engineer for avionics design and flight test programs. From IBM she moved to the Draper Laboratory as task leader for the Dolphin Navigation System Upgrade and remained with Draper for more than 20 years. During those years at the laboratory, she served as technical director for various research and development programs involving autonomous spacecraft, aircraft, robotics systems, and underwater vehicles. A member of the Institute of Electrical and Electronic Engineers and the American Institute of Aeronautics and Astronautics (AIAA), she was named AIAA Software Engineer of the Year 2004—New England Sector. A former member of the Naval Studies Board (2008–2013), she also served on the National Academies' Committee on Capability Surprise for U.S. Naval

Forces, Committee on National Security Implications of Climate Change on U.S. Naval Forces, and Committee on the "1,000 Ship Navy"—A Distributed and Global Maritime Network. Most recently, she served as Co-Chair of the National Academies' Committee on Mainstreaming Unmanned Undersea Vehicles into Future U.S. Naval Operations. She has also served as Chair for the Transportation Research Board's Committee for Review of the National Naval Responsibility for Naval Engineering Program. She received a B.S. in electrical engineering from Cornell University and an M.S. in computer engineering from the National Technical University. She currently serves as a member of the President's Council of Cornell Women.

RADM Thomas J. Eccles (NAE) is the Chief Executive Officer of Trident Maritime Systems, LLC. He served for more than 30 years in the U.S. Navy, retiring in 2013 as the Chief Engineer for ships, submarines, aircraft carriers, and their weapons and systems. His fields of expertise include naval operations and engineering, submarines, deep sea diving, and salvage operations. RADM Eccles led submarine design and construction programs and was responsible for research and development submarines, submarine escape and rescue systems, and atmospheric diving systems. His Flag Officer assignments included Deputy Commander for Undersea Warfare and Undersea Technology in the Naval Sea Systems Command (NAVSEA), and Commander of the Naval Undersea Warfare Center, before becoming NAVSEA's Chief Engineer in September 2008. He is member of the Marine Board of the National Academies of Sciences, Engineering, and Medicine and previously served on the National Academies' Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future. RADM Eccles earned a B.S. in electrical engineering, an M.S. in mechanical engineering, the Naval Engineer degree, and an M.S. in management of technology from the Massachusetts Institute of Technology.

Jaye Falls is an Assistant Professor in the Department of Naval Architecture and Ocean Engineering at the U.S. Naval Academy. She previously served as a consultant to the Oracle BMW Racing Team for the 2003 America's Cup, supporting the design and structural analysis of the racing yacht hull, mast, and appendages. She also worked as a Senior Engineer in the Proteus Engineering Division at Anteon Corporation performing ship design and analysis for monohull, multihull, and submarine vessels. Prior to working for Anteon, she worked as a Naval Architect at the Naval Surface Warfare Center, Carderock Division. She served on the National Academies of Sciences, Engineering, and Medicine Study to Update Coast Guard Vessel Stability Standards. Dr. Falls earned a Ph.D. in aerospace engineering from the University of Maryland, College Park; an M.S. in ocean engineering from the Massachusetts Institute of Technology; and a B.S. in naval architecture and marine engineering from the Webb Institute of Naval Architecture.

Barry M. Horowitz (**NAE**) joined the University of Virginia (UVA) faculty as a Professor in the Systems and Information Engineering Department in September 2001, after a research and industrial career involving the application of systems engineering to many large and complex systems. He assumed the role of the Department Chair in 2009. Since joining UVA, he has focused his research efforts on wireless systems and a systems engineering approach for addressing cybersecurity. From 2006 to 2013 he served as the UVA research site director for the National Science Foundation–sponsored Industry/University Cooperative Research Center (I/U CRC) called WICAT (Wireless Internet Center for Advanced Technology). He has been leading a U.S. Department of Defense–sponsored research project on embedding cybersecurity resilience solutions into systems, referred to as System Aware Cyber Security. The project includes work on cybersecurity for airborne surveillance systems onboard unmanned vehicles. From 1969 through 1996 he was employed in a variety of positions at the MITRE Corporation, including the past 5 years as the President and the Chief Executive Officer. He chaired and served on numerous National Academies of Sciences, Engineering, and Medicine committees, including the Naval Studies Board. He was elected as a member of the National Academy of Engineering in 1996 and has served as a Cybersecurity Commissioner for the Commonwealth of Virginia from 2014 through 2016. Dr. Horowitz earned a B.S. from City College of New York, an M.S. from New York University, and a Ph.D. from New York University, all in electrical engineering.

Lauren J. Kessler is a Distinguished Member of the Technical Staff at the Charles S. Draper Laboratory, where she has led the Intelligent Automated Systems and the Resilience and Fault Tolerance groups. She has been a key contributor to the laboratory's unmanned underwater vehicle (UUV) efforts, focused on the human operator engagement with the autonomous vehicles. She was the software systems safety lead for the autonomous path and mission planning system and led projects on automated hydrocarbon extraction rigs, lunar surface systems autonomy software architectures, and autonomous precision lunar landing mission management. She is currently working on the fault-tolerant flight computer software development for the DreamChaser unmanned spacecraft. Previously, she was a lead engineer at Northstar and Avidyne for the development and certification of a general aviation next generation Air Data/Attitude/Heading Reference System and a precision approach navigation device for the GPS-Wide Area Augmentation System. Her areas of expertise center on human-in-the-loop and mission-critical systems, including war-gaming simulations, human-embedded autonomous systems, avionics, and human decision aides. She is a commercially rated helicopter pilot and advanced aviation ground instructor, and serves in the Civil Air Patrol in Massachusetts and on the University of Colorado Aerospace Engineering Sciences External Advisory Board. She earned an M.S. from Boston University.

Annette J. Krygiel served 38 years in U.S. Department of Defense (DOD) organizations with missions in mapping and imagery, including the Aeronautical Chart and Information Center, the Defense Mapping Agency (DMA), the Central Imagery Office (CIO), and the National Geospatial-Intelligence Agency. Her assignments spanned management and development of geodetic and gravimetric programs, telecommunications applications for mapping, and the management of large-scale computer systems. She was a program manager for the Digital Production System, then one of DOD's largest software developments, providing DMA the capability to transform the mapping and charting process with revolutionary digital technologies. She later summarized lessons learned on large-scale systems' integration in her book *Behind the Wizard's Curtain: An Integration Environment for a System of Systems*. She became DMA's Chief Scientist until her appointment by the Secretary of Defense as the Director of the CIO, a Combat Support Agency operating as the functional manager of the defense and intelligence imagery community. As an independent consultant for many years, Dr. Krygiel participated on many advisory panels and teams and also served on the National Academies of Sciences, Engineering, and Medicine's Naval Studies Board for 6 years. She earned a D.Sc. in computer science from Washington University in St. Louis.

VADM Fred M. Midgette retired from the U.S. Coast Guard in 2018 after serving as the Commander of the Pacific Area. In this capacity, he served as the operational commander for all Coast Guard missions within half of the world that spans from the Rocky Mountains to the waters off the East Coast of Africa. He previously served as the Deputy Commandant for Operations where he was responsible for developing operational strategy, policy, guidance, and resources that address national priorities. Other Flag Officer assignments include service as the Senior Military Advisor to the Secretary of Homeland Security and Commander of the Ninth Coast Guard District. He specialized in afloat operations serving in seven Coast Guard cutters, commanding four of them; and additionally, he qualified as a Surface Warfare Officer aboard a U.S. Navy destroyer. He was the 14th Gold Ancient Mariner of the Coast Guard, which is an honorary position held by an officer with more than 10 years of cumulative sea duty who has held the qualification as a Cutterman longer than any other officer. He earned a B.S. in civil engineering from the U.S. Coast Guard Academy, an M.S. in management from Rensselaer Polytechnic Institute, and an M.A. in national security and strategic studies from the U.S. Naval War College.

CDR Matthew Pickett is the Co-Founder and the President of Oceans Unmanned, a nonprofit organization with the mission to facilitate the use of unmanned technologies for environmental research and monitoring. He retired in 2007 from the National Oceanographic and Atmospheric Administration (NOAA) as the Commander after serving 20 years, providing operational support for NOAA ocean and coastal research missions aboard ships, small boats, aircraft, and SCUBA diving. His NOAA career included 4 years as the Chief of the Remote Sensing Division Flight Branch and 3 years as the Superintendent of the Channel Islands National Marine Sanctuary. His aviation experience consists of multiple Federal Aviation Administration ratings, including an Airline Transport Pilot, Seaplane Rating, and Remote Pilot Certificate. He earned a B.S. in mechanical engineering from West Virginia University.

Sean T. Pribyl, Esq., is a lawyer and a Senior Claims Executive with Gard AS P&I Club in Arendal, Norway, where he advises on legal matters related to marine incidents and serves on Gard's autonomous systems workgroup. Most recently, he was an attorney with Blank Rome LLP in Washington, DC, with a practice focused on maritime international law, unmanned systems, and environmental and regulatory compliance. He is a widely published author in treatises and publications on topics related to maritime law and advanced automation in the transportation sector, and he is a regular speaker at international conferences and seminars on topics related to maritime law and unmanned/autonomous systems. He is an active participate on several international industry workgroups addressing legal issues with advanced autonomy in the transportation sector, including the International Working Group on Maritime Autonomous Surface Ships at the Comité Maritime International. He served for 6 years as a Coast Guard judge advocate where he was an attorney-advisor to Coast Guard program offices on legal and policy matters related to unmanned systems, and he is a licensed merchant mariner (Deck Officer) with 8 years of service aboard commercial ships. Mr. Pribyl is also a member of the National Academies of Sciences, Engineering, and Medicine's Marine Board and a Proctor in Admiralty with the U.S. Maritime Law Association. He earned a J.D. from Washburn University School of Law and an M.A. in national security and strategic studies from the U.S. Naval War College.

Chuck E. Thorpe is a Professor of computer science at Clarkson University. He has previously served both as the Provost and the Dean of Arts and

Sciences at Clarkson. He spent the bulk of his career with the Carnegie Mellon University Robotics Institute (1979–2012), including the Director of the institute. The institute's Navlab group built a self-driving car in 1989; drove autonomously across the United States in 1995; and contributed to both U.S. Department of Defense (Autonomous Land Vehicle) and U.S. Department of Transportation automation programs and projects (Automated Highway Demonstration and Single Vehicle Roadway Departure Countermeasures). He continues as an Adjunct Professor of robotics with Carnegie Mellon. He has more than 120 refereed publications in robotics. Dr. Thorpe has often been called to serve on scientific or advisory committees; he has served on several studies for the National Academies of Sciences, Engineering, and Medicine and national and international advisory committees. Dr. Thorpe earned a Ph.D. in computer sciences from Carnegie Mellon University.

Appendix C

Invited Speakers and Presenters at Committee Meetings

September 25–26, 2019

Scott Craig, System/Air Domain Lead, Office of RDT&E, U.S. Coast Guard
CDR Sara Wallace, Deputy, Office of Requirements and Analysis, U.S. Coast Guard
CDR Chad Thompson, Chief, Unmanned Aircraft Systems, Office of Aviation Forces, U.S. Coast Guard
RDML Timothy Gallaudet (U.S. Navy, Ret.), Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, National Oceanic and Atmospheric Administration (NOAA)
Bradley Koeckeritz, Division Chief, Unmanned Aircraft Systems, U.S. Department of the Interior
Jason Stack, Director; Ocean, Atmosphere, and Space Research Division; Portfolio Manager for Autonomy; Office of Naval Research
Scott Miller, Assistant Section Chief, Aviation Surveillance Branch, Federal Bureau of Investigation (FBI)
Michael Ilmanen, Acting Unit Chief, Field Flight Operations, FBI

November 4–5, 2019

Peter Beling, Professor, Engineering Systems and Environment, University of Virginia
VADM Michael Connor (U.S. Navy, retired), Chief Executive Officer, ThayerMahan Inc.

Francesca D'Arcangelo, Systems Analyst, Homeland Protection Systems, MIT Lincoln Laboratory
Joseph Bondaryk, Chief Technology Officer, Apollo Autonomy
James Bellingham, Director, Woods Hole Oceanographic Institute
Glen Gawarkiewicz, Senior Scientist, Woods Hole Oceanographic Institute
Steve Brodet, Applications Engineer, Hydroid

February 19–20, 2020

Timothy Bennett, Air Domain Awareness Program Manager, Science and Technology (S&T), U.S. Department of Homeland Security (DHS)
Joseph Wawro, Executive Director, Joint Requirements Council, DHS
Michael Romanowski, Aircraft Certification Service (AIR) Director of the Policy & Innovation Division, Federal Aviation Administration (FAA)
Donald Siebers, Lead Program Manager, Vulcan Inc.
Namrata Kolla, Lead User Engagement & Data Analyst, Vulcan Inc.
CAPT Pete Small, Navy Unmanned Maritime Systems Program Office, U.S. Navy
Michael Smitsky, Senior Manager, Advocacy and Government Relations, Association for Unmanned Vehicle Systems International
Donald McCormack, Executive Director for Naval Surface Warfare Center and Naval Undersea Warfare Center, U.S. Navy
John Sherman, Associate Director of National Intelligence and Chief Information Officer, Director of National Intelligence
Eric Downes, Deputy Chief Information Officer for Intelligence, U.S. Coast Guard
Anthony Schmidt, Director of Rapid Prototyping, Experimentation, and Demonstration, Naval Air Warfare Center Aircraft Division, U.S. Navy

April 28, 2020

Rear Admiral Matthew Sibley, Assistant Commandant for Capability, U.S. Coast Guard
CDR Maria Richardson, UAS Joint Program Office (JPO) Supervisor, U.S. Coast Guard
LCDR Steven Arnwine, Operations Officer, USCGC Munro, U.S. Coast Guard
Francisco Castillo, Aviation Attorney, Office of the Chief Counsel, FAA

Appendix D

Levels of Automation

Unmanned systems can be automated or autonomous. Automated systems or equipment are controlled by a rigid set of rules that allow no deviations. This kind of automation assumes that an operator performs any requirements and decision making that the automated sequence is not instructed to do through its set of rigid rules.[1] In contrast, autonomous systems can independently formulate multiple courses of action and can select one to pursue in order to achieve the objectives prescribed to it. In essence, autonomous systems imply a higher order of autonomy, and their development requires the introduction of multiple automation sequences and artificial intelligence to enable equipment to work autonomously without the need of an operator.

"Level of automation" refers to the degree to which a task is automated; it reflects the level of human control versus computer control of a given task. Over the years equipment and vehicle developers and manufacturers have established a set of defining levels of automation to fit their industries. However, because of the unique operating environment in the maritime domain, autonomy levels or degrees used in other modes of transport, such as the automotive industry, are not considered to be directly transferrable to, for example, vessels.

Efforts to standardize terms applicable to the development and evaluation of unmanned systems for maritime domain awareness (MDA) need to account for an array of factors such as level of human interaction, task

[1] Defense Science Board. 2016. "Summer Study on Autonomy." https://fas.org/irp/agency/dod/dsb/autonomy-ss.pdf.

complexity, and operational environment.[2] The degree to which these factors apply to a given system provide valuable information about not only the developers and analysts, but also the end user. To that end, this section offers three examples of competing options for evaluating the various levels or degrees of autonomy under which a vessel may operate. These standards are illustrative only and do not represent all the various proposals in this area. Essentially, the international debate about what may emerge as an internationally recognized standard is ongoing.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

The National Institute of Standards and Technology (NIST) in collaboration with other government and industry experts defined four levels of automation in its Autonomy Levels for Unmanned System Framework.[3] First, NIST's framework defines the term autonomous operations of an unmanned system (UMS) as those in which the UMS "receives its mission from either the operator who is off the UMS or another system that the UMS interacts with and accomplishes that mission with or without further human-robot interaction."[4]

The framework also defines four levels of UMSs. These levels are designed to offer a structure of increasing autonomy, with automation rising from one level to the next.

Remote Control

"A mode of UMS operation wherein the human operator controls the UMS on a continuous basis, from a location off the UMS via only her/his direct observation. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the human operator."[5]

[2] H. Huang, J. Albus, E. Messina, R. Wade, and W. English. 2004. "Specifying Autonomy Levels for Unmanned Systems: Interim Report." SPIE Defense and Security Symposium 2004, Conference 5422, Orlando, Florida. https://www.researchgate.net/publication/228767910_Specifying_autonomy_levels_for_unmanned_systems_interim_report.

[3] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

[4] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0, p. 15. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

[5] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0, p. 23. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

Teleoperation

"A mode of UMS operation wherein the human operator, using sensory feedback, either directly controls the actuators or assigns incremental goals on a continuous basis, from a location off the UMS."[6]

Semi-Autonomous

"A mode of UMS operation wherein the human operator and/or the UMS plan(s) and conduct(s) a mission and requires various levels of human-robot interaction. The UMS is capable of autonomous operation in between the human interactions."[7]

Fully Autonomous

"A mode of UMS operation wherein the UMS accomplishes its assigned mission, within a defined scope, without human intervention while adapting to operational and environmental conditions."[8]

INTERNATIONAL MARITIME ORGANIZATION

Another framework, specifically for unmanned surface ships, has also been developed by the International Maritime Organization (IMO)—the global regulatory body for international shipping.[9] The IMO defines a Maritime Autonomous Surface Ship (MASS) as a ship with decision support system(s) that, to various degrees, can operate independently of human interactions. The IMO defined four degrees of autonomy for MASS. The framework recognizes, however, that MASS could operate at one or more of these levels within the duration of a voyage. The four degrees are as follows, although a MASS could operate at one or more degrees of autonomy during the duration of a single voyage:

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[6] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0, p. 23. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

[7] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0, p. 23. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

[8] National Institute of Standards and Technology. 2008. "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology." NIST Special Report 1011-I-2.0, p. 22. https://www.nist.gov/sites/default/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf.

[9] International Maritime Organization. 2018. "IMO takes first steps to address autonomous ships." http://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx.

1. "Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.
2. Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.
3. Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
4. Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself."[10]

The IMO's aim was to complete the scoping exercise by 2020, and the next steps in the IMO's agenda to scope MASS were set to (1) identify current provisions of IMO instruments and assess whether and how they could be applicable to ships with varying degrees of autonomy and (2) conduct an analysis to determine the most appropriate way to address MASS operations, taking into account the human interactions, state of technology, and operational factors. This work is progressing rapidly; the first step has been completed, and in June 2019, the IMO approved a set of interim guidelines for MASS trials.[11]

The next step is to analyze and determine the most appropriate way to address MASS operations, taking into account, inter alia, human element, technology, and operational factors to identify the need for:

- Equivalences as provided for by the instruments or developing interpretations; and/or
- Amending existing instruments; and/or
- Developing new instruments; or
- None of the above as a result of the analysis.

Reporting of the updated results of this regulatory scoping exercise for the use of MASS was included on the agenda for MSC 102.[12]

[10] International Maritime Organization. 2018. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx.

[11] World Maritime News. 2019. "IMO Approves Autonomous Ship Trial Guidelines." https://worldmaritimenews.com/archives/279047/imo-approves-autonomous-ship-trial-guidelines.

[12] MSC 102 was scheduled for May 13–22, 2020, but because of the impact of COVID-19, was postponed without a new date determined.

TABLE D-1 Levels of Control from the UK Marine Industry Alliance

Level	Name	Description
0	Manned	MASS is controlled by operators aboard
1	Operated	Under Operated control all cognitive functionality is within the human operator. The operator has direct contact with MASS over, for example, continuous radio (R/C) and/or cable (e.g., tethered underwater unmanned vehicles and remotely operated vehicles). The operator makes all decisions and directs and controls all vehicles and mission functions.
2	Directed	Under Directed control some degree of reasoning and ability to respond is implemented into MASS. It may sense the environment, report its state, and suggest one of several actions. It may also suggest possible actions to the operator, such as, for example, prompting the operator for information or decisions. However, the authority to make decisions is with the operator. MASS will act only if commanded and/or permitted to do so.
3	Delegated	MASS is now authorized to execute some functions. It may sense environment, report its state, and define actions and report its intention. The operator has the option to object to (veto) intentions declared by MASS during a certain time, after which MASS will act. The initiative emanates from MASS, and decision making is shared between the operator and MASS.
4	Monitored	MASS will sense environment and report its state. MASS defines actions, decides, acts, and reports its action. The operator may monitor the events.
5	Autonomous	MASS will sense environment, define possible actions, decide and act. The unmanned vessel is afforded a maximum degree of independence and self-determination within the context of the system capabilities and limitations. Autonomous functions are invoked by the on-board systems of occasions decided by the same, without notifying any external units or operators.

UK MARINE INDUSTRIES ALLIANCE

In addition, the UK Marine Industries Alliance Code of Practice for Maritime Autonomous Systems (Surface) for craft less than 24 meters (version 3.0, November 2019)[13] recognizes six levels of control: Manned, Operated, Directed, Delegated, Monitored, and Autonomous. Table D-1, from the Maritime Autonomous Surface Ships Industry Conduct Principles and Code of Practice, describes these six levels.

[13] Maritime UK. 2019. "*Maritime Autonomous Surface Ships (MASS) UK Industry Conduct Principles and Code of Practice*." https://www.maritimeuk.org/media-centre/publications/maritime-autonomous-surface-ships-industry-conduct-principles-code-practice.

As stated in this UK Code of Practice, "these definitions for Level of Control should be considered alongside the IMO Degrees of Autonomy since levels of control may be different for different functions aboard the same MASS."[14]

BUREAU VERITAS

Also within the context of maritime shipping vessels, in October 2019 the international certification agency Bureau Veritas published its Guidelines for Autonomous Shipping. In this guidance, Bureau Veritas defines the following levels of automation:[15]

- Degree A0—Human operated
- Degree A1—Human directed
- Degree A2—Human delegated
- Degree A3—Human supervised
- Degree A4—Full automation

Table D-2 from the Bureau Veritas guidance publication provides a quick description of the nature of these levels of shipping automation.

Finally, a fourth consideration may emerge from the International Organization for Standardization (ISO) because it has established a working group on Smart Shipping and a task group on MASS and is currently drafting new guidance on "Ships and marine technology—Terminology related to automation of Maritime Autonomous Surface Ships (MASS)."[16] It is too soon to evaluate the ISO's proposed degrees of automation, but it will be worth monitoring.

NORWEGIAN FORUM FOR AUTONOMOUS SHIPS

The Norwegian Forum for Autonomous Ships considers "Operational autonomy levels" and bridge manning levels as presented in Table D-3.[17]

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[14] See UK Code of Practice, p. 21.

[15] Bureau Veritas. 2019. "Guidance Note NI 641 DT R01 E: Guidelines for Autonomous Shipping." Paris La Defense. http://erules.veristar.com/dy/data/bv/pdf/641-NI_2019-10.pdf.

[16] Proposed terminology for MASS submitted by ISO, MSC 102/5/18 (February 11, 2020). http://nfas.autonomous-ship.org/resources/msc-102-5-18.pdf.

[17] Combining the manning levels with the operational autonomy levels, this table defines different types of ship autonomy. http://nfas.autonomous-ship.org/resources/autonom-defs.pdf.

TABLE D-2 Degrees of Shipping Automation as Advised by Bureau Veritas

Degree of Automation		Manned	Definition	Information Acquisition	Information Analysis	Authority to Make Decisions	Action Initiated By
A0	Human operated	Yes	Automated or manual operations are under human control. Human makes all decisions and controls all functions.	System Human	Human	Human	Human
A1	Human directed	Yes/No	Decision support: system suggests actions. Human makes decisions and actions.	System	System Human	Human	Human
A2	Human delegated	Yes/No	System invokes functions. Human must confirm decisions. Human can reject decisions.	System	System	Human	System
A3	Human supervised	Yes/No	System invokes functions without waiting for human reaction. System is not expecting confirmation. Human is always informed of the decisions and actions.	System	System	System	System
A4	Full automation	Yes/No	System invokes functions without informing the human, except in case of emergency. System is not expecting confirmation. Human is informed only in case of emergency.	System	System	System	System

TABLE D-3 Operational Autonomy Levels from the Norwegian Forum for Autonomous Ships

	Manned Bridge	Unmanned Bridge (crew on board)	Unmanned Bridge (no crew on board)
Decision Support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained Autonomous		Constrained autonomous	Constrained autonomous
Fully Autonomous			Fully autonomous

AMERICAN BUREAU OF SHIPPING

The American Bureau of Shipping, Advisory on Autonomous Functionality[18] identifies four main levels of automation based on "Sheridan's levels of automation." In increasing level of autonomy, the four levels from the American Bureau of Shipping specify the following:

1. Manual
   - No machine augmentation of human function
     - The computer offers no assistance: human must make all decisions and take all actions
2. Smart
   - Passive decision support: Human augmentation of human function
     - The computer offers a complete set of decisions/actions alternatives
     - The computer narrows the selection of decisions or actions to a few alternatives
     - The computer suggest one alternative
     - The computer executes the suggestion if the human approves
3. Semi-Autonomy
   - Human in the loop: human augmentation of machine function
     - The computer allows the human a restricted amount of time to veto the suggestion and then executes
     - The computer executes automatically, then informs the human

[18] See https://ww2.eagle.org/en/innovation-and-technology/digital/autonomy/autonomy-advisory.html.

4. Autonomy
    - No human augmentation of machine function
        - The computer informs the human, but only if queried by the human
        - The computer informs the human, but only if the computer decides to do so
        - The computer makes all decisions, acts autonomously, and ignores the human

SOCIETY OF AUTOMOTIVE ENGINEERS

The Society of Automotive Engineers defines six levels of automotive automation,[19] summarized in Table D-4.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

Finally, a consideration may emerge from the ISO because it has established a working group on Smart Shipping and task group on MASS and are currently drafting new guidance on "Ships and marine technology—Terminology related to automation of Maritime Autonomous Surface Ships (MASS)."[20] One proposal from the ISO to the IMO is to define automation as "pertaining to a process or device that, under specified conditions, can function without human intervention (definition is based on ISO/TR 11065)." It is too soon to evaluate the ISO's proposed degrees of automation, but it will be worth monitoring.

[19] Intel Explainer: 6 Levels of Autonomous Driving. https://newsroom.intel.com/news/autonomous-driving-hands-wheel-no-wheel-all/#gs.9pb4gk.

[20] ISO/AWI 23860. *Ships and marine technology—Terminology related to automation of Maritime Autonomous Surface Ships* (MASS). https://www.iso.org/standard/77186.html; see also proposed terminology for MASS Submitted by ISO, MSC 102/5/18 (February 11, 2020). http://nfas.autonomous-ship.org/resources/msc-102-5-18.pdf.

TABLE D-4 Levels of Automotive Automation from the Society of Automotive Engineers

	Level 0 **No Automation**	**Level 1** **Driver Assistance**	**Level 2** **Partial Automation**	**Level 3** **Conditional Automation**	**Level 5** **High Automation**	**Level 5** **Full Automation**
Driver	In charge of all the driving	Must do all the driving, but with some basic help in some situations	Must stay fully alert when vehicle assumes some basic driving tasks	Must be always ready to take over within a specified period of time when the self-driving systems are unable to continue		No human driver required. Steering wheel options. Everyone can be a passenger in this vehicle
Vehicle	Responds only to inputs from the driver, but can provide warnings about the environment	Can provide basic help, such as automatic emergency braking or lane keep support	Can automatically steer, accelerate, and brake in limited situations	Can take full control over steering, accelerations, and braking under certain conditions	Can assume all driving tasks under nearly all conditions without any driver attention	In charge of all the driving and can operate in all environments without need for human intervention

Appendix E

Legal and Policy Issues

The purpose of this Appendix is to provide further analysis of prevailing legal authorities and policy issues identified in the report and to serve as guidance and a primer upon which the Coast Guard can rely to fully assess current unmanned systems (UxSs) capabilities and develop next steps toward the full range of perceived UxS operations.

Part I builds on the discussion in Chapters 3 and 6 with legal and policy considerations for each UxS domain.

Part II expands on legal and policy considerations and offers a survey of relevant precedent, guidance, and resources to support legal and policy assessments and decision making.

PART I

A discussion of legal and policy considerations for each UxS domain now follows.

Unmanned Maritime Vehicles/Vessels (UMVs)[1]

Currently, the Coast Guard has no UMVs in its inventory. The Coast Guard has converted a Coast Guard small boat into a remotely controlled/autonomous vehicles, although this is strictly for research and development (R&D) purposes at this point. The Coast Guard Research and Development

[1] For purposes of this Appendix, the term "UMV" is used to encompass all maritime surface watercraft UxS.

Center (RDC) is also testing "contractor-owned and -operated" unmanned surface vehicles (USVs).[2] Thus, because the Coast Guard does not currently possess any UxS surface assets, the committee finds no perceived impact to use of such assets in current operations.

However, as the Coast Guard considers investment in UMVs to augment current maritime domain awareness (MDA) operations, the Coast Guard needs to clearly identify what legal requirements must be met for lawful UMV operation under relevant and prevailing authorities in order to identify potential legal obstacles, and if necessary, overcome them.[3] To date, the committee understands that the Coast Guard has not developed any formal legal opinions on UMV compliance under prevailing legal frameworks, although sister services and near-peer competitors are developing and utilizing UMVs.[4]

Specifically, the area of law surrounding UMVs is both emerging and relatively untested as the development of emerging UMV technologies are challenging current applications of legal regimes governing UMV operations, which in turn is spurring significant debate in the domestic and international legal communities. Essentially, technology has outpaced the relevant regulations because existing legal regimes generally contemplated manned ship operations, or at least with a "human in the loop," when they were initially developed, such as the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), Inland Navigation Rules, and United Nations Convention for the Law of the Sea (UNCLOS).[5] This

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[2] UMV testing is being conducted under the RDC's OTA contract/use agreements with Saildrone Inc. and Spatial Integrated System (https://www.dcms.uscg.mil/Our-Organization/Assistant-Commandant-for-Acquisitions-CG-9/Newsroom/Latest-Acquisition-News/Article/2093872/coast-guard-awards-contracts-for-maritime-domain-awareness-study). The text of these OTA contracts was not available to the committee. However, it is the understanding of this committee that the contractors have assumed the risk and responsibility for COLREGS compliance, and thus the Coast Guard's legal exposure is perceivably limited when contracting with these vendors.

[3] For example, the "legal questions and challenges linked to autonomous shipping, as well as the solutions needed to resolve them, will differ depending on what choices are made in relation to manning, crew location, and autonomy level." Henrik Ringbom. 2019. *Regulating Autonomous Ships—Concepts, Challenges and Precedents, Ocean Development & International Law.* DOI: 10.1080/00908320.2019.1582593; see also Comité Maritime International. *International Working Group Position Paper on Unmanned Ships and the International Regulatory Framework* (March 29, 2017). https://comitemaritime.org/wp-content/uploads/2018/05/CMI-Position-Paper-on-Unmanned-Ships.pdf.

[4] UMV-related legal issues are the subject of much academic research and publication in both the United States and internationally (e.g., International Maritime Organization [IMO], Danish Maritime Authority, Port Authority of Singapore).

[5] In fact, initial IMO documents on increased automation in shipping were introduced in 1964. See IMCO Doc. MSC VIII/11 ("Automation in Ships"). While related, the COLREGS and UNCLOS are distinct agreements with divergent purposes and effects.

legal conundrum is compounded by the dearth of current precedent directly related to UMV operations on which operators could otherwise rely for guidance.[6] Consequently, stakeholders and scholars continue to assess the use of UMV operations under the existing regulations, laws, treaties, and conventions, and they have yet to reach universal consensus.[7]

As such, one of the most prevalent operational considerations is whether an envisaged platform or watercraft will be deemed a "vessel" because such determination involves questions of fact, law, and policy.[8] Therefore, a threshold matter is determining a respective UMV platform's "legal status" because there are numerous types of UxS platforms that vary in size and capabilities with different designations.[9] Furthermore, whether a given UMV is deemed a "vessel" also depends on a review of the context of the purpose, classification, design, and operating characteristics of a respective UMV.[10]

Of the relevant international conventions, the most formative appear to be the COLREGS that apply "to all *vessels* upon the high seas and in all waters connected therewith navigable by seagoing *vessels*," including warships[11] (emphasis added). Notably, while the COLREGS do not specifically preclude operation of UMVs, a Coast Guard UMV would be expected to

[6] See Maritime Law Association of the United States, *Response of MLA to CMI Questionnaire re Unmanned Ships*, at 12, https://comitemaritime.org/wp-content/uploads/2018/05/CMI-IWG-Questionnaire-Unmanned-Ships-US.pdf (stating their research "failed to discover any case law spawned by any such collision" of an autonomous ship). In addition, besides the efforts in this space being made in the United States, the legal issues surrounding UMVs are the subject of much academic research and publication, and a topic of great relevance to foreign and international regulators (e.g., IMO, Danish Maritime Authority, Maritime and Port Authority of Singapore).

[7] For example, UMV operations may comply with existing rules and laws subject to legal interpretation, perhaps through exceptions or equivalencies under the relevant legal instruments.

[8] For example, a status determination assesses the extent to which a UMV will be "1) entitled to exercise certain navigational rights; 2) allowed particular immunities; 3) eligible to carry out a number of important maritime functions; 4) subject to other international maritime legal regimes; and 5) entitled to exercise belligerent rights." Andrew J. Norris. 2013. *Legal Issues Associated with Unmanned Maritime Systems*, at 21, U.S. Naval War College, https://works.bepress.com/andrew_norris1/1; see also Daniel Vallejo. 2015. Electric currents: programming legal status into autonomous unmanned vehicles. *Case Western Reserve Journal of International Law* 47(1):405–428.

[9] Terms could include "vessel," "ship," "vehicle," "system," "device," or "watercraft," although maritime laws and rules are largely devoid of reference to watercraft other than "vessels" or "ships." See Part II for further discussion.

[10] The determination of "vessel" status is primarily imputed through U.S. statute (1 U.S.C. § 3) and IMO conventions with reference to definition of "ship" or "vessel." See Craig H. Allen. 2018. Determining the legal status of unmanned maritime vehicles: formalism vs functionalism. *Journal of Maritime Law & Commerce* 49:477–514, at 493.

[11] See Part II of this Appendix for further discussion on the COLREGS. The COLREGS Inland Rules of Road also apply to all "vessels" upon the inland waters of the United States.

certify the UMV as seaworthy under a preventative layered approach and conform to the general maritime law requiring the exercise of good seamanship in all respects.[12] In other words, the COLREGS need to be translated into programming code when integrated into a UMV.[13] Such programming could conceivably achieve compliance with certain COLREGS, perhaps through a method which factors in both the strict conformity with the obligatory decision making and historical dependency on human common sense in executing rules in all circumstances.[14] In fact, the committee is aware of several technological developers who take the position that compliance with the COLREGS is indeed achievable through programming that allows a UMV to understand and act on a codified set of navigational requirements.[15]

Thus, to best assess risk and make well-informed decisions, the Coast Guard could develop legal and policy opinions contemplating the legal parameters for each prospective UMV, including how the Coast Guard will ensure legal compliance and whether provisions may be available for exemptions and equivalencies under mandatory instruments, taking into account the applicability and processes related to making, amending, and

[12] COLREGS Rule 2 discusses obligations of good seamanship. Given the rapidly developing advent of UMVs, the issues of whether the COLREGS are still fit for purpose and whether there is no need for the Rules to be totally revised are of much debate in the international legal community. See, for example, "COLREGS: Still Fit for Purpose?" at https://www.maritime-executive.com/editorials/colregs-still-fit-for-purpose.

[13] See World Maritime University, "Transport 2040 Autonomous Ships: A New Paradigm for Norwegian Shipping—Technology and Transformation" at https://commons.wmu.se/cgi/viewcontent.cgi?article=1072&context=lib_reports.

[14] It is worth emphasizing that COLREGS Rules contemplating human interaction or presence would likely be applied differently to a remotely-controlled vessel with a human tasked with controlling or monitoring the vessel as compared to a so-called "fully autonomous" (operating at highest degree of autonomy) vessel.

[15] A principle question is to what extent the COLREGS allow or prohibit an artificial intelligence (AI)- or information technology (IT)-driven autonomous collision avoidance system. The Committee is aware of developers in both the military and commercial sectors who have evidenced that compliance with COLREGS through computer algorithms or artificial intelligence is purportedly achievable, see, for example, (1) Mayflower Autonomous Ship, https://newsroom.ibm.com/2020-03-05-Sea-Trials-Begin-for-Mayflower-Autonomous-Ships-AI-Captain; (2) Leidos *Sea Hunter*, https://www.leidos.com/sites/g/files/zoouby166/files/2019-12/FS-Maritime-Autonomy-Leidos.pdf; (3) Rolls-Royce MAXCMA, https://www.theengineer.co.uk/autonomous-vessels-collisions; (4) Sea Machines 300, https://maritime-executive.com/corporate/sea-machines-names-first-boat-builder-to-offer-autonomous-technology; and (5) Guardian by Marine AI, https://marineai.co.uk/products. The committee has neither requested nor assessed the underlying scientific data that supports these positions.

interpreting treaties.[16] Moreover, such determinations could involve a case-by-case threshold "legal status" determination of the respective platform to address the "is it a vessel?" conundrum that considers the size and type of platform, how the platform is utilized, and where the platform is utilized. Of critical import in such an analysis is an assessment of whether a UMV can navigate in a demonstrably safe and prudent manner and whether technical noncompliance is deemed a reasonable legal risk.[17]

And, as testing of a UMV is integral to assessing its capabilities and legal risk, the Coast Guard could evaluate the use of current U.S. Navy or National Oceanic and Atmospheric Administration (NOAA) ranges for testing UMVs.[18] The Coast Guard could utilize testing opportunities to clarify to what extent UMVs are subject to and comply with the COLREGS, how legal risk and allocation of responsibilities for gaining relevant use permissions is being obtained, what privileges and immunities are afforded the UMV and operator (e.g., "public vessel"), and which party is responsible for the handling of the data collected.[19] The U.S. Navy could be a useful indicator of these issues given their continued growth in

[16] To its credit, the Coast Guard has already developed some legal guidance on vessel status determinations and could build on its historical vessel determination precedent, in particular, the Coast Guard "paddleboard" memorandum of October 3, 2008. That memorandum determined that a paddleboard "is a vessel under 46 U.S.C. §2101," and more notably, offered a useful multi-prong legal test to assist in determining "what is a vessel." See Part II for operational factors under current legal precedent.

[17] Of note, these legal and policy opinions could include analysis of UMV operations under the various COLREGS Rules, which likely present the most challenges to compliance, including but not limited to Rule 2 (Good Seamanship); Rule 5 (Lookout); Rule 6 (Safe Speed); Rule 7 (Risk of Collision); Rule 8 (Action to Avoid Collision); and Rule 19 (Conduct in Restricted Visibility). The U.S. government has considered options other than definitive COLREGS application for "Unmanned Maritime Systems," see, for example, Letter from J.G. Lantz, Director, Commercial Regulations and Standards, U.S. Coast Guard, COMDT (CG-5PS), to Ki-tack Lim, Secretary General, International Maritime Organization (Jan. 15, 2016), http://www.imo.org/en/About/strategy/Documents/Member%20States%20-%20tdc/United%20States%20-%20Input%20to%20TDCs.pdf. See Part II for further discussion.

[18] Interim guidelines for Maritime Autonomous Surface Ships (MASS) trials, MSC.1/Circ.1604 (14 June 2019), http://www.imo.org/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1604%20-%20Interim%20Guidelines%20For%20Mass%20Trials%20(Secretariat).pdf.

[19] Such legal analysis could assess the potential application of the waiver of sovereign immunity for civil liability in admiralty incidents involving U.S. public vessels under the Suits in Admiralty Act, 46 U.S.C. § 30901–30918 (2018), Public Vessels Act, 46 U.S.C. §§ 31101–31113 (2018), the so-called "Pennsylvania Rule" (The Pennsylvania, 86 U.S. at 125). As UxS platform concepts mature, and in parity with sister services, the Coast Guard could take into account whether arming UxS in support of operations is desirable (i.e., use of warning shots or disabling fire to support Maritime Law Enforcement [MLE], self-defense, etc.). See Part II for further discussion.

the testing of UMVs, in particular because no objections have been raised regarding U.S. Navy UMV operations.[20]

Ultimately, the legal and policy decisions on UMVs could add value to the Coast Guard in the near term.[21] And, it would benefit the Coast Guard if such legal analysis was developed on the recommendations and guidance of senior decision makers within the organization with clearly articulated parameters for an intended UMV operation.[22]

Unmanned Underwater Vehicles (UUVs)

In terms of UUV, the Coast Guard possesses 12 tethered remotely operated vehicles (ROVs) referred to as the "Fusion" manufactured by Strategic Robot Systems. And, the Coast Guard RDC has started a project to coordinate and conduct lab and field tests of long-range autonomous underwater vehicles, remote environmental monitoring units, autonomous underwater vehicles and unmanned aircraft systems (UASs) in ice conditions to verify accuracy of sensors and UxSs.[23]

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[20] A Ghost Fleet Overlord unmanned surface vessel (USV) conducted a roundtrip 1,400 nautical mile voyage from the Gulf Coast to Norfolk, Va., while autonomously navigating and following COLREGs to safely operate among commercial traffic. See https://news.usni.org/2020/06/23/program-office-maturing-usvs-uuvs-with-help-from-industry-international-partners; see also "Sea Hunter USV Autonomously Navigates from California to Hawaii," at https://www.unmannedsystemstechnology.com/2019/01/sea-hunter-usv-autonomouslynavigates-from-california-to-hawaii; Other international strategic partners are also developing UxS (e.g., UUV, USV), such as the UK, Australia, Canada, New Zealand, and Singapore (e.g., Singapore Navy Protector USV was deployed for maritime surveillance and force protection duties in the Northern Arabian Gulf and the Gulf of Aden, https://www.mindef.gov.sg/oms/navy/careers/our-assets/protector-unmanned-surface-vessel.html#:~:text=Our%20Assets-,Protector%20Unmanned%20Surface%20Vessel,or%20from%20ships%20at%20sea).

[21] For example, COLREGS Rule 5 (Lookout) "presents a rule-based challenge for direct application to UMSs, which can be overcome by a broad reading of the rule or an amendment that exempts UMSs from Rule … a broad reading of Rule 5, considering sensors the functional equivalent of 'sight and hearing,' is reasonable, noting that UMSs are being developed with sensors advanced enough to meet judicial requirements for the Rule." Christopher C. Swain, 2018. Towards greater certainty for unmanned navigation, a recommended United States military perspective on application of the "Rules of the Road" to unmanned maritime systems. *Georgetown Law Technology Review* 3:119–161, at 141.

[22] It bears emphasis that ambiguity in classifying a respective surface platform could prove useful depending if, for example, the Coast Guard finds that a respective fit-for-purpose "vessel" is unable to fully comply with the COLREGS and undue risk of negligent operations exists, and designation as a "vehicle" or other similar term aligns more appropriately with the intended purpose of the UxS. For a more fulsome analysis of this issue, see Part II.

[23] The U.S. Department of Homeland Security Science & Technology Directorate posted a Request for Information for a project (conducted on behalf of the Coast Guard) exploring use of long-range autonomous underwater vessels for detection and mapping of oil spills on the surface and subsurface and under ice.

However, such subsurface operations generally fall outside the purview of the COLREGS, and thus there are little to no perceived legal impediments to such operations.[24] However, the Coast Guard could still conduct an operational assessment for such types of subsurface and tethered remotely operated vehicle operations to review the varying levels of risk. And, as the U.S. Navy and NOAA are currently utilizing prototype UUVs, maintaining a collaborative approach and close communications with these entities could benefit the Coast Guard as a way to leverage lessons learned and best practices in development of the means to meet legal compliance.[25]

Unmanned Aircraft Systems (UASs)

The Coast Guard has the legal authority, if not the capacity yet, to deploy UASs[26] in domestic and international airspace subject to compliance with governing rules.[27] As with UMVs, UAS technology has outpaced regulations, and consequently while the Coast Guard has legal authority to operate UASs for MDA, current legal regimes do not enable unrestricted UAS support of Coast Guard MDA operations.

As detailed in Chapter 4, the Coast Guard has deployed contractor-owned and -operated medium-range UASs on National Security Cutters (NSCs) in offshore areas, and has provided commercial off-the-shelf short-range small UASs (sUASs)[28] to seven field units for use in domestic airspace through the Group-1 UAS Prototype Program Initiative.[29] In 2018, the Coast Guard conducted maritime-based Drone Evaluations and Training at Singing River Island (Pascagoula, Mississippi) to evaluate mapping

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[24] Part XIII of UNCLOS does provide some guidance on subsurface operations for scientific research purposes. See https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

[25] See, for example, NOAA Unmanned Systems Strategy (February 2020), at https://nrc.noaa.gov/LinkClick.aspx?fileticket=0tHu8Kl8DBs%3D&tabid=93&portalid=0.

[26] For purposes of this section, the term UAS is used as defined in COMDTINST M3710.1H as "an unmanned aircraft and the equipment necessary for the safe and efficient operation of that aircraft. An unmanned aircraft is a device that is used, or is intended to be used, for flight in the air with no onboard pilot." Other terms include UAV, drone, remotely piloted vehicle, remotely piloted aircraft, and remotely operated aircraft.

[27] 14 C.F.R. § 91.101 ("Flight Rules") prescribes flight rules governing the operation of aircraft within the United States and within 12 nautical miles from the coast of the United States. However, regulations that include the term "civil aircraft" in their applicability do not apply to public aircraft operations (e.g., 14 C.F.R. Part 91).

[28] Per 14 C.F.R. § 1.1, "small unmanned aircraft" means an unmanned aircraft weighing less than 55 lb. on takeoff, including everything that is on board or otherwise attached to the aircraft.

[29] ALCOAST 004/18 - JAN 2018 AUTHORIZED USE OF COAST GUARD UNMANNED AIRCRAFT SYSTEMS (UAS), at https://content.govdelivery.com/accounts/USDHSCG/bulletins/1d0fcb5.

technologies to support missions such as oil spill response, search and rescue, and post-storm damage assessment.[30] Currently, Coast Guard personnel (4 pilots and 10 sensor operators) serve in the CBP-USCG UAS Joint Program Office, which is operating Long-Range UAS MQ-9 Predator to provide land and MDA in support of (1) southern border and littoral surveillance and (2) Joint Interagency Task Force South; however, all MQ-9 aircraft, ground control stations, and equipment in that program are owned by U.S. Customs and Border Protection (CBP).

A UAS is considered an "aircraft" as defined in the Federal Aviation Administration's (FAA's) authorizing statutes,[31] and therefore Coast Guard UAS operations in the National Airspace System (NAS)[32] are subject to FAA regulations.[33] The FAA imposes stringent legal requirements that restrict government operations of UASs to personnel who have UAS pilot licenses, and there are numerous rules concerning where UASs can be flown.

More specifically, no person may operate a UAS in the NAS without specific authority, and consequently, the Coast Guard generally has three options to lawfully operate a UAS in the NAS under the prevailing FAA regulations:

1. Voluntarily adhere to the flight rules under 14 C.F.R. part 107 ("Part 107"). The Part 107 operating rules allow operations of UAS weighing less than 55 lb. at or below 400 ft. above ground level for visual line-of-sight (VLOS) operations during daylight hours only. The rules also address airspace restrictions and pilot certification.
2. Fly under the statutory requirements for public aircraft operations (PAO) (49 U.S.C. § 40102(a) and § 40125). Operate with a Certificate of Waiver or Authorization (COA) to be able to self-certify UAS and operators for flights performing governmental functions. For UAS PAO, the specific authority required is the COA.

[30] U.S. Department of Homeland Security. *Snapshot: Testing and Training with Drones*. https://www.dhs.gov/science-and-technology/news/2018/04/23/snapshot-testing-and-training-drones.

[31] 49 U.S.C. § 40102(a)(6).

[32] The NAS is "the common network of U.S. airspace; air navigation facilities, equipment and services, airports or landing areas … shared jointly with the military." See http://www.faa.gov/air_traffic/publications/media/pcg_4-\03-14.pdf.

[33] The FAA is the federal agency responsible for maintaining the safety and efficacy of the U.S. aviation system. Pursuant to 49 U.S.C. § 40103, the FAA has exclusive sovereignty over domestic airspace from "the ground up," and thus regulates UAS/UAV/remotely piloted aircraft as "aircraft." Domestic airspace is the airspace above U.S. territory and extends 12 nautical miles from shore.

3. Obtain a blanket public COA, which would permit nationwide flights and the option to obtain emergency COAs under special circumstances.[34]

Although the Coast Guard may lawfully operate sUASs for MDA in domestic airspace subject to the above requirements, some regulatory limitations present a legal barrier to expanded flight operations. The most notable of these limitations is the requirement under Part 107 that the remote pilot in command, the visual observer (if one is used), and the person manipulating the flight control of the sUAS must be able to maintain VLOS of the sUAS throughout the entire flight.[35] Other limitations under Part 107 include restrictions on operations from a moving vehicle or aircraft (§ 107.25),[36] daylight-only operations (§ 107.29), operations over people (§ 107.39), operation in certain airspace (§ 107.41) and general operating limitations (§ 107.51).[37] Also, the United States is still developing a capability to effectively manage national airspace UAS traffic, commonly referred to as the UAS Traffic Management infrastructure.[38] Thus, some regulatory limitations may present a barrier to the Coast Guard's ability to execute its full range of contemplated UAS capabilities for MDA.

Generally, when Coast Guard aircraft are operated in accordance with titles 10, 14, 31, 32, or 50, and when not used for commercial purposes, Coast Guard UAS qualify as PAO.[39] PAO are limited by statute to certain government operations within U.S. airspace and must comply with certain general operating rules applicable to all aircraft in the NAS. The FAA has limited oversight of PAO, although such operations must continue to comply with the regulations applicable to all aircraft operating in the NAS, and

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[34] The Coast Guard has a blanket FAA UAS COA (Blanket Area-Public Agency, 2019-AHQ-100-COA) for operations in Class G airspace allowing the Coast Guard to operate UAS up to 1,200 ft. *See also* Appendix (D) to COMDTINST M3710.1H.

[35] 14 C.F.R. § 107.31.

[36] See, for example, "Planck Aerosystems, the First Autonomous Drone Company That Developed the Ability to Launch and Land Drones on a Moving Vehicle and Boats, Lands $2 Million Contract with DoD," at https://techstartups.com/2019/09/30/planck-aerosystems-first-autonomous-drone-company-developed-ability-launch-land-drones-moving-vehicle-boats-lands-2-million-contract-dod.

[37] Group-1 UAS Prototype Program Initiative units were provided with the Yuneec Typhoon-H hexacopter, and the units were limited by the operational constraints established in FAA Part 107 including daytime operations, maximum altitude of 400 ft., and within VLOS only. See U.S. Coast Guard. January 2019. *Group-1 UAS Prototype Program Initiative (GUPPI) Operational Evaluation and Testing of Short-Range UAS (SR-UAS) at Various Geographical Locations*. USCG CG-711 Report.

[38] U.S. Department of Homeland Security Science & Technology Directorate. *Snapshot: Working with NASA to Secure Drone Traffic.* https://www.dhs.gov/science-and-technology/news/2019/02/12/snapshot-working-nasa-secure-drone-traffic.

[39] 49 U.S.C. § 40125(c). Public aircraft status exists only within U.S. airspace.

the Coast Guard remains responsible for oversight of the operation, including aircraft airworthiness and any operational requirements.[40]

The COA process establishes mandatory provisions to ensure that the level of safety for domestic UAS flight operations is equivalent to that of manned aviation. COAs are unique to the intended mission and specifies the time period, location, circumstances, and conditions under which the UAS must be operated; and, are not required for UAS operations within special use airspace or Due Regard operations beyond 12 nautical miles from shore.[41]

Furthermore, in international airspace,[42] the Coast Guard possesses the authority and ability to operate UASs, although similar legal restrictions exist as in domestic airspace on achieving full use of UASs. When operating outside the NAS, Coast Guard UASs are required to operate in accordance with appropriate international authorities, specifically, the International Civil Aviation Organization (ICAO) flight rules that govern operations in international airspace.[43] When UAS operations from a Coast Guard cutter (e.g., NSC) cannot comply with ICAO regulations, Coast Guard UASs are required to operate with Due Regard for the safety of all other aircraft consistent with Operations *Not Conducted Under ICAO Procedures* and DoDI 4540.01.[44] When Due Regard operations are conducted, full responsibility for separation between Coast Guard aircraft and all other aircraft, both public and civil, falls on the Coast Guard—operational airspace deconfliction is the responsibility of the operational and tactical commanders.

Notably, tactical aircraft operations from cutters usually cannot be conducted in compliance with ICAO regulations when deemed not practical

[40] For a summary of PAO, see FAA Advisory Circular No: 00-1.1B "Public Aircraft Operations—Manned and Unmanned," athttps://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_00-1.1B.pdf.

[41] In this regard, the Coast Guard has developed comprehensive guidance regarding UAS flight authorizations, for example, before conducting UAS operations within the NAS outside of special use airspace, a flight clearance shall be obtained from CG-711. See also COMDTINST M3710.1 H, App. D(A)(5) and "General Flight Rules" (Ch. 4(C)): Coast Guard aircraft [including UAS] flights "shall be conducted in accordance with the rules, regulations, or recommended procedures specified by the publications in the following rank ordered list. Where conflicting regulations or varying procedures exist, the higher ranking publication shall be followed: Coast Guard; Directives; Federal Aviation Regulations, 14 C.F.R. § 91 and 97 and FAA Manuals; Joint FAA/Military Documents; DOD Publications."

[42] Generally defined as airspace greater than 12 nautical miles from shore.

[43] See Annex II of the Convention on International Civil Aviation (Chicago Convention); see also 14 C.F.R. § 91.

[44] See U.S. Department of Defense Instruction (DoDI) 4540.01 (Use of lnternational Airspace by U.S. Military Aircraft and for Missile and Projectile Firings), at https://www.hsdl.org/?abstract&did=801464.

and compatible with the mission.[45] Notably, Due Regard may be exercised by utilizing "alternative means" if approved by the appropriate authority, and obligations may be met using analytic methods such as airspace density analyses, ground-based sense-and-avoid radar systems, and other approved procedures or technologies. More specifically, for UAS to comply with Due Regard provisions, one of the following provisions must be met:

1. The UAS must be operated in visual meteorological conditions and the airspace around the sUAS must be under constant VLOS observation from the aircraft commander or a visual observer in communication with the aircraft commander.
2. The UAS may be temporarily operated in less than visual meteorological conditions when required by operational needs if the aircraft commander determines that there is acceptable risk to other aircraft. The aircraft commander must utilize all available resources and information in assessing an acceptable level of risk before conducting such operations with due regard for all other aircraft. Any aircraft operations in reduced visibility must be of no greater extent or duration than required.
3. The UAS must be under continuous surveillance by, and in communication with, the cutter or other surface or airborne facility providing the surveillance. This is typically satisfied by the NSC's air surveillance radar to allow for beyond visual line of sight operations.
4. The UAS must be equipped with a Military Department-certified system that is sufficient to provide separation between itself and other aircraft.[46]

To conduct successful beyond VLOS flight operations from a cutter (a desirable facet of expanding MDA), achieving and maintaining satisfactory Due Regard compliance is critical. To this end, the Coast Guard currently relies on shipboard air search radar (ASR) to ensure continuous surveillance by, and in communication with, the cutter or other surface or airborne facility providing the surveillance.[47] Thus, during UAS operations the ASR

[45] COMDT (CG-7) Memorandum (Dec. 23, 2018), CUTTER-BASED SMALL UNMANNED AIRCRAFT SYSTEMS (sUAS) CONCEPT OF OPERATIONS (CONOPS) AND VIGNETTES.

[46] DoDI 4540.01; see also CUTTER-BASED SMALL UNMANNED AIRCRAFT SYSTEMS (sUAS) CONCEPT OF OPERATIONS (CONOPS) AND VIGNETTES (CG-711 Memo 3710).

[47] For example, ScanEagle's sensors provides a 20 nautical mile swath of sight. See DoDI 4540.01, 3.c.(1)(a): Aids to visual observation, such as binoculars or periscopes, may be employed consistent with the applicable Military Department's guidance.

is critical to Due Regard compliance as such operations could be restricted in instances where the ASR is inoperable.[48]

Counter-Unmanned Aerial Systems (C-UASs)

Several U.S. laws generally prohibit the use of C-UAS technology in the United States, which were developed to protect the NAS, civil use of electromagnetic spectrum, and constitutional and privacy rights of U.S. persons.[49] Nonetheless, the Coast Guard has narrowly defined authority to use kinetic means for C-UAS sunder applicable law and policy, subject to applicable restrictions and policies.[50] For example, while the Coast Guard has the authority to establish a safety zone in navigable waters or a security zone in land and water, only the FAA may regulate or secure the airspace above the respective safety or security zone. Accordingly, attempts to restrict small sUAS operations in the maritime domain must include consultation with the FAA (and interagency partners as applicable).[51]

The Coast Guard has been developing its capacity to utilize C-UASs over the past several years, and as the C-UAS programs mature, it would be beneficial for the Coast Guard to develop more legal and policy work to support their deployment and operations. In June 2017, Coast Guard began to pursue C-UAS authorized actions under the U.S. Department of Defense (DOD) to support its maritime escort mission, whereby certain DOD assets require Coast Guard escorts when operating in and out of their homeports.[52] The Coast Guard obtained express authority to counter

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[48] See DoDI 4540.01 and CGC STRATTON memo 3500 dated November 28, 2017 (FOUO); see also Coast Guard Maritime Security Cutter, Large (WMSL) Class ScanEagle (SE) Unmanned Aircraft Systems (UAS) Standard Operating Procedures (SOP), CG-711 NOTICE 3710 dated July 11, 2017; see also DOD General Planning (GP) Flight Information Publication (FLIP), Chapter 8, or DoDI 4540.01, Operations Not Conducted Under ICAO Procedures. COMDTINST M3710.1H, App. D.

[49] See Part II for a survey of applicable C-UAS laws; see also *FAA Law Enforcement Guidance for Suspected Unauthorized UAS Operations* (Version 5), issued August 14, 2018, at https://www.faa.gov/uas/public_safety_gov/media/FAA_UAS-PO_LEA_Guidance.pdf.

[50] See DHS Counter Unmanned Aircraft Systems Legal Authorities, at https://www.dhs.gov/sites/default/files/publications/dhs_cuas-legal-authorities_fact-sheet_190506-508.pdf. The DHS Cybersecurity and Infrastructure Security Agency (CISA) is taking a lead in many of these C-UAS activities https://www.cisa.gov/publication/uas-fact-sheets.

[51] In support, the developing Remote Identification (Remote ID) rule will require UASs in flight to provide identification information to address safety, national security, and law enforcement concerns and also enable federal security agencies (Coast Guard) to better assess threats when a UAS appears to be flying in an unsafe manner or where the UAS is not allowed to fly. See Remote Identification of Unmanned Aircraft Systems (FAA-2019-1100), at https://www.regulations.gov/document?D=FAA-2019-1100-0001.

[52] See Title 10 U.S.C. § 130i (Protection of Certain Facilities and Assets from Unmanned Aircraft).

illicit UAS activity, although such capabilities were limited because the C-UAS authority was either restricted to a specific mission or under the auspices of another department.[53] In support, Coast Guard use of force (UOF) Policy and Maritime Security and Response Operations (MSRO) Policy Letter 02-18 authorizes Coast Guard operational units to employ readily available kinetic means in defense of self/others critical infrastructure. In international waters, there are no restrictions on the use of C-UAS technology that operates on the radio frequency (RF) or global positioning system (GPS) spectrum, and when the Coast Guard is operating under DOD Tactical control, Coast Guard Patrol Forces Southwest Asia (PATFORSWA) cutters may employ kinetic and non-kinetic (i.e., C-UAS) means to counter UAS pursuant to DOD guidance.[54] And, Maritime Force Protection Units are authorized to use C-UAS technology in accordance with MSRO Policy Letter 06-18 only in defense of self/others or critical infrastructure.

Notably, on October 5, 2018, the President signed into law the Preventing Emerging Threats Act of 2018 (the act), the first statutory grant of authority for the U.S. Department of Homeland Security (DHS) to explicitly counter UAS threats.[55] This law permits authorized DHS personnel to take protective measures that are necessary to mitigate a credible threat that an unmanned aircraft or UAS poses to the safety or security of a covered facility or asset and permits authorized DHS component personnel to detect, identify, monitor, and track UAS without prior consent; warn the operator of a UAS, including by electromagnetic means; disrupt control, seize control, or confiscate a UAS without prior consent; and use reasonable force to disable, damage, or destroy a UAS. The DOJ *Guidance to Protect Facilities from Unmanned Aircraft and Unmanned Aircraft Systems* further supports and clarifies the Coast Guard's C-UAS authority.[56]

Currently, Coast Guard is conducting an operational pilot to "test and evaluate C-UAS capabilities used to detect, identify, and mitigate UAS that

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[53] Department of Homeland Security Office, Inspector General. June 25, 2020. *DHS Has Limited Capabilities to Counter Illicit Unmanned Aircraft Systems*. DHS OIG Report OIG-20-43. https://www.oig.dhs.gov/sites/default/files/assets/2020-06/OIG-20-43-Jun20.pdf.

[54] See 10 U.S.C. § 130i: authority to take actions to mitigate threats posed by unmanned aircraft to safety and security of a "covered asset or facility" that directly relates to select mission areas, including nuclear deterrence/missile defense.

[55] Codified at 6 U.S.C. § 124n; https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title6-section124n&num=0&edition=prelim.

[56] Guidance Regarding Department Activities to Protect Certain Facilities or Assets from Unmanned Aircraft and Unmanned Aircraft Systems (April 13, 2020), https://www.justice.gov/ag/page/file/1268401/download; https://www.justice.gov/opa/pr/attorney-general-barr-issues-guidance-protect-facilities-unmanned-aircraft-and-unmanned.

pose a credible threat to "covered facilities or assets."[57] And, the Coast Guard RDT&E is conducting projects on maritime C-UAS and airborne C-UASs.[58] While the Coast Guard has relatively limited authorities for use of C-UASs, these authorities are still somewhat restricted and evolving, and thus the Coast Guard could ensure that a legal assessment has been completed related to the designing, testing, procuring, and use of C-UAS technology to ensure compliance with applicable laws and DHS/Coast Guard policies.

PART II

A survey of relevant authorities, precedent, guidance, and resources that may be useful to assess Coast Guard UxS legal and policy considerations now follows.

Legal Authority Overview

Relevant Coast Guard authorities related to execution of its 11 statutory missions include but are not limited to:

- **Primary Duties of the Coast Guard.** Sets out the primary duties of the Coast Guard, including its role as a specialized service in the Navy during time of war. 14 U.S.C. 2; See generally 33 C.F.R. 1-199; 46 C.F.R. 1-199; 33 C.F.R. Part 1; and 46 C.F.R. Part 2.
- **General Functions and Powers.** Sets out the general functions and powers of the Coast Guard including establishing aids to navigation, controlling the movement of vessels, conducting oceanographic research, saving life and property at sea, and enforcing federal law. 14 U.S.C. 81, 88, 89, 91, and 94; Executive Order (E.O.) 7521 (covering the use of vessels for ice breaking operations in channels and harbors); 6 U.S.C. § 468 (2017), Homeland Security Act, Pub. L. No. 107-296, § 888, 116 Stat. 2135, 2249-50 (2002).
- **Commandant; General Powers (Testing).** For the purpose of executing the duties and functions of the Coast Guard the Commandant

[57] See Privacy Impact Assessment for the U.S. Coast Guard Counter-Unmanned Aircraft Systems Pilot DHS/USCG/PIA-030, October 28, 2019, at https://www.dhs.gov/sites/default/files/publications/privacy-pia-uscg030-cuas-october2019.pdf. The Coast Guard will conduct the pilot testing through 2020, after which its C-UAS program may become fully operational.

[58] Respectively, (1) Project #7812: Methods to detect, track, identify, and defeat illicit use of unmanned aircraft systems in the maritime environment and (2) Project #7821: Technology and tactics to secure airspace from small Unmanned Aircraft Systems (sUAS). See https://www.dcms.uscg.mil/Portals/10/CG-9/Acquisition%20PDFs/FY20%20RDTE%20Project%20Portfolio.pdf?ver=2019-10-24-154528-393.

may conduct experiments and investigate, or cause to be investigated, plans, devices, and inventions relating to the performance of any Coast Guard function, including research, development, test, or evaluation related to intelligence systems and capabilities. 14 U.S.C. 504(a)(4).

- **Coast Guard as an Armed Force.** The Coast Guard is a military service and at all times a branch of the armed forces in the U.S. Department of Homeland Security, except when operating as a service in the Navy; and sets out policies concerning the Coast Guard's role as a service in the Navy during time of war. 14 U.S.C. § 1, 3, 4; 10 U.S.C. 101(a)(4). See generally 33 C.F.R. 1–199; 46 C.F.R. 1–199; 33 C.F.R. Part 1; 46 C.F.R. Part 2. It is the only armed force with organic law enforcement authority. See also Pub. L. No. 107-296 (The Homeland Security Act), establishing the U.S. Department of Homeland Security and providing the organic parameters and authorities related to the agency.
- **Vessel Boardings.** The Coast Guard may board any vessel subject to the jurisdiction of the United States, whether on the high seas, or on waters over which the United States has jurisdiction, to make inquiries, examinations, inspections, searches, seizures, and arrests for the prevention, detection, and suppression of violations of U.S. laws. 14 U.S.C. § 89.
- **Navigation Safety.** The Coast Guard maintains broad authority over navigation safety in the navigable waters of the United States, including the ability to order vessels to operate as directed. 33 U.S.C. § 1223.
- **Naval Safety and Security.** The Coast Guard can control the anchorage and movement of vessels in the navigable waters of the United States to ensure the safety and security of U.S. naval vessels. 14 U.S.C. § 91.
- **Waterway Security.** When the President determines that U.S. national security is endangered, the Coast Guard may enforce regulations concerning the movement or anchorage of vessels within U.S. territorial waters, including vessel seizure and forfeiture, and may fine and imprison the master and crew for noncompliance. 50 U.S.C. § 191.
- **Assistance.** The Coast Guard may use its personnel and facilities to assist federal, state, and local agencies when Coast Guard assets are especially qualified to perform a particular activity. 14 U.S.C. § 141; see also 14 U.S.C. 142–148.
- **Pollution Response.** The Coast Guard may respond to discharges or threats of discharges of oil and hazardous substances into the

navigable waters of the United States and promulgate certain pollution prevention regulations. 33 U.S.C. § 1321.

- **Vessel Inspections.** The Coast Guard prescribes regulations for the inspection and certification of vessels. 46 U.S.C. § 3306.
- **Customs.** The Coast Guard has the authority to enforce customs laws, including anti-smuggling regulations. U.S.C. Title 19.
- **Maritime Security.** The Coast Guard has a key role in preventing maritime transportation security incidents, which includes the implementation of international security standards. 46 U.S.C. VII.
- **Intelligence Community.** The Coast Guard is a member of the intelligence community. U.S.C. Title 50.
- **Living Natural Resources.** The Coast Guard safeguards fisheries and marine-protected resources by enforcing living natural resource authorities such as the Magnuson-Stevens Fisheries Conservation and Management Act 16 U.S.C. § 1801, the Lacey Act 16 U.S.C. §§ 3371–3378, the Endangered Species Act 16 U.S.C. §§ 1531–1544, and the National Marine Sanctuaries Act 16 U.S.C. §§ 1431–1445.

Maritime Zones and Airspace Boundaries

The Coast Guard operational areas overlap with recognized U.S. and international geographic regimes, and thus add to jurisdictional complexity. Therefore, it is imperative to understand the maritime zones and airspace in which Coast Guard UxS operations will be conducted throughout the maritime domain to ensure compliance with applicable laws and regulations.[59] To this end, the United Nations' Law of the Sea (UNCLOS) Convention provides relevant jurisdictional classifications for sea boundaries and airspace:[60]

- **Baseline (0 Nautical Miles).** The boundary line dividing the land from the ocean as marked on charts, typically described as the low waterline along the coast.

[59] See NOAA Office of General Counsel website "Maritime Zones and Boundaries," at http://www.gc.noaa.gov/gcil_maritime.html; see also Coast Guard Publication 3-0, Operations (February 2012), Ch. 3.2.

[60] UN Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 3, 21 I.L.M. 1261, entered force Nov. 1, 1994. https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf. The United States is not a party to UNCLOS, although since 1983 it has asserted that the navigation and overflight provisions of the convention are reflective of customary international law, and thus the United States operates in conformity with those provisions. Ronald Reagan, Statement by the President, 19 WEEKLY COMP. PRES. DOC. 383 (March 10, 1983); see also U.S. Department of State Office of Ocean and Polar Affairs "Law of the Sea" and "Limits of the Sea," https://www.state.gov/key-topics-office-of-ocean-and-polar-affairs/#law.

- **Internal Waters.** All U.S. waters shoreward of the baseline, including all waters on the U.S. side of the international boundary of the Great Lakes.
- **State Waters (0–3 Nautical Miles; 0–9 Nautical Miles for Florida and Texas and Gulf Coast).** State-managed waters historically related to areas of public interest such as fishing, cultural heritage, recreation, environmental protection, and commerce.
- **The Territorial Sea/National Airspace (0–12 Nautical Miles).** The waters within the belt that is 12 miles wide and adjacent to the U.S. coast measured seaward from the baseline. For the purpose of enforcing some domestic U.S. laws, the territorial sea extends only 3 miles seaward of the baseline. Under the Chicago Convention, "National Airspace" composes the land and territorial waters, thus the non-sovereign portion of airspace is beyond 12 nautical miles.[61]
- **Customs Waters.** Generally defined as the waters shoreward of a line drawn 12 miles from the baseline (including territorial sea and inland waters with ready access to the sea).
- **Contiguous Zone (12–24 Nautical Miles).** Area adjacent to the territorial sea and extending 24 nautical miles from the baseline over which a nation exercises control over laws related to customs, sanitary, fiscal matters, and immigration. The airspace beyond 12 nautical miles from land is considered international airspace.
- **Exclusive Economic Zone ("EEZ") (12–200 Nautical Miles).** An area adjacent to the territorial sea and extending 200 nautical miles from the baseline over which a nation exercises control necessary to protect exploration, exploitation, conservation, and management of living and nonliving natural resources within the waters, seabed, and subsoil of the zone.
- **International Waters.** Waters seaward of the outer limit of the territorial sea of any nation, but including the high seas, EEZ, and contiguous zones (when claimed seaward of the territorial sea).
- **High Seas (Beyond 200 Nautical Miles).** Areas of the ocean beyond domestic jurisdiction.

Figures E-1 and E-2 illustrate the legal boundaries ocean and airspace.

[61] The Convention on International Civil Aviation ("Chicago Convention") also provides context on these boundaries, International Civil Aviation Organization (ICAO), *Convention on Civil Aviation ("Chicago Convention")*, December 7, 1944, (1994) 15 U.N.T.S. 295, https://www.icao.int/publications/pages/doc7300.aspx. While the Chicago Convention and its Annexes, including Annex 2, are generally not applicable to State aircraft (e.g., military), the Convention does place requirements on States regarding the interaction between military and civil aircraft.

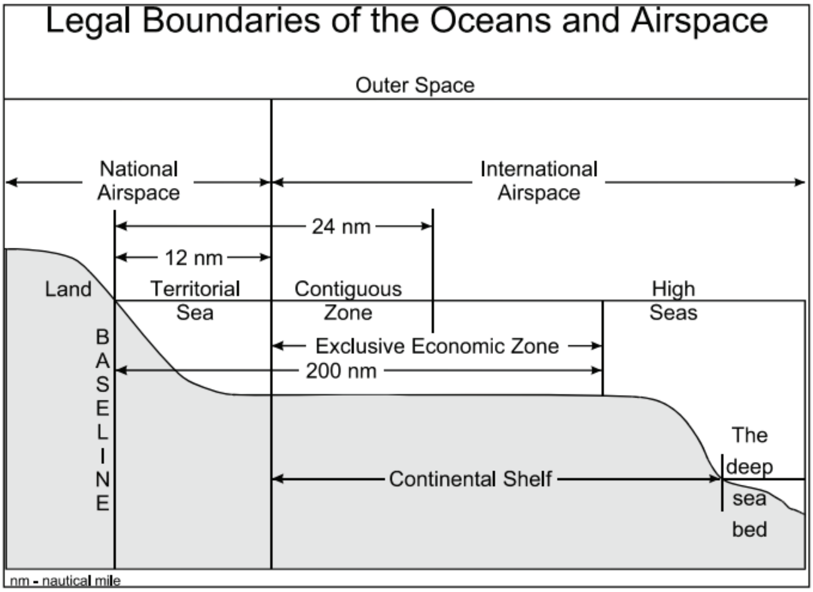

FIGURE E-1 Maritime zones—legal boundaries of the oceans and airspace.
SOURCE: U.S. Department of Defense.[62]

Legal Considerations for UMV

As discussed in Chapters 3 and 6 and Part I, in order to determine legal rights and obligations when operating a particular UMV, a threshold issue will be how to characterize the UMV given the language in key domestic statutes, regulations, and international laws, which primarily govern operations by "vessels" or "ships."[63] Efforts toward compliance with governing legal authorities has invariably raised issues of fact, policy, and law, including the critical question of "is it a vessel?"

Adding to the complexity of this legal status determination, industry and military services alike have been developing a range of terminology used in describing UMVs, often depending on the degree of autonomy the vehicle has, whether it is used in combat, and whether it is below, on, or above the surface of the water. To illustrate, the literature supporting this

[62] U.S. Department of Defense. 2007. "The Commander's Handbook on the Law of Naval Operations." https://www.jag.navy.mil/documents/NWP_1-14M_Commanders_Handbook.pdf.

[63] The literature indicates that terms used to describe a UxS have been varied, including but not limited to ship, watercraft, vessel, vehicle, system, object, device, equipment, flotsam/jetsam, contrivance, and marine debris.

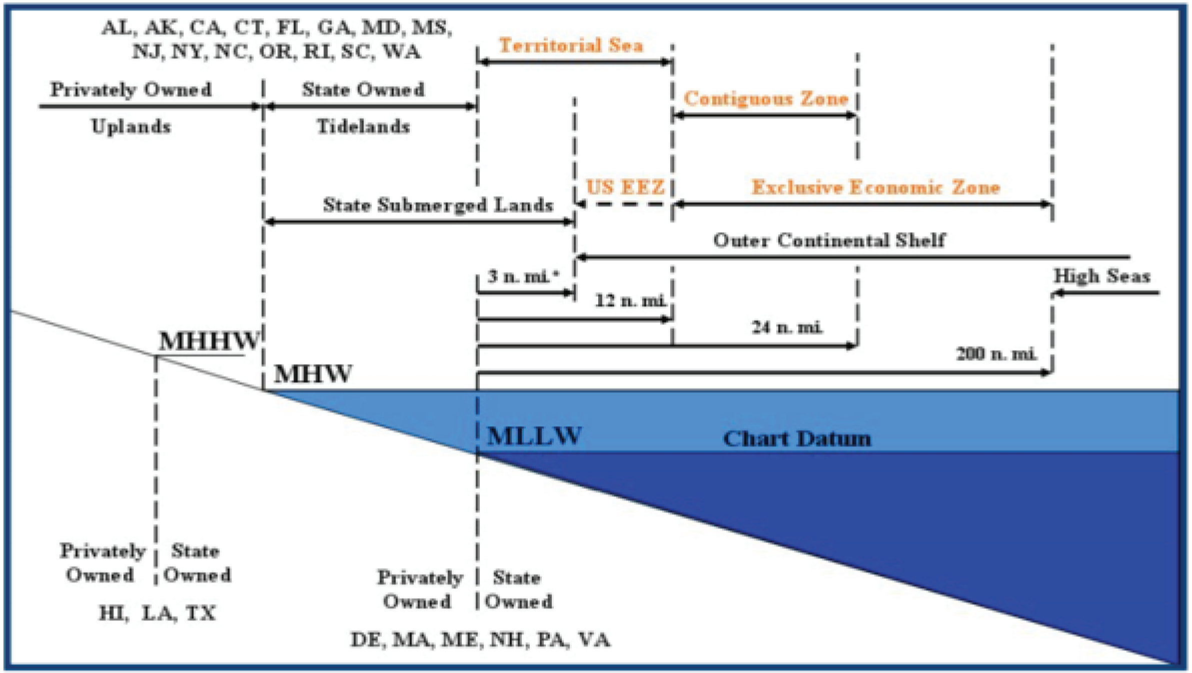

FIGURE E-2 Limits of U.S. maritime zones (highlighted in orange).
SOURCE: NOAA Office of Coast Survey.[64]

[64] National Oceanic and Atmospheric Administration. "Maritime Zones of the United States." https://nauticalcharts.noaa.gov/data/docs/gis-learnaboutmaritimezones1pager.pdf.

report has revealed there is no universally accepted name for an unmanned maritime vehicle (UMV), and the general position in the governmental, scientific, legal, and technical communities has yet-to-be aligned as illustrated by the following non-exhaustive list:

- Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV)
- Autonomous Sea Drone (ASD)
- Autonomous Surface Vehicle (ASV)
- Autonomous Underwater Vehicle (AUV)
- Highly Automated Ship System (HASS)
- Marine Unmanned Vehicle
- Marine Unmanned Vessel
- Maritime Autonomous Surface Ship
- Maritime Autonomous Vehicle
- Merchant Autonomous Surface Ship (MASS)
- Ocean Data Drone
- Optionally Manned Vessel (OMV)
- Remotely Operated Vehicle (ROV)
- Ship with Periodically Manned Bridge
- Smart Ships
- Uncrewed Surface Vessel
- Unmanned Combat Surface Vehicle (UCSV)
- Unmanned Combat Underwater Vehicle (UCUV)
- Unmanned Combat Vehicle (UCV)
- Unmanned Craft (UC)
- Unmanned Maritime System (UMS)
- Unmanned (or Crewless) Maritime Vehicle (UMV)
- Unmanned Surface Robot (USR)
- Unmanned Surface Vehicle (USV)
- Unmanned Underwater (or Undersea) Vehicle (UUV)
- Unmanned Vehicle (UV)

For an example of classification of autonomous maritime systems and autonomous ship types see Figure E-3.

To this end, a key legal consideration will be whether the Coast Guard procures and operates a platform characterized or classified as listed above taking into account the level of autonomy (or advanced automation) at which the UxS intends to operate since this will be relevant to how a respective platform fits into the prevailing legal framework. Observations on the "legal challenge involved" are illustrated in Figure E-4.

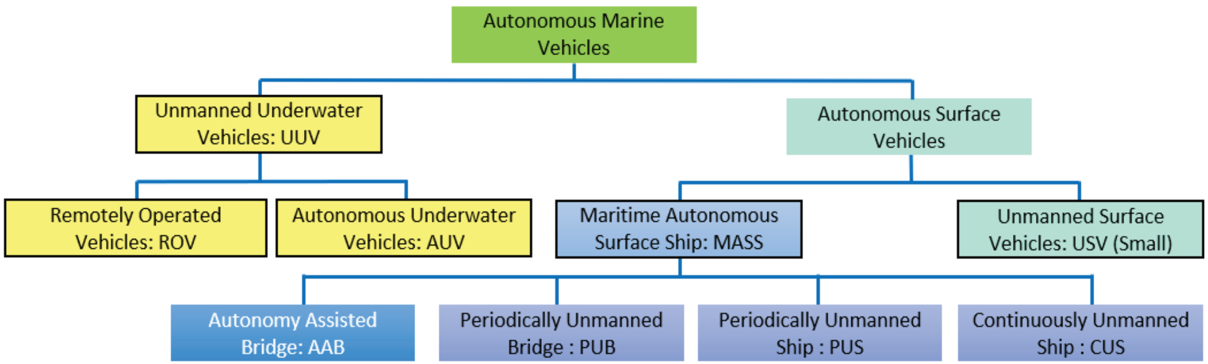

FIGURE E-3 Classification of autonomous maritime systems and autonomous ship types.
SOURCE: Norwegian Forum for Autonomous Ships (NFAS).[65]

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[65] Norwegian Forum for Autonomous Ships. "Definitions for Autonomous Merchant Ships," p. 7, Fig. 4, http://nfas.autonomous-ship.org/resources/autonom-defs.pdf.

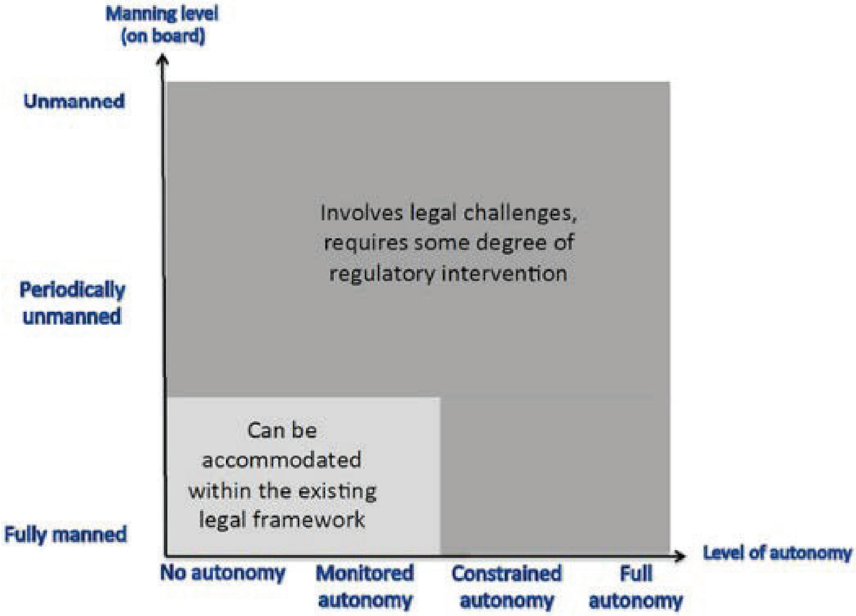

FIGURE E-4 Nature of the legal challenge.
SOURCE: Henrik Ringbom.[66]

Considering the consequences under domestic and international law and in support of maintaining a rules-based order in the maritime domain, the Coast Guard's contemplated operations may require addressing key questions such as the following:[67]

- What markings and insignia must a UMV carry and display?
- What navigation rights does a UMV have on the high seas and in coastal State waters?
- What are the UMV's obligations with respect to other vessels and mariners?

[66] H. Ringborn. 2019. Regulating autonomous ships—concepts, challenges and precedents. *Journal of Ocean Development & International Law* 50(2–3):8. https://www.jus.uio.no/nifs/english/research/events/2019/regulating-autonomous-ships-concepts-challenges-and-precedents.pdf.

[67] List adopted from Craig H. Allen, Determining the legal status of unmanned maritime vehicles: formalism vs functionalism, *Journal of Maritime Law & Commerce* 49:488–490, at 477 (including more expansive list of similar questions).

- Can a UMV be employed in law enforcement actions, including in hot pursuit (see UNCLOS Article 111)?
- Must UMV shoreside operators hold a crewmember rating (e.g., boatswain)?
- Is the shoreside operator of a remotely-controlled UMV the craft's "Commanding Officer"?
- What is the role of the programmer (or program team) of a fully autonomous UMV in determining responsibility for decision making?
- Do government-owned UMVs have sovereign immunity as warships, or are they subject only to "sovereign ownership" immunity as U.S. property?

In support of this analysis, there are several sources of authority on which the Coast Guard may rely to assist with the threshold question of whether a UMV is a "vessel," including international law, domestic law, and U.S. policy.

International Legal Framework

- Vienna Convention on the Law of Treaties, art. 31, May 23, 1969, 1159 U.N.T.S. 331, entered into force Jan. 27, 1980.
- 1982 U.N. Convention on the Law of the Sea (UNCLOS), Dec. 10, 1982, 1833 U.N.T.S. 3, 21 I.L.M. 1261, entered into force Nov. 1, 1994.
    - UNCLOS allocates a number of rights and responsibilities regarding "ships" and "vessels," but does not define either term. Notably, the United States is not a party to UNCLOS, but asserts that the navigation and overflight provisions of the Convention are reflective of customary international law and that the United States therefore operates in conformity with those provisions. See Ronald Reagan, Statement by the President, 19 WEEKLY COMP. PRES. DOC. 383 (Mar. 10, 1983); U.S. Oceans Policy, 83 DEP'T STATE BULL., June 1983, at 70, 22 I.L.M. 464 (1983).
- COLREGS or "Rules of the Road"[68]: Generally, the COLREGS consist of two sets of rules: (1) the International Rules and (2) the Inland Rules:
    - Convention on the International Regulations for Preventing Collisions at Sea, Oct. 20, 1972, T.I.A.S. 8587, 28 U.S.T. 3459 (COLREGS); Amendments to 72 COLREGS effective June 1,

[68] Citations in this report and Appendix to the "COLREGS" are to the International Rules unless otherwise specified.

1983 (48 FR 28634). ("These [International] Rules shall apply to all vessels upon the high seas and in all waters connected therewith navigable by seagoing vessels.")[69]
    - Inland Navigation Rules, 33 C.F.R. § 83.03(q) (2017). ("Inland Waters means the navigable waters of the United States shoreward of the navigational demarcation lines dividing the high seas from harbors, rivers, and other inland waters of the United States and the waters of the Great Lakes on the United States side of the International Boundary.")

Understanding that the ability of the UMV to intelligently maneuver through detection technology will drive much of any legal analysis on its applications, and thus the current case law[70] on the COLREGS may be instructive in preparing relevant legal and policy memorandums:[71]

- Rule 2 (Good Seamanship and Special Circumstances) provides: "Nothing in these Rules shall exonerate any vessel … from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seaman" allowing for a "departure from these Rules necessary to avoid immediate danger."[72]
    - *Yang-Tsze Ins. Ass'n v. Furness, Withy & Co.*, 215 F. 859 (2d Cir. 1914)
    - *Thurlow v. United States*, 295 F. 905 (D. Mass. 1942)
    - *The Llanover* [1945] 78 Lloyd's List Lloyd's Register (LR) 198 (Eng.)
- Rule 3 (General Definitions) provides: "the word 'vessel' includes every description of watercraft, including nondisplacement craft,

[69] See https://www.navcen.uscg.gov/pdf/navRules/navrules.pdf.

[70] Credit to the U.S. Navy Admiralty & Maritime Law Division (Code 11) and CDR Chris Swain, U.S. Navy, for this survey of COLREGS-related case law.

[71] It is "an open question whether the COLREGS apply to UMSs, creating an uncertain regulatory environment for unmanned systems and manned vessels that encounter them." Christopher C. Swain. 2018. Towards greater certainty for unmanned navigation, a recommended United States military perspective on application of the "Rules of the Road" to unmanned maritime systems. *Georgetown Law Technology Review* 3:119–161, at 123. For robust discussion on this issue, see, for example, Craig H. Allen. 2018. Determining the legal status of unmanned maritime vehicles: formalism vs functionalism. *Journal of Maritime Law & Commerce* 49:477–514; Natalie Klein. 2019. Maritime autonomous vehicles within the international law framework to enhance maritime security. *International Law Studies* 95:244–271; Daniel Vallejo. 2015. Electric currents: programming legal status into autonomous unmanned vehicles. *Case Western Reserve Journal of International Law* 47:405–428.

[72] The incorporation of "good seamanship" through automated navigation into UMV may prove challenging.

wing-in ground craft and seaplanes, used or capable of being used as a means of transportation on water."

  - For a survey on relevant case law on the U.S. domestic maritime law concerning the definition and classification of "ships" and "vessels" in the context of "unmanned ships," see the Maritime Law Association of the United States, Response of MLA to CMI Questionnaire re Unmanned Ships.[73]

- Rule 5 (Lookout)[74] states: "[e]very vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and risk of collision."
  - *The Ottawa*, 70 U.S. (3 Wall.) 268 (1865)
  - *The Ariadne*, 80 U.S. (13 Wall.) 475 (1871)
  - *The Tokio Marine & Fire Ins. Co., Ltd. v. Flora MV*, No. CIV. A. 97–1154, 1999 U.S. Dist. LEXIS 267 (E.D. La. 1999), *aff'd*, 235 F.3d 963 (5th Cir. 2001)
  - *The Manchioneal*, 243 F. 801 (2d Cir. 1917)
  - *Mar. & Mercantile Int'l L.L.C. v. United States*, No. 02-CV-1446, 2007 U.S. Dist. LEXIS 19792 (S.D.N.Y. Feb. 28, 2007)
  - *The Illinois*, 103 U.S. 298 (1880)
  - *Ellis Towing & Transp. Co. v. Socony Mobil Oil Co.*, 292 F.2d 91 (5th Cir. 1961)
  - *Stevens v. United States Lines Co.*, 187 F.2d 670 (1st Cir. 1951)
  - *The Sarasota*, 37 F. 119 (S.D.N.Y. 1888)
  - *In re Interstate Towing Co.*, 717 F.2d 752 (2d Cir. 1983)
  - *In re Ballard Shipping Co.*, 823 F. Supp. 68 (D.R.I. 1993)
  - *In re Delphinus Maritima, S.A.*, 523 F. Supp. 583 (S.D.N.Y. 1981)
  - *In re Flota Mercante Grancolombiana, S.A.*, 440 F. Supp. 704 (S.D.N.Y. 1977)

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[73] Response of MLA to CMI Questionnaire RE Unmanned Ships, at https://perma.cc/D6Z5-63UJ.

[74] Applying Rule 5 directly to UMV operations may present the greatest legal obstacles. For example, some scholars have suggested that inclusion of the words "sight" and "hearing" indicate that observation is based on human characteristics, or that a "formal" approach should be applied to COLREGS treaty interpretation or amendment codified in the Vienna Convention on the Law of Treaties. Others suggest pragmatic or "functional" approaches to COLREGS interpretation are appropriate and that legal risk can be justified if UMV can prove safe and prudent operations; in support, some opine that the IMO has not adopted a strictly literal interpretation of the Rule 5 requirements in the past, and it "is therefore possible that electronic instruments and equipment can replace the human function of observation, assuming that the technologies used are at least as effective and safe as diligent humans performing the lookout functions." See European Maritime Safety Agency, "SAFEMASS Study of the Risks and Regulatory Issues of Specific Cases of MASS," at http://www.emsa.europa.eu/emsa-documents/latest/item/3892-safemass-study-of-the-risks-and-regulatory-issues-of-specific-cases-of-mass.html.

- *Reading Co., Inc. v. Pope & Talbot, Inc.*, 192 F. Supp. 663 (E.D. Pa. 1961), *aff'd*, 295 F.2d 40 (3d Cir. 1961)
- *United States v. Motor Ship Hoyanger*, 265 F. Supp. 730 (W.D. Wash. 1967)
- *The Bristol*, 4. F. Cas. 159 (S.D.N.Y. 1873) (No. 1891)
- *Cabins Tanker Indus., Inc. v. The Rio Maracana*, 182 F. Supp. 811 (E.D. Va. 1960)
- *The Bright*, 38 F. Supp. 574 (D. Md. 1941)
- *The Volund*, 181 F. 643 (2d Cir. 1910)
- *The Madiana*, 63 F. Supp. 948 (S.D.N.Y. 1944)
- *Commonwealth & Dominion Line v. United States*, 1925 AMC 1575 (E.D.N.Y. 1925)
- *Doran v. United States*, 304 F. Supp. 1162 (D.P.R. 1969)

• Rule 6 (Safe Speed) states: "[e]very vessel shall at all times proceed at a safe speed so that she can take proper and effective control to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions."
  - *Otal Invs. Ltd. v. M.V. Clary*, 494 F.3d 40 (2d Cir. 2007)
  - *The Umbria*, 166 U.S. 404 (1897)
  - *Union Oil Co. of California v. The San Jacinto*, 409 U.S. 140 (1972)
  - *The George H. Jones*, 27 F.2d 665 (2d Cir. 1928)

• Rule 7 (Risk of Collision) states: "Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists…."
  - *In re Ocean Foods Boat Co.*, 692 F. Supp. 1253 (D. Or. 1988)
  - *Paterakis v. United States*, 849 F. Supp. 1106 (E.D. Va. 1994)
  - *In re G&G Shipping Co., Ltd. of Anguilla*, 767 F. Supp. 398 (D.P.R. 1991)
  - *Fireman's Fund Ins. Cos. v. Big Blue Fisheries, Inc.*, 143 F.3d 1172 (9th Cir. 1998)
  - *Ching Sheng Fishery Co., Ltd. v. United States*, 124 F.3d 152 (2d Cir. 1997)

• Rule 8 (Action to Avoid Collision) states: "Any action taken to avoid collision shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship…."
  - *In re Ocean Foods Boat Co.*, 692 F. Supp. 1253 (D. Or. 1988)
  - *In re G&G Shipping Co., Ltd. of Anguilla*, 767 F. Supp. 398 (D.P.R. 1991)
  - *Mar. & Mercantile Int'l L.L.C. v. United States*, No. 02-CV-1446, 2007 U.S. Dist. LEXIS 19792 (S.D.N.Y. Feb. 28, 2007)

- Rule 19 (Conduct in Restricted Visibility) applies: "to vessels not in sight of one another when navigating in or near an area of restricted visibility…."
    - *Hellenic Lines, Ltd. v. Prudential Lines, Inc.*, 730 F.2d 159 (4th Cir. 1984)

Besides COLREGS, other international conventions simply use the term "ship" or "vessel" without purporting to define it. Table E-1 provides a summary of these definitions by Craig H. Allen.[75]

Domestic Legal Sources

Besides international law and conventions, the Coast Guard may rely on domestic statute, regulation, and policy in formulating determinations as to the legal status of a respective asset or platform.

For example, under U.S. statute, the word "vessel" includes every description of watercraft or other artificial contrivance used, or capable of being used, as a means of transportation on water. This definition does not distinguish between manned and unmanned watercraft (1 U.S.C. § 3).

And, while domestic operational authorities may vary from international counterparts, the application of emerging technologies to UMV present novel issues in admiralty law including those related to doctrines of seaworthiness, limitation of liability, and in rem liability.[76] For admiralty incidents involving U.S. public vessels, including matters related to liability and waivers of sovereign immunity, the following statutes and case law if informative:

- Suits in Admiralty Act, 46 U.S.C. § 30901–30918 (2018)
- Public Vessels Act, 46 U.S.C. §§ 31101–31113 (2018)
- *Canadian Aviator, Ltd. v. United States*, 324 U.S. 215 (1945)
- *The Pennsylvania*, 86 U.S. 125, 1998 AMC 1506 (1873) (establishing the "Pennsylvania Rule")
- *Lozman v. City of Riviera Beach, Florida*, 133 S. Ct. 735, 2013 AMC 1 (2013).
    - This is the leading U.S. case on determining "what is a vessel." There, the U.S. Supreme Court held that a permanently moored

[75] Craig H. Allen. 2018. Determining the legal status of unmanned maritime vehicles: formalism vs functionalism. *Journal of Maritime Law & Commerce* 49:477–514, Table 1.

[76] See Michal Chwedczuk. 2016. Analysis of the legal status of unmanned commercial vessels in U.S. admiralty and maritime law. *Journal of Maritime Law & Commerce* 47(2):156–166. See also Christopher C. Swain. 2018. Towards greater certainty for unmanned navigation, a recommended United States military perspective on application of the "Rules of the Road" to unmanned maritime systems. *Georgetown Law Technology Review* 3:119–161, at 151–154.

TABLE E-1 "Ship" and "Vessel" Definitions by Various International Conventions

Instrument	Definition
COLREGS	Rule 3(a): The word "vessel" includes every description of watercraft, including non-displacement craft Wing-In Ground craft, and seaplanes, used or capable of being used as means of transportation on water.
SOLAS	No single definition. See, e.g., Reg. I/3(a)(i)–(vi), Reg. V/2.3: "All ships" mean any ship, vessel or craft irrespective of type and purpose.
MARPOL	Art. 2(4): "Ship" means a vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushioned vehicles, submersibles, floating craft, and fixed or floating platforms.
UN Convention on Registration of Ships	Art. 2: "Ship" means any self-propelled sea-going vessel used in international seaborne trade for the transport of goods, passengers, or both with the exception of vessels of less than 500 gross registered tons.
London Dumping Convention	Art. III(2): "Vessels and aircraft" means waterborne or airborne craft of any type whatsoever. This expression includes air cushioned craft and floating craft, whether self-propelled or not.
Hague Convention	Art. 1(d): "Ship" means any vessel used for the carriage of goods by sea.
SALCON 1989	Art. 1(b): "Vessel" means any ship or craft, or any structure capable of navigation.
CLC Convention (and Fund Convention)	Art. I1: "Ship" means any sea-going vessel and any seaborne craft of any type whatsoever actually carrying oil in bulk as cargo.
OPRC Convention	Art. 2(3): "Ship" means a vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushion vehicles, submersibles, and floating craft of any type.
SUA Convention	Art. 1: "Ship" means a vessel of any type whatsoever not permanently attached to the sea-bed, including dynamically supported craft, submersibles, or any other floating craft.
Lisboa Rules (not a treaty)	"Vessel" means any ship, craft, machine, rig, or platform whether capable or navigation or not, which is involved in a collision.

SOURCE: Craig H. Allen. 2018. Determining the legal status of unmanned maritime vehicles: Formalism vs functionalism. *Journal of Maritime Law & Commerce* 49:477–514, Table 1.

houseboat was not a vessel because "a reasonable observer, looking to the home's physical characteristics and activities, would not consider it to be designed to any practical degree for carrying people or things on water." The Court opined that the 1 U.S.C. § 3 definition of "vessel" must be applied in a practical, not a theoretical way.

- *Evansville & Bowling Green Packet C. v. Chero Cola Bottling Co.*, 271 U.S. 19, 22 (modifying interpretation of 1 U.S.C. § 3 by determining that the word "capable" should be read "practically capable").
- *Stewart v. Dutra Constr. Co.*, 543 U.S. 481, 2005 A.M.C. 609 (2005) (adopting the statutory definition of "vessel" set out at 1 U.S.C. § 3 without limit as to the size or purpose of the vessel).
- *The Robert W. Parsons*, 191 U.S. 17, 2010 A.M.C. 542 (1903) (suggesting the basic criterion used to decide whether a structure is a vessel is the purpose for which it is constructed and the business in which it is engaged).

Coast Guard Legal Interpretations

The issue of "what is a vessel" is not a novel matter for the Coast Guard. In fact, in its *Legal Determination on Vessel Status of Paddleboard* (Oct. 3, 2003), the Coast Guard Boating Safety Division (CG-5422) promulgated a determination on whether the Coast Guard considers a "paddleboard" to be a vessel. In that determination, the Coast Guard established a five-pronged test for determining whether any given watercraft is capable of being classified as a "vessel," provided here in relevant part:

1. Whether the watercraft is "practically capable" of carrying persons or property,
2. Whether the useful operating range of the device is limited by the physical endurance of its operator,
3. Whether the device presents a substantial hazard to navigation or safety not already present,
4. Whether the normal objectives sought to be accomplished by the regulation of a device as a "vessel" are present, and
5. Whether the operator and/or cargo would no longer be safe in the water if the device became disabled.

As the Coast Guard acknowledged in that determination, the criteria outlined above will not be applicable to every watercraft for which there is a question of status, and there is no set formula for making vessel determinations—each determination must be made on an individual basis.[77]

U.S. DOD Navy Legal Interpretations and Guidance

The U.S. Navy has also promulgated guidance on which the Coast Guard can rely in evaluating legal status of UMVs, for example:

- U.S. Navy, Marine Corps & Coast Guard, *Commander's Handbook on the Law of Naval Operations*, NWP 1-14M/MCTP 11-10B/COMDTPUB P5800.7A (2017)
- DoD Directive 3000.09 (2012) (Change 1, May 8, 2017), *Autonomy in Weapon Systems*[78]

The Navy has also granted exemptions from regulatory and certification requirements for certain unmanned surface vehicles under 33 U.S.C. 1605 (Navy and Coast Guard vessels of special construction or purpose).

- Specifically, the Navy has "certified that Unmanned Surface Vehicles with hull numbers 11MUC0601, 11MUC0602, 11MUC0603 and 11MUCO604 are vessels of the Navy which, due to their special construction and purpose, cannot fully comply with the following specific provisions of 72 COLREGS without interfering with its special function as a naval ship." See 32 C.F.R. § 706.2; 73 FR 200 (Oct. 15, 2008), 60947–60948.
- E.O. 11964 of January 19, 1977, Implementation of the Convention on the International Regulations for Preventing Collisions at Sea, 1972
    - With respect to the number, positions, range, or arc of visibility of lights or shapes required of the 1972 COLREGS, this E.O. provides that the "Secretary of the Department in which the Coast Guard is operating is authorized, to the extent permitted by law, to promulgate such rules and regulations that are necessary to implement the provisions of the Convention and International Regulations."

[77] See https://homeport.uscg.mil/Lists/Content/Attachments/537/Ahmanson%20Attachments.PDF.

[78] See https://fas.org/irp/doddir/dod/d3000_09.pdf.

Best Practices

The Coast Guard Navigation Safety Advisory Council (NAVSAC)[79] has published "Unmanned Vehicles/Vessels" (2011) (Resolution 11-02) and "Unmanned Maritime Systems Best Practices" (Resolution 16-01):

- NAVSAC (Resolution 11-02) made recommendations that the U.S. Coast Guard sponsor amendments to both the Inland Rules and COLREGs that, among other measures, amends Rule 5 to exclude unmanned surface vessels from the look-out requirement by adding "manned" before "vessel," and to "promulgate an interpretive rule under 33 C.F.R. Parts 82 and 90 to provide that a vessel being operated remotely is considered to be manned and must comply with the applicable Navigation Rules and annexes."[80]
- NAVSAC (Resolution 16-01) provides guidance and information on "Unmanned Maritime Systems Best Practices" to UMS owners and operators on matters concerning UMS development and operations in the maritime environment.[81]

Maritime UK has also published the voluntary *Maritime Autonomous Surface Ships (MASS) UK Industry Conduct Principles and Code of Practice,* which provides practical guidance for the design, construction, and safe operation of autonomous and semi-autonomous MASS less than 24 meters (November 2019, ver. 3).[82]

LR *Code for Unmanned Marine Systems* (Feb. 2017) is a goal-based code that takes a structured approach to the assessment of unmanned marine systems (UMSs) against a set of safety and operational performance requirements.[83]

[79] NAVSAC is a federal advisory committee authorized by Title 33 U.S.C. 2073 and chartered under the Federal Advisory Committee Act (Pub. L. 92-463; Title 5 U.S.C. App.).

[80] See https://homeport.uscg.mil/Lists/Content/Attachments/726/NAVSAC%20-%20May%202011%20meeting%20-%20summary%20record.pdf. To date, these NAVSAC recommendations have not been adopted by the Coast Guard.

[81] See https://maddenmaritime.files.wordpress.com/2016/06/navsac-resolution-16-01-unmanned-maritime-systems-ums-best-practices-final-05-may-2016.pdf.

[82] See https://www.maritimeuk.org/documents/478/code_of_practice_V3_2019_8Bshu5D.pdf. Notably, in 2017 the United Kingdom Ship Register signed its first "autonomous vessel," the 7.2 meter *C-Worker 7*.

[83] See https://www.lr.org/en/latest-news/new-code-to-certify-unmanned-vessels-announced; see also LR *Cyber-enabled ships ShipRight procedure assignment for cyber descriptive notes for autonomous & remote access ships.*

Current Regulatory and Collaborative Projects

Ongoing projects may provide useful guidance to the Coast Guard on UMV.

Domestic[84]

- Coast Guard *Request for Information on Integration of Automated and Autonomous Commercial Vessels and Vessel Technologies into the Maritime Transportation System*, Docket No. USCG-2019-0698 (85 Fed. Reg. 48548, Aug. 11, 2020)[85]
- E.O. 13859, Maintaining American Leadership in Artificial Intelligence, 84 Fed. Reg. 3967 (14 Feb. 2019)[86]
- U.S. Department of Transportation (DOT) Automated Vehicles Activities, *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0 (AV 4.0)*[87]
- Maritime Administration (MARAD)[88]
- U.S. Committee on the Marine Transportation System[89]
- The Smart Ships Coalition of the Great Lakes-Saint Lawrence[90]
- SUNY Maritime College Maritime Global Technologies Innovation Center[91]
- Ship Operations Cooperative Program U.S. Maritime Autonomous Vessel Consortium[92]
- Association for Unmanned Vehicle Systems International, Unmanned Maritime Systems (UMS) Advocacy Committee[93]

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[84] The Coast Guard is an active participant in many of these groups.

[85] See https://www.govinfo.gov/content/pkg/FR-2020-08-11/pdf/2020-17496.pdf.

[86] See https://www.govinfo.gov/content/pkg/FR-2019-02-14/pdf/2019-02544.pdf.

[87] See https://www.transportation.gov/av/4; see also *Federal Register Notice*, DOT-OST-2019-0179 (USDOT and the White House Office of Science and Technology Policy [OSTP] inviting public comment on AV 4.0).

[88] See, for example, Achieving Critical MASS conference (July 2019), at https://www.maritime.dot.gov/about-us/foia/presentations-achieving-critical-mass-conference-july-2019.

[89] See https://www.cmts.gov/topics.

[90] See https://smartshipscoalition.org. In January 2018, the Coast Guard was briefed on the concept of operations for a Great Lakes autonomous vessel testbed and received a draft plan from the Michigan Office of the Great Lakes and the Great Lakes Research Center detailing the potential test area, the types of testing it could support, and requirements for operation and risk mitigation. The assumption is that operation of autonomous surface vessels and vehicles and autonomous underwater vehicles in the Marine Autonomy Research Site will still be subject to USCG regulations that involve the state of maneuverability, commonly accepted Rules of the Road and other requirements.

[91] See https://www.nymic.org.

[92] See http://www.socp.us/article.html?aid=106.

[93] See https://www.auvsi.org/our-impact/advocacy-initiatives/ums-advocacy-committee.

International

- International Maritime Organization (IMO) MASS Regulatory Scoping Exercise (RSE): The Coast Guard is an active participant in the RSE,[94] which focuses only on surface vehicles, and each instrument related to maritime safety and security, and to liability and compensation, and for each degree of autonomy, provisions will be identified which:
  - apply to MASS and prevent MASS operations; or
  - apply to MASS and do not prevent MASS operations and require no actions; or
  - apply to MASS and do not prevent MASS operations but may need to be amended or clarified, and/or may contain gaps; or
  - have no application to MASS operations.

The IMO's MASS scoping exercise initially decided on four degrees of unmanned surface ship autonomy:[95]

1. **Degree one:** Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
2. **Degree two:** Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
3. **Degree three:** Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
4. **Degree four:** Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

[94] The Coast Guard is the lead agency responsible for representing the U.S. interests and coordinating with appropriate U.S. agencies, stakeholders, and nongovernmental organizations for all work conducted at the various levels of the IMO. See IMO Autonomous Shipping, at http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx; see also Henrik Tunfors, Swedish Transport Agency, Presentation at 5th UK MASRWG Conference, January 15–16, 2020, IMO Regulatory Scoping Exercise on MASS, at https://www.maritimeuk.org/documents/544/Henrik_Tunfors_suw9wJK.pdf.

[95] Notably, these four degrees were largely based on the U.S. submission to MSC 99/5/12, Comments on document MSC 99/5/5, Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS).

The IMO Committees involved in the RSE are the Maritime Safety Committee (MSC), Facilitation Committee, and Legal Committee.[96] To date, the first step of the RSE has been completed,[97] and the next step is to analyze and determine the most appropriate way of addressing MASS operations, taking into account, inter alia, human element, technology and operational factors. The analysis will identify the need for:

- Equivalences as provided for by the instruments or developing interpretations; and/or
- Amending existing instruments; and/or
- Developing new instruments; or
- None of the above as a result of the analysis.

Other significant projects include:

- Comité Maritime International Working Group on Maritime Autonomous Surface Ships (CMI IWG MASS)[98]
- Autonomous Shipping Initiative for European Waters (AUTOSHIP)[99]
- European Maritime Safety Agency SAFEMASS[100]
- International Network for Autonomous Ships (INAS)[101]
- EU Advanced, Efficient and Green Intermodal Systems (AEGIS)[102]
- Maritime Unmanned Navigation through Intelligence in Networks[103]
- British Ports Association Autonomous Shipping in Ports Network[104]

Legal Considerations for UASs

As with surface assets, Coast Guard UASs are obligated to comply with legal jurisdictional limitations and operate aircraft under the applicable legal authority.

[96] For a list of conventions by Committee, see http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx.

[97] The aim is to complete the regulatory scoping exercise in 2020. See also Note by the Secretariat: Status report – Progress of the regulatory scoping exercise, MSC 105/5 (January 31, 2020).

[98] See https://comitemaritime.org/work/mass. The CMI IWG MASS has been assisting the RSE with review of the analysis on instruments under the purview of the Maritime Safety Committee, which identifies horizontal legal issues. See summary of results of analysis of IMO instruments under the purview of the MSC, MSC 102/5/16 (Feb. 11, 2020).

[99] See https://www.autoship-project.eu.

[100] See http://emsa.europa.eu/mass.html.

[101] See http://www.autonomous-ship.org/members.html.

[102] See http://aegis.autonomous-ship.org.

[103] See http://www.unmanned-ship.org/munin/#:~:text=MUNIN%20aims%20to%20develop%20and,a%20shore%20side%20control%20station.

[104] See https://www.britishports.org.uk/news/ports-eyeing-up-autonomous-shipping-possibilities. The BPA has issued a "call for evidence" for interested parties to feed in information on topics related to autonomous shipping.

Domestic Framework

As referenced in Chapter 6 and Part I, the FAA is the lead federal agency for regulating UAS operations in the NAS.[105] For example, Figure E-5 provides an illustration of the FAA guidance for small UAS operations within the NAS.

- See also Federal Aviation Administration, 14 C.F.R. Part 91 Docket No. FAA-2006-25714, *Unmanned Aircraft Operations in the National Airspace System*: Clarifying FAA's current policy concerning operations of unmanned aircraft in the National Airspace Systems.[106]

International Framework

Also referenced in Chapter 6 and Part I, ICAO is the international authority responsible for ensuring aviation safety and protecting the public from aviation hazards. When a U.S.-registered pilot is operating beyond 12 nautical miles over the high seas, operators generally must comply with rules under Annex II of the Convention on International Civil Aviation (Chicago Convention) (14 C.F.R. § 91).

FAA policy dictates conformity with ICAO Standards and Recommended Practices to the maximum extent practicable.[107] The ICAO Model UAS Regulations and supporting Advisory Circulars offer a template for Member States to adopt or to supplement their existing UAS regulations.[108] And, ICAO has published the UAS Toolkit to "assist States in realizing effective UAS operational guidance and safe domestic operations."[109]

- For a comprehensive summary identifying and prioritizing gaps in UAS operations, see *Standardization Roadmap for Unmanned Aircraft Systems, Version 2.0, Prepared by the ANSI Unmanned Aircraft Systems Standardization Collaborative (UASSC)* (June 2020).[110]

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[105] See https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/17_phak_ch15.pdf.

[106] See https://www.faa.gov/uas/resources/policy_library/media/frnotice_uas.pdf.

[107] See https://www.icao.int/safety/SafetyManagement/Pages/GuidanceMaterial.aspx.

[108] See https://www.icao.int/safety/UA/Pages/default.aspx.

[109] See https://www.icao.int/safety/UA/UASToolkit/Pages/Narrative-Background.aspx.

[110] This Roadmap has examined 78 issue areas, identified a total of 71 open gaps and corresponding recommendations across the topical areas of airworthiness; flight operations (both general concerns and application-specific ones including critical infrastructure inspections, commercial services, and public safety operations); and personnel training, qualifications, and certification.

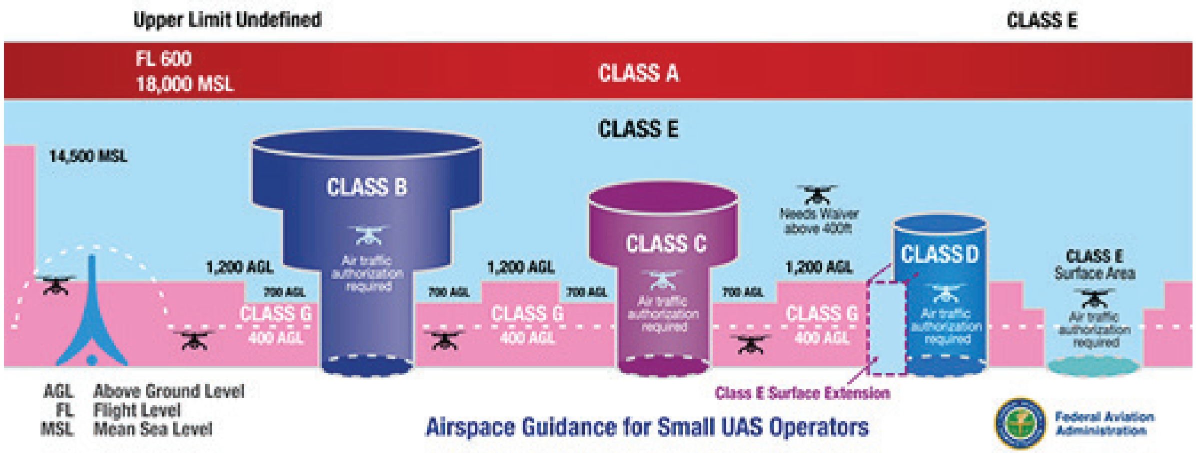

FIGURE E-5 FAA guidance for small UAS operations.
SOURCE: FAA.[111]

[111] See https://www.faa.gov/uas/recreational_fliers/where_can_i_fly/airspace_101.

Coast Guard Policy and Guidance

The Coast Guard relies on several policy and guidance documents to ensure safe UAS operations, including but not limited to:

- COMDTINST M3710.1H, *Air Operations Manual* (26 Oct. 2018), Ch. 4-8 (General Flight Rules) and Ch. 4-13, 4-14 (Operations Over High Seas/Due Regard)
- COMDTINST M3710.2 (series), Shipboard-Helicopter Operational Procedures Manual
- CG711NOTE3710, *Coast Guard Maritime Security Cutter, Large (WMSL) Class ScanEagle (SE) Unmanned Aircraft Systems (UAS) Standard Operating Procedures (SOP)*
- CG-711 Memo 3710 (23 Dec 2018), *Cutter-Based Small Unmanned Aircraft Systems (sUAS) Concept of Operations (CONOPS) and Vignettes*
- U.S. Coast Guard, *Coast Guard Unmanned Aircraft System (UAS) Strategy* (Washington, DC, Jan. 12, 2009)
- CG-711 Amendment to Interim Flight Clearance (Jan. 31, 2018) (series)
- ALCOAST 004/18 (Jan. 2018), *Authorized Use of Coast Guard Unmanned Aircraft Systems* (UAS)
- DoDI 4540.01 (series), *Use of International Airspace by US Military Aircraft and for Missile and Projectile Firings*

Given that the Coast Guard may evaluate weaponizing UAS in support of Coast Guard missions, while bearing in mind potential "human in the loop" requirements, this literature provides useful guidance on that topic:

- Michael R. Sinclair, *For a Few Armed [Drones], Judiciously Stationed, Might at a Small Expense Be Made Useful Sentinels of the Law: The Sufficiency of Existing Law as Applied to the U.S. Coast Guard's Inevitable Use of Unmanned Aircraft Capable of Employing Airborne Use of Force in the Maritime Counter-Drug Mission*, Loyola Maritime Law Journal 18(1), 2019[112]
- Craig Allen Jr., *Armed Drones: The Coast Guard's Next New Frontier?*, 143 U.S. Naval Institute Proceedings, 2017

[112] Taking the position that "current international and U.S. law provides no obstacle for the Coast Guard, should it decide to employ armed UAS, even UAS with great degrees of autonomy, in the execution of AUF operations, provided the Coast Guard continues to employ its existing policy, which requires a Flag officer-level Statement of No Objection ('SNO') before employing warning shots and disabling fire on the high seas, in the counter-drug mission space."

- CRS Defense Primer: *U.S. Policy on Lethal Autonomous Weapon Systems*, December 19, 2019

Interagency/Service Guidance

The Coast Guard's use of a respective UAS platform may be impacted by interservice and interagency UAS guidance and restrictions, including those referenced in Chapter 6 and those listed here:

- The FY 2020 National Defense Authorization Act Section 848 prohibits the procurement of Chinese manufactured UAS and UAS components.[113]
- The U.S. Army has issued a directive banning drones made by the Chinese company DJI. (See DAMO-AV Memorandum [2 Aug. 2017] Discontinue Use of Dajiang Innovation (DJI) Corporation Unmanned Aircraft Systems.)

[113] See https://www.congress.gov/116/bills/s1790/BILLS-116s1790enr.pdf; (a) PROHIBITION ON AGENCY OPERATION OR PROCUREMENT.—The Secretary of Defense may not operate or enter into or renew a contract for the procurement of—

(1) a covered unmanned aircraft system that—

(A) is manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(B) uses flight controllers, radios, data transmission devices, cameras, or gimbals manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(C) uses a ground control system or operating software developed in a covered foreign country or by an entity domiciled in a covered foreign country; or

(D) uses network connectivity or data storage located in or administered by an entity domiciled in a covered foreign country; or

(2) a system manufactured in a covered foreign country or by an entity domiciled in a covered foreign country for the detection or identification of covered unmanned aircraft systems.

(b) EXEMPTION.—The Secretary of Defense is exempt from the restriction under subsection (a) if the operation or procurement is for the purposes of—

(1) Counter-UAS surrogate testing and training; or

(2) intelligence, electronic warfare, and information warfare operations, testing, analysis, and training.

(c) WAIVER.—The Secretary of Defense may waive the restriction under subsection (a) on a case by case basis by certifying in writing to the congressional defense committees that the operation or procurement is required in the national interest of the United States.

(d) DEFINITIONS.—In this section:

(1) COVERED FOREIGN COUNTRY.—The term "covered foreign country" means the People's Republic of China.

(2) COVERED UNMANNED AIRCRAFT SYSTEM.—The term "covered unmanned aircraft system" means an unmanned aircraft system and any related services and equipment.

  - See also Navy memorandum (24 May 2017), *Operational Risks with Regards to DJI Family of Products*.
- The Department of the Interior (DOI) has issued an order titled *Temporary Cessation of Non-Emergency Unmanned Aircraft Systems Fleet Operations* (19 Jan. 2020), which effectively calls for the "temporary cessation of non-emergency unmanned aircraft systems fleet operations" in order to ensure that "cybersecurity, technology and domestic production concerns are adequately addressed."[114]
- The Coast Guard follows these DOD and DOI restrictions on UAS procurement for the sake of comity and in support of its role and requirements in joint, combined, and interagency operations.

However, procurement options appear to have recently expanded as DOD's Defense Innovation Unit announced in August 2020 that five "drones" have been tested, approved, and available for government use.[115] It remains to be seen how this will impact the Coast Guard, although the five Defense Innovation Unit (DIU)-approved drones that reportedly should appear on the GSA schedule are as follows:

- Skydio's X2-D
- Parrot's Anafi USA
- Altavian's M440 Ion
- Teal Drones' Golden Eagle
- Vantage Robotics' Vesper

Current Regulatory Projects and Collaborative Efforts

Although there are several ongoing domestic and international regulatory and collaborative projects, it is important to note that the Coast Guard is actively engaged with embedded aviation liaisons or personnel at the FAA, DHS, and CBP.

- DHS S&T UAS Program
- DOT's UAS Integration Pilot Program (IPP)[116]

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114 See https://www.doi.gov/sites/doi.gov/files/elips/documents/signed-so-3379-uas-1.29.2020-508.pdf; see also U.S. Department of the Interior Unmanned Aircraft Systems (UAS) Integration Strategy (2015–2020).

115 The U.S. government grounded DJI—but here are the five drones it just approved (Aug. 20, 2020), https://www-theverge-com.cdn.ampproject.org/c/s/www.theverge.com/platform/amp/2020/8/20/21376917/drone-us-government-approved-dod-diu-uas-blue-china.

116 Testing sites for UASs are of potential benefit to Coast Guard UAS operations. See GAO-20-97 (Jan. 9, 2020), UNMANNED AIRCRAFT SYSTEMS: FAA Could Better Leverage Test Site Program to Advance Drone Integration. https://www.gao.gov/products/GAO-20-97.

- NOAA UAS Program
- FAA UAS Test Site Program[117]
- Alliance for System Safety of UAS through Research Excellence
- ICAO Unmanned Aircraft Systems Advisory Group[118]
- World Economic Forum Centre for the Fourth Industrial Revolution[119]
- European Union Aviation Safety Agency: Drones—regulatory framework timeline[120]
- UK Maritime and Coastguard Agency (MCA)[121]
- Maritime Port Authority of Singapore (MPA)[122]
- ANSI Unmanned Aircraft Systems Standardization Collaborative[123]

Law Enforcement, Privacy, and Data Collection Considerations

Sensors and systems aboard UxSs that will observe and store data may be subject to legal considerations. Access to information requires appropriate permissions, individual security certification, and system security certification to ensure adherence to legal requirements and domestic and international policies, procedures, and agreements. The dissemination of sensitive, proprietary, and classified information will demand a broad-reaching architecture with safeguards to ensure multilevel security and information assurance.

DHS and DOJ Guidance

- DOJ, DHS, FAA, and Federal Communications Commission *Advisory on the Application of Federal Laws to the Acquisition and Use*

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[117] The FAA Modernization and Reform Act of 2012 (FMRA 2012) directed the Federal Aviation Administration (FAA) Administrator to initiate a 5-year program to establish six UAS test sites to support the FAA in integrating UASs into the NAS.

[118] See https://www.icao.int/safety/UA/Pages/Unmanned-Aircraft-Systems-Advisory-Group-(UAS-AG).aspx.

[119] See https://www.weforum.org/centre-for-the-fourth-industrial-revolution.

[120] See https://www.easa.europa.eu/drones-regulatory-framework-timeline.

[121] See https://www.suasnews.com/2020/05/the-uk-drones-pathfinder-programme-announces-new-pathfinder-led-by-the-maritime-and-coastguard-agency/#:~:text=A%20ground%2Dbreaking%20new%20project,and%20international%20counter%20pollution%20obligations.

[122] MPA has partnered with Airbus, the Infocomm Media Development Authority, and M1 Limited to conduct coastal 5G standalone network trials at the Singapore Maritime Drone Estate. See https://www.porttechnology.org/news/mpa-partners-with-airbus-and-m1-to-conduct-5g-drone-trials.

[123] DHS Security Science & Technology Directorate is a “Premier Partner.”

of Technology to Detect and Mitigate Unmanned Aircraft Systems (Aug. 2020)[124]

- DHS *Best Practices for Protecting Privacy, Civil Rights & Civil Liberties in Unmanned Aircraft Systems Programs* (Dec. 18, 2015) offers best practice guidance that accounts for protections of privacy, civil rights, and civil liberties.
- DHS *Unmanned Aircraft Systems Considerations for Law Enforcement Action*
- DHS *Privacy Impact Assessment for the Aircraft Systems*
- CBP *Office of Air and Marine Unmanned Aircraft System Operations and Privacy Policy*
- CBP (March 27, 2017), *Fiscal Year 2017 Report to Congress, Use of Unmanned Aircraft Systems in Joint Operations with State, Local, and Tribal Partners* Presidential Memorandum: *Promoting Economic Competitiveness While Safeguarding Privacy, Civil Rights, and Civil Liberties in Domestic Use of Unmanned Aircraft Systems*
- U.S. Department of Justice (DOJ) *Domestic Use of Unmanned Aircraft Systems (UAS)*[125]
- DOJ Guidance to Protect Facilities from Unmanned Aircraft and Unmanned Aircraft Systems[126]
- DOJ National Institute of Justice Report, *Considerations and Recommendations for Implementing an Unmanned Aircraft Systems (UAS) Program*[127]
- International Association of Chiefs of Police *Recommended Guidelines for the Use of Unmanned Aircraft*
- International Association of Classification Societies *Recommendation on Cyber Resilience*, No. 166 (Apr. 2020)

[124] See https://www.dhs.gov/sites/default/files/publications/20_0817_ogc_interagency-legal-advisory-uas-detection-mitigation-technologies.pdf. This advisory document recommends a thorough understanding of how a system functions and the applicable law to ensure that, if UAS detection and mitigation technologies are employed, they will be used effectively, responsibly, and legally. To that end, the advisory poses several critical "questions to consider" related to legal compliance.

[125] Requires UASs to be operated consistent with the U.S. Constitution, and offers guidance on protection of privacy, civil rights, and civil liberties.

[126] See https://www.justice.gov/opa/pr/attorney-general-barr-issues-guidance-protect-facilities-unmanned-aircraft-and-unmanned.

[127] See https://www.ncjrs.gov/pdffiles1/nij/250283.pdf.

Counter-UAS (C-UAS) Authorities

Several U.S. laws that generally prohibit the use of C-UAS technology in the United States. These laws were developed with the purpose of protecting the NAS, civil use of electromagnetic spectrum, GPS, constitutional rights, and privacy rights of U.S. persons. Prior to taking action against either a UAS, whether in flight or not, or a possible operator of a UAS, it is recommended that the Coast Guard develop plans and procedures detailing the actions of its personnel and consult legal counsel to verify the legality of those actions. Some specific federal statutes to consider are included here.

U.S. Laws That Protect Civil Aviation/NAS and the Electromagnetic Spectrum/GPS

- Aircraft Sabotage Act (18 U.S.C. § 32) prohibits "willful destruction," that is, damaging, disabling, or destroying an aircraft.
- Aircraft Piracy Statute (49 U.S.C. § 46502) prohibits seizing or exercising control of an aircraft.

U.S. Laws That Protect Civil Aviation/NAS and the Electromagnetic Spectrum/GPS

- Signal Interference Laws (47 U.S.C. §§ 301, 333, 501, 503, 510) prohibit the use of unlicensed radio communications and willful or malicious interference to any licensed radio communication (i.e., the use of RF jammers) and of any GPS jammers within the United States.
- The Computer Fraud and Abuse Act (18 U.S.C. § 1030) may prohibit cyber-based C-UAS methods (signal interference).

U.S. Laws That Protect Constitutional and Privacy Rights of U.S. Persons

- The Wiretap Act (18 U.S.C. § 2510–2522) may prohibit the use of a C-UAS system that acquires the contents of signals or instructions between a controller and UAS without a court order.
- The Penn/Trap Statute (18 U.S.C. § 3121–3127) may prohibit the use of a C-UAS system that "records" or "captures" non-content signals without a court order.

Coast Guard Policy

- Maritime Security Response Operations (MSRO) Policy Letter 06-18 *Planned C-UAS for Maritime Force Protection Units*: Maritime Force Protection Units are authorized to use C-UAS technology in accordance with the noted policy letter in defense of self/others critical infrastructure only; no restrictions on the use of C-UAS technology that operates on the RF or GPS spectrum in international waters.
- Coast Guard Use of Force Policy and MSRO Policy Letter 02-18: Authorizes Coast Guard operational units to employ readily available kinetic means in defense of self/others critical infrastructure.

DHS C-UAS Legislation

- The Preventing Emerging Threats Act of 2018 grants DHS statutory authority to counter credible threats from UASs to the safety or security of a covered facility or asset, including to disrupt control of the UAS or unmanned aircraft, without prior consent, including by disabling the UAS or unmanned aircraft by intercepting, interfering, or causing interference with wire, oral, electronic, or radio communications used to control the UAS or unmanned aircraft; seize or exercise control of the UAS or unmanned aircraft; seize or otherwise confiscate the UAS or unmanned aircraft; and use reasonable force to disable, damage, or destroy the UAS or unmanned aircraft.[128]

Acquisition Authorities

The acquisition process ensures that affordable, capable, and sustainable systems are obtained within planned cost, schedule, and performance parameters. Organizational risk is reduced when an acquisition program is identified, designated, and monitored under appropriate leadership oversight.

As referenced in this report, programmatic and technical specifications need to be addressed as part of the procurement decision making. Successful identification of acquisition programs requires a coordinated effort between the sponsor, resource, acquisition, and other stakeholders within the Coast Guard. Several acquisition authorities are available to the Coast Guard,

[128] See https://www.congress.gov/115/bills/s2836/BILLS-115s2836rs.pdf; https://www.cisa.gov/sites/default/files/publications/19_0502_cisa_dhs-cuas-legal-authorities-factsheet.pdf.

and selection of the most appropriate procurement mechanism for UxSs is dependent on the scale and scope of the asset to be acquired.

- **Federal Acquisition Regulation:** This is the primary regulation for use by all executive agencies in their acquisition of supplies and services with appropriated funds.
- **Level 3—Non-Major Acquisition Program:** The Coast Guard defines a Level 3 acquisition program as obtaining either:
    - a capital asset with an estimated Acquisition Cost of less than $100 million and an estimated life-cycle cost (acquisition cost as well as operations and maintenance costs) of less than $300 million; or
    - a service with an annual cost of less than $100 million. These do not include Level 1 and Level 2 acquisitions, which are larger and managed under the Major System Acquisition Manual (MSAM), COMDTINST M5000.10 (series) (see Reference (e)). In addition, facilities and construction are excluded.
- **Coast Guard Research, Development, Test, and Evaluation (RDT&E) Program:** This program enhances acquisition and mission execution by helping transition new technologies into the Service's operational forces as the Coast Guard's sole office conducting applied RDT&E experimentations and demonstrations.
- **Memoranda of Understanding:** The Coast Guard Research and Development Center establishes memoranda of understanding to promote partnerships, foster collaboration, and leverage and pursue research efforts of mutual benefit to all parties.
- **DHS Cooperative Research and Development Agreements (CRADAs):** An agreement between one or more federal laboratories and one or more non-federal parties under which the government, through its laboratories, provides personnel, services, facilities, equipment, intellectual property, or other resources with or without reimbursement (but not funds to non-federal parties) and the non-federal parties provide funds, personnel, services, facilities, equipment, intellectual property, or other resources toward the conduct of specified research or development efforts that are consistent with the mission of the laboratory.[129]

[129] See https://www.dhs.gov/publication/st-crada-definitions.

- **Other Transaction Authority (OTA):**[130] Legally binding agreements exempt from the Federal Acquisition Regulation (FAR). OTAs allow DHS to work with nontraditional contractors that would otherwise not do business with the federal government because of strict intellectual property and government cost-accounting standard requirements. According to the Homeland Security Act of 2002, DHS may enter into OTAs only for research and prototype projects, and DHS policy defines the two forms of authorized OTAs:
  1. Research OTAs provide assistance to non-federal participants to broaden the collective homeland security technology knowledge base rather than a deliverable to satisfy an existing or immediate government need, and
  2. Prototype OTAs are used to carry out projects to develop prototypes used to evaluate the technical or manufacturing feasibility of a particular technology, process, or system. These OTAs require a deliverable (i.e., prototype(s)) that satisfies an existing agency need.
- **Silicon Valley Innovation Program:** The DHS S&T Silicon Valley Innovation Program (SVIP) reaches out to innovation communities across the nation and the world to harness the commercial R&D ecosystem for technologies with government applications and to co-invest in and accelerate technology transition-to-market.[131]
- **DHS S&T Small Business Innovation Research Program:** The Small Business Innovation Research and Small Business Technology Transfer programs are highly competitive programs that encourage domestic small businesses to engage in federal research/research and development (R/R&D) with the potential for commercialization.
- **Unsolicited Proposals:** Companies that have an innovative and unique product or service that may be of interest to the Coast

[130] The Homeland Security Act of 2002, Section 831. See also DHS OIG Audit (OIG-18-24) (November 30, 2017), U.S. Department of Homeland Security's Use of Other Transaction Authority, at https://www.oig.dhs.gov/sites/default/files/assets/2017-12/OIG-18-24-Nov17.pdf; DHS OIG Audit OIG-19-44 (May 30, 2019), Audit of DHS' Issuance and Management of Other Transaction Agreements Involving Consortium Activities. The S&T SVIP issued its first Innovation Other Transaction Solicitation (OTS)—HSHQDC-16-R-B0005—in Dec. 2015. The OTS describes the overall program framework and eligibility criteria. Individual calls describing specific technical areas and use cases will be issued under the Innovation OTS in the future.

[131] See https://www.dhs.gov/science-and-technology/svip; DHS News Release. *The Department of Homeland Security Science and Technology Directorate (S&T) awarded Planck Aerosystems, Inc. of San Diego, California, $200,000 to begin testing its autonomous small Unmanned Aircraft System (sUAS) in operational settings*, August 29, 2019, https://www.dhs.gov/science-and-technology/news/2019/08/29/news-release-st-awards-200k-san-diego-company-suas-testing.

Guard, and that it is not already commercially available to the government, can submit an unsolicited proposal under Part 15.6 of the FAR.

- **Defense Innovation Unit (DIU):** The unit accelerates the adoption of commercial technology throughout the military and the growing the national security innovation base. DIU aims to move from problem identification to prototype contract award in 60–90 days. Prototype projects typically run from 12–24 months and are administered according to OTA. Upon completion, successful prototypes may transition to follow-on production-OTAs or FAR-based contracts.[132]

Other considerations:

- **The International Traffic in Arms Regulations (ITAR):** Regulates the export and temporary import of defense articles and services governed by 22 U.S.C. 2778 of the Arms Export Control Act (AECA) and E.O. 13637. The International Traffic in Arms Regulations (ITAR, 22 CFR 120–130) implements the AECA.[133]
- Things to Consider for Unmanned Aircraft Systems (UAS) Procurement.[134]
- Free Technology Decision Tool to assist in the decision to purchase an sUAS.[135]
- For a detailed discussion on Coast Guard acquisitions, including UAS programs, see LCDR John Egan, Coast Gaurd, *The Unmanned Initiative: A Strategic Appraisal of Coast Guard Unmanned Aerial Systems, Joint Forces Staff College Thesis* (June 18, 2011).

[132] See https://www.diu.mil. The Coast Guard has assigned fulltime liaisons between Coast Guard and DIU.
[133] See https://www.pmddtc.state.gov.
[134] See https://www.ncjrs.gov/pdffiles1/nij/250283.pdf.
[135] See https://www.justnet.org/pdf/Technology-Decision-Tool.pdf.